2012

Sea Level Rise and Sustainability of the Nigerian Coastal Zone

Popoola, Olusola Olalekan

http://hdl.handle.net/10026.1/907

Copyright Statement

SEA LEVEL RISE AND SUSTAINABILITY OF THE NIGERIAN COASTAL

ZONE

by

OLUSOLA OLALEKAN POPOOLA

A thesis submitted to Plymouth University in partial fulfilment for the degree of

DOCTOR OF PHILOSOPHY

School of Marine Science and Engineering

Faculty Science and Technology

January 2012

Olusola Olalekan Popoola

Sea Level Rise and Sustainability of the Nigerian coastal Zone

Abstract

Globally, sea levels have risen in the last century, and various projections suggest substantial increases in sea level due to climate change in this century. In Nigeria, there are no up-to-date sea level rise (SLR) assessments for the coast. Much of the Nigerian coast is low lying with the consequence that a 1 to 3 metres rise in sea level, which may result from eustatic or climate change, will have a catastrophic effect on the human activities in these regions. This study examines the consequences of continued sea level rise with a focus on erosion and inundation for the Nigerian coast and considers the coastal management practices of coastal partnerships (CPs).

The Nigerian coast has been delineated according to distinct geomorphological units, which include the Barrier, Mud, Delta and Strand coasts. The Bruun model has been used to compute shoreline recession along the Nigerian coast with the exception of the Mud coast. A Geographic Information System (GIS) was used to develop inundation models and examine the impact scenarios that SLR will have on critical elements, which include land, population, economic activity (Gross Domestic Product), urban extent, agriculture and wetlands with the aid of high quality spatially disaggregated global data. A case study approach was used to assess the management practices of Pro-Natural International Nigeria; Niger Delta Wetland Centre, Niger Delta Development Commission; and Flood Erosion and Coastal Zone Management, Rivers State with the aid of a suite of systemic sustainability appraisal indices.

Results indicate that shoreline recession will be mild along the coast while substantial loss due to inundation of the critical elements is expected for all the scenarios considered. The sustainability assessment indicates that the CPs did not meet the required standard for sustainability, however there was evidence of constructive management in some of them. This study has been able to provide up-to-date baseline data concerning the vulnerability of the coast to SLR for the four coastal systems in Nigeria. The coastal sustainability assessment, which is the first ever in Nigeria, reflects the need for corrective measures in the management practices of the CPs to achieve a sustainable coast in the light of coastal hazards.

Table of Contents

List of Tables

List of Figures

List of Maps

Glossary

AVVA	Aerial Videotape-Assisted Vulnerability
CIAT	International Centre for Tropical Agriculture
CIESIN	Centre for International Earth Science Information Network
CoSS	Coastal Sustainability Standard
CPs	Coastal Partnerships
CZM	Coastal Zone Management
EU	European Union
FECOZM	Flood Erosion and Coastal Zone Management
GDP	Gross Domestic Product
GDP*mer*	Gross Domestic Product at market exchange rate
GGI-B2	Greenhouse Gas Initiative B2 Scenario
GIS	Geographic Information System
GLWD-3	Global Lakes and Wetlands Database version 3
GPWv3	Gridded Population of the World, Version 3
GRUMPv3	Global Rural-Urban Mapping Project version 3
IAIA	International Association for Impact Assessment
ICOM	Integrated Coastal and Ocean Management
ICZM	Coastal Zone Management
IFPRI	The International Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis
IOC	International Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Analysis
NDDC	Niger Delta Development Commission
NDWC	Niger Delta Wetland Centre
NIOMR	Nigerian Institute of Oceanographic and Marine Research

PAGEv2   Pilot Analysis of Global Ecosystems version 2

PI   Performance Indicator

PNIN   Pro-Natural International Nigeria

PPP   Polluter Pay Principle

RLRL   Revised Local Reference Level

SLR   Sea Level Rise

SQL   Structured Query Language

SRTM v3   Shuttle Radar Topographic Mission version 3

UNSCD   United Nations Commission on Sustainable Development

WAIS   West Antarctic ice sheet

WG-ID   Working Group on Indicators and Data

WGS   World Geodetic System

WRI   World Resources Institute

Symbols

$d_{L,1}$ Depth of closure annual scale (m)

$d_{L,100}$ Depth of closure century scale (m)

H_b Root mean square breaker height (m)

h_c Depth of Closure (m)

H_o Deep-water wave height (m)

$\hat{H}_S / H_s$ Significant Wave Height (m)

L_o deep-water wavelength (m)

T_w Wave Period (s)

w width of the shoreface (m)

Z_{berm} Berm height (m)

Δy Shoreline retreat due to sea level rise (m)

Acknowledgement

Authors Declaration

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award without prior agreement of the Graduate Committee.

This is a self-funded study.

Relevant scientific seminars and conferences were regularly attended at which work was often presented; external institutions were visited for consultation and training purposes and papers prepared for publications.

Publications:

Popoola O.O., Abbott V.J., Glegg G., (2011) Impact of Sea Level Rise: Barrier Coast, Nigeria. Impact Assessment and Responsible Development for Infrastructure, Business and Industry IAIA11 Proceedings 31st Annual Meeting of the International Association for Impact Assessment

Presentations, courses and Conferences
Coastal Sustainability Standard (2009): An assessment of the Nigerian coast, Plymouth Marine Science Partnership (PMSP)

Working with Spatial Analyst (2009). Geographic Information System (GIS) Training programme at ESRI UK, Aylesbury UK.

Impact of Sea Level Rise: Barrier Coast, Nigeria (2011): International Association for Impact Assessment conference, Puebla, Mexico.

Sea Level Rise and Coastal Wetland Sustainability: Delta coast Nigeria (2011). Marine and Coastal Policy Forum, Plymouth University

Word Count of main body of thesis: **71,685**

                                Signed…………………………….

                                Date……………………………….

CHAPTER ONE

1.0   Introduction

1.1   The coast

The coast is the part of land most affected by its proximity to the sea and that part of the sea most affected by its proximity to the land (Hinrichsen, 1998). The coast comprise about 20% of the earth's surface (United Nations, 2002) and two-thirds of the world cities occur in the coast (Crooks and Turner, 1999). About 44% of the world's population lives within 150 kilometres of the ocean (United Nations, 2002).

Coastal zones are dynamic and the processes that occur within them provide diverse and productive ecosystems useful for the human population (Kay and Alder, 2005). The dynamic nature of the coast has made it possible for it to be influenced by human activities thus making it difficult to proffer solutions to its management. Coastal areas are important in terms of natural resources and are rich with diverse species, habitat types and nutrients (Souto *et al.,* 2009). The ability of the coast to sustain a wealth of economic activity (Crossett *et al.,* 2004), which includes employment creation, recreation and tourism, waterborne commerce and energy and mineral production have been the driving forces of population migration to the coasts (Bookman *et al.,* 1999). Coastal ecosystems are highly productive with significant biological diversity, rich fishery resources and significant seabed minerals (Cummins *et al.,* 2005).

Coasts accommodate the world's primary ports for commerce, fish, shellfish and seaweed production for both human and animal consumption; and they are also a considerable source of fertilizer, pharmaceuticals, cosmetics, household products and construction materials (Burke *et al.,* 2001). Coastal ecosystems store and distribute nutrients, filter pollutants from inland freshwater systems and protect shorelines from

erosion and storms; while shorelines and oceans play a vital role in regulating global hydrology and climate, and are a major carbon sink and oxygen (Burke *et al.,* 2001). Coastal areas contribute to global food security and Postel (1997) revealed that oceanic systems yield 80 million tons of seafood per year valued at $50-$100 billion.

The various human uses of the coastal zone which cannot be fully quantified include storm surge protection, water filtration, waste discharge and dispersal, industrial power plant cooling and as well as the socioeconomic and ecological importance of the coastal zone (Tobey and Volk, 2002). However, Costanza *et al.* (1997) in their research were able to place the annual value of $12.57 trillion on coastal services and natural capital (excluding that of the open sea) which is ahead of all other ecosystem categories (Tobey and Volk, 2002). The result of densely populated coastal regions is the inflicting of stresses on the finite coastal systems and resources (Cummins *et al.,* 2005). It includes the overexploitation and depletion of fish stocks; reduction in water quality due to pollution from ships (GESAMP, 2001) and land-based sources; and the intensification of global climate change which results from fossil fuels and will have severe consequences for coastal ecosystems and coastal inhabitants (Watson *et al.*, 1997).

As classified by Connolly *et al.* (2001), the impacts on coastal areas include pressure as a result of coastal development and coastal agriculture bringing about pollution in rivers and lakes and reduced coastal water quality. Others include coastal erosion and flooding and tourism and recreational use, which threaten areas of high ecological and resource value. Also coastal industry, ports and harbours lead to loss of habitats, the disturbance and dispersal of contaminated sediments; over-fishing; direct discharge of urban wastewater, domestic sewage and industrial inputs leading to poor water quality and

exploitation of offshore oil and gas which could bring about pollution as a result of accidental spills.

Most coastal zone problems centre on the issue of conflict or trade-offs in terms of biodiversity, pollution control and erosion control against short-term economic development, employment, shelter and food security, and many others in a sea of uncertainty due to climate change (Kay and Alder, 2005). Continuous pressure has consistently been applied to the coastal environment as a result of human impacts coupled with global climate change (Cummins *et al.,* 2005) which if not properly maintained will produce serious environmental consequences. The need to protect the marine environment has led to initiatives to maintain, restore and improve specified qualities of coastal ecosystems and their associated human societies (Olsen, 2003).

1.2   Changes in the coastal zone (Sea Level Rise)

There have been dramatic changes to the global climate in the last century which has brought about increasing adaptation and some problems especially in the coastal environments (Williams *et al.*, 2009). Climate change effects are not uniform but vary considerably from one region to the other and one of its major long-term outcomes is increasing sea level rise (Nicholls *et al.,* 2007). It has been asserted that the impacts of sea level rise are already evident in many coastal communities (FitzGerald et al., 2008, IPCC, 2007b, Nicholls et al., 2007) which in the long-term will bring about significant changes to coastal landforms, ecosystems, estuaries, waterways, and human populations and development in the coastal zone (Nicholls *et al.,* 2007, FitzGerald *et al.,* 2008). These changes in the coastal system occur because of flooding, inundation, and coastal erosion which may occur and bring about a shift in the shoreline as well as the movement of barrier islands, wetlands, beaches landward as sea levels increase. These

changes usually bring about loss of coastal habitats with its adverse impacts on both animal and plant species that depend on them (Williams *et al.*, 2009). Therefore there is a need to understand how sea level rise will affect coastal regions as this can form the basis by which the sea level rise phenomenon on the coast can be addressed both in the short and long term. However, determining the rates of relative and global sea level rise has posed great challenges for the research community as well as coastal policy makers and managers (Williams *et al.*, 2009).

Results from various literature suggests that global sea level rise has accelerated over the past 15 years and that the magnitude of this rise is likely to be more in this century compared to the last (Meehl *et al.,* 2007, Rahmstorf *et al.,* 2007, Jevrejeva *et al.,* 2008). According to IPCC (2007), the average sea level on a global scale rose at an average of 1.8 (1.3 to 2.3) millimetres (mm) per year between 1961 and 2003 but the increase experienced between 1993 and 2003 of 3.1 (2.4 to 3.8) mm per year was faster. In projecting into the future, IPCC (2007) estimated that continued greenhouse gas emissions would raise the temperature by between 1.1 and 6.4^{o}C, and sea level rise estimates would be in the neighbourhood of 0.18 and 0.59 metres within this century. However, this estimate does not include the accelerated melting of the glaciers and polar ice-sheets.

Population has increased in the coasts, and there has been development of large cities around the coast. Eight of the largest ten cities in the world are sited on the coast. Indeed as at 2007, there has been an increase in coastal population with more than 600 million people presently living in low elevation coastal zone areas (McGranahan *et al.,* 2007). Together with the development of cities around the coast, the eventual rise in sea level will put a lot of population and coastal cities in a position where they will

experience significant risks. There is a need for the scientific community to be able to assess the likely effects of sea level rise on the coast and to examine environmental and sea level rise policies. Policies should aim to produce alternative planning and management activities to ensure sustainability of the coastal environment. This will allow society and the environment to adapt to predicted and actual sea level rise. This is the focus of this research.

In managing and minimising the impact of sea level change, various options have emerged for protecting land from inundation, erosion, and flooding. For shorelines, shore protection measures have been agreed to protect developed shores, which, together with retreat policies such as development setback and managed realignment seem to be best practice. It is the view of scientists and coastal managers that if adequate plans are not made now, it could limit the flexibility of future generations to implement preferred adaptation strategies (Titus *et al.,* 2009). Therefore, the onus is on the scientists to ensure the best approach to identifying the impact of sea level rise is developed, making use of the best form of spatial database in which the uncertainty levels are minimal.

Presently, various methodologies exist to assess the impact of rise in the levels of the sea (Gutierrez *et al.*, 2009). Coastal changes are driven by complex and interrelated processes, which make it difficult to ascertain the contribution of sea level rise on the coast. However, in many coastal environments, inundation will be the primary response (Gesch *et al.,* 2009). It is therefore essential that there are accurate delineations of potential inundation zones to meet the challenge of a comprehensive determination of the potential socioeconomic and environmental impacts of predicted sea level (Gesch *et al.,* 2009). In Nigeria, the aerial videotape-assisted vulnerability analysis (AVVA) has

been used to estimate land loss (French *et al.,* 1995), however, a different methodology, the application of geographic information systems (GIS) is employed in this research across a wider set of elements that are vulnerable to the effects of sea level rise. Since sea level rise impact assessment often relies on elevation datasets, these type of data have been employed in many studies such as Dasgupta *et al.* (2007) for predicting sea level rise impacts with the production of vulnerability maps and statistical summaries. However, for the elevation datasets it is highly recommended that the accuracies and the uncertainties of the dataset need be understood, as this will directly affect the reliability and usefulness of sea-level rise impact assessments. The results of sea level rise impact assessment is thus important as this will inform governments, coastal planners, managers and other stakeholders how best to prepare for adaptation in the eventuality of rising sea levels.

1.3   Integrated Coastal Zone Management

In the United States, the Coastal Zone Management (CZM) Act has been enacted in 1972 and was amended in 1996. The act was passed in recognition of the importance of meeting the challenge of continued growth in the coastal zone (Gill *et al.,* 2009). Major land loss of many parts of the United States coastline resulted in the CZM programme and legislation to mitigate erosion with the aid of basic retreat policies. The challenge facing most CZM programmes include

> "protecting life and property from coastal hazards; protecting coastal wetlands and habitats while accommodating needed economic growth; and settling conflicts between competing needs such as dredged material disposal, commercial development, recreational use, national defence and port development" (Gill *et al.,* 2009).

However, most CZM programmes are inherently sectoral in nature. This has brought about institutional barriers and uncoordinated actions in most coastal environments. Integrated Coastal Zone Management (ICZM) has been able to solve the sectoral nature of CZM initiatives as it attempts a more comprehensive approach. ICZM synchronizes coastal management actions in such a way that they are consistent with and support a broader set of overarching national goals for the coastal zone (Post and Lundin, 1996). The basic goal is to make the coastal zones sustainable i.e. making progress towards a viable coastal environment without jeopardising the ability of the future of the coast to be sustainable. ICZM was thus established in the Rio conference to be the mechanism by which sustainability or a sustainable coast could be achieved (Tobey and Volk, 2002). ICZM makes use of the principles of sustainability in maintaining the coast. It is essential that measurement of progress made towards attaining sustainability through a coastal management and sustainability appraisal of the coast including consideration of environmental, economic and social principles should be carried out. This process is aimed at ascertaining the level of sustainability of the coast with the aim to improve the areas that are lacking. An ICZM framework will be ideal in successfully managing the coast in a sustainable manner.

1.4   Research Aim and Objectives

The task for this research is to estimate the likely impact that sea level rise will have on coastal environments in Nigeria. It seeks to assess the reaction of the coasts to scenarios of rising sea levels in terms of erosion and inundation and to assess how government and coastal partnerships' practices are primed towards achieving a sustainable coast.

The aim of the study is therefore summarised as follows:

To Implement a standardised functional mechanism to evaluate the ability of ICZM initiatives in delivering sustainable development in the light of accelerated sea level rise on the Nigerian coast

The objectives to achieve the aim are as follows

1   Estimate shoreline retreat due to erosion as a result of sea level rise in the Nigerian coast

2   Estimate the extent of impacts inundation as a result of sea level rise will have on the Nigerian coast

3   Review and critically assess the tenets of Integrated Coastal Zone Management and the application of sustainability indices to the assessment of the Nigerian coast.

4   Evaluate sea level rise models and the coastal sustainability model with a view to communicating coastal information to progress towards a sustainable coast.

1.5   Structure of the Thesis

This thesis starts with a review of the literature relating to sea level rise and sustainable development at the coast in Chapter 2. Sea level rise (SLR) was first discussed with the opening theme of how SLR will affect coastal regions. It then progressed to review estimates that have been made for global sea level rise in this century. Following this is a review of the response of the coast to sea level rise which is evidenced through shoreline retreat and inundation as well as the assumptions and criticisms of assessing and predicting shoreline changes due to erosion and as well inundation of the coast. The second part of this work identifies ICZM as a measure that will solve coastal problems most effectively. It then goes on to consider the evolution and the theoretical

underpinnings of ICZM. Sustainable development of the coast is the goal; hence there was a detailed review of the methods by which sustainability can be appraised and then the rational for deciding which operating mechanism to use for this study. The Chapter concludes with an overview of the coastal management initiatives in Nigeria.

Chapter 3 gives a detailed explanation of the research methodology. The methodology is in two stages. The first stage details the procedure employed in estimating the impact of sea level rise on the Nigerian coast. An erosion model is employed to predict shoreline changes with sea level rise scenarios; also, inundation maps were produced with the aid of a Geographic Information System (GIS) to display the extent of inundation for the different coasts and for each critical element that will be affected in the event of accelerated rise in sea level. Stage 2 identifies the philosophical and theoretical underpinnings of selecting case studies for operating a model for assessing progress made towards achieving sustainability in the Nigerian coastal zone. A sustainability appraisal system was adopted to be operated to the full with the involvement of four coastal partnerships (organisations) involved in coastal management activities in the Nigerian coastal zone. The last part of this Chapter details a review of the Nigerian coastal profile.

Chapter 4 titled 'Shoreline Retreat in the Nigerian coast and Sea Level Rise' presents the results in terms of the extent of shoreline retreat and the area extent that will be eroded in the event of accelerated sea level rise. Four scenarios (0.5, 1, 2, 3 metres by year 2100) of SLR were considered in the analysis. The scenarios highlight the extent of land that will recede if the sea continues to rise for each of the scenarios. This, with the use of the Bruun model, produces results for the base year (2010) and is then projected for year 2050 and 2100.

Chapter 5, titled 'Impacts of Sea Level Rise due to Inundation', focuses on estimating vulnerable zones to inundation when sea rises. A GIS was used to build models to display regions that will be vulnerable to scenarios of SLR. The SLR scenarios employed are 1, 2, and 3 metres. Six critical elements were identified to illustrate how they will react to scenarios of sea level rise. The critical elements are: land, elevation, economic activity (expressed in Gross Domestic Product), urban extent, agricultural extent, and wetland area. Inundation maps are the product of this Chapter.

Chapter 6 is an assessment of ICZM initiatives within the principles of sustainable development. This Chapter relates to stage 2 of the methodology and in particular the operation of the sustainability appraisal system with respect to the four chosen case studies. For each of these case studies the coastal partnerships are assessed against the standard and a summary analysis was made.

The results of the analysis carried out in the preceding Chapters inform Chapter 7, which is a synthesis of the results obtained. The efficacy of the results for both erosion and inundation was validated. The Chapter concludes by making a judgement as regards to the operability of the sustainability appraisal system in Nigeria.

Chapter 8 defines the overall conclusions relevant to this research and draws out recommendations for adapting to SLR and proposal for ICZM initiatives in Nigeria. The Chapter also identifies the contribution of this research, and potential areas for development and future research.

CHAPTER TWO

2.0   Sea Level Rise and Integrated Coastal Zone Management

2.1   Introduction

This Chapter is a review of the concepts and framework for theories in assessing the

varied impacts of sea level rise and sustainability assessment in the Nigerian coast.

There has been much literature about rising sea levels and assessing its impacts in the

coast as well as coastal sustainability. This chapter deemed it necessary to provide a

review of literature to support the work carried out in this research and as well provide a

supplement and support for the numerous literatures in this field.

2.2   Sea Level Rise and the need for coastal management

Research has revealed that global sea level is rising and at an accelerated rate. The

major likely cause is the increase in the concentration of Greenhouse Gas emissions

(Anderson *et al.,* 2009). The level of the sea is raised by warmer temperatures via

expanding ocean water, melting glaciers and a possible increase in the rate at which ice

sheets discharge ice and water into the oceans (Anderson *et al.,* 2009). A major

challenge for scientists and coastal policy makers and managers is understanding how

sea level rise will likely affect coastal regions and how the coast can be managed

sustainably (Williams *et al.*, 2009). The implication of increasing sea level includes

flooding, erosion and threats to coastal cities in the form of stronger storms, which

could have a debilitating effect on residential communities, infrastructure, beaches,

wetlands, and ecosystems (Anderson *et al.,* 2009).

2.2.1   Sea Level Rise Estimates

The essence of sea level rise scenarios includes: guidance on additional research and

modelling efforts; justifying modifications of engineering designs; altering the land-use

planning process to accommodate rising sea level; and developing impact assessments

to help national policy makers decide the appropriate level of attention warranted by global warming issue (Titus and Narayanan 1995).

In the 20th century, estimates indicate that global sea level rose at a rate of about 1.7mm/yr. however with the advent of satellite observations since the early 1990s; there is more accurate sea level data with near global coverage that shows that global sea level has been rising at about 3mm/yr. (IPCC, 2007). In the Third Assessment Report (TAR) of the IPCC, sea level rise estimates was estimated to be in the range of 0.8 to 2.2mm/yr. (IPCC, 2001). The amount of uncertainty i.e. +/- 0.7mm/yr. was due to lack of information on anthropogenic land water change. Indeed, the TAR listed several sea level rise estimates on a global scale. The Intergovernmental Panel on Climate Change (IPCC) through its working groups estimated the extent of sea level rise in the last century and made projections for this century. In projecting sea level rise estimates, the IPCC's AR4 indicates, global sea levels could rise up to 59 centimetres by 2100 (IPCC., 2007). However, this estimate was relative to the base period adopted which is from 1980 to 1999 and it does not include contributions from Greenland and Antarctica (IPCC., 2007, Meehl *et al.*, 2007 and Anderson *et al.*, 2009). The IPCC projection (18 to 59 cm by 2100) is a likely range, which fundamentally indicates that the actual rise may be lower or higher (Williams 2009). Hence, there exist uncertainties in the estimates of sea level rise rates.

Uncertainties in sea level rise projections could be due to the amount of climate change due to the variation in future Greenhouse Gas emissions (POSTnote, 2010). In addition, there are uncertainties in the physical models used for sea level rise projections (POSTnote, 2010). This has necessitated that the IPCC in the AR4 specifies a model-based range of sea level rise scenarios. Another source of uncertainty could be in the

area of inadequate information as regards the net rate of discharge from the ice-sheets. Incidentally, these rates are not included in the IPCC estimates and therefore form part of the limitations of the IPCC physical climate models. This has now provoked alternative approaches to estimate sea level rise. The semi-empirical approaches with the philosophy that sea level rise rate is comparative to the amount of global warming have provided reliable alternatives (Rahmstorf, 2010). "The difference between the semi-empirical estimates and the model-based estimates of the IPCC" is that the IPCC estimates assumes a near-zero influence of the Greenland and Antarctic ice sheets whereas observations have shown that the degree at which ice sheets are losing mass is increasing over the past two decades (Rahmstorf, 2010).

There has been a call for the estimation of the upper-bound estimate for SLR in this century as there has been new data on rates of deglaciation in Greenland and Antarctica. These ice sheets contain enough water to raise the sea level by almost 70 metres and small changes in their volume will have significant effects (Dasgupta *et al.,* 2007). There have been suggestions by climate scientists (Rahmstorf, 2007) that global sea level will rise up to 1m in this century and hence the need that a global rise of 1m by year 2100 should be considered for future planning and policy discussions (Williams *et al.*, 2009). However, Vermeer and Rahmstorf (2009) proposed a model to link global surface temperature and sea level. Their study revealed that a central estimate of sea level rise is 1.24 metres by 2100. This result coincides remarkably well with a completely independent assessment of glaciological constraints by Pfeffer *et al.,* (2008) which estimated the rate of sea level rise by 2100 to be between 0.8 and 2 metres (Overpeck and Jeremy, 2009). In addition, the semi-empirical model (the H++) used in the UK was able to derive the upper bound of sea level rise around the UK to be 1.9 metres in the next hundred years (POSTnote, 2010). This accordingly shows that there

is a probability for sea levels to rise up to 2m by the end of this century. However, for all these estimates with recent researches, there exist assumptions, which contain substantial uncertainties. Therefore, the SLR estimates give a context and a starting point for refinements in SLR forecasts based on clearly defined assumptions (Pfeffer *et al.,* 2008). Other sources of uncertainties still exist which could cause increased SLR such as the terrestrial water storage; the number, size and catchment areas of marine-based outlet glaciers in the Glacier Ice Cap (GIC), which have not yet been included in many sea level rise estimates, would make improvements in SLR estimates difficult (Pfeffer *et al.,* 2008).

Recent studies that estimate global sea level indicate a greater increase compared to the IPCC estimates but agree with the estimates mentioned earlier. These studies have included deglaciation and the melting of the Antarctic in their sea level rise projections. For example, Hanna *et al.,* (2005), combined surface loss estimates with the widespread glacier flow acceleration in Rignot and Kanagaratnam, (2006) and were able to calculate a doubling of the amount of the deglaciation. In their work, Krabill *et al.,* (2004) estimated ice sheet loss of 74 +/- 11Gt/yr. between 1997 and 2003 in Greenland which thus indicate that its contribution to SLR is about double the projections of the IPCC. Velicogna and Wahr (2006), estimated that there has been a significant decrease in the Antarctic ice sheet between 2002 and 2005; the rate was put at 152+/- 80 cubic kilometres of ice per year and that a significant part of this loss came from the West Antarctic ice sheet (WAIS). The WAIS which is about 14% of the entire Antarctic ice sheet could collapse as a result of human-induced global warming which could trigger global sea levels without it having to melt up to approximately 5 to 6 metres (Tol *et al.,* 2005). The semi-empirical models have predicted sea level rise rates of higher than 1 metre by year 2100. The upper end of these projections still seem uncertain but its

usefulness is in providing upper limits in coastal adaptation plans, where current physical models of future sea level rise is inadequate (POSTnote, 2010).

Expert opinions have been able to indicate that significant sea level rise may occur much earlier than previously thought (Vaughan and Spouge, 2002) and recent studies (Rahmstorf et al., 2007) and (Jevrejeva et al., 2008) suggest the approaching of the higher end of the IPCC estimates. This has brought about academic studies in the significant increases in SLR (Dasgupta *et al.,* 2007). Although the science needed to assign probability to these high scenarios is not well established, studies of this nature are however necessary because of the grave implications it could have in vulnerable coastal regions (Williams *et al.*, 2009).

2.2.2   Uncertainties in Sea Level Rise Assessment

The major use of sea level rise assessments has been in identifying coastal population (Kettle, 2010) and land at risk (Gesch *et al.,* 2009). However, numerous sources and types of uncertainty, which limit confidence in the accuracy of modelled results are embedded in the data and assumptions used to develop these assessments (Kettle, 2010). The sources and types of uncertainties that compromise the accuracy of sea level rise assessments usually arise from the following: measuring and monitoring sea level errors (Woodworth, 2006). Others include: determining trends (Jevrejeva et al., 2006); estimating trajectories of change (Bindoff *et al.,* 2007, IPCC.,2007); predicting social change (Moser, 2005); predicting shoreline change (Slott *et al.,* 2006); and using inadequate data and methods to quantify the impacts (Kettle, 2010). Many sea level rise assessments have been unable to provide detailed information concerning the impacts in coastal environments. This is because most of these assessments have not presented the impacts with the degree of confidence and uncertainty in the elevation data employed that is optimal for decision-making (Gesch *et al.,* 2009). Many elevation dataset used

for sea level rise assessments are poorly suited for detailed inundation mapping especially regions with gently sloping landscape (Ericson *et al*., 2006; Rowley *et al*., 2007; McGranahan *et al*., 2007). Gesch *et al.,* (2009) also noted that the elevation datasets have elevations rounded up only to whole metre intervals, which renders the overall vertical accuracy to be poor when, compared to the intervals of predicted sea level rise over the next century. Vertical accuracy is an expression of the overall quality of the elevation dataset in comparison to the true ground elevations at corresponding locations and for proper quantitative use of elevation data, its vertical accuracy must be known and understood (Gesch *et al.,* 2009). Digital Elevation Models (DEMs) are often used in sea level rise assessments because they are computationally efficient and inexpensive to obtain (Kettle, 2010). Typically, they use low-resolution data due to the unavailability of higher resolution data (Kettle, 2010). Most DEMs are rounded up to a whole feet or metres, referenced to mean sea level with horizontal resolution of about 30 and 90 metres, while some to 1 kilometre. Errors in DEMs are a function of the collection process, processing, quality control of data and geographic characteristics of the land (Hodgson *et al.,* 2003). Many DEMs have global or near-global extent and many studies (Small and Nicholls, 2003; Ericson *et al*., 2006; Gesch *et al*., 1999; Rowley *et al*. 2007; and Hastings and Dunbar, 1998) have used them (GTOPO30) in sea level rise assessments.

The Shuttle Radar Topographic Mission (SRTM) elevation dataset has broader coverage and improved resolution over the GTOPO30 and is available at about 90-metre resolution with near global coverage (Gesch *et al.,* 2009). Various studies, for example McGranahan *et al*., (2007); Demirkesen *et al*., (2007, 2008) have employed the SRTM elevation dataset for their sea level rise assessments; the former for estimates of population at risk and the latter land use/land cover classes in the delineated vulnerable

areas. Many of these studies acknowledged the limitations of their results because of the source data they used, and clearly list the caveats for proper use of the maps, which indicates that the maps are useful in depicting broad implications of sea level rise, but not appropriate for site-specific decision-making (Gesch *et al.,* 2009). With the numerous researches in sea level rise assessments, significant progress still needs to be made to improve the science-based information needed for decision-making. This is because in most sea level rise assessments, the quality of the available input data and the common tendency to overlook the consequences of coarse data resolution and large uncertainties ranges has hindered the usefulness and applicability of many results (Gesch *et al.,* 2009).

Among the limitations of sea level rise studies, include the use of lower resolution DEMs with poor vertical accuracies. There is need for better elevation information to give credence to SLR assessments. Another major limiting factor in sea level rise assessments is the lack of consideration of uncertainty of input elevation data. There is a need for rigorous accuracy testing for vertical errors and its measurement in elevation datasets (Gesch *et al.,* 2009). The overall vertical error is a measure of the uncertainty of the elevation information. In a sea level rise analysis carried out by Kettle (2010), to investigate how uncertainty in DEMs and future SLR lead to different estimates of the population at risk throughout Charleston County, South Carolina, three scenarios were illustrated to represent the projected range of SLR by 2100. The scenarios are 37 cm, 80 cm and 2m for low, medium and high scenarios respectively. Results indicate that uncertainty within DEMs and SLR contributes to substantially different estimates of population at risk (Table 2.1). The uncertainty in DEMs alone contributes to estimates of population at risk that range from 2 to 104,000 people for the 37 cm SLR scenario. Results also illustrate the sensitivity of DEMs to different SLR scenarios. Specifically,

these DEMs did not reveal a difference between the 37 and 80 cm SLR scenarios. This is because elevation units are reported in whole metres and thus lack the sensitivity to detect changes in sea level that occur between integers.

Table 2.1   Population at risk for different SLR scenarios and DEMs

	Modelled population at risk to SLR		
SLR Scenario	Over-predicted Elevation	Reported Elevation	Under-predicted Elevation
37 cm	104,200	50,351	2
80 cm	104,200	50,351	2
2 m	166,621	98,365	32,646

Source: (Kettle, 2010)

Another example to illustrate the importance of the accounting for vertical uncertainty in sea level rise vulnerability assessment is the study carried out by Gesch (2009). In his assessment, four elevation datasets were used to compare delineated areas in a 1-metre sea level rise scenario. The details are in Table 2. Even in the NED dataset that has an approximate horizontal resolution of 30 metres, the delineation of the 1-metre (m) zone is more than double when the elevation uncertainty is considered. This therefore calls into question the reliability of any conclusions drawn from the delineations. From Table 2.2, the DEMs do not have the capability to accurately delineate a 1-metre sea level rise inundation zone. Lidar is more appropriate because it has less uncertainty. This has necessitated SLR assessment to incorporate a range of values in reporting the size of the inundation area for a given sea level rise scenario, especially for sites where high accuracy lidar data are not available (Gesch 2009).

One other major sea level rise assessment study is in estimating the extent of shoreline retreat. Many models exist currently but all their parameters are subject to uncertainties. These parameters are discussed in section 3.4.1.1 in relation to the model used to estimate shoreline retreat along the Nigerian coast.

Table 2.2   The area of potential inundation from a 1-metre sea-level rise as calculated from four elevation datasets, as well as the area of inundation when the uncertainty of the elevation data is considered.

Elevation Data	Area <=1 Metre in Elevation (sq. km)	Area <=1 Metre in Elevation at 95% Confidence (sq. km)	% Increase in Vulnerable Area when Elevation Uncertainty is Included
GTOPO30	6,205	14,986	141.5%
SRTM	470	6,860	1360.6%
NED (DEM source)	4,014	8,578	113.7%
NED (lidar source)	4,195	4,783	14%

Source (Gesch, 2009)

In estimating sea level rise in Nigeria, there was the consultation of past studies and dataset. Fonteh *et al.*(2009) obtained tide data from TOPEX/Poseidon satellite which indicates a sea level rise of between 1.8 to 2.2 mm/yr. in Calabar, Nigeria for the period 1948-2003. The Revised Local Reference Level (RLRL) data and satellite altimetry data between 1993-2003 indicates a relative SLR of 3.1 mm/yr. with a range of lower 95% confidence levels and upper 95% confidence levels of 2.3 and 3.8 mm respectively (IPCC, 2007c). With the tidal predictions obtained from the Nigerian Navy (2008), the upper level is approximately 4.5 mm/yr. If this rate of change continues until 2100, then sea level would have risen to 40.5 cm (0.4 m). This is lower than the IPCC estimates of 59 cm by year 2100. However, with the discussion forgoing, increase in GHG emissions and contributions from Greenland and Antarctica will ensure sea level rise estimates to exceed the IPCC high estimates of 86 cm by 2100.

2.2.3 Need for Coastal Management

Coastal communities and habitats will be increasingly affected by climate change impacts due to sea level rise (Field *et al.,* 2007). Coastal systems will be affected. There could be land loss through inundation; erosion of coastal lands; migration of coastal landforms and habitats; increased frequency and extent of storm-related flooding; wetland losses; and increased salinity in estuaries and coastal freshwater aquifers (Williams *et al.*, 2009). Other impacts that could exacerbate the impacts of sea level rise include severe droughts and storm intensity, and continued rapid coastal development (Nicholls *et al.,* 2007). Human induced impacts also are detrimental to the success of the coast (Sutherland, 2004). With increasing SLR, the effects, which are cumulative, will be felt on both the natural ecosystems and human developments; hence, the need for new and innovative coastal zone management and planning approaches to be employed on the coast, otherwise there will be increasing vulnerability of coastal development and coastal population (Williams *et al.*, 2009).

The need for coastal zone management stems from clear evidence that coastal resources are being compromised; coastal uses are in conflict; or the coastal environment is facing destruction from natural hazards and man-made activities (Sutherland, 2004). Coastal zone management is vital in preventing the weakening and devaluing of coastal resources and making coastal regions susceptible to sea-level rise (Sutherland, 2004). This is supported by (Watson *et al.,* 2001). He stated

> "Integrated coastal zone management (ICZM) is an iterative and evolutionary process for achieving sustainable development by developing and implementing a continuous management capability that can respond to changing conditions, including the effects of climate change".

ICZM is therefore an effective tool for managing the coast as well as an adaptation strategy for sea level rise. The main goals in managing coastal zones are to enable sustainability of the various coastal resources, the livelihood of the community that depends on these resources now and in the future, and mitigating the adverse effects of climate change and its effects such as sea level rise. ICZM is valuable because it has been regarded as the means of by which sustainable development can be achieved on the coast. Sutherland (2004) stressed that ICZM is a tool for good governance of coastal spaces and an adaptation strategy for sea level rise.

2.3   Shoreline Retreat

The effects of sea level rise include among others increased effects of storm surges, erosion and inundation. Rising sea level will increase shoreline erosion. Changing storm patterns and associated changes in wave erosion can intensify coastal erosion along parts of the coastline (McNamara *et al.,* 2011). According to Bruun (1962); Slott *et al.* (2006) and IPCC. (2007a) many coastal areas are predicted to experience high rates of shoreline erosion with increases in the level of the sea and shifting storm patterns which will bring about changes in the configuration of coastlines. Notwithstanding the trend in erosion, there has been an increase in developments along the coastline (Pilkey *et al.,* 1998) which has seen more valuable economic developments coincident with the line of the land water interface (Slott *et al.,* 2008).

Variations in the dynamic interaction of physical processes include natural factors such as storms, waves, currents, sand sources and sinks and relative sea level rise; human activities include dredging, dams and coastal engineering; and the geological character of the coast and the nearshore ensures that most coastlines undergo long-term erosion at highly varying rates (Williams *et al.*, 2009). Scientists find it increasingly difficult to

estimate shoreline changes linkages to sea level rise. This is because of the complex interactions that occur on the coast as well as its dynamic nature which allows it to respond to many driving forces (of which there is comparative inadequate understanding of the linkages between the driving forces) which ultimately contribute to shoreline changes (Cooper and Pilkey, 2004, Williams et al., 2009). Although there is much work done and scientific consensus that climate change is accelerating sea level rise and affecting coastal regions, there are still uncertainties predicting in any detail the reaction of the coast to future sea level rise in concert with other driving processes (Williams *et al.*, 2009). Scientists have the task of informing policy makers and managers what the implication of shoreline changes will have on the coast such as ecological damages, economic losses, and societal problems. In spite of the lack of understanding of the various driving factors and their linkages in contributing to shoreline changes, there have been a lot of appraisals and one of them and the most popular is based on the concept known as 'Bruun Rule' (Cooper and Pilkey, 2004).

2.3.1   The Bruun Rule

The Bruun model is one of the most popular developed models for predicting shoreline change driven by sea level rise on sandy coasts. The model considers the two-dimensional shoreline response to a rise in sea level and a fundamental assumption of the model is that the cross-shore shape of the beach profile, assumes an equilibrium shape over time that translates upward and landward as sea level rises (Gutierrez *et al.,* 2009).

Other assumptions of the model as stated by Gutierrez *et al.* (2009) includes the following

- The upper beach is eroded due to landward translation of the profile.

- The material eroded from the upper beach is transported offshore and deposited such that the volume eroded from the upper beach equals the volume deposited seaward of the shoreline.

- The rise in the near-shore seabed because of deposition is equal to the rise in sea level, maintaining a constant water depth.

- Gradients in long-shore transport are negligible.

The Bruun rule has been applied to estimate erosion rates and shoreline changes (Leatherman et al., 2000); (Leatherman, 2001) and (Zhang et al., 2004). It has been criticised by some researchers pointing out that there are a lot of uncertainties with the concept (Thieler et al., 2000, Cooper and Pilkey, 2004). The reasons put forward include the assumption of profile equilibrium which is difficult to meet on all the coast; the assumption that relative sea level rise always causes shoreline retreat without considering accretion processes which usually take place even under rapid sea level rise (Cooper and Pilkey, 2004). Another assumption that makes the concept difficult to apply on all coasts is the assumption that all sand movement on the shore-face is related to waves. In addition is the assumption of the presence of the depth of closure at the base of the shore-face, and no rock or mud outcrops on the shore-face, and that no sand is lost or gained in a lateral or perpendicular direction from the beach (Cooper and Pilkey, 2004). Criticisms of this model relate to its restrictive assumptions, the omission of important variables, and its reliance on out-dated relationships and erroneous relationships (Cooper and Pilkey, 2004). With regards to the assumption that relative sea level rise always causes shoreline retreat, it has been illustrated that many shorefaces accrete as sea rises which has been due to the abundance of sediment in the nearshore (Thom, 1983); this is not the case for the Nigerian coast especially the Mud and the Delta coast as sediments are cut off. Variables that are important in shoreline erosion are not included in the Bruun model. This includes, the possibility of rock or

mud outcrops on the shoreface, rip currents, storm surge ebb currents, wind driven up and down-welling wave driven up and down-welling, tidal currents, wind amplified longshore currents, and the slope of the coastal plain (Cooper and Pilkey, 2004). With regards to criticisms based on out-dated and erroneous concepts, the shape of the shoreface described by a profile of equilibrium works for some shorefaces but is not universally acceptable (Pilkey *et al.,* 1993). However, with the criticisms levelled against the model, it has been applied widely in coastal management because the model addresses a very important societal problem and there is no simple, viable quantitative alternative (Cooper and Pilkey, 2004). Its application has however been categorised by Cooper and Pilkey (2004) into the following five categories

- Application of the Bruun Rule for coastal management either (a) without question, or (b) after acknowledgement of some shortcomings;
- Non application because of recognition that a site does not meet the assumptions required by the Bruun Rule (still recognising it as a valid concept);
- Incorporation of the concept into other models such that it becomes hidden;
- Rejection of the concept that the Bruun rule relates sea-level rise and shoreline retreat;
- Application of the mechanism (with caveats and/or modification) for basic science.

This study applied the Bruun rule however with the acknowledgement of its shortcomings.

2.3.2 Significance of the Limitations of the Bruun Model
The limitations of the Bruun model include as explained by Ranasinghe *et al.* (2007) is as follows:

The Bruun Rule does not include three-dimensional variability, as it assumes two-dimensional (cross-shore) sediment movement only. Therefore, the rule

does not include alongshore gradients in longshore transport (such as a regional transport rate); alongshore features or structures such as headlands, engineering structures and nearshore reefs that control the shoreline shape due to their impact upon sediment transport; or estuaries/inlets which may act as both source and sink for sediments in the nearshore zone.

The Bruun Rule is only applicable on 'equilibrium' beach profiles, that is, it is not applicable at beaches where there is on-going profile change (for example, the profile is still evolving to the most recent rise/fall in sea level, or change in sediment supply). In addition, the Bruun Rule does not allow for a majority of fine sediments in the dune, which when eroded would be too fine to deposit and remain in the nearshore, and it does not allow for variations in sediment between the nearshore, beach berm and dune.

The significance of all the limitations of the Bruun model, which is evidence in its criticisms as discussed by Rollason *et al.,* (2010) includes:

- In terms of cross-shore and long-shore transport, the model cannot be used to calculate transport under waves even though it is an equilibrium cross-shore profile;
- The model does not have the capability to predict beach erosion hazards for planning purposes. It does not have the capability to model short term (hourly) to long term (up to 100 years) shoreline response. The model cannot model recovery between storms and storm erosion;
- In terms of storm demand, the model cannot calculate long-shore and cross-shore transport during storms, to represent design storm effects along a beach unit;

- Concerning shoreline response to existing wave climate variability and future wave climate due to climate change, the Bruun model is incapable. The model cannot be run with time series (height, period and direction) to represent existing and projected changes to wave climate with climate change;

- In terms of predicting recession due to sea level rise, the analysis that can be performed with the model is limited to unstructured open, long coastlines only. The model is unable to account for regional longshore transport and effects of coastal structures. There is a tendency that the model will underestimate or overestimate recession on shorelines with structural features that interact with longshore and cross-shore transport.

The Bruun model in predicting shoreline retreat can best be referred to as an order of magnitude estimate based on its many assumptions as there are very few coastlines that satisfy its assumptions. As noted by the Department of Environment Climate Change and Water (DECCW, 2010), the Bruun Rule should only be considered a 'coarse, first-order approximate'. The parameters that define the Bruun model are also subject to criticisms due to the uncertainties that surround it. Indeed the need to estimate the depth of closure, with the use of nearshore bathymetry data or the application of the Hallermeier, adds an additional factor of potential error with the estimates of the Bruun model (Rollason *et al.,* 2010). A major significance of the limitations of the Bruun model is that it underestimates the potential for erosion. This was revealed in the study carried out by Rollason *et al.,* (2010) that compares recession rates prediction due to sea level rise between the Bruun model and the Shoreline Evolution model.

With the many assumptions of the Bruun rule, other models to predict sea level rise driven shoreline changes have been developed. These include: the generalised Bruun rule, the Shoreline Translation Model (STM), a rules-based geomorphic shoreline

change model, the Historical Trend Extrapolation, sediment budget, and the coastal vulnerability index (Gutierrez *et al.*, 2009). The generalised Bruun rule by Dean and Maurmeyer (1983) is an adapted and modified form of the Bruun model which was used to apply to barrier islands. Cowell *et al.* (1992) developed the Shoreline Translational Model (STM). The STM incorporates numerous parameters, which characterises the influence of the geological framework into sea-level rise driven shoreline change for barrier islands. Stolper *et al.* (2005) developed GEOMBEST which simulates barrier island evolution in response to sea level rise. However, these models are still subject to more research to advance scientific understanding and inform management (Gutierrez *et al.*, 2009).

The Historical Trend Extrapolation model depends on aerial photographs, global positioning systems (GPS) surveys and most recently, Google Earth, and are used to estimate change rates of shorelines over time periods. This model has been used to predict future shoreline positions and is widely used for coastal management and planning purposes (Leatherman, 1990, Komar *et al.,* 1999). However, for cases involving accelerated sea level rise and assessing its impacts few studies have incorporated shoreline change rates into long-term predictions (Kana *et al.,* 1984, Leatherman, 1984).

The Sediment Budget approach evaluates the sediment mass balance in the coast. This approach involves the quantification and evaluation of the gains and losses of sediment to a portion of the shore which allows for the identification of the changes in the volume of sand in a location compared to adjacent portions of the shore over a time period (Gutierrez *et al.*, 2009). A major drawback to this approach is obtaining accurate measurement - of beach profiles, dunes, and cliff positions - with minimal error; and it

is indeed difficult and costly to collect these types of data; and it requires high-density measurements to evaluate changes in one part of the beach and compare it to another (Gutierrez *et al.*, 2009).

The Aerial Videotape-Assisted Vulnerability (AVVA) analysis is another method developed to assess the physical, economic and societal impacts of sea level rise. The technique involves videotaping the coastline from a small plane at low altitude to capture the relative aspect of the land to the sea, coastal geomorphology, coastal land use etc. (Leatherman *et al.,* 1995). The AVVA technique is the first attempt and a preliminary investigation to obtain quantitative assessment of the implications of coastal land loss in response to sea level rise (Leatherman *et al.,* 1995, Nicholls R.J *et al.,* 1993). The AVVA technique has been used by a lot of authors (Dennis *et al.,* 1995a, French *et al.,* 1995, Dennis *et al.,* 1995b, Volonte and Nicholls, 1995) for comprehensive studies of sea level rise impacts because the technique is a quick and cost effective tool for sea level rise assessments. In Nigeria the technique was employed by French *et al.* (1995) to obtain a quantitative assessment of sea level rise impacts.

2.3.3   Accounting for Uncertainty in Shoreline Change Assessments
The coast is a dynamic and high complex environment. This is because there are many processes interacting either dependently or independently to various extents and the scientific community has not yet been able to represent all the processes. The uncertainty that climate change adds to the existing processes in the coastal zone has made the task of prediction of the impacts of coastal hazards more difficult. This complexity has necessitated assumptions and the development of models which many times exclude some variables. This thus indicates that results from any assessment technique are an estimate and not an absolute outcome (Rollason *et al.,* 2010).

With the Bruun model, the variables involved include the depth of closure, berm height, sea level rise and width of shoreface profile. The depth of closure depends on a parameter, the significant wave height, which is the "average wave height of a third of the highest waves in a wave record" (Masselink and Hughes, 2003). The depth of closure is strengthened by the Hallermeier equation (Equation 2, section 3.4.3.1), though uncertainties revolve round this parameter. A potential source of uncertainty is how the wave data measurement are conducted and the validity of the wave data. For example, the National Data Buoy Centre (NDBC) of the US National Oceanic and Atmospheric Administration (NOAA) reported biases in published wave data from certain, identifiable moored buoy stations at some time- periods. The bias is that the wave spectra and significant wave heights were underreported (NDBC, 1995). For each of the locations where the wave data had been reported, the error margin is about 0.4m. The wave database for this study is the Global Wave Statistics developed by BMT Fluid Mechanics (BMT ARGOSS). The model used by BMT ARGOSS is grid based and has a resolution of 1.25 by 1 degree (approximately 140 km by 111 km). The resolution is a potential source of uncertainty. For berm height estimates, the parameters involved based on the equation of Takeda and Sunamura (1982) include the breaker height (wave height) and wave period. The parameter breaker height involves constituents that include wave period and wave height. Therefore, the sources of uncertainties for estimating the berm heights are the wave period and wave height. The width of the shoreface profile also brings about different levels of uncertainty with it, which mostly is due to how the shoreface profile is measured.

The assumptions of the concept as stated by Gutierrez *et al.* (2009) includes the following

- The upper beach is eroded due to landward translation of the profile.

- The material eroded from the upper beach is transported offshore and deposited such that the volume eroded from the upper beach equals the volume deposited seaward of the shoreline.

- The rise in the near-shore seabed because of deposition is equal to the rise in sea level, maintaining a constant water depth.

- Gradients in long-shore transport are negligible.

2.4   Inundation

Inundation of floodplains occurs in response to sea level rise. Continued increase in sea level will provide a higher base for storm surges to build on and diminishes the rate at which low-lying areas drain, thereby increasing the risk of flooding (Gill *et al.,* 2009). Floodplains are areas that are susceptible to flooding. They are normally dry lands but could be inundated from any natural water source. Floodplains support rich ecosystems, the cycling of nutrients, habitats for microscopic organisms, provide breeding grounds for species, food for birds, are valuable for agriculture because of their high fertility, provide access to fresh water, cheap transportation via rivers and the development of flat land (Gill *et al.,* 2009). The major causes of coastal flooding are tides, storms, and waves which can breakdown coastal defences and inundation of low-lying areas, potentially causing damage to life and property (Wolf, 2009). Significant impacts may occur in the coast if the sea rises. This could involve loss of valuable properties, displacement of population and other societal factors (Wolf, 2009). Projections made concerning present and future sea level rise points to the fact that many floodplains are at risk. Wolf, (2008) was able to estimate that the assets of the UK, at risk of coastal flooding is worth billions of pounds and that this applies to most coastal countries. The impact of developments on the flood plain could be devastating. In the flood of the Mississippi Basin in 1993, about 50 people were killed; more than 70,000 evacuated

and 50,000 homes were damaged (on about 27,000 square miles) across nine states (Gertz, 2008). Indeed, cropland extent of more than 16000 square miles was flooded and in total, the estimated loss is around $16 billion (Gertz, 2008). Developments on the flood plains of New Orleans on 29 August 2005 brought about a devastating inundation even though there was the building of flood defences (levees). New Orleans lies on delicate marshlands and well below sea level, with the Mississippi River running through it (Blenford, 2005). Similarly, in Lagos, increasing water levels and rainfall ensured that the city was inundated on 10 July 2011. There was blockage of water channels and drainages because of high tide, indiscriminate dumping of refuse and building of houses along channels which ensured that the effects were devastating (Akinboade, 2011). The devastation involved the deaths of 25 people (Akoni *et al.*, 2011).

Inundation will be the primary response to sea level rise (Gesch *et al.*, 2009). The task globally is to quantify the various effects rising sea levels will have on coastal systems and to ascertain areas along the coast that will be vulnerable to inundation. Higher degrees of inundation occur in area of gentle slopes. Therefore elevation is a critical factor in assessing the potential impacts of inundation (Gesch *et al.*, 2009).

Up till now, there has been much literature on how coastal processes have contributed to coastline and environmental change (Leatherman, 1990, Komar, 1998, Dean and Dalrymple, 2002, FitzGerald *et al.*, 2008, French *et al.*, 1995) but there have been few studies that have incorporated the use of elevation as a suitable form of dataset to ascertain how vulnerable coastal regions will be to increased sea level rise (Gesch *et al.*, 2009). Sedimentary processes are known to occur on beaches, barrier islands, and wetlands in the retreat and build-up of coastal landscape, but in settings where the entry

of sediment is minimal and wetlands are absent or unable to build vertically in response to rising water levels, the elevation of the land determines the extent of inundation (Gesch *et al.,* 2009). This is the case especially in the Delta coast of Nigeria as transportation of sediments from the River Niger has been cut off and the coast is more dependent on its elevation in its fight against inundation. As explained by Tilman *et al.* (1989) the Kainji Lake reservoir which was commissioned in December 1968 traps a significant portion of the sediment load of the Niger River which makes the Niger Delta receive less sediment. A large proportion of the coastal regions in Nigeria are low-lying and heavily developed. These include the Bar beach area in the Barrier that has been undergoing a lot of engineering construction lately and other areas like the Lekki Peninsula that has undergone a lot of sand-filling to enable residential buildings and high rise developments of high economic value to be constructed. In these areas, inundation will be the likely response to rising sea levels and elevation will play a vital role in determining the extent of inundation. For this study, elevation was adopted to depict coastal areas at risk of potential inundation as this is meant to communicate the adverse effect of sea level rise, with the aim, that the information provided would help decision-making process by policy makers in how best to manage, adapt, mitigate, and reduce the risk due to rising seas.

With inundation analysis, the two main indicators that have been used variously in sea level rise analysis have been the estimated impacts it will have on (a) land and (b) population for different sea level rise scenarios. Other studies have attempted to estimate the impacts for a specific indicator. Following are examples of sea level rise studies and the methods employed:

- Anthoff *et al.* (2006) included tidal range data and gross domestic product per capital indicator;

- the ICF International (2007) examined sea level rise impacts on transportation infrastructure with the use of transportation infrastructure indicator;

- the sea level affecting marshes model (SLAMM) used by (Glick *et al.,* 2008) used wetland indicator to assess the potential impacts of SLR on wetlands and others who have use one or a combination of other indicators to assess potential impacts; and

- (Dasgupta *et al.,* 2007, Dasgupta *et al.,* 2009) used six indicators (land area, population, GDP, urban areas, agricultural land and wetlands) to estimate the impacts of sea level rise in 84 developing countries.

This study adopted the Dasgupta *et al.* (2007) approach to estimate impacts in the Nigerian coasts. The approach involves the use of GIS to model sea level rise impacts and elevation as the basis for sea level rise vulnerability. It uses a set of indicators, which gave a broader analysis of the effects of sea level rise for scenarios ranging from 1 to 5 metres. This is in agreement with the speculations that sea level rise would greatly exceed 1 metre and could be up to 3 metres in this century (Dasgupta *et al.,* 2007). In addition if the Greenland and WAIS break up it might produce sea level rise of approximately 5 to 6 metres in this century (Tol *et al.,* 2005). Dasgupta et al (2007) estimated impacts of 84 countries to sea level rise by grouping 84 countries into five zones. Nigeria is among the twenty-nine countries grouped in the Sub-Saharan Africa zone. This study employed the methodology to estimate impacts for the four geomorphic zones of the Nigerian coast. The coasts will suffer the primary effects of rising sea levels; therefore, results were presented in relation to the coast that is examined.

2.5   Impacted Phenomena

Sea level rise brings about devastating effects, which could include loss of land, population displacement, loss of economic gain, loss of urban infrastructures and amenities, rural areas will be affected, agricultural lands submerged, wetlands impacted and even the disruption of the ecosystem. Dasgupta *et al.*(2007), applied a set of homogeneous indicators for five SLR scenarios for 84 developing countries which include Nigeria. The indicators used by Dasgupta *et al.* (2007) are land, population, gross domestic product (GDP), urban extent, agricultural extent, and wetlands for SLR scenarios of 1 to 5 metres. The study was able to find out that in the developing world, hundreds of millions of people will be displaced by SLR with severe economic and ecological damage (Dasgupta *et al.,* 2007).

2.5.1   Land

The land area that is at risk of inundation from sea level rise are low-elevation lands which will bring about serious and direct environmental impacts such as increased beach erosion, loss of vital agricultural and cultural resources and inundation of many kilometres of coastal land (Rowley *et al.,* 2007). In an analysis to determine the land area that will be inundated in Nigeria, French *et al.* (1995) estimated that about 17,968 sq. km of land will be lost in a 1 m SLR scenario.

2.5.2   Population

Coastal populations will be severely impacted in the event of sea level rise increase. Increasing sea levels will ensure that a substantial number of people living in the coastal areas will become increasingly vulnerable to its impacts (Small and Cohen, 2004). Displacement will occur, then migration of people from their homes possibly to urban centres. In Nigeria, about 12% of the total country's population is found at the coast and according to French *et al.* (1995) about 2.5 million people could be displaced in a 1m

SLR scenario. This study makes a near estimate of the population that will be at risk in the event of increasing levels of sea in the Nigerian coast. Current sea level rise assessments in Nigeria that focus on impacts on coastal populations have relied the 1991 census, there has not been any sea level rise assessment allowing for the growth rate of Nigeria to estimate the impacts of SLR on the coastal populace. With the 2011 United Nations population estimates, Nigeria has a population of about 166 million people. With a population growth rate at 3%, it has been estimated that the population of Nigeria will be about 400 and 730 million by 2050 and 2100 respectively (UN, 2011). With various studies indicating that, more than 10% of the world's population live in the world's low elevation coastal zones and with about 14% of the developing world's population living in the coastal zones (McGranahan et al. 2007), the population that will be at risk in Nigerian coastal zone will be enormous. Hence, it is essential to be able to estimate the number of people that will be displaced in the event of sea level rise by 2100. In addition, the local, state and federal government units will need spatially specific information on the vulnerability of specific population groups in Nigeria for planning adaptation and mitigation strategies (Curtis and Schneider (2011).

2.5.3   Gross Domestic Product (GDP)

GDP is the primary indicator in determining the health of the economy (Investopedia, 2011). It refers to the total market value of goods produced or purchased by all sectors of the economy, which includes the value of exports minus imports in a given year. Economic growth is said to occur when there is a growth in GDP. With classical growth theory (Solow, 1956), GDP is referred to as output which is a function of technology, physical capital and human capital and in expanded growth frameworks there is the addition of production factors which include natural capital and social capital. The limits of GDP are usually seen in their capability to measure welfare growth. These

limits are reiterated by CMEPSP (2009), which include (1) the difficulty in measuring quality improvement in goods and services which may lead to under or overestimation of GDP growth; and (2) government-produced goods and services measured through their input value only which may lead to underestimation of output change if productivity increases. Even though GDP has its shortcomings in measuring economic production (CMEPSP, 2009), it is still an indicator that is essential in a sea level rise vulnerability assessment. For example, Dasgupta *et al.* (2007) measured the impact of projected sea level rise assessment on GDP.

GDP is measured at market exchange rate (MER) and purchasing power parity (PPP). GDP at MER are simple to compute and gives a precise measure of the value of the output the country trades (CIA, 2011). However, it may not capture the value of the larger set of goods produced by the country. PPP is often a more preferred approach because it is the sum value of all goods and services produced in a country (CIA, 2011).

In Nigeria, 95% of foreign exchange earnings and nearly 80% of budgetary revenues are obtained from the oil sector (CIA, 2011). With regards diversifying the economy away from the capital-intensive oil sector, the Nigerian government have not been successful (CIA, 2011). Between 2007 and 2010, there was a noticeable rise in the country's GDP due to "increased oil exports and high global crude prices in 201" (CIA, 2011). The estimate of GDP growth rate for 2011 is 6.9% (Global Finance, 2011).

A considerable portion of global GDP is produced in coastal zones with coastal regions experiencing higher GDP growth (Ci: grasp, 2010). Therefore, in an event of accelerated sea level rise, the economic health of a nation will be under severe threat. In the event of rising sea level, the GDP that will be impacted could be estimated as a

function of elevation versus GDP; the concentration of economic activity (and assets) in coastal zones are expected to increase due to the concentration of both population and economic activity in coastal areas (Brooks *et al.,* 2006). The impacts are enshrined in the loss of productive land, costs of relief and reconstruction after coastal storm and flood events, loss of livelihoods, and impacts on trade and markets (Brooks *et al.,* 2006).

2.5.4 Urban Extent

Urban extent includes the area covered by housing and the infrastructure such as transportation highways, ports, airports, industrial regions, factories, urban amenities refineries, and power stations. These housing and high value infrastructures will be severely affected by inundation and the cost of replacement would be very high. The consequence of inundation to the smallest component of an intermodal transportation system can cause a much larger system shutdown (Gill *et al.*. 2009). Many of the urban amenities in Nigeria are already vulnerable to flooding which will be exacerbated with rise in sea level. Example is the flood that occurred in Lagos in July 2011 that had severe impacts on the urban facilities such as weakening housing structures which eventually led to collapse of buildings and the flooding of notable structures which include the Silver Bird Communications in Lekki, and Channels Television Isheri North Lagos (Akoni, 2011). The urban centres in the Nigerian coast are more in the Barrier coast. This is because Lagos, which was the former capital of Nigeria, now represents the largest commercial city.

2.5.5 Agricultural Extent

In a study conducted by Nichols and Leatherman, a 1 m sea level rise in Egypt will lead to between 12% and 15% of agricultural land lost, 16% of national rice production lost in Bangladesh, and tens of thousands of agricultural land lost in China (Nicholls and

Leatherman, 1995). Loss of agricultural lands could lead to famine in the coastal regions.

2.5.6 Wetlands

With the expected increase in sea level rise, wetlands will be subjected to inundation. There is need for effective management of highly valuable coastal wetland habitats and resources which will only be improved by an

> "in-depth assessment of the effects of accelerated sea level rise on wetland vertical development, the horizontal processes of shore erosion and landward migration affecting wetland area, and the expected changes in species composition of plant and animal communities" (Nicholls *et al.*, 2007).

Human activities threatens urban wetland ecosystems which results to loss of habitat and species, pollution of water, reduction in water resources, and contributions to climate change (Ramsar, 2011). The Ramsar convention in its contribution towards achieving sustainable development has as its treaty the aim to conserve and apply the "wise use" of wetlands through local and national actions and international cooperation (Ramsar, 2011). This involves the maintenance of wetland's ecological character achieved through putting into practice ecosystem approaches within the framework of sustainable development (Ramsar, 2011).

2.6 Integrated Coastal Zone Management

2.6.1 Principles and antecedents of Integrated Coastal Zone Management

Coastal Zone Management (CZM) is an attempt to resolve the increasing pressures on coastal resources and the term 'integrated' was a later addition as it becomes obvious that the effective management of coastal areas requires an inter-sectoral approach (Cummins *et al.*, 2005). Integrated Coastal Zone Management (ICZM), is the adoption of a joined up approach towards the many different interests in both the land and marine

38

components of the coast and also the process of harmonizing the different policies and decision making structures, to encourage concerted action towards achieving specific goals' (DEFRA, 2010). Different government agencies usually carry out duties relating to different aspects of the same physical areas and different uses of the coastal zone. They often undertake the same or similar tasks and sometimes, encountering conflicts with other agencies due to inharmonious and competing objectives of their authorised obligations (Encora, 2009). Merging and or separating some ministries, organisations or agencies, physically or based on mandates, which are some techniques used by the government, has not been successful in yielding the desired results of increased effectiveness in government and reduced duplication of endeavour and resource spending (Encora, 2009). Hence, there is a need to adopt ICZM in managing the coast.

Important aspects of ICZM includes its comprehensive approach which takes into account all the sectoral activities that affect the coastal zone and its resources and its ability to deal with economic and social issues as well as environmental/ecological concerns (Post and Lundin, 1996). The aim of ICZM, is to synchronize coastal management actions in such a way that they are consistent with and support a broader set of overarching national goals for the coastal zone (Post and Lundin, 1996).

At the United Nations Conference on Environment and Development (UNCED), which led to the Earth Summit in Rio de Janeiro, in 1992, coastal nations were encouraged to develop their own ICZM programs. There the Agenda 21 Action Plan was adopted by all 180 nations (Post and Lundin, 1996). Initially, the concept of sustainable development gained wider recognition when the Brundtland Report (1987) alerted the world to the urgency of making progress toward economic development that could be

sustained without depleting natural resources or harming the environment, which went on to define sustainable development as

"development that meets the needs of the present without compromising the ability of future generations to meet their own need" (WCED, 1987).

However, it gained wider prominence and political legitimacy when the ICZM was included as one of the principal recommendations of Agenda 21 towards sustainable development (Cummins *et al.,* 2005). The Rio Conference thus establish ICZM to be the vehicle of sustainable coastal development (Tobey and Volk, 2002).

The aim of the Agenda 21 was that national governments should ensure that all policies develop instruments, which make markets work for the environment and channel development down sustainable paths. Other positive outcomes include

- greater emphasis on the need for all sectors of society to participate in the formation of effective national strategies for sustainable development, in so doing increasing the levels of participation and democratisation within national societies; and the

- 'Rio Declaration', which called for the eradication of poverty worldwide and proposed 27 principles to help guide international action on environment, development and economic responsibilities. (UNCED, 1992).

In order to ensure the successful follow-up of the United Nations Conference on Environment and Development (UNCED), there was the establishment of United Nations Commission on Sustainable Development to check and give an account on the implementation of the Earth Summit agreements at the various levels of governance and acts as the focal point for the governance of sustainable development. The World Summit on Sustainable Development which is one of the 'Rio Clusters' was able to

review the progress made towards sustainability since the Rio conference (O'Riordan, 2003). By year 2000 as compared to 1993, Sorenson (2000) stated that the number of coastal nations engaged in ICZM activities at the national and/or sub-national levels increased to 95 from 57 and that developing countries have accounted for the increased number of ICZM activities. Indeed, the total number of ICZM efforts in developing countries increased to 284 which accounts for 45% of the total efforts in the world (Sorenson, 2002). However the numbers of efforts as well as the number of nations involved in ICZM activities could be deceiving as the database being used revealed quantity as opposed to quality (Sorenson, 2002).

The developing countries to fund ICZM projects received international donations. For example as Rivera-Arriaga (2005) referred to an earlier work in 2002 (PhD thesis) which put the approximate total of international donations to Latin America as $1.263 billion. The World Bank invested $175 million in lending operations in the Asia-Pacific region; while the United Nations agencies, the Global Environment Facility, bilateral development assistance agencies, and private foundations have also been major sources of grants for ICZM (Tobey and Volk, 2002). USAID provided funding of $32 million for ICZM activities in the fiscal year of 2000 (USAID, 2001). Even though the scale of effort needed to address coastal development and resource management issues are low, the international environmental treaties and donations have increased in recognition of the importance of the coasts for humanity and the natural systems they support (Tobey and Volk, 2002). Olsen (2003) outlined that ICZM initiatives must be sustainable over long periods of time, be capable of being adapted to often changing conditions, and provide the mechanisms to encourage particular forms of resource use and collaborative behaviours among institutions and user groups. The overall goal of ICZM is to improve the quality of life of human communities who depend on coastal resources while

maintaining the biological diversity and productivity of coastal ecosystems (GESAMP, 1996) and to promote sustainable coastal development. The literature on ICZM explains its differences from other forms of coastal management practices (Beatley *et al.,* 2002, Cicin-Sain and Knecht, 1998, Olson, 2002, Olsen, 2003, Tobey and Volk, 2002, Westcott, 2004). ICZM involves the creation of institutional mechanisms to coordinate the activities of different spheres of government as well as the fragmented efforts of different sectors and actors involved in diverse coastal activities (Glavovic, 2006).

> "ICZM is thus a dynamic and on-going process of coastal governance that seeks to overcome both vertical and horizontal fragmentation to reconcile the diverse interests and needs of coastal stakeholders in the pursuit of sustainability. Integration is realised over time. It is built on evolving dialogue, cooperation, and coordination and includes sectoral, governmental, institutional, geographic or spatial, temporal, disciplinary, and research-education-policy integration. In contrast to ad hoc, sector-based management efforts, ICZM focuses attention on the coastal system as a whole (recognizing linkages that extend from catchments through the coast to the ocean), and compels decision makers to take into account the system-wide and long-term consequences of their decisions and actions (and/or inaction)"(Glavovic, 2006).

To advance the practice of the discipline of ICZM, concepts, principles and methods are needed which allow for greater cross-fertilization with other conservational practitioners and disciplines (Tobey and Volk, 2002). The cross-cutting principles are related to it being responsive and adaptive; participatory and deliberative; integrated, application of science to management; and capacity building (Tobey and Volk, 2002). Principles are useful in ICZM because:

- they can be used to articulate the most important aspects of an ICZM programme in a clear and accessible way;

- their general nature enables the same set of principles to be applied in diverse circumstances making them an appropriate means of addressing the vast diversity and complexity of coastal issues and circumstances;

- decisions are adapted to particular circumstances while maintaining a focus on achieving the overall purpose as a result of the flexibility intrinsic in applying a set of principles; and

- the principles produce decisions which are consistent with the overall purpose or core values of the ICZM programme irrespective of the sectoral agency making such decisions because they produce powerful integrating effect and apply across sectors if applied in a balanced way (FAO, 2006).

The principles of ICZM have been highlighted in various literature; including (Sorenson, 1997, Tobey and Volk, 2002); and the European Union which identifies six principles as:

- Adopting a wide ranging view of inter-related problems;

- Decision making based on good data and information;

- Allowing for unforeseen future developments

- Working with natural forces;

- Involving all stakeholders and all relevant parts of the administration;

- Using a range of instruments, which include laws, plans, economic instruments, information campaigns, Local Agenda 21s, voluntary agreements, promotion of good practices, for coastal management.

(DG Environment Nuclear Safety and Civil Protection, 2001)

In 2002, the European Parliament and Council adopted a recommendation on implementing ICZM in Europe. The European Commission (EC) document recommends that Member States "take a strategic approach to the management of their coastal zones. This involves among others:

- protection of the coastal environment, based on an ecosystem approach preserving its integrity and functioning, and sustainable management of the

natural resources of both the marine and terrestrial components of the coastal zone;

- recognition of the threat to coastal zones posed by climate change and of the dangers entailed by the rise in sea level and increasing frequency and violence of storms;

- appropriate and ecologically responsible coastal protection measures, including protection of coastal settlements and their cultural heritage;

- sustainable economic opportunities and employment options;

- a functioning social and cultural system in local communities;

- adequate accessible land for the public, both for recreational purposes and aesthetic reasons;

- in the case of remote coastal communities, maintenance or promotion of their cohesion;

- improved co-ordination of the actions taken by all the authorities concerned, both at sea and on land, in managing the sea-land interaction.″ (European Commission, 2002)

In Chapter 2 of the EC document, Member States were encouraged to develop national strategies with eight key principles revolving issues that have to do with coastal legislation, institutions, and stakeholders, to implement an integrated approach to management of the coastal areas. The eight key principles are:

- A broad holistic approach

- Taking a long-term perspective

- Adaptive management

- Specific solutions and flexible measures

- Working with natural processes

- Participatory planning

- Support and involvement of all relevant administrative bodies

- Use of a combination of instruments

Chapter 3 of the EC document recommends that Member States conduct an overall stocktaking to analyse which major actors, laws and institutions influence the management of the coastal zones while Chapter 4 recommends the development of national strategies to implement the principles for ICZM based on the result of stocktaking. (European Commission, 2002).

Despite the articulation of ICZM principles, together with its acceptance as a key solution to solving coastal issues, its development and implementation at the moment exist in 'virtual isolation' in relation to the land and sea divide's policies and practice (Smith *et al.*, 2011). Since ICZM is a paradigm within the field of coastal management, its attributes need to be well developed (Fletcher and Smith 2007) to achieve the intended purpose.

2.6.2 Sustainability

The essence of ICZM is a sustainable management of the coast. This is the type of management that takes the social concerns and economic interests into account as well as safeguarding the ecology (Hannelore *et al.,* 2006). The social, economic and ecological categories of sustainability are the 'three pillars' of sustainability or 'three legged stool' or the 'triple bottom line' (TBL). These three categories have been criticised based on their use. There are notions that the three legs of the stool be balanced to ensure all round sustainability. There are counter arguments that the environment leg of the stool should be the floor on which other legs should stand (Dawe and Ryan, 2003), hence making the environment more important than the economy and

the social concerns of sustainability. Other arguments explained that the TBL tends to highlight potentially competing interests rather than the linkages and interdependencies between them, making the task of integration extremely difficult and promoting trade-offs, often at the expense of the environment (Sheate *et al.,* 2003, Jenkins *et al.,* 2003, Gibson, 2001).

The various perspectives of sustainability have led to the categorisation of sustainability to 'strong' sustainability and 'weak' sustainability. Strong sustainability advocates for no trade-off between all aspects of sustainability (there is a win/win/win situation), and it looks after future generations as well as short-term benefits of development. On the other hand, weak sustainability allowed for some losses providing net capital is maintained or increased (Morrison-Saunders, 2011). The weak sustainability dominates the global economy which allows for environmental loss as against economic gains, indeed, the environment is now valued in monetary terms (Bell and Morse, 2008).

The difficulty on agreeing on a single definition in the application of the concept of sustainability has made the concept to be highly contested. The sustainability or sustainable development literature has reflected its trans-disciplinary nature (Pezzoli, 1997). Most of the definitions revolve around integration of environmental, social and economic dimensions of development (Bond and Morrison-Saunders, 2010). In simple terms sustainability could be said to be related to "what is to be sustained, for whom and over which time frame?" (Morrison-Saunders, 2011). However, the various definitions have strengthened the argument for sustainability but without necessarily progressing it because its interpretation has been tuned with the author's aims which has added to the lack of consensus (Bell and Morse, 2008). It is surprising that with the ubiquitous use and popularity, sustainability still lacks a concrete definition. However, while there is

no formal definition, the principles define what should and should not be done in order for sustainability to become a reality (Bell and Morse, 2008). This is supported by Earll (2005) that argument about the definitions of sustainability does not matter too much but rather understanding the key concepts and characteristics that underpin sustainability (Earll, 2005) will bring about the intended benefit.

With the enormous criticisms against 'sustainability' the question now is should the term 'sustainability' or 'sustainable development' still be regarded as what is needed to ensure that the needs of the future generations are not jeopardized due to the actions of the present? Is the concept enough and sufficient to tackle the environmental problems, issues that deal with biophysical integrity, global climate change, reduction in biodiversity and sea level rise? Is there need for another concept to replace sustainable development since it has been heavily criticised for its shortcomings? Alternatively, can there be new insights into sustainability or modifications to its applicability not only in theory but practically? With the good intentions of the 'Rio Cluster' have there been any identifiable improvements resulting from all the global actions? There have been global summits and practical attempts to deliver sustainable development but they have been flawed as a result of "no coherent scientific underpinning, nor independent appraisal or evaluation, with no clean line of accountability" and, for the most part "no formal codes of practice" (O'Riordan, 2003). Unless there is serious deliberations to amend the areas of its shortcomings many will still regard it as a vague, vacuous, and complicated concept and the goals of sustainability will not be achieved even though the intentions theoretically are good. However, it seems there is light in the tunnel.

Recent works have brought about a pragmatic framework for the routine application of sustainability (Earll, 2005). In the UK, there are a lot of studies and actions as regards promoting sustainability. One of those is the UK national strategy, which was reviewed

in 2005, and the 'securing the Future: delivering UK sustainable development strategy' stems from this review (DEFRA, 2005). The highlight of the goal of the strategy is as follows:

> "To enable all people throughout the world to satisfy their basic needs and enjoy a better quality of life, without compromising the quality of life for future generations'. Achieving the goal is an integrated way through a sustainable, innovative and productive economy that delivers high levels of employment; and a just society that promotes social inclusion, sustainable communities and well-being. This is to be done in ways that protect and enhance the physical and natural environment, and use resources and energy as efficiently as possible. Government must promote a clear understanding of and commitment to sustainable development so that all people can contribute to the overall goal through their individual decisions" (DEFRA, 2005).

The priorities identified include sustainable consumption and production; climate change and energy; natural resource protection and environmental enhancement; and, sustainable communities. In achieving this, the strategy states it will be guided by five principles, which are:

- "living within environmental limits;
- ensuring a strong, healthy and just society;
- achieving a sustainable economy;
- promoting good governance; and,
- using sound science responsibly" (DEFRA, 2005).

In the UK, there are a number of the Planning Policy Statements that are relevant to the incorporation of coastal sustainability into planning decisions and through the Local Government Association, strategies have been set for long term goals for the coast (Gallagher 2006). The UK national strategy has been so useful because it has led organizations to take account of sustainable development and incorporating the concept into their structure and to a certain extent there is a general acceptance of the concept and its relevance in coastal management (Gallagher 2006). A fundamental principle of ICZM is to make possible sustainable development of the coast.

2.6.3 Sustainability Assessment: Indicators

With the growing interest in the concept of sustainability, impact assessment studies have been reassessed by scholars to take account of the sustainable development agenda (Gibson, 2001, IAIA, 2002). The primary aim of sustainability assessment as a policy tool is to ensure planning and decision-making move towards sustainability.

> "Sustainability assessment is often described as a process by which the implications of an initiative on sustainability are evaluated, where the initiative can be a proposed or existing policy, plan, programme, project, piece of legislation, or a current practice or activity" (Pope *et al.*, 2004).

Sustainability assessment involves enlightening decision-makers and structuring the process of decision-making in such a way that they can develop and validate plans or projects from the viewpoint of sustainable development, thus its purpose is to ascertain whether a plan or project will be an advancement on all domains of sustainability (Verheem and Draaijers, 2006).

Sustainability assessment evolved from practitioners of Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) (Sheate W *et al.*, 2003) and they make valuable contributions towards sustainability. Indeed Gibson (2001) stated that

> "Environmental assessment processes…are among the most promising venues for application of sustainability-based criteria. They are anticipatory and forward-looking, integrative, often flexible, and generally intended to force attention to otherwise neglected considerations".

Pope *et al.* (2004), identified two contemporary approaches to sustainability assessment; and they are the EIA-driven integrated assessment and the objectives-led integrated assessment. The former is reactive, usually applied after a proposal has already been conceptualised whereas the latter which has its origin in SEA reflects a desire to achieve a particular outcome defined by integrated environmental, social, and economic

objectives (Pope *et al.,* 2004). However, Pope *et al.* (2004), went further to state with relation to their analysis that both approaches can be described as 'direction to target' approaches and that they do not make significant contributions to sustainability. This view is also supported by various scholars amongst which include Fuller, (2002), Sadler, (1999), George, (2001) that proposals are to be sustainable on their own and not to be assessed for their contribution to sustainability. The summary of sustainability assessment as identified in Pope *et al.* (2004) is as follows:

> Sustainability assessment has been defined in theory but not evident in practice. It aims at determining whether an initiative is actually sustainable in terms of contribution to sustainability. It allows society to define what is meant by 'sustainability', and then to compare initiatives against this definition. In the treatment of impacts, it begins not from a 'trade-off' perspective between impacts, but from the idea that 'sustainability' may be more than the sum of parts. In relation to 'target' limitations, decisions are made upon a clear concept of what is meant by 'sustainability' and defining criteria.

Formulation of long-term strategic objectives will be needed in achieving the coastal sustainability and the development of a set of indicators is one of the ways to control and support sustainable coastal management (Hannelore *et al.,* 2006). Indicators reduce the number of measurements necessary to give an exact description of a situation (OECD, 2003). They are essential for measuring progress towards achieving set goals, measure and communicate the successes and failures of fighting unsustainable trends and promoting sustainable approach to development (Dalal-Clayton and Krikhaar, 2007). This constitute a key tool for evaluating the effectiveness of policies (European Commission, 2005), and provide crucial guidance for policymaking processes (Bossel, 1999), in particular regarding the better integration of policies horizontally across sectors, and vertically between different levels of government.

Indicators simplify the communication of positive and negative developments to politicians, administrators, the public and others (OECD, 2003). Indicators have been used in many fields including environmental management. Environmental indicators appropriately evaluate the level of sustainable management and facilitate further improvement. There is however no single 'perfect' indicator or set of indicators but they are usually modified to their expected use (SECRU, 2001). Practitioners see sustainability indicators as increasingly important tools in the implementation of sustainable development. In 1995, the UNCSD adopted a working list of 134 indicators with the aim of having an agreed set of indicators for all countries to use by year 2001. This has been achieved by the UK Government who established a set of indicators that cover the spectrum of government activities (Gallagher, 2006). This is the UK Government Development Strategy "Securing the Future". It contains 68 indicators - 20 UK Framework indicators and a further 48 indicators to monitor progress.

2.6.4 Coastal Sustainability Indicators

Sets of indicators have been developed both for measuring the sustainability of coastal zone development and the implementation of ICZM policies. Coastal indicators provide policy-makers and the public with reasonable signs of changes in the coast, assisting coastal policy decision making and allowing the public to judge how the coast is performing overall. 'Sustainability at the coast can only be maintained if the ecosystem and other natural assets that generate the resources used by man can be managed in a sustainable manner', therefore indicators are necessary to gauge and monitor progress (SECRU, 2001).

There are efforts made to develop indicators of coastal sustainability and many are still in the process especially applying sustainability indicators to the coast putting into consideration the uniqueness and nature of the coast in question. With regards coastal

sustainability, progress has been only relatively recent concerning specific indicator sets. The themes of indicators for measuring the state of coastal zones have concentrated on the state of the coastal environment with little regard for economic or social aspects of a sustainable coastline and limited link to an integrated management approach such as ICZM. Hence the need for ICZM specific indicators to assess the success it is having (SECRU, 2001).

In terms of the technical framework, the 'pressure-state-response' (PSR) was adopted by various organizations amongst which include the United Nations Commission on Sustainable Development (UNSCD) even though the framework shows clear limitations when tied to sustainable development (Hametner and Steurer, 2007), and the EEA introduced the driving forces and impact indicators to produce the 'driving forces-pressure-state-impact-response' (DPSIR) model. The limitations to the PSR framework as highlighted by Pinter *et al.* (2005) include uncertainties regarding the "underlying causal linkages the framework implies, and oversimplification of complex inter-linkages between issues". At the various levels, there is the development of variety of scales for sustainable development indicators but none is specific to the coast (SECRU, 2001).

Another theme of consideration in assessing the state of the coast is the target audience. Most State of the Environment reports and their associated indicators have been chosen and presented in a manner intended to be clear and easily understood to local communities and the general public because they relate to issues people are more likely to identify with and be concerned about (SECRU, 2001). The development of the headline indicators

detached 'indicators from a larger set, raise public awareness and focus public attention on key issues, provide a clear assessment towards progress in sustainable development, and integrates levels of indicators to build a national picture of trends and conditions of the environment'. However, connection between the effectiveness of most coastal management activities and the state of the environment does not exist (SECRU, 2001)

The design and application of evaluation as a component to ICZM and its associated indicators is less recognised in comparison to many environmental management programmes due to its recent development. As reported by SECRU (2001), suitable outcome indicators are needed to be able to find a relationship between ICZM effort and its impact on the coast. However, ICZM initiatives focusing on outcomes are rare, many of them are performance or capacity evaluations rather than outcome evaluations (Lowry *et al.,* 1999). This is due to certain reasons which include inappropriate documentation of baseline conditions and clear objectives to enable quantifiable and rigorous objective assessment, the infancy of coastal management endeavours, insufficient data, its complexity, lack of indicators that link effort with changing coastal conditions, and the expensive nature of outcome evaluations (Lowry *et al.,* 1999). Another reason is the sectoral nature of coastal management initiatives and indicators to measure progress, and the lack of a harmonised methodology that can be widely applied to many sectors which is evident in the Europe integration indicators (SECRU, 2001)

The Schema d'Amenagement Integre du Littoral (SAIL) developed a set of indicators classified by sectors in 2002. This set of indicators was deemed not to be appropriate to measure sustainable development on the coast and hence its further development. This led to the establishment of the EU ICZM 'Expert group', which then set up a Working Group on Indicators and Data (WG-ID) in order to draw up a list of indicators and assist in coordinating the definition of the way member state should calculate the indicators (Françoise Breton *et al.,* 2006). Also it is for the purpose of advising the group on ways

in which indicators-based assessment could be taken forward (Pickaver *et al.,* 2004). This brought about the recommendation of two sets of indicators. The first is a set of progress indicators to measure implementation of ICZM, and the other, a core set of 27 sustainability indicators for the coastal zone (Françoise Breton *et al.,* 2006).

The progress indicators attempted to bring together coastal and marine practitioners and other stakeholders from different organizations, operating at different spatial scales − national, regional and local (Pickaver *et al.,* 2004). The progress indicators - 4 phases and 31 actions - have been noted by Pickaver *et al.* (2004) as not completely exhaustive but are comprehensive enough to allow progress in ICZM to be measured. However, the actions show what is needed, with the aid of a straightforward, step-wise methodology to pass from a situation where no ICZM is being used to one where it is being fully implemented by being grouped into a series of four, discrete, ordered, and continuous phases. Phase 1 of the progress indicator is to determine if planning and management are taking place in the coastal zone. The phase contains five discrete actions. Phase 2 contains seven discrete actions and deals with determining if a framework exists for taking ICZM forward. The third phase contains 12 representative actions and they seek to know if most aspects of an ICZM approach to planning and managing the coast are in place and functioning reasonably well. The fourth phase with 7 actions is to assess if an efficient, adaptive and integrative process is embedded at all levels of governance and is delivering greater sustainability of the coast (Gilbert and Pickaver 2005). The sustainability indicators are divided into seven groups according to the seven goals of the EU ICZM Recommendation

Using either of the progress or sustainability indicators will not be indicative of how successful ICZM is in reversing declines in coastal regions but the application of the

two sets of indicators (Pickaver, 2008). The progress indicator when 'augmented' with a number of other sustainable indicators will enhance the measurement of progress in sustainable development of the coast (Pickaver, 2008).

There have been other attempts to develop indicators for measuring progress and outcomes in sustainable development in the coast. The International Oceanographic Commission (IOC) in 2006 developed a set of indicators, known as the Integrated Coastal and Ocean Management (ICOM) to measure progress, and sustainability of the coast. The ICOM indicators are of three types, which reflect the three elements of ICOM. They are:

- Governance indicators measure the performance of programme components, as well as the progress and quality of interventions and of the ICOM governance process itself;

- Ecological indicators reflect trends in the state of the environment. They are descriptive in nature if they describe the state of the environment in relation to a particular issue (e.g. eutrophication, or over-fishing). They become performance indicators if they compare actual conditions with targeted ecological conditions;

- Socioeconomic indicators reflect the state of the human component of coastal and marine ecosystems (e.g. economic activity) and are an essential element in the development of ICOM plans. They help measure the extent to which ICOM is successful in managing human pressures in a way that results not only in an improved natural environment, but also in improved quality of life in coastal areas, as well as in sustainable socioeconomic benefits.

In total, the indicators are 37, which include 15 governance indicators, 9 ecological indicators and 13 socio economic indicators.

- The governance indicators are meant to achieve sustainable development of multiple uses of coastal areas; maintain vital ecological processes, life support systems and biological diversity in the coast; reduce vulnerability of coastal and ocean areas and their inhabitants to natural and human-induced hazards; analyse and address implications of development, conflicting uses and interrelationships among physical processes and human activities in ocean and coastal areas; and promote linkages and harmonization among coastal and ocean sectors and activities

- The ecological indicators are meant to maximise the benefits derived from coastal and marine ecosystems, while conserving their biophysical properties on which their health and productivity depend.

- Also, the socioeconomic indicators focus on the interaction between the marine and the terrestrial environments (Cicin-Sain and Knecht, 1998, IOC, 2006)

Comparing the ICOM indicators, and the WG-ID indicators, there are many similarities. The governance indicators are quite similar to the progress indicators except for some few indicators in ICOM not featured in the progress indicator such as the governance indicator, which deals with the existence and functioning of a conflict resolution mechanism, and the indicator, which deals with the incorporation of integrated management into educational and training curriculum. The other way round, action that deals with sea level rise and extreme weather condition in the progress indicator is not reflected in the ICOM governance indicators. The ecological and socioeconomic indicators of ICOM are also similar to the sustainability indicators of the WG-ID in the parameters employed.

From the understanding of environmental management, Earll (2005) said there is now available a pragmatic framework for the routine application of sustainability. He highlighted that in the 1980s the 'lifecycle' of products or 'cradle to grave' aspects of production was the routine of discussion then. There have been a lot of meetings under the title Marine Environmental Management which have grown spectacularly in the last two decades and has moved environment from a peripheral to mainstream consideration (Earll, 2005). Many environmentalists have pointed out sustainability as the key goal to which to aspire (Earll, 2005). He pointed out that the key concepts that underpin sustainability include: integration, precaution, holism, intergenerational equity, the need to integrate social, economic and environmental issues and many others (Earll, 2005). He was able to demonstrate that through the lifetime management systems, a framework is in place for testing and applying most of the constructs of sustainability. Gallagher *et al.* (2004), was able identify 'key constructs' of sustainability in the context of coastal management in conjunction with professional coastal practitioners in the UK.

The concept of 'balance' has been viewed by Gallagher *et al.*, (2004) as the main component of sustainability while other relevant components concerns issues like participation, planning, long-term views, along with responsibility. Gallagher *et al.* (2004) were able to identify twenty three key constructs inherent in the concept of sustainability by conducting a national survey of coastal managers in the UK. From these Gallagher (2006) was able to identify the key theoretical and normative constructs inherent in the development of a coastal sustainability standard. The characteristics of the principles or the six resultant composites include

- The equality of importance and weight in developing a coastal sustainability standard; and

- Representation of the minimum number of discrete principles needed to consider the issue of coastal sustainability in its entirety.

Table 2.1 shows the resultant composites from the constructs or mobile concepts of sustainability.

Table 2.3:   Constructs of Coastal Sustainability

Resultant Composites	Constructs of Sustainability
Planning	Planning, Futurity, Reflectivity, Adaptive
Participation	Participation, Acceptability, Transparency, Trust
Communication	Communication, Education and training
Integration	Integration, Holism
Responsibility	Responsibility, Precautionary, Regulation, Conservation and resource efficiency, Stewardship, Scientific Efficacy, Problem solving
Balance	Balance, Equity, Quality of Life, Success

(Gallagher, 2006)

The coastal sustainability standard is similar to the Marine Stewardship Council in terms of principles and criteria (Gallagher, 2006). The Marine Stewardship Council (MSC) is an independent non-profit organization that has established a global environmental standard for sustainable and well-managed fisheries. The mission of MSC is to promote the best environmental choice in seafood. With many experts, as claimed, there has been the development of standards for sustainable fishing and seafood traceability (MSC 2009).

Gallagher (2006) noted the MSC standard mechanism offered many beneficial characteristics, which are relevant to the operation of the Coastal Sustainability Standard (CoSS). The positives of the MSC standard include approval of the use of a

variety of different performance indicators; and assessment of evidences, both in qualitative and quantitative forms. This has been highlighted by Gallagher (2006) that the MSC standard is adaptive and spatially specific which he considered to be strengths advantageous to the development of the CoSS.

One of the major implications of using the CoSS is that there is a shift from the individual area approach or sectoral management to a more holistic, wide ranging management (Gallagher, 2006). He stated that the CoSS is dynamic, open to development, modification and refinement on an ongoing basis and can therefore be adopted in assessing progress towards ICZM in Coastal Partnerships (CPs) and as a mechanism for comparative review between different Coastal Partnerships. The standard has been tested to offer some efficacy to the appraisal of ICZM initiatives and has been effective in addressing the concept of 'integration' which is lacking in most sustainable development indictors for measuring progress on the coast (Gallagher, 2006). The efficacy of the CoSS is as follows:

> "The CoSS clearly reflects the relationship between sustainable developement and ICZM. It is appropriately designed and accurate in its deployment – this is seen in its flexibility as both quantified and qualified information are considered to have equal validity. Inherent subjectivity in scoring has been minimized through the use of a set of guidelines, definition of terminology, explanation of intent and examples of relevant evidence. The application of the CoSS has revealed a series of shortcomings inherent within the ICZM initiatives in the UK which include structural barriers and lack of appropriate resources needed for the Coastal Partnerships to operate successfully. Also, the use of the CoSS will enable the identification of inherent weakness in ICZM initiatives, by identifying areas of appropriate change and help the ICZM to progress".
>
> (Gallagher, 2006)

Another aspect to the development of the COSS is to reflect systems thinking in coastal management initiatives. As has been previously discussed, a number of indicator suites for the coast have been proposed including the EU Working Group on Indicators and

Data (WG-ID, 2004). However, these indicator sets are subject to critique from a number of perspectives, most notably on the basis their reductionist nature, and its vagueness (Gallagher, 2006). This reductionist approach emphasises the use of methods developed in the natural sciences (Easterby-Smith *et al.,* 2002), to determine verifiable laws which in turn, predict and explain the world around us in terms of cause and effect (Clayton and Radcliffe, 1996).

Further development has brought about the 'post-positivism' thinking as well as constructionism, advocacy/participatory, and pragmatism, when studying human behaviours and actions (Creswell, 2003). From various schools of thought, Creswell (2003) elucidate that pragmatism offers the best means of progression because it is pluralistic by allowing for a mixture of methods to be utilised; and it is problem-centred and practice oriented. Another positive aspect of this paradigm is that it evaluates the consequences of actions.

One of the benefits of this pragmatic approach as mentioned by Capra (1996) is its ability to employ 'systems theory' which can be considered as an alternate paradigm and reflects the nature of holism, which encapsulates the world as an integrated whole rather than a dissociated collection of parts. 'Systems' thinking is useful for investigating complex situations and it involves a holistic approach that looks at the behaviour of wholes, and the many interconnections between the components using a variety of methods (Open University, 2011). Two key principles as discussed by Gallagher (2006) are involved in systems thinking. The first is structure i.e. they exist in hierarchies, where sub-systems fit into larger systems, and where each level of system in the hierarchy has one or more unique emergent properties. Second, is communication which explains that elements within and between systems are connected and

communicate with each other thus enabling feedback to occur and for the system to remain stable. It has been acknowledged that the systems approach is the best appropriate to manage the coastal zone as the dynamics of the coast critically depend on interactions and feedbacks operating within the multidimensional entity and in particular on interactions and feedbacks between natural and social processes (Van Der Weide, 1993).

The application of systems thinking in the pragmatic approach has offered a useful alternative and it has the capability of offering a greater degree of efficacy than the others offer. Though the development of suites of indicators to assess the effectiveness of ICZM in achieving its goals are relatively new, slow, and many have been opened to some conjecture (Gallagher, 2006), progress in this area is evident in the two sets of indicators developed by the WG-ID (2004). The first, the progress indicator that assesses the degree of ICZM implementation and second, the sustainable development indicators aimed at enabling an assessment of the coastal status. The progress and sustainability indicators have been under criticism based on its methodology. Gallagher (2006) itemised the criticisms as follows:

> "Firstly, they are vague and open to a degree of conjecture that would appear insurmountable in its present guise. Secondly, it is not clear how the 'progress indicator' specifically relates to the 'indicators for sustainable development of the coast', which raises the question of whether the two indicators sets specifically apply to progress of sustainability through ICZM. Thirdly, they are criticised on the basis of their reductionist nature".

The CoSS is preferred for this study based on the efficacy already discussed in the foregoing. A comparison in Table 2.2 reflects the major suites of coastal indicators considered in this study and putting into consideration issues such as the function, number of indicators, and methods of assessment of the parameters involved. An important issue for discussion is the method of assessment employed by the various

suites of indicators. Out of the indicators set, the Coastal Sustainability Standard employs a full quantitative technique in the measurement of the various criteria of assessment. The progress indicator adopted the binary assessment of the actions. This gives either a yes or no answer. It did not provide a means by which the 'yes' answer could be qualified. The sustainability indicators of the WG-ID are purely qualitative. The IOC adopted a number of measurements which include the binary 'yes/no', semi-quantitative - which seek to know for example, the current status (which include 'under development', and 'in place') of coastline covered by integrated management plans but it is not revealing the level by which the status 'under development' and 'in place' is.

Other methods of assessment employed by the IOC include the identification of parameters, qualitative assessment, and the provision of general guidelines. The CoSS with its scoring criteria was able to indicate if a criterion is in operation or not, the status of the criterion, as well as qualifying the status. The CoSS employed both qualitative and quantitative methods in assessing and analysing the various criteria, provision of a set of guidelines to minimise subjectivity in the scoring system, which promotes objectivity, repeatability, and transparency, producing the potentials for comparative audits and analysis on a periodic basis between the CPs.

This study will thus adopt the Coastal Sustainability Standard and its inherent principles as the methodology to assess sustainability in the coast. Section 2.6.5 is a review of the six principles of the Coastal Sustainability Standard together with the criteria for each principle and the guidelines for scoring.

Table 2.4:   Summary of Coastal sustainability Indicators

Suite of Indicators	Function	Number of Indicators	Method of assessment	Reference
Progress	Governmental/Performance	31	Yes/No, (Binary),	Pickaver *et al.* (2006)
Sustainability	Ecological, Socioeconomic	27	Identification of parameters Qualitative	WG-ID (2004)
Integrated Coastal and Ocean Management	Governmental/Performance Ecological, and Socioeconomic	37	Yes/No, (Binary), semi-quantitative, Identification of parameters, Qualitative general guidelines	International Oceanographic Commission (2006)
Coastal Sustainability Standard	Governmental/Performance Ecological, and Socioeconomic	54	Identification of parameters Suite of guidelines for each parameter Rank from 0 to 10 (qualitative and quantitative)	Gallagher, (2006)

2.6.5   Coastal Sustainability Standard's principles, criteria and guidelines

In the development of the CoSS, Gallagher, (2006) was able to deconstruct sustainability into six principles with a set of criteria against which both qualitative and quantitative assessment of coastal management initiatives could be established. The combined set of principles and criteria represents the basis of the coastal sustainability standard. Following is a brief review of the six principles.

2.6.5.1   Planning

Planning is a process and it is a representation of a course of action by which intentions are stated and detailed proposals are made to achieve balance between enabling development to take place and protecting the environment (Gaunt *et al.,* 2006) for the purpose of achieving the stated goal through reflection and evaluation. The three main components of planning are:

- determining aims for what is to be achieved in the future;

- clarifying steps required to achieve those aims;

- measures that must be put in place to monitor a plan's effectiveness in meeting its anticipated aims (Kay and Alder, 2005).

Planning has undergone paradigm changes, which brought about different models in planning. Among them, include the synoptic or comprehensive model, disjointed incremental planning, and advocacy planning. Out of the models of planning, the comprehensive model itemises all the steps, coordinates and integrates every sector in the system. The comprehensive model is a continuous process that starts with the intentions by defining the goal and objectives, continues to the review and feedback stage, and then leads to the redefining of goal and objectives. The planning process is iterative and based on cyclical evaluation, system development, implementation, and monitoring and review which involves reflection on past actions in accordance with defined goals for the purpose of enabling change (Gallagher, 2010). The core ideas of planning include it being

- spatially specific;

- sustainable;

- integrative;

- inclusive (Royal Town Planning Institute, 2001); and

- temporally related;

- objective;

- performance based;

- testable; and

- adaptive and self-regulating (Gallagher, 2010).

2.6.5.2   Participation

This principle has to do with the role transparency plays in every decision taken by individuals, stakeholders and organisations. Public participation is portrayed by Arnstein (1969) is the citizen's power in decision-making. The citizen's power starts from the stage of partnership, then moves on to delegated power, and then high up on the ladder is citizen control (Arnstein, 1969). Except citizen power is activated, there is no form of legitimacy in plan and decision-making process. Participation aims at encouraging open discussion and the sharing of needs and ideas and in the working of solutions rather than trying to change the view of the participants (Clark, 1998). Participation involves information giving, information gathering, shared working, deciding together, and empowerment (European Commission, 1999) to foster trust and acceptance. Specific criteria of the principle involves

- diversity of stakeholders;

- sustainability of involvement;

- solution based; and

- Transparent

2.6.5.3   Communication

Communication involves imparting of information to advance understanding and ultimately improves behaviour and attitudes with regards coastal sustainability. As defined by Gallagher (2010), communication is "a process enabling capacity building to take place through the effective flow of information". Good communication is essential as it "keeps people in the picture, provides opportunities for dialogue, for discussing and resolving problems; and helps to attract and sustain interest to get things done" (European Commission, 1999). Specific criteria for the principle include

- diversity of techniques;
- raising awareness and education;

- effective use of language;

- and a two-way process (Gallagher, 2010).

2.6.5.4 Integration

Integration in coastal management is an attempt to avoid fragmentation and to bring together disparate elements into a single coastal management system (Kay and Alder, 2005). A single agency will find it impossible to manage the coast in a successful way because of the complexity of the coast thus integrated coastal management, which involves collaboration, and coordination among multiple sectors will be appropriate. A simple idea to integration is holism, i.e. application of a systems-based approach to coastal management (Gallagher, 2010). Integration is fundamental to ICZM and it a tool by which ICZM assessment can be made (Firn Crichton Roberts Ltd and Graduate School of Environmental Studies University of Strathclyde, 2000). Specific criteria according to Gallagher (2010) should involve

- different forms of integration;

- co-ordination of different subject disciplines;

- solution based; and

- systems based

2.6.5.5 Responsibility

This principle relates to the application of 'due care' on the coast with appropriate and practical tools and techniques to enable improvements in coastal sustainability (Gallagher, 2010). This will involve the use of best practicable means, environmental impact assessment (EIA), the precautionary principle, life cycle analysis, risk assessment and management, the polluter pay principle, and ecosystem-based approach among a host of others. There should be the integration of these tools in an ICZM plan. This principle focuses on three characteristics and they are:

- legally based;

- operate, apply and broaden existing management tools and techniques; and

- exhibit risk reduction and 'due care' (Gallagher, 2010).

2.6.5.6   Balance

This has to do with maintaining integrity between the environment, economic development, and social factors, which has been a fundamental attribute or principle of sustainable development. The main aim is maintaining the integrity of the natural environment, providing economic prosperity and equal opportunity for people to benefit from a better quality of life (Gallagher, 2010). Considerations of this nature is actually based on value judgments relative to the situation and also the decision either to achieve strong or weak sustainability (Bell and Morse, 2008). Hence, the need for an effective process that weighs up such value judgments as well as identifying specific changes in the status of individual areas (Gallagher, 2010). The specific criteria for measuring balance as highlighted by Gallagher (2010) should reflect the following characteristics

- identify key status quality; and

- relationship focused

2.7   ICZM in Nigeria

Integrated coastal zone management has not been practiced in Nigeria, but there are many coastal management practices that take place along the coastline. At the Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central Africa Region (also known as the Abidjan Convention) in 1981, its protocols was adopted and Nigeria is one of the 14 countries that ratified the protocols (UNEP, 1981). The Abidjan convention recognised the environmental uniqueness and natural resources as well as the threats and necessity of action in the marine and coastal environment of the West African region which led to

the formulation of an Action Plan to protect and develop the region's marine and coastal environment (UNEP, 1981).

Nigeria, following the Abidjan convention has embarked on a comprehensive assessment of the status of the Nigeria coastal zone (UNEP, 2002). The report was able to identify the major problems of the Nigerian coast and they are overexploitation of fisheries; coastal and marine pollution; oil spills; coastal erosion and flooding; physical modification and destruction of habitats; climate change and sea level rise, and invasive species. Recommendations of urgent actions needed to mitigate the listed problems were made. Among them include: monitoring of coastal and marine processes for integrated management of degraded ecosystems, mitigating coastal erosion using environmentally friendly options, development of national climate change plan of action, and coastal protection from flooding and erosion resulting from sea level rise (UNEP, 2002).

Various government bodies have been set up to tackle coastal problems in Nigeria. In the amended constitution of 1984, three tiers of government – Federal, State, and Local - exist in Nigeria and they are allowed within a certain amount of power to make legislation, laws, and edicts on the environment. Apart from these, other agencies are involved in activities that aim to deliver a sustainable coast. A joint Ministerial committee was set up by the Federal Government to coordinate the activities of these agencies through consultations. There are national, states, and local government legislations and edicts designed to guarantee sustainable management of the coast. The Federal Ministry of Environment has a national jurisdiction for all environmental issues. It has also produced the National Policy of Environment. The policy's objective include "securing a quality environment; conserving and using natural resources for the benefit

of the present and future generations; restoring, maintaining and enhancing ecosystems and ecological processes"; raising public awareness and promoting understanding of the essential linkages between environment and development; and liaising with other countries and international organisations and agencies to achieve the stated objectives (UNEP, 2002).

Despite some legislative attempts to conserve the Nigerian coastal and marine area, there have not been strategic actions to the preservation and sustainability of the coast. It could be argued that there are inadequate laws; inadequacies in government policies and lapses in responsibilities; poor database, poor awareness and communication which limits the flow of information and the ability of stakeholders to participate fully in sustaining the coast. ICZM by its attribute is what is needed to ensure a sustainable coast. The United States enacted the Coastal Zone Management Act, and in the UK the Marine Bill is enacted which put into consideration largely the fundamentals of ICZM. There is no ICZM act in Nigeria, except for the piecemeal and sectoral approaches, which have limited sustainability potentials. However, sequel to the Lagos flood in July 2011, the House of Representatives of Nigeria has urged the President to assent to the National Climate Change Bill passed by the Nation Assembly in 2010 (Nzeshi, 2011). Even though, there have been interests all over Africa with regards to an integrated system of coastal management, Nigeria is yet to develop and adopt ICZM as a solution to the marine and coastal problems. The various interests are seen in the various conferences and agreements made. Examples of some of them include

- the Arusha Conference on ICM in Eastern Africa, held in Tanzania in April 1993;
- the Seychelles Workshop on ICM in February 1995;
- the Abidjan and Nairobi Conventions on ICM;

- the Pan-African Conference on Sustainable Integrated Coastal Management (PACSICOM), held in Maputo in July 1998; and

- the Conference on 'Cooperation for Development and Protection of the Marine and Coastal Environment in Sub-Saharan Africa', held in Cape Town, South Africa, in December 1998 under the sponsorship of the Advisory Committee on Protection of the Sea (ACOPS) and the United Nations Environment Programme (UNEP).

At the last-named conference, 30 Sub-Saharan African countries were represented, 27 of them at the ministerial level (Hewawasam, 2002).

The development of ICZM in Nigeria could seem like a daunting task, as major issues need addressing. Firstly, the acceptance that a single-sector approach or any form of sectoral approach cannot address the multi-sectoral identified issues of the coast. Secondly, there needs to be the availability of adequate institutional and human capacity; bridging of knowledge gaps through the application of necessary information acquisition technique and its sharing to advance knowledge; application of ecosystem approach to coastal sustainability, and a wider scope and provision of funding for immediate and long term goals (Hewawasam, 2002).

Information is critical to the development of any ICZM plan especially when planning is to be made for long-term situations. For example, the phenomenon of rising sea levels which is a major element of this study. This study estimates the impacts rising seas will have on the Nigerian coast with the aim of it being an information base/data that can be worked with on a large scale. There should therefore be planning for data management and archiving at the national level of government. The important issues to consider in

data management include, the volume of data; quality control and assessment mechanism of data to ensure its correctness and reliability; consistency and integrity of the data; clear procedures for updating the data; availability of documentation and metadata; access options for the data; backup of data; and long-term data archival (Masalu, 2008).

CHAPTER THREE

3.0 Research Methodology

3.1 Introduction
This research considers the effects of sea level rise (SLR) on the Nigerian coast with the aim of employing and developing models of sea level rise to estimate erosion and inundation for four SLR scenarios. The research is not about proposing isolated measures to mitigate and adapt to rising sea levels, but to highlight the extent of the impacts of sea level rise on the coast and to assess organisations involved in managing the coast to ascertain how sustainable their practices are. This Chapter outlines and justifies the research methodology employed in order to fulfil the research aims and objectives. It starts by stating the specific methodology in relation to the research and segmenting them into stages, and then identifying the limitations.

3.2 Methodological approach and design
Studies, especially by Creswell (2003), identified various methodological approaches to research. These include qualitative approaches, quantitative approaches that are already established and traditional research methods, and the mixed method approach developed by Creswell. This study adopts the mixed method approach because of its pragmatic philosophical assumptions. The methods of enquiry are sequential, concurrent and transformative. It involves the use of both open and closed questions, pre-determined approaches and both qualitative and quantitative data and analysis. The study employs a variety of methods in a multi stage process to build logically and enhance the validity of the research outcomes.

3.3   Research Stages

This study is divided into two distinct research stages. It ascertains the reaction of the coast with projected sea levels considering various indicators that are important along the coast. The case study approach is adopted for this research. This was done using field observation, semi-structured interview, questionnaires to obtain information relating to coastal management, collecting spatial datasets, and applying Geographic Information Systems (GIS) to analyse the impact of sea level rise on each of the indicators considered in the case studies.

A principal objective of this research is to ascertain progress made towards sustainability. This is a gauge to know how the coastal partnerships are prepared or preparing for natural hazards such as sea level rise. A sustainable coast is the goal, and managing the coast in a sustainable way is one of the adaptation measures in the event of sea level rise or other forms of climate change related problems. The following is the breakdown of the stages

Stage 1: Models for sea level rise impacts: This involves the use and the development of sea level rise models for shoreline change due to erosion and inundation of the coast respectively. The models were then used to determine the impact of sea level rise on the Nigerian coast:

Stage 2: Operation of the Coastal Sustainability Standard: This involves the selection of appropriate case study Coastal Partnerships (CPs) in the Nigerian coastal zone to ascertain progress towards achieving sustainable development in the Nigerian coasts.

3.4   Stage 1: Models for sea level rise impacts

This research uses the model proposed by Bruun (1962) to calculate erosion due to sea level rise. The research calibrated the parameters involved (section 3.4.3.1). For inundation analysis, GIS was used to develop inundation models for each indicator considered and for the SLR scenarios considered in this study. Maps were produced to display the extent of inundation on the critical elements on the coasts considered for this study.

3.4.1   Sea Level rise Scenario and Timescales

This study does not provide a forecast of future rates of sea level rise but evaluates the implications of four sea level rise scenarios over the next century for shoreline retreat with three of the scenarios for inundation analysis. The scenarios are based on a combination of the twentieth century sea level rise rates especially the global mean scenarios using the IS92a greenhouse-gas emissions scenario and the cooling effects of aerosols by Warrick *et al*. (1996) and empirical estimates of sea level rise by the end of this century.

- Scenario 1: the IPCC AR4 estimates for sea level rise by 2100 ranges between 0.18 and 0.59 cm for the low and high estimates respectively. However, this model-based range excludes future rapid dynamical changes in ice flow. This estimate is much lower than the TAR, which was based on Warrick et al. (1996) estimates. The Warrick *et al.*. (1996) estimate of sea level is 0.2m, 0.49m and 0.86m for the low (no acceleration), middle and the high estimates respectively. For the low estimate of this study, the middle estimate of Warrick *et al.*. (1996) was adopted and for mathematical reasons this was estimated to be 5.55mm/yr. over a period of 90 years. This thus amount to 0.5m, which represent the low scenario of this study.

- Scenario 2: IPCC in its TAR report gave a range of 9 to 88cm if the ice sheet uncertainty is included but reports from semi empirical tests have proved that the IPCC estimates is underestimated (Rahmstorf, 2007; Jevrejeva *et al.,* 2008; Pfeffer *et al.,* 2008; Vermeer and Rahmstorf, 2009; Overpeck and Jeremy, 2009). Conclusions from many climate scientists including Rahmstorf (2007) suggest that sea levels will rise up to 1 metre by the end of this century therefore the scientific community with thoughtful precaution suggests that a global sea level rise of 1m to the year 2100 should be considered for future planning and policy discussions (ref). Therefore sea level rise of 1m by 2100 is the middle scenario for this study

- Scenario 3: The high scenario for this study assumes a 2m sea level rise by 2100. This is based on various observations of climate scientists that have reported that glacier flow loss acceleration, the Greenland and the Antarctica (West Antarctic Ice Sheet) loss is more than double the TAR estimates of the IPCC in the last decade (Rignot and Kanagaratnam, 2006; Hanna *et al..* 2005; Krabill *et al;* 2004 Velicogna and Wahr, 2006). Indeed semi empirical tests have revealed that the upper end of sea level rise estimates will be about 2m by 2100 (Rahmstorf, 2007; and Pfeffer *et al.,* 2008, POSTnote, 2010).

- Scenario 4: This scenario is the extreme sea level rise estimate – 3m by 2100. This scenario is considered in this study because of the increasing concern that human-induced global warming could cause the WAIS to collapse (Mercer 1978), which may trigger up sea level rise in excess of 5m (Tol *et al.*, 2006). This has triggered research to model estimated impact of significant increases in SLR. This research considers only a 3m SLR under the extreme climate scenario by 2100. Dasgupta (2007), has already claimed that if there is continued growth

of greenhouse gas emissions and associated global warming, SLR could be 3m

by the end of the century.

The time scales associated for SLR for this research is principally 90 years, bringing

projections up to the end of this century. Many climate scientists including the IPCC

have proposed this timeframe to aid future planning and policy discussions. Therefore,

all SLR impacts are projected to the year 2100. For the 2050 sea level rise impact

projection, this research used this as a highlight of the extent of impact by 2050 but not

considered important for the study. However, in the SLR scenario using the IS92a

greenhouse-gas emissions scenarios of Warrick *et. al.,* (1996), the low, medium and

high estimates by 2050 were proposed.

3.4.2 Data Requirement

In order to use and develop sea level rise models, the key data requirements are focused

on erosion and inundation. The following is the list of data and their sources used in this

study and the parameters that have in-built uncertainties.

3.4.2.1 Erosion Data

The data needed to estimate erosion includes depth of closure, wave data (used to

calculate significant wave heights), sea level rise estimates for Nigeria, beach width and

berm data. Uncertainties are incorporated into the calibration of these data which forms

the parameters of the Bruun model. These data form the parameters of the Bruun model.

Depth of closure

Nicholls *et al.* (1998) define the depth of closure as the boundary between the upper and

lower shoreface which can be used to deduce a seaward limit to significant cross-shore

sediment transport. Depth of closure is widely used within coastal engineering as an

empirical measure of the seaward limit of significant cross-shore sediment transport on sandy beaches (Nicholls *et al.,* 1998). The depth of closure is applied in the estimation of coastal budgets, numerical models of coastal change, beach nourishment design and the disposal of dredged material (Masselink and Hughes, 2003). The prediction of the depth of closure remains a difficult task as there are limited models to predict it (Nicholls *et al.,* 1998).The depth of closure can be determined if high-quality, repetitive morphological surveys of the shoreface are available (Masselink and Hughes, 2003). Uncertainty revolves with the major parameter of the depth of closure, which is the significant wave height. This uncertainty was accounted for by conducting a basic sensitivity analysis in section 4.4. For this study, these data are not available; hence the equation proposed by Hallermeier (1981) was employed (see section 3.4.3.1).

Wave data
In estimating the depth of closure using the Hallermeier (1981) equation, wave data is crucial. The Global Wave Statistics Online (BMT Fluid Mechanics, 2010) database provided the wave data for the study established on long-term (more than 130 years) wind and wave statistics for all the world's ocean. The wave data is based on visual observations of wind speed and wave height obtained from the UK Meteorological Office. Other sources of data could be considered and the sources of data currently available are usually classified into instrumental (including remote sensing from satellites); hindcast (estimated from wind field analysis); and visual (BMT Fluid Mechanics, 2010). The database covers over a hundred worldwide and 31 European sea areas; and is populated with results such as wind speed probabilities, extreme wave heights, wave height and period joint probabilities, and storm and calm persistence statistics (BMT Fluid Mechanics, 2010). However, with 104 sea areas for the whole world, that for Nigeria extends from Sierra Leone to Cameroon (Abbott *et al.,* 2011). This is a major uncertainty with the wave data. A basic sensitivity analysis conducted in

section 4.4 of this study uses other wave heights obtained from different sources (e.g. Surfline/Wavetrak, Inc, 2011; and Surf- forecast, 2011) to determine the extent of uncertainty of the sensitivity analysis. The data was used to estimate the mean annual significant wave height and wave period for the Nigerian coast.

Sea level rise estimates
This data was obtained from the Hydrographic Office of the Nigerian Navy. The details of this is mentioned in section 2.2.1

Width of Shoreface
The Google Earth satellite image was used to determine the width of the shoreface. The coastline width is a consequence of the tidal range and the slope of the beach. Without knowing the time (tidal state) of the Google Earth image, an estimate of width of shoreface was measured from the water line – relating to the depth of closure to stable features. *In situ* measurements were carried out and these measurements were verified from the Satellite image. Uncertainties exist in the measurement and with the satellite image with resolution of about 15 metres. For example, a location along the coast suggests that the width of shoreface is about 43 metres but the measurement on the satellite image records it as 41 metres. Comparing the results of the measurement in the *in situ* data to the satellite image for the locations shows approximately +/- 5 metres difference. This forms the basis of the sensitivity analysis conducted in section 4.4. Measurement on the satellite image involves dividing the coastline into a segment of 5km, 10km and other lengths depending on the attribute of a specific segment of the coastline. Within each segment, three measurements were taken at three sites, which were then averaged to give the width of the shoreface for each coastal segment. Figure 3.1 shows the width of shoreface in the illustration of the Bruun rule.
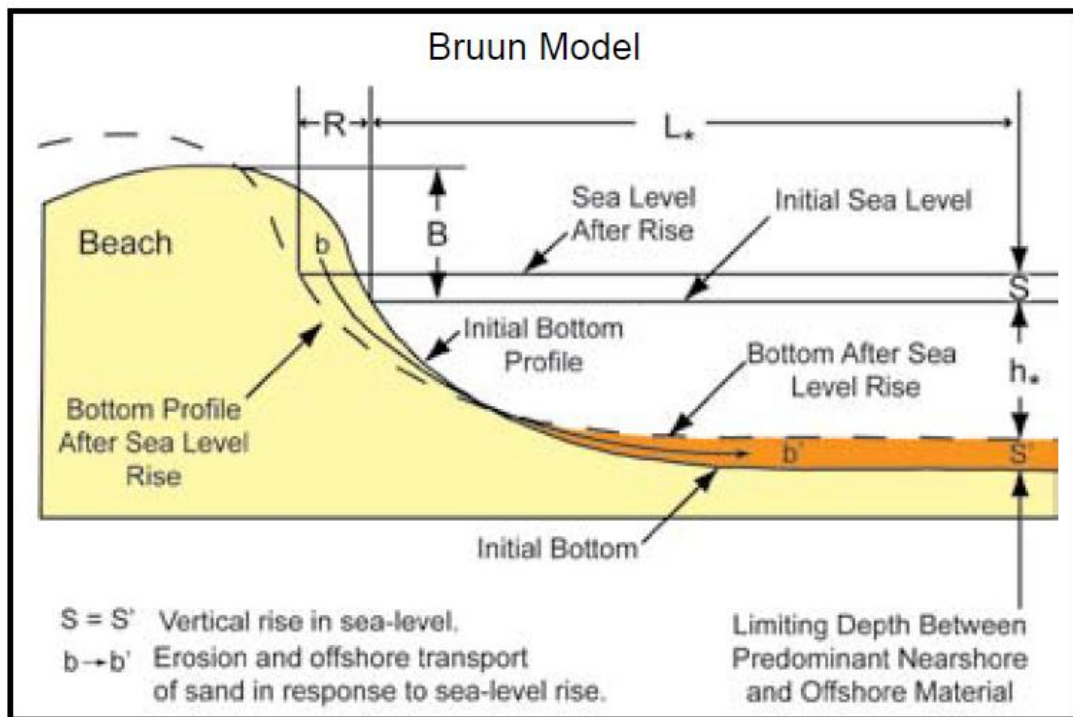
Figure 3.1: **(Source: Gutierrez et. al., 2009): The basic dimensions of the shoreface illustrating the Bruun model. L$_*$ is the width of shoreface also represented as w.**

Berm height data

This is another parameter useful in computing shoreline changes. Berms are the first line of defence of the beach which protects the backshore and coastal dunes from erosion under mild wave conditions and during the early phase of a storm (Masselink and Hughes, 2003). Berms are dynamic and respond rapidly to change in wave conditions; indeed large wave height or period results in higher berms (Masselink and Hughes, 2003). Estimating the berm height for this study involves the use of validated equations since there was no data available. It also involves estimating the wave breaker height as it is embedded in the equation proposed by Takeda and Sunamura (1982). The uncertainties revolving the estimation of the berm height include the calibration of the significant wave height and the wave period. The sensitivity analysis conducted in section 4.4 accounted for these uncertainties.

3.4.2.2   *Inundation Data*

Table 3.1 is the summary of the data that was used to estimate the extent of inundation

on the four coasts.

Elevation

The elevation data is from the Shuttle Radar Topographic Mission (SRTM) digital

elevation model (DEM) with a global coverage. The horizontal grid spacing is 3 arc-

seconds (approximately 90 metres at the equator). The horizontal coordinate system is

referenced to the World Geodetic System 84 (WGS84) and has a vertical spacing of 1 m.

The absolute horizontal accuracy is +/-20m at 90% confidence level, the vertical

accuracy is +/-6.13 m at 95% confidence level (CIAT, 2005). The vertical accuracy

represents the uncertainty in the SRTM elevation data. The uncertainty in the elevation

dataset is accounted for in sections 5.5 and 7.2.2.1 the uncertainty in the elevation

dataset.

Table 3.1:   Summary of Data Sources

Dimension	Dataset Name	Unit	Resolution	Sources
Elevation	SRTM Version 3	sq. km	90 m (Horizontal) 1 m (Vertical)	CIAT (2005)
Population	GPW-3	Population counts	1 km (Horizontal)	CIESIN & CIAT (2005)
Economic activity	GGI-B2	Million US Dollars	1 km (Horizontal)	(IIASA, 2007)
Urban extent	GRUMP V-3	sq. km	1 km (Horizontal)	CIESIN, & IFPRI, (2005)
Agricultural extent	PAGE Version 2	sq. km	1 km (Horizontal)	WRI & IFPRI (2005)
Wetlands	GLWD-3	sq. km	1 km (Horizontal)	(Lehner and Döll, 2004)

Population

The Gridded Population of the World, Version 3 (GPWv3) was used in this analysis.

The GPWv3 is the most detailed version of the GPW and provides globally consistent

and spatially explicit human population information and data for use in research, policy making, and communications (The Center for International Earth Science Information Network and International Centre for Tropical Agriculture, 2005). The GPW adopts a simple population algorithm gridded at 30 arc-seconds (approximately 1 km at the equator). The spatial reference is WGS84.

Economic Activity (Gross Domestic Product)

In estimating economic activity that will be at risk in the event of rising sea levels, the spatially explicit socio-economic data of the Greenhouse Gas Initiative Program was employed. The data is a demographic-economic development scenario for the period 1990-2100 with a ten-year interval and based on three scenarios. The resolution level for this spatial dataset is 30 arc-seconds and the grid coordinate system is un-projected latitude/longitude. The data is given per grid cell and each is quantified in monetary terms in US$1990. From the estimations made, period 2010 was selected.

Urban Extent

This research uses the Global Rural-Urban Mapping Project (GRUMP). The alpha edition used for this study is a development on GPWv3 with the incorporation of urban and rural information, providing new insights into urban population distribution and the global extents of human settlements (CIESIN & CIAT, 2005). Just like the GPWv3 it provides globally consistent and spatially explicit human population information and data for use in research, policy making, and communications (CIESIN & CIAT, 2005). The resolution of the GRUMP is 30 arc-seconds (1 km) and its horizontal datum is the WGS84. The cell value is integer, where 1 = rural and 2 = urban

Agricultural Extent

The dataset for agricultural extent is the PAGE Global Agricultural Extent version 2 with a 1 km resolution (World Resources Institute and The International Food Policy

Research Institute, 2005). This dataset identifies approximately 200 seasonal land cover regions (SLCRs) per continent based on the interpretation of a series of satellite images captured every 10 days over the period April 1992 to March 1993. The horizontal coordinate system is in decimal degrees with abscissa and ordinate resolution of 1 km at the equator, and the cell size is 1 km. For the geodetic model, the horizontal datum is Clarke1866. The dataset contains 18 classes: Table 3.2 shows codes and the classes of the agricultural element.

Wetland

The wetland data Global Lakes and Wetlands Database version 3 (GLWD-3) used for this study was developed by Lehner and Döll (2004). The GLWD-3 dataset is a global raster map that comprises lakes, reservoirs, rivers, and different wetland types (Table 3.3) at 1 km resolution. The dataset could be used as an estimate of wetland extents, and to identify large-scale wetland distributions and wetland complexes (Lehner and Döll, 2004).

Table 3.2:   Label codes for Agricultural elements

Cell Codes	Label
10	Cropland
11	Plantations
13	Cropland / Pasture
14	Agriculture with forest
41	Primarily Forest (>60%)
42	Primarily Grassland (>60%)
60	Non-vegetated / Sparsely vegetated

Table 3.3:   Label codes for Wetland elements

Cell Value	Lake or Wetland Type
1	Lake
3	River
4	Freshwater Marsh, Floodplain
5	Swamp Forest, Flooded Forest
6	Coastal Wetland (incl. Mangrove, Estuary, Delta, Lagoon)

3.4.3   Methods: Models for sea level Rise

The Bruun model forms the basis of the determination of erosion due to sea level rise for this research. Section 3.4.3.1 discusses the use of model's parameters.

3.4.3.1   Erosion

Bruun rule states that a typical concave-upward beach profile erodes sand from the beach face and deposits it offshore to maintain constant water depth. It is represented by these inputs as equation 1:

$$\Delta y = S (w/hc+B) \ldots\ldots\ldots\ldots\ldots\ldots.. (1)$$

Where Δy is the retreat due to sea-level rise, S is the sea-level rise, w is the active profile width, B is the berm height, and h_c is the depth of closure. The research applied Hallermeier's (1981) equation to calculate the depth of closure in equation 2

$$h_c = 2\hat{H}_S + 11\delta\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (2)$$

Where $\hat{H}_S$ is the mean annual significant wave height (defined as the annual mean height of the highest one-third of waves measured each day) and δ is the standard deviation of $\hat{H}_S.$ The method and the instrument of collection as well, as how it is stored and categorised determines the uncertainty of the significant wave heights. In section 4.4 and 4.4.1, this uncertainty is discussed and analysed.

Takeda and Sunamura (1982) predicted the berm (B) height using the equation below:

$$Z_{berm} = 0.125H_b^{5/8}(gT^2)^{3/8} \ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where Z is the berm height (metres), H_b is the root mean square breaker height (metres), g is gravity, which is 9.81 m/s^2, and T is the period (seconds). An uncertainty that is important for consideration in equation (3) is the wave period (see section 4.4.2). Masselink and Hughes (2003) state that the larger the wave height and/or wave period, the larger the vertical wave run-up and hence the higher the berm. With the derivation of the depth of closure and berm height, equation (1) is expanded into equation (4) by substituting equations (2) and (3) in (1). This produces equation 4

$$\Delta y = Sw \, / \, \{2\hat{H}_S + 11\delta\} + \{0.125H_b^{5/8}(gT^2)^{3/8}\} \ldots\ldots\ldots \quad (4)$$

In his work, Komar (1998) was able to predict the breaker height H_b by proposing the following equation:

$$H_b = 0.39g^{0.2} (T_w H_o^2)^{0.4} \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where T_w is wave period and H_o is wave height in deep water. H_o depends on the sea state which is a function of the wind velocity, fetch and duration (Le Roux, 2007). Once again, uncertainty in equation (5) have to do with the H_o . In the absence of wave data the H_o could be useful. However since the wave data is available for this study, it was used in calculating the breaker height. The uncertainty that revolve around the significant wave height is also put into consideration as was applied in section 4.4.2 in a basic sensitivity analysis.

The next step is substituting equation (5), into equation (4) to produce equations (6), as follows:

$$\Delta y = Sw \, / \, \{2\hat{H}_S + 11\delta\} + \{0.125(0.39g^{0.2} (T_w H_s^2)^{0.4})^{5/8}(gT^2)^{3/8}\} \ldots\ldots\ldots\ldots \quad (6)$$

Equation (6) is adopted to calculate the extent of erosion in the three geomorphic zones (i.e. Barrier, Delta and Strand coasts) of the Nigerian coast for the base year 2010, which was then projected for years 2050 and 2100. Erosion extents were not produced for the mud coast, as the Bruun rule is not valid for estimating erosion in muddy coasts because of the preponderance of silt and mud (French *et al.,* 1995). With the many applications of the Bruun rule to provide a base estimate for shoreline erosion, muddy coasts were never intended to be predicted using the model (Bruun, 1988, Cooper and Pilkey, 2004). Erosion occurs on muddy coasts but this research has not been able to find a suitable method for its estimation.

3.4.3.2 Inundation Models

This section deals with the development of models to ascertain the impact of sea level rise on the four coasts considered in this study as well as the six indicators to showcase inundation extents for each sea level rise scenario. A summary of the steps and method to achieve this is as follows

- A Geographic Information System (GIS) was employed to overlay the critical impact elements (land, population, agriculture, urban extent, wetlands, and GDP) with the inundation zones projected for 1, 2 and 3 m SLR scenarios.

- Spatially disaggregated data were obtained from various public sources (see Table 3.1).

- The mosaic function was applied to merge the different elevation models. An overlay analysis was performed within the study area and of the mosaic elevation data. Inundation zones were derived from the terrain models by performing a geoprocessing query which extracted pixel values of 1, 2, and 3.This was then overlaid with the case studies to extract vulnerable regions to scenarios of 1 to 3 metres.

- Inundation estimates for the critical elements were derived by overlaying the inundation zones with the appropriate exposure surface dataset.

- The horizontal datum used is the World Geodetic System (WGS 1984) projected to a Transverse Mercator and metric grid (WGS_1984_UTM_Zone_31N) for area calculation.

- For the value of pixels in the population surface (units in population counts), the exposure is calculated by multiplying its grid count value and then summing. This was then overlaid with the inundation zone. For the GDP surface, the same procedure was applied as with the population surface but the grid count value was further multiplied by a coefficient which was used to code the grid cells for the GDP*mer* (Market Exchange Rate) data. This coefficient represents US$1990 per grid cell. Use of this coefficient is a methodology adopted by IIASA (2007) as an Integrated Assessment Modelling Framework to downscale spatially explicit projections of economic and demographic growth. The other dimensions (i.e. land, urban extent, agricultural extent and wetland extent) were measured in square kilometres.

3.4.3.3 Developing Inundation Models for sea level rise

Intrinsic to this research is an analysis to enable the examination of geographic patterns in the dataset, which involves models that mimic the real world with the combination of several layers of data. The maps produced in the course of this research (Chapter 5) are the results of models developed within the GIS framework. Models were employed in this research as it helps to automate geoprocessing workflow, share geoprocessing knowledge, and record and document methodology. This research used the ArcGIS 9.3.1 ModelBuilder to develop the models for SLR. The Model's anatomy as used in this research consists of the project data, tools, and derived data. The input dataset were the project data, the tools were obtained from the Arctoolbox in ArcGIS, and then a

process (geoprocessing), delivered the derived dataset. The derived datasets (in this instance it has become the input dataset) were combined with other geoprocessing tools to produce another set of data.

This study is about communicating coastal information concerning sea level rise and therefore it is important to share knowledge in preparation of data for analysis and modelling the workflow. The method applied in this research to communicate information follows the four steps in Table 3.4

Table 3.4   Basic GIS Project Steps Adopted

Steps	Tasks
Determine the objectives of the project	- Identify the problem to solve - Break down the problem into measurable criteria - Determine data requirements
Build the database and prepare the data for analysis	- Identify and obtain relevant data - Design and implement the database - Add spatial and attribute data to the database - Manage and modify the data
Perform the analysis	- Determine methodology and sequence of operations - Process the data - Evaluate and interpret the results - Refine the analysis as needed and generate alternatives
Present the results	Create final products for intended audience

Source: ESRI Training Manual, (2005-2008).

The objective is to quantify vulnerability to inundation because of sea level rise on the coast. The measurable criteria involve determining the elements that will be more vulnerable to sea level rise. Spatial datasets that relate to these elements were

determined. The second step involved the building of the database and preparation of the data for analysis. In this step, the relevant datasets were identified and obtained from various public sources, they were imported into ArcGIS, and geodatabases were created to store them. In addition, the dataset examined within ArcGIS necessitated a balance in the coordinate system as well as building attribute tables for the database. Data management tools such as "clip", "mosaic", etc. were used to modify the data in terms of its spatial extents to prepare them in a form by which they can be used for analysis.

The next step, the analysis, involves the determination of the logic and sequence of operations. It actually requires the determination of the workflow of the project and using the right set of tools for the geoprocessing exercise. The application of the geoprocessing tools with the input dataset enables the processing of the data, which then yields another set of data, which could serve as an input for the next procedure in the workflow.

The Research interpreted the final output, which represents the results. Results were refined and presented in maps in Chapter 5 of this research. Figure 3.2 depicts as an example the model used to determine inundation zones within the elevation dataset employed.
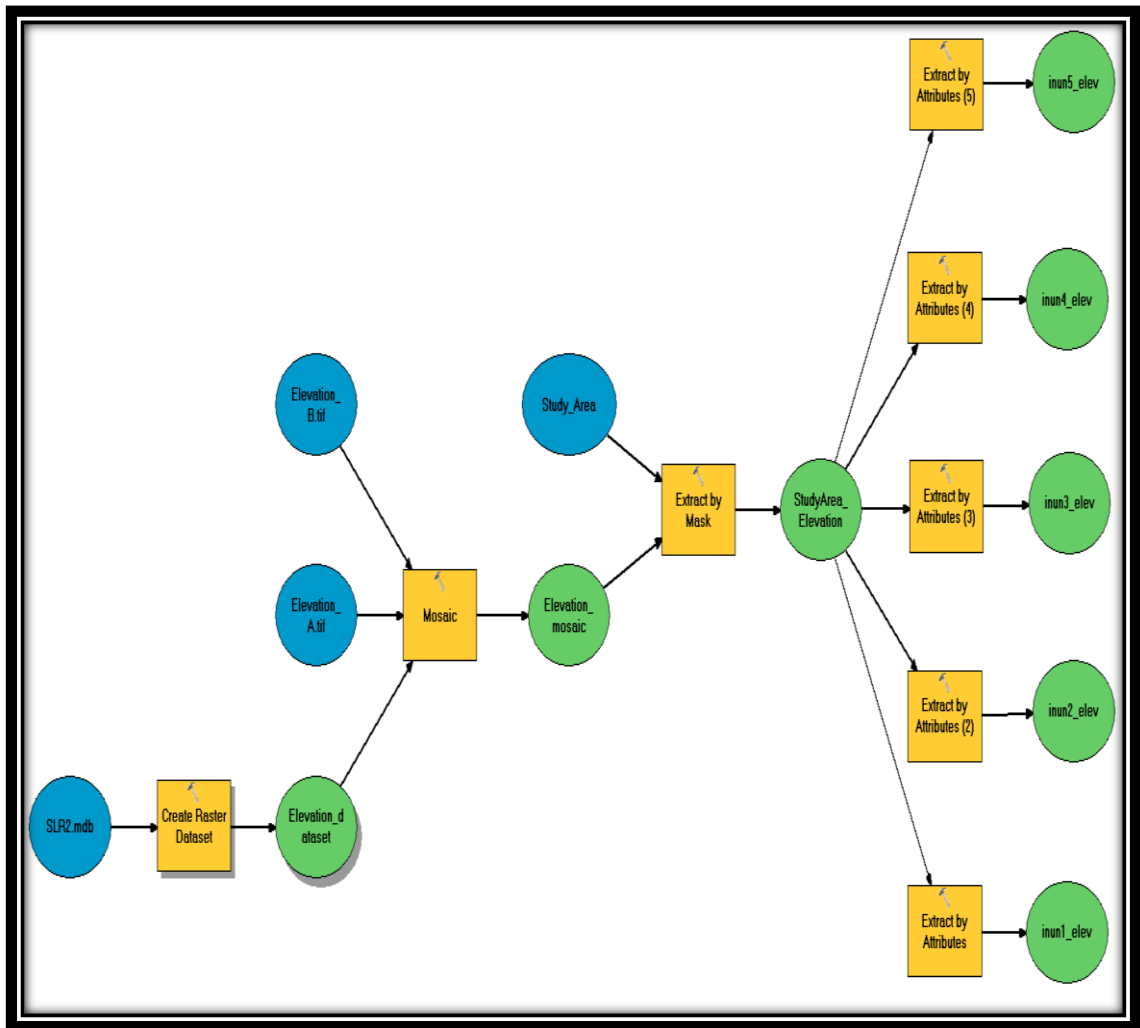
Figure 3.2:   Model depicting inundation zones in an elevation data set

An important task to the analysis of this research is finding the right tools that will be needed all through the analysis stages, and creating and customising the tools in a toolbox. The index and the search tabs within the ArcToolbox were used to find the location of the tools within the ArcToolbox. For the efficiency of the workflow of this research, there is the need to create and customise a toolbox because the tools were meant to be used many times in the course of the analysis. The toolbox created for this analysis is named 'SLR_Toolbox' (see Figure 3.3).
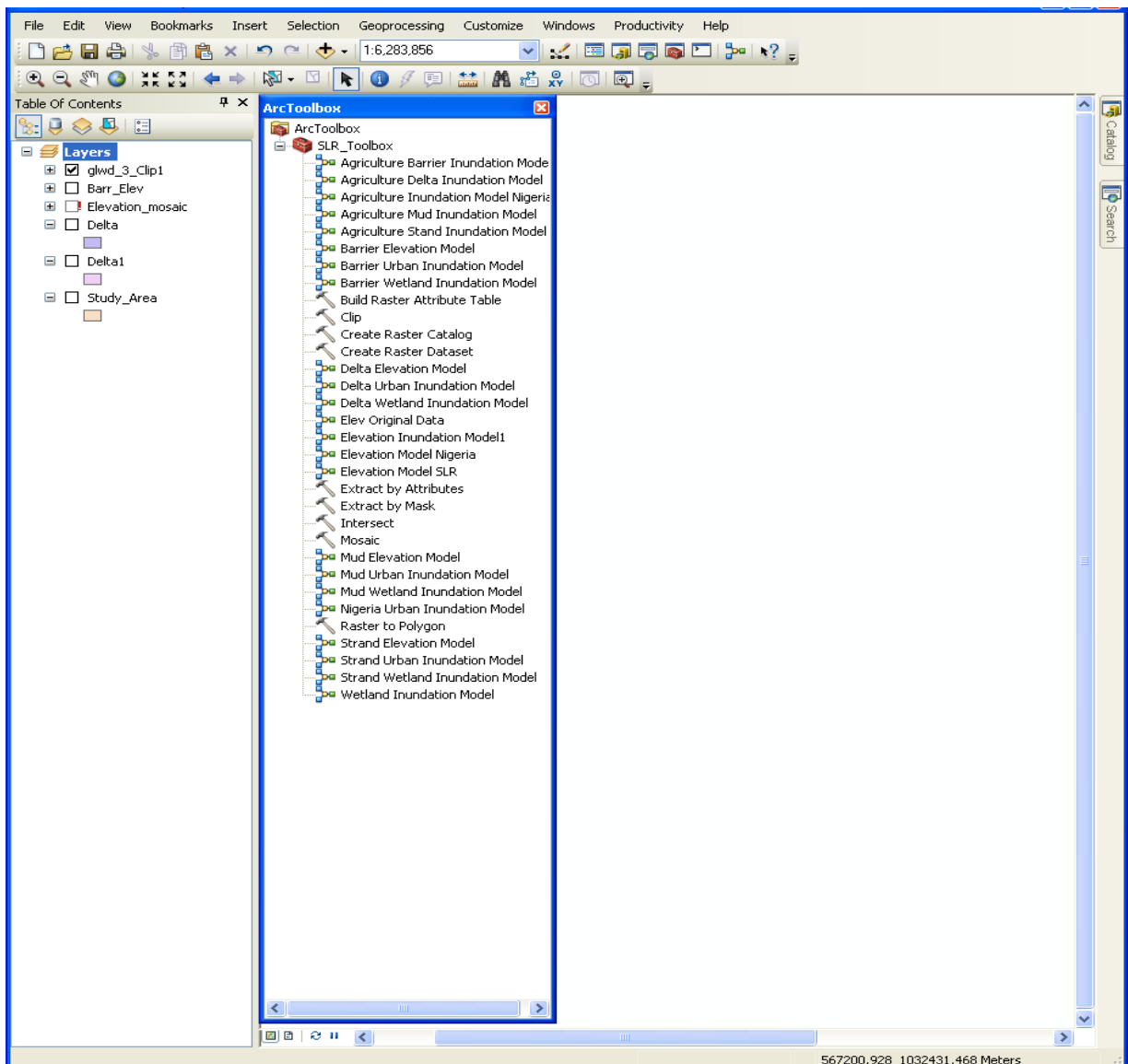
Figure 3.3: **Toolbox for Sea Level Rise Inundation Analysis. Toolbox contains the geoprocessing tools (hammer shape) for SLR analysis and the models to run a process.**

Tools needed for the analysis were then transported from the system toolbox of the ArcToolbox into the newly created toolbox. The tools necessary for sea level rise analysis include the "Build Raster Attribute Table", "Create Raster Dataset", "Clip", "Extract By Attributes", "Extract By Mask", "Intersect", "Mosaic", and "Raster to Polygon". The Clip tool, which creates a spatial subset of a raster dataset, was needed to generate the area of interest from the datasets obtained. Most of the datasets are global; therefore, the clip tool is important in delineating it according to the area of interest. The Build Raster Attribute Table, which is located within the Data Management Tools, adds

a raster attribute table to a raster dataset or updates an existing one. The Create Raster Dataset also located in the Data Management Tools creates a raster dataset as a file or in a geodatabase. In this research, this tool was used to create a raster dataset for the two elevation datasets obtained. The Mosaic tool, which merges multiple input raster dataset into an existing raster dataset, was then applied to join the two elevation datasets into one seamless raster dataset. The intersect tool located in the Analysis Tool was used in this research to compute a geometric intersection of the input features. The features especially the Study Area feature which was used to find the area of overlap between other features for example Barrier, Mud, Delta, and Strand features. The Raster to polygon tool (Conversion Tool) was employed in the analysis because calculations were more easy made in a vector feature rather than a raster in some datasets.

Extract by Attributes (Spatial Analyst Tool), is one tool, which is critical to this research as it extracts the cells of a raster based on a logical query. It involves the input of a raster dataset, the use of the QueryBuilder to create an SQL expression used to select a subset of raster cells. In this research, SQL expression to determine inundation zones for example determining land area that will be inundated in a 1 metre SLR scenario, the 'StudyA_Elev1' represents the input raster, then a query which shows the value of the input dataset and an expression of "VALUE" <=1 was built. With this expression all cells that are less than or equal to 1 are extracted to form the inundation zone in a 1 metre sea level rise scenario. This same procedure was applied to account for the other scenarios considered in this study. The other important tool is the Extract by Mask (Spatial Analyst Tool). This is used to overlay the inundation zones with the critical elements identified in this study. The manner of the operation of the tool is that it extracts the cells of the inundation zones that correspond to the areas defined by a mask. In this case, the mask refers to the critical elements, which include population,

GDP, urban area, agricultural area, and wetland area. By this operation inundation zones for the critical elements were determined. With the determination of the tools as well as their functions in this project, the ModelBuilder in ArcGIS was used to generate and as well validate the sea level rise analysis conducted with the use of geoprocessing tools. The outcome is the production of models by running the tools and processes in the model for sea levels. For example from Figure 3.2, Figure 3.4 was adapted to simplify and to show the derivation of inundation zones in an elevation dataset.

The first few processes, which involve creating a raster dataset and mosaic in Figure 3.2, are eliminated from Figure 3.4. The "Elevation_stat" in Figure 3.4 is the same as the "Elevation_mosaic" in Figure 3.2. "Elevation_stat" is a raster dataset that contains attributes for a large area in Nigeria whereas the "Study_Area" input is a feature dataset, which delineates the area extent of the Study Area for this analysis. The tool "Extract by Mask" was used to extract the cells of the "Elevation_stat" to correspond with the area extent of the "Study_Area" to produce an output feature dataset that was named as "StudyA_Elev1" which later formed the input dataset for the next operation. The next operation is determining inundation zones for the sea level rise scenarios.
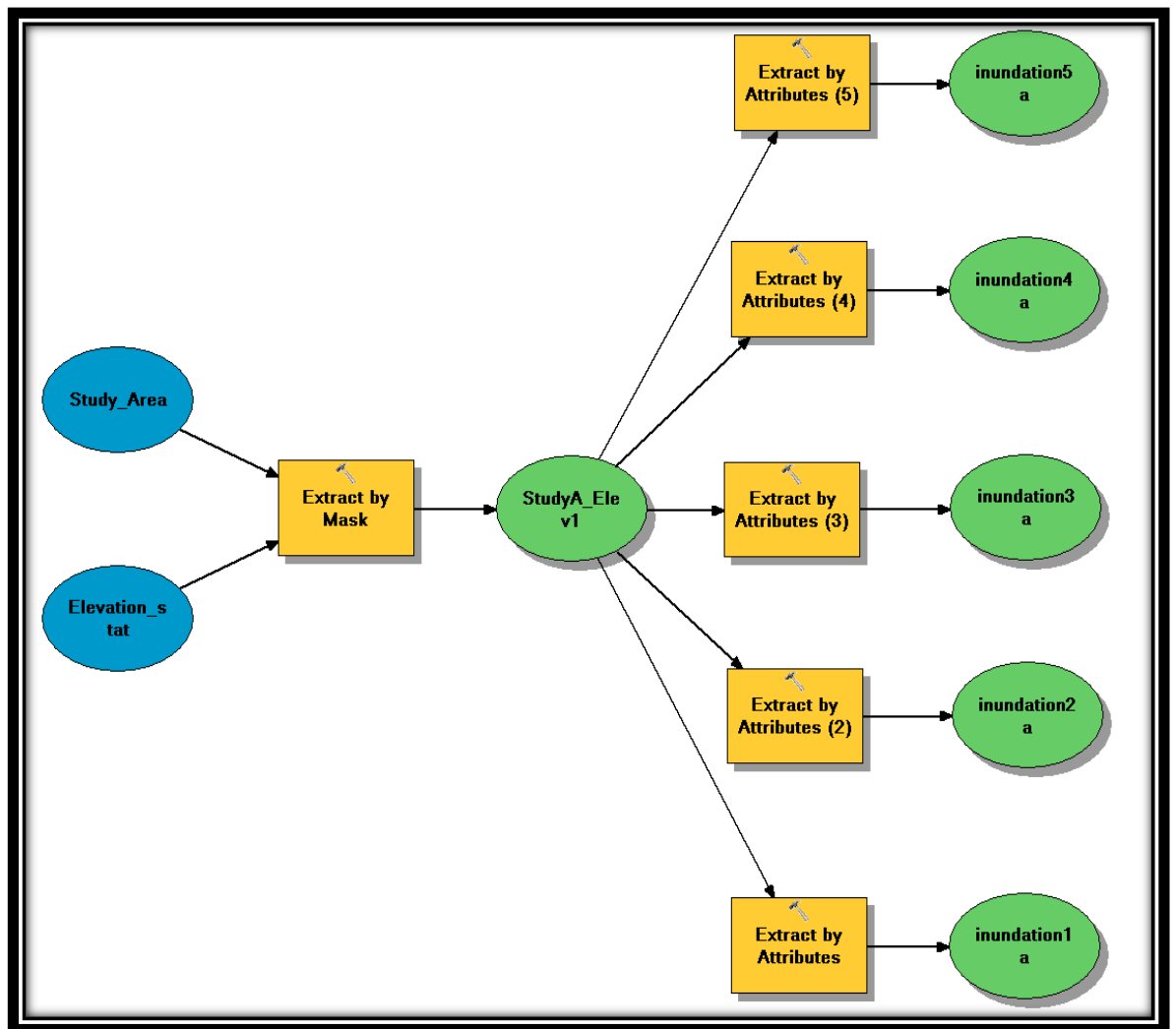
Figure 3.4: **Simplified Model depicting inundation zones in an elevation dataset**

For this task the tool, "Extract by Attributes" was used and as explained earlier, the tool involves the building of a query expression depending on the scenarios required. The output is inundation maps for each of the scenarios considered in this research. Furthermore, the need to determine inundation zones for the critical elements necessitated overlay analysis to be performed. This involves the use of a spatial analyst tool "Extract by Mask" (its functions already described in the preceding paragraph). The result of this task is the development of models which can be run at any time to find out the extent of inundation for a given sea level rise scenario for any critical element considered in this research. An example is in Figure 3.5. This model highlights the extent of inundation of the urban land area in Nigeria. The "ngaurextents.asc" which is a

raster dataset represents the total urban area in Nigeria while "StudyArea_gdp" – a feature dataset, represents the delineated study area for this research. Both serve as input parameters into the model. The geoprocessing tool Extract by Mask was introduced into the model to extract the cells of the "ngaurextents.asc" that correspond to the area defined by "StudyArea_gdp" in an overlay analysis. The result of this process yields an output raster dataset, which was named "urb_StudyA". The next stage involves overlaying inundation zones for each scenario as produced from the elevation dataset with the "urb_StudyA". Once again, the "Extract by Mask" tool was employed to perform the geoprocessing task, which then produced the inundation outputs for the scenarios. The model was then run to validate the processes. This procedure was repeated substituting the right inputs for all the models that were built to display the extent of inundation in the various critical elements for all the sea level rise scenarios considered in this research.

Documentation is essential to this type of project as it acts as reminder of the reasons for choices of tools and methodology. It is also essential in communicating with others, and allowing them to be able to run the models built to access the necessary coastal information as it relates to sea level rise. This will be vital for various stakeholders and coastal managers to appreciate and take advantage of the work done and form a basis for decision-making. Documentation is also a means by which this research has been validated by describing the methods, parameters and tools used in this research.

3.5   Stage 2: Operation of the Coastal Sustainability Standard

This stage involves the identification of ICZM case study initiatives or Coastal Partnerships (CPs) in order to audit the CPs against the principles and criteria of the appraisal system. The rationale is to enable an evaluation of the various CP against the

Coastal Sustainability Standard (CoSS) and its application in the Nigerian coastal context. This could be a vital tool for assessing and improving coastal sustainability in the light of impending coastal hazards such as sea level rise. In doing this, the following steps were employed:

- Identification and selection of appropriate CPs that are willing to participate in the research.

- Operation of the CoSS
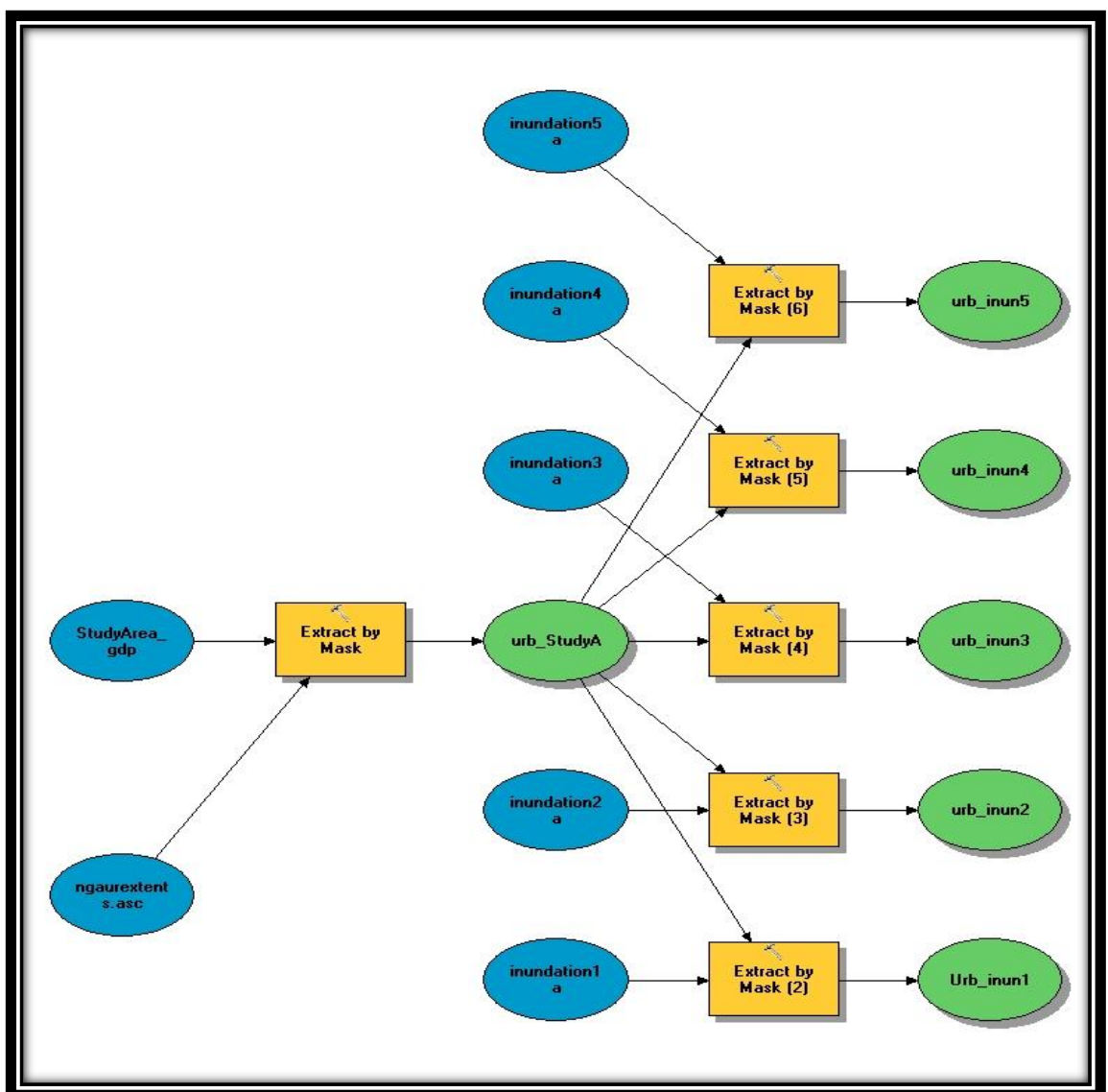
Figure 3.5:   Model depicting inundation zones in Urban Extent Element

3.5.1   Case study approach and selection

The case study approach was chosen for this stage of the research. This approach has to do with studying a phenomenon within its real-life setting therefore ensuring issues are studied in depth from a variety of perspectives (Kitchin and Tate, 2000). The idea is to make use of the appraisal system developed to assess sustainability in the activities of coastal partnerships by operating and assessing how applicable it will be in the Nigerian setting. Therefore it is more efficient to adopt the case study approach as "case studies tend to be holistic rather than deal with isolated factors"; and the approach "allows researchers to use a variety of sources, a variety of types of data and a variety of research methods as part of the investigation" (Denscombe, 2007).

There is need to justify the selection of the CPs that will be assessed and this needs to be a deliberative, transparent and rational selection of the case studies to be considered (Gallagher, 2006). As identified by Denscombe (2007) there are a number of criteria that could be used to justify the selection of particular case studies. The criteria are as follows:

- Suitability criteria – this includes: typical instance, extreme instance, test-site for theory, and least likely instance
- Pragmatic criteria – this includes: intrinsically interesting, willingness to participate and a matter of convenience
- No real choice criteria – the study is a part of commissioned research, there are unique opportunities

Suitability criteria: This involves the identification of the salient characteristics of the ICZM case studies and they are classified as; the nature of the area and the threat facing it; the nature of the development of the CPs, its age and operating structure (Gallagher,

2006). These thus produce the four characteristics of the criteria as itemised in Gallagher (2006) and they are:

- The environmental characteristics and boundaries of the management area

- The human impact and development status of the area

- The antecedence and status of the management process

- The management structure and resources

Pragmatic Criteria: Denscombe (2007) identified three criteria for the pragmatic view. First is the fundamental interest of the case studies depending on their characteristics and functions within the Nigerian coastal zone. This thus enables having an appropriate mix of relevant variables, suitable to enable rigorous evaluation of the method. Second is the willingness of the CPs to participate in the process. Many CPs were not willing to get involved because of them being 'too busy'. Third is the convenience criterion, which relates to the location and the ease to reach the CPs.

No real choice criteria: This criterion was not operated, as there were no restrictions of choice in the form of either directed funding or specifically unique research opportunities.

In selecting the coastal partnerships, the various institutions that deal with the protection, management and development of the coastal environment were put into consideration. The pilot study conducted reveals that the following institutions are involved in the wellbeing of the coast.

- Ministry of Environment

- Federal Ministry of Aviation (Department of Meteorology)

- Federal Ministry of Defence (Navy)

- Federal Ministry of Transport (National Maritime Authority)

- Federal Ministry of Foreign Affairs (International Negotiations and Agreements)

- Federal Ministry of Solid Minerals (Regulations Mining in the Coastal Zone)

- Federal Ministry of Petroleum Resources (Department of Petroleum Resources)

- Federal Ministry of Justice (Adjudication and Drafting of Ecological laws and policies

- Federal Ministry of Water Resources

- Federal Ministry of Lands

- Niger Delta Development Commission

- Nigerian Institute for Oceanography and Marine Research

- Petroleum Training Institute

- Pro-Natura International, Nigeria

- Niger Delta Wetland Centre

- Nigerian Environmental Society

Out of these, only the following are directly involved in coastal management

- Ministry of Environment

- Federal Ministry of Petroleum Resources

- Niger Delta Development Commission

- Nigerian Institute for Oceanography and Marine Research

- Pro-Natura International, Nigeria

- Niger Delta Wetland Centre

- Nigerian Environmental Society

The Ministry of Environment is in two hierarchies - federal and state. The Federal Ministry of Environment have their branches in all the states of the federation and it is

under the control of the Federal Government. On the other hand, the State Ministry of Environment is under the various State Governments. For this study, the Federal Ministry of Environment and State Ministry of Environment was chosen as a typical representative of other states on the coast under the Ministry of Environment. The Federal Ministry of Petroleum Resources is responsible for all the oil companies that operate in the Nigerian coast. Noteworthy among the oil companies are Shell Petroleum Development Company (SPDC), Chevron, Nigerian National Petroleum Corporation (NNPC) and Exxon Mobil. SPDC and NNPC were chosen for this study; SPDC to represent the multi-national oil companies while NNPC represents the indigenous oil companies.

Based on these considerations nine CPs were selected and they are

- Soil Erosion Flood Control and Coastal Zone Management Department, Federal Ministry of Environment(SEFCCZM)

- Niger Delta Development Commission (NDDC)

- Flood Erosion and Coastal Zone Management, State Ministry of Environment, Rivers State (FECOZM)

- Shell Petroleum Development Company (SPDC)

- Nigerian National Petroleum Corporation (NNPC)

- Nigerian Institute for Oceanography and Marine Research (NIOMR)

- Pro-Natura International Nigeria (PNIN)

- Niger Delta Wetland Centre (NDWC)

- Nigerian Environmental Society

Table 3.5 details the suitability selection characteristics and Table 3.6 summarises and justifies the selection of these coastal partnerships based on the selection criteria.

Table 3.5   Case study suitability selection characteristics

	Environmental characteristics and boundaries of the management area	Human impact and development status of the area	Antecedence and status of the management process	Management structure and resources
Pro-Natural International (PNI)	Estuarine area with coast Management area covers the four states of the Delta (Bayelsa, Rivers, Akwa Ibom and Cross Rivers)	Mainly rural with considerable urban and industrial impacts	Started in 1995 A non-governmental organization	Led by a Board of trustees registered with the Corporate Affairs Commission The management have a steering group supported by topic groups
Flood Erosion and Coastal Zone Management, State Ministry of Environment, Rivers State (FECOZM)	Estuarine area with coast Management area covers the whole Rivers State	Both urban and rural Impact of sand mining and oil production	Started in 2000 It is a governmental agency	Led by the Commissioner of Environment Management under the control of the Director of FECOZM Project officers
Niger Delta Development Commission Rivers State (NDDC)	Estuarine area and immediate terrestrial hinterland Management area covers the nine Niger Delta States	Both urban and rural Threats to habitats of species, and human wellbeing as a result of oil exploration and exploitation	Started in 2000 It is a governmental agency	The Executive Chairman The managing team headed by the Managing Director Project officers
Soil Erosion Flood Control and Coastal Zone Management Department, Federal Ministry of Environment, Rivers State (SEFCCZM)	Estuarine area and immediate terrestrial hinterland Management area covers the whole of Rivers State	Both urban and rural Impact of sand mining and oil production	Started in 1999 It is a governmental agency	The Minister of Environment The Director of SEFCCZM
Niger Delta Wetland Centre (NDWC)	Estuarine area with coast and low water mark	Mainly rural but with major oil industry impacts	Started in 1998	Project officers Support staff

			Privately owned (A Non-Governmental Organization)	
	The management area covers selected regions in two States	Threats to species and their habitats Important areas for tourism		
Nigerian Institute of Oceanography and Marine Research (NIOMR)	Estuarine area and immediate terrestrial hinterland Management area covers the whole coastline states	Both urban and rural Threats to habitats of species, and human wellbeing as a result of oil exploration and other human activities.	Started in 1975. It is an offshoot of the Marine Research Division of the Federal Department of Fisheries	National Coordinator, Product Manager and other projects staff
Shell Petroleum Development Company (SPDC)	Offshore and Onshore, Management covers the whole coastline	Both Urban and rural Threats to habitats of species, and human wellbeing as a result of oil exploration and other human activities.	Started oil production in 1956	Director, Project staff
Nigerian National Petroleum Corporation (NNPC)	Offshore and Onshore, Management covers the whole coastline	Both Urban and rural Threats to habitats of species, and human wellbeing as a result of oil exploration and other human activities.	Established in 1971 NNPC manages the joint venture between the Nigerian government and multinational corporations	Group Managing Director and other directors in various units.
Nigerian Environmental Society (NES)	Terrestrial hinterland and the coast	Both urban and rural urban and industrial impacts, natural and human impacts	Inaugurated in 1985	National President Other executive members

Table 3.6: Summary of selection criteria

	Suitability Criteria	Pragmatic criteria	Selection
Pro-Natural International (PNI)	Test site for theory	• Interesting • Willingness to cooperate • Convenient	Yes
Niger Delta Wetland Centre (NDWC)	Test site for theory	• Interesting • Willingness to cooperate • Convenient	Yes
Flood Erosion and Coastal Zone Management, State Ministry of Environment, Rivers State (FECOZM)	Typical Instance	• Interesting • Willingness to cooperate • Convenient	Yes
Niger Delta Development Commission Rivers State (NDDC)	Test site for theory	• Interesting • Willingness to cooperate • Convenient	Yes
Soil Erosion Flood Control and Coastal Zone Management Department, Federal Ministry of Environment, Rivers State (SEFCCZM)	Typical Instance	• Interesting • Willingness to cooperate • Convenient	No
Nigerian Institute of Oceanography and Marine Research (NIOMR)	Test site for theory	• Interesting • Could not cooperate • Convenient	No
Shell Petroleum Development Company (SPDC)	Typical instance	• Interesting • Not willing to cooperate • Convenient	No
Nigerian National Petroleum Corporation (NNPC)	Test site for theory	• Interesting • Not willing to cooperate • Convenient	No
Nigerian Environmental Society (NES)	Typical Instance	• Interesting • Not convenient	No

The suitability criterion satisfies two of the instances i.e. the test site for theory and typical instance. PNIN and NDWC were classified as test sites for theory based on a large geographical coverage, apparent openness to engage public participation, the length of time over which they have been attempting to achieve their aims and most importantly their uniqueness in the way they handle their programmes. FECOZM and SEFCCZM were classified as typical instances on the basis that what happens in these two agencies is not different from what obtains in other coastal states since they are all under the same ministry i.e. the Ministry of Environment. However to avoid duplication of results the SEFCCZM was not selected. The selection of FECOZM is based on the premise that it fully represents a typical function of what happens in all the coastal states being a state ministry rather than the Federal ministry that depends on instructions from the headquarters in Abuja. NDDC is classified as a test site for theory because of its larger coverage area. Although the length of time by which it has been seeking to achieve its aims is less than 10 years, the agency is working towards improving social and environmental conditions in the Niger Delta. No organisation has the same or similar objectives. NIOMR is also classified as test site for theory because that is the only recognized institute conducting marine research in the coastal area. SPDC was considered as a typical instance to represent the other multinational companies involved in oil exploration while NNPC a test site for theory and NES a typical instance.

Out of the nine cases, only the Nigerian Environmental Society (NES) was not convenient to conduct an interview. This is because it is not located within the coastal zone but in the Federal Capital Territory (Abuja). Funding limits prevented travel to Abuja. One of the cases (NIOMR) could not cooperate while two (SPDC and NNPC) were not willing to cooperate (Table 3.2). This thus means that this research conducted interviews with four coastal partnerships.

3.5.2 Methods Employed for sustainability appraisal

This stage of the research employed the CoSS as an appraisal system in assessing the level of progress CPs in Nigeria have made towards achieving the goals of ICZM and sustainable development. The system requires its full operation in order to enable evaluation. In doing this, suitable approaches were employed which involved a series of personal meetings and interviews to elicit the relevant information.

Pilot Study

This research embarked on a pilot study to identify the organisations involved in managing the coastal zone. In addition, the questions that made up the semi-structured interview were tested out before the main investigation with the intention to assess the adequacy of the instruments for data collection. This was carried out with Mr Patrick Adekoya, the Community Relations Coordinator at Shell Petroleum Development Company, Nigeria Limited.

Participant Selection

Detailed meetings were arranged with the officers of the CPs in order to access the relevant data and evidence relating to each criterion of the CoSS. This research is aware that the criteria used to determine the participant group would have an impact upon the quality of responses. Criteria that could be decided upon as stated by (Gallagher, 2006) include:

- Peer recognition – demonstrable reputation;

- Contributions to literature – referred publication list;

- Extensive background in trans-disciplinary coastal sustainability problem solving;

- Clearly related or cross transferable knowledge on specific issues; and

- Identifiable roles and responsibilities in coastal management

Since this research is applying the coastal sustainability standard as a system of appraisal, coupled with the fact that the standard main attribute is systems based i.e. normative in its approach, the identifiable roles and responsibilities in coastal management criteria was considered most suitable in selecting participants in the systems appraisal. This approach clearly linked the results of the survey to practical coastal management on the ground. The number of participants corresponds to the number of CPs selected.

Instruments

"The flexibility of personal interviews through the use of 'open' questions allows the interviewer to gain a greater depth of understanding through prompting further questions and allows answers to be substantiated or supplemented through recourse to documentation or other evidence" (Frankfort-Nachmias and Nachmias, 1996) has made it more suitable for this work as opposed to other sampling methods. A semi-structured questionnaire (interview) was produced which was carried out with the chosen CPs. The semi-structured questionnaire encapsulates the principles and criteria of the CoSS. The semi-structured questionnaires were open ended in order to elicit and encourage the maximum level of detail in the responses. The research proceeded with transcribing responses from an audio format. The responses were processed with the aid of a content analysis technique to determine the level of progress towards ICZM and sustainable development attained by each coastal partnership. A tape recorder was used to record the responses as this ensures that issues discussed can be referred to at any time, which aids the rationality of the assessment as to the appropriateness of the scores ascribed to it. For ethical reasons, letters were sent ahead across to these officers to let them know that the interview will be recorded as well as to seek their consent to do so.

Assessment of Responses

This research lends itself to the adoption of the details of the coastal sustainability standard. Apart from the scoring guidepost, a performance guidance note developed by Gallagher (2006) proved to be indispensable. The guidance note served to maximise the level of objectivity in the sustainability assessment. There are sets of criteria for each principle and for each criterion, a set of scoring guidelines are provided which informs the scores with respect to the guideposts. In terms of interpretation and assessment, many of the criteria and associated performance indicators are straightforward. For example, the third criterion in the principle of planning states that the management system is clearly defined with individuals and organisations having clear lines of responsibility. The question asked in this case is is there a clear management structure identifying organisations, individuals and responsibilities? The question asks for evidence of proof as regards clearly defined responsibilities in the form of management structures. If individuals and organisations with management responsibilities are known, has their responsibilities and interactions been determined. If determined, then to what extent? According to the performance guidance note, for a management structure to be clearly stated,

> "There should be a definition of the approach, the role and responsibility of the different structural bodies and their terms of reference. Ideally, this would be expressed using a diagrammatic representation of the structure. In addition, there should be a list of the representative organisations and individuals contributing to each structural body. In addition, this information should be available through all forms of exogenous partnership communications such as annual reports and websites (Gallagher, 2006).

The performance guidance note improves clarity and transparency and supports the assessment with definitions, interpretation and the identification of possible performance indicators.

Data analysis and criteria scoring

Based on the responses, this research presents the results of the analysis. A content analysis was conducted by transcribing the details of the interview into an Excel spread sheet. The content analysis states the principles, their associated criteria, the scoring guideposts, the CPs, comments and evidence from the officers interviewed, sources of information and rationality of awarding the scores based on the performance guidance note. These were carried out in a case study approach to give a holistic assessment of the CPs. In addition, the research embarked on a comparative assessment to give more insights into the similarities and differences between the CPs. The CoSS, which was developed around a framework of principles and criteria, forms the framework on which the semi-structured questionnaire was based. The principles: planning; participation; communication; integration; responsibility; and balance were deconstructed from 23 theoretical constructs inherent in sustainability (Gallagher *et al.,* 2004). Gallagher (2006), was able to develop criteria to assess these principles. These principles and criteria were employed to the full to assess sustainability in the Nigerian coastal zones with the case studies selected. A performance guidance note which contains the principles and criteria developed by Gallagher (2006) which forms the guidepost for the scoring of each criteria was employed on assessing progress made towards sustainability in the Nigerian coast.

The performance guidance note forms a scoring system for the standard. It is ordinal in nature and uses a scale of 0 – 10. The standard has four defined points of reference, which are 0, 3, 7, and 10. A score of 0 means total failure, scores less than 3 also means failure and need for a corrective action. A score of 3 represents the threshold of constructive management. Scores above 3 shows there is some evidence of proactive coastal management. Scores between 3 and 6 might just indicate that there are one or two elements that are performing poorly or that all the criteria are performing sub-optimally. Management systems whose scores are between 3 and 6, are likely to find it

easier to effect corrective actions than those that are less than 3. A score of 7 denotes a mark of achievement either on the part of a specific criterion or for the aggregated mark of the principle as a whole. This score means the required standard has been met and that the management system is operating in a manner by which it can foster sustainable development. A score greater than 7 simply indicates the degree of excellence employed in that specific management area. The scoring criterion is highlighted in Table 3.7.

Table 3.7:   Scoring System scale and meanings (Performance Indicator)

Score	Meaning
10 9 8	Evidence of Exceptional and well developed management technique
7	**Standard achievement mark**
6 5 4	Evidence of some constructive management in operation
3	**Threshold of constructive management**
2 1 0	Failure and requirement for corrective action

(Gallagher, 2006)

3.6   Scope and Limitations of the Methodology

For erosion analysis, four scenarios were calculated; they are 0.5; 1; 2; and 3 metres. The rate of sea level used in this analysis is 4 mm/year. Basing this analysis on the IPCC projected middle range estimates and the upper limit in Nigeria for sea level rise by year 2100. This research made projections for the Barrier, Delta, and Strand coasts. Concerning inundation, the scope covers the three coasts listed above and the Mud coast. Vulnerability to inundation was determined along the coast with a projected sea level rise of 1-3 metres. The scope of the data used was dependent on the elements deemed important and which will be vulnerable to SLR (see section 3.4.2.2). For the

sustainability assessment, the scope is restricted to CPs in Nigeria, and their attempt to manage the coastal zone.

The research was limited by some factors. Firstly, the erosion in the Mud coast was not estimated because the Bruun model does not support its application on a muddy coast. This research has not been able to identify simple models to adopt in estimating erosion in the Mud coast. Secondly, there is unavailability of data (high quality, repetitive morphological surveys of the shoreface) to feed into the variables of the coastal erosion model. For example, the estimation of the depth of closure was based on wave data, which was an average of the whole coast (refer to wave data in section 3.4.2.1). This ensures that the different depths of closure of the different coasts could not be estimated. This applies also to the estimation of the berm height. In terms of vulnerability to inundation, the study was limited in terms of the accuracy of the results, which was reflected in the maps produced. The elevation dataset is only 90 m horizontal resolution. For a more detailed study, a 30m horizontal resolution or higher resolution dataset would be more appropriate. However, these types of datasets are not available for the Nigerian coast. In addition, in terms of vertical resolution, the dataset has 1 m resolution and therefore estimates of impacts can only be made for sea level rise of 1 m intervals. The impacts of inundation were assessed using existing populations, socio-economic conditions, and patterns of land use. There was no attempt to predict their future states. This is because there is generally a rapid increase in the coastal areas and so the impacts when projected into the future are underestimated especially for SLR impacts on population and GDP. Lastly, there was a difficulty in assessment of progress towards sustainability in some CPs as there was little or inadequate information available. This in itself highlighted gaps in the coastal management process on the Nigerian coast.

3.7 Study Area

3.7.1 Nigerian Coastal Profile

The Nigerian coastline is approximately 853 km long and lies between latitude 6°25' and 13°48'N and longitude 2°45' and 14°5'E. The Nigerian coastline stretches from Republic of Benin on the west and Cameroon on the east (Map 3.1). Nigeria's total land and water area is 923,768 sq. km, with the area of the land being 910,768sq. km while that of water is 13,000 sq. km (CIA, 2011). Nigeria's continental shelf extends from the shore to the 200m depth (Central Intelligence Agency, 2011).

The Nigerian climate is tropical, characterized by high temperatures and humidity as well as marked wet and dry seasons. The coastal area has an annual rainfall ranging between 1,500 and 4,000 mm (Kuruk, 2004). Between October and May, sea surface temperatures range from 27°-28^oC, while during the rainy season of June to October; the range is between 24° and 25^oC. The surface water is typically oceanic surface water of the Gulf of Guinea with salinity generally less than 35ppt. In the Niger Delta, salinity ranges between 27-30ppt in January to March and 28 − 30ppt in June to September. Low salinity values are due to the influx of fresh water from the numerous estuaries of the Niger Delta. The Nigerian coast is home to a sizeable number people and economic activities with over 20% of the population inhabiting coastal areas (CEDA, 1997). Eight States of the thirty-six are located in the coastal zone (Map 3.2).
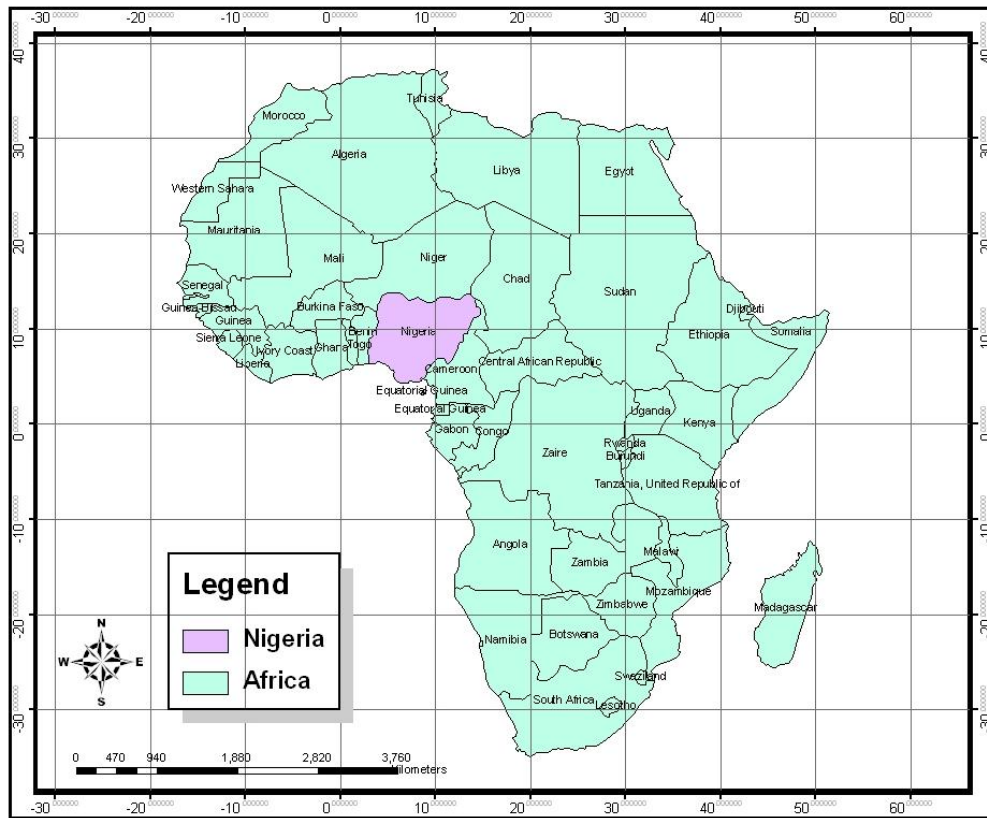
Map 3.1:   Map of Africa showing Nigeria - Adapted from ESRI, (2009)
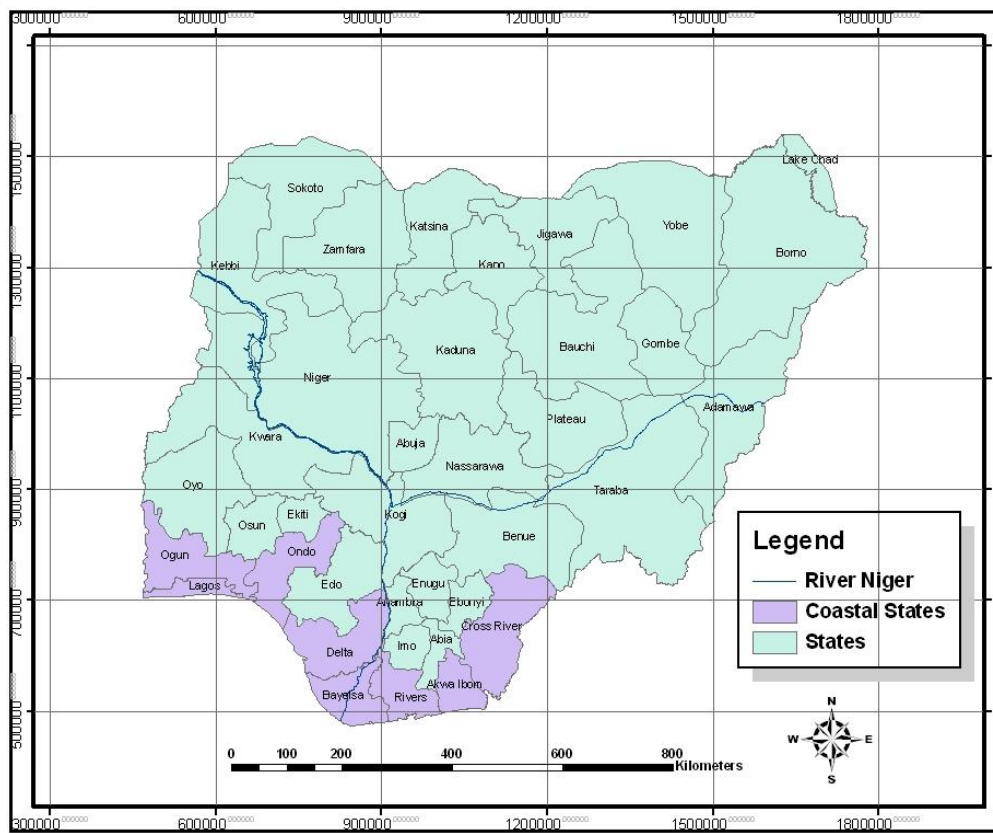
Map 3.2:   Map of Nigeria Showing the Coastal States - Adapted from ESRI, (2009)

The Nigerian coastal zone and its resources have vast implications for the economy. Some of the important resources include fish and shellfish (such as shrimps, lobsters, oysters, crabs and molluscs). Other physical resources are, timber, sand, gravel, and limestone. Onshore, the Nigerian coastal area is dominated by extensive stretches of sandy beaches - barrier islands, lagoons, estuaries, mud beaches, creeks and a deltaic complex (CEDA, 1997). The Niger Delta, a major geomorphic feature in the Nigerian coastal zone is a repository for oil and gas - Nigeria's main source of foreign exchange. Other uses of the Nigerian coastal zone include transportation, communication, defence, and recreation (CEDA, 1997). Economic activities on the coast include agriculture, fishing, mining, oil extraction, manufacturing of textiles, food, wood pulp, and paper production.

Barrier coast
The Barrier coast, which is located between Badagry and Ajumo, east of Lekki town extends for about 210 km. The morphology is determined by coastal dynamics and drainage (Ibe, 1988). The coast is characterised by a sandy barrier with width varying from 0.5 to 21 km (French *et al.,* 1995). Narrow beach ridges along the coastline are aligned parallel to the coastline and the beaches are erosive as a result of the lack of exoreic rivers or streams that would have compensated for the sand lost from longshore current action (Okude and Ademiluyi, 2006). As a result there is the absence of developing spits along the Barrier coast (Okude and Ademiluyi, 2006). Most of the coast has a low-lying elevation, which includes the wetlands behind the barrier islands and the lagoons.

Mud Coast
The Mud coast extends for about 80 km and lies next to the Barrier coast in the eastward direction. It is characterised by medium to coarse silt, with small quantities of fine to medium sand (French *et al.,* 1995). The Mud coast is low-lying at elevations of

0.8 to 1.8 metres (which are lower than the height of many spring tides). Such higher

tides are recorded at Awoye/Molume town resulting in frequent flooding in the rainy

season. (French *et al.,* 1995). Erosion rates have been recorded to be high in some

locations along the Mud coast.

Delta Coast
The Delta coast is extensive and occupies more than half of the total area of the

Nigerian coastline. It starts from the mouth of the Benin River for about 400 km to the

mouth of the Imo River. The Delta's ocean coast is fronted by 20 barrier islands,

characterised by low, narrow sandy beaches (Ibe, 1988). Elevations are very low in the

Delta and elevations of between 1 to 3 metres are noticeable along the coast. Very little

sediment is being transported to the Delta coast since the construction of the Kainji

reservoir that traps significant amounts of the sediment load of the Niger River (Tilman

et al., 1989). Erosion rates as recorded in some locations range from 15-24 metres

annually.

Strand Coast
The characteristics of the Strand coast include a moderately wide, gently sloping beach

face that changes into beach ridge plains and a few small swamps extending to the shore

(Ibe, 1988). The coast is further backed by a relatively narrow strip of mangrove

swamps and they are subject to frequent and extensive flooding (French *et al.,* 1995).

The coast is about 100 km long and it lies between the Imo River and the Nigerian

boarder on the east with Cameroon. Erosion of the coast has also been recorded at some

locations and rates of 10-13 metres were recorded at Ibeno-Eket station (Ibe, 1988).

The study area was delineated based on the established geomorphic classification of the

Nigerian coast (Awosika LF *et al.,* 2000). Map 3.3 shows the four coasts in relation to

the coastal states along the coastline. This delineation was used entirely in the course of this research.
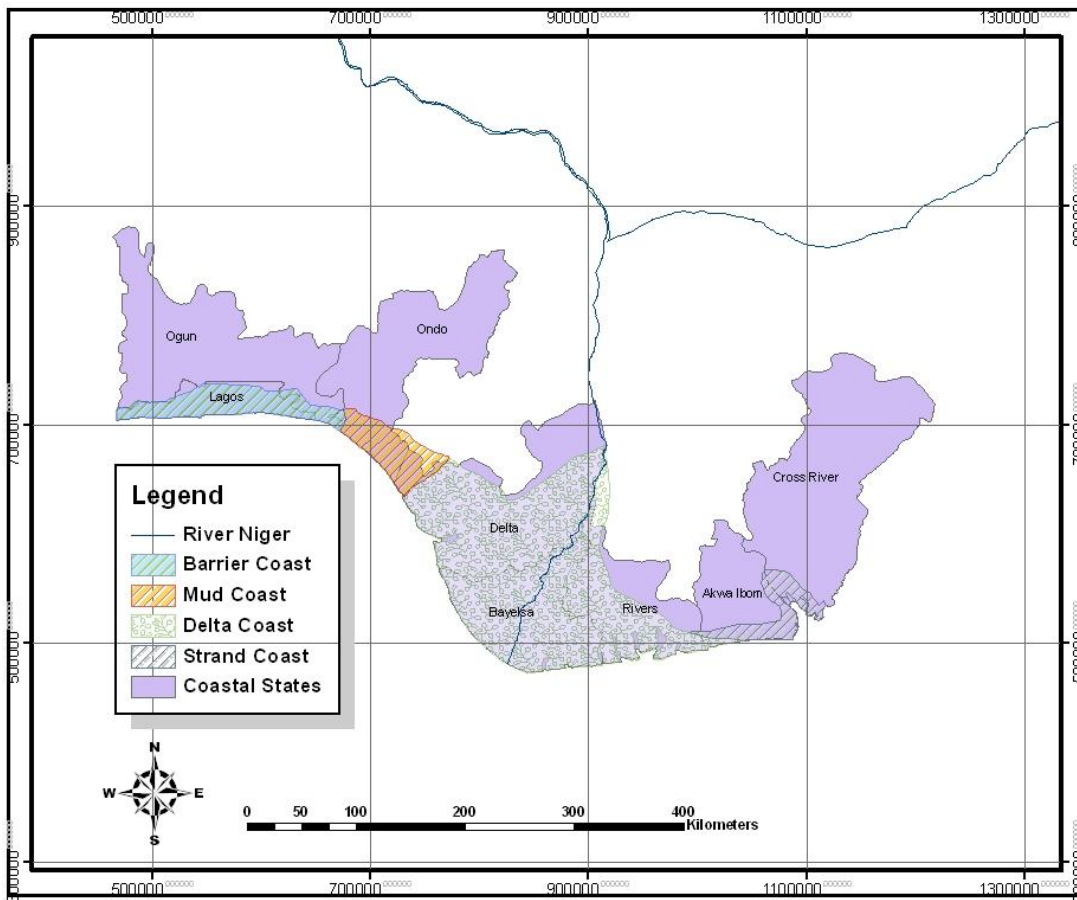
Map 3.3:   **Delineation of the Study Area from the Coastal States**

Adapted from French *et al.* (1995).

CHAPTER FOUR

4.0   Shoreline Retreat in the Nigerian coast due to Sea Level Rise

4.1   Introduction

This Chapter presents the results of the analyses conducted to ascertain the impact sea level rise will have on the case studies. With sea level rise of 4 mm/year adopted for this study, it means that the level of sea would have risen to 0.16m and 0.36m by year 2050 and 2100 respectively. Therefore, an accelerated rise in sea levels, which could be experienced due to thermal expansion and the possibility of the melt of the glaciers, forms the basis of this Chapter. This study has embarked on ascertaining the extent of erosion for four sea level rise scenarios, which are 0.5; 1; 2 and 3 metres by year 2100. A 0.5 m sea level rise (SLR) by 2100 translates to 5.55 mm/yr. 1 m SLR by 2100 translates to 11.1 mm/yr. per year; 2 m will mean 22.2 mm/yr. while 3 m SLR will mean 33.3 mm/yr. Results are presented to show the total area that will be lost and the length of recession in the projected years. Projections were made for the base year 2010 and then 2050 and 2100.

4.2   Case Studies

Land area that will be eroded was estimated with each of the scenarios. The case studies for this Chapter are Barrier, Delta, and Strand coast. There is no consideration of the Mud coast because the Bruun model adopted did not support estimating erosion in muddy coasts (see section 3.4.2.1). The presentation follows a case study approach.

4.2.1   Barrier Coast

Erosion extents were estimated for the Barrier coast both for the upper and lower range. The variable responsible for the range is the depth of closure. The length of the Barrier coast was estimated to be about 206km with the aid of the measuring tool from Google

Earth image. The area extent that will be eroded for the scenarios of SLR projected for year 2050 and 2100 for Barrier coast is presented in Table 4.1. In a 1 m SLR by year 2100, eroded land will be between 0.23 and 0.37 sq.km. With the scenarios used in this study, the amount of land that will be eroded in a 3 m SLR scenario by year 2100 is about 1.12 sq.km.

Table 4.1:   Barrier Coast: Projected Land Area Eroded (sq. km)

Scenarios of SLR (m)	Year		
	2010 (sq. km)	2050 (sq. km)	2100 (sq. km)
0.5 (5.55 mm/yr.)	0.001 – 0.002	0.05 – 0.08	0.11 – 0.19
1 (1.11 mm/yr.)	0.003 - 0.004	0.10 – 017	0.23 – 0.37
2 (2.22 mm/yr.)	0.005 - 0.008	0.20 – 0.33	0.46 – 0.75
3 (3.33 mm/yr.)	0.008 - 0.012	0.30 – 0.50	0.69 – 1.12

In a further analysis, the research estimated recession along the Barrier coastline for the five scenarios. This is presented in Figure 4.1 to Figure 4.3 with length of the coastline on the horizontal (x) axis, the extent of land eroded on the vertical (y) axis while the data marker both for the low and high estimates shows the amount of land that will recede at a particular location. Map 4.1 depicts the spatial locations with low and high erosion rate. The map is a complement to Figures 4.1 to 4.3. The erosion extent ranges between 0.003 and 0.012 metres for the lower estimate and 0.005 and 0.02 metres for the upper estimate in a 0.5 metres SLR projection made for 2010 while in a 1 m SLR, between 0.61 and 2.09 metres; and 0.99 and 3.41 metres were projected for the lower and higher estimates for year 2100. In an 11.1 mm/yr. SLR, the lowest erosion zone recorded is between latitude 6.42 and 6.43; and longitude 3.55 and 3.74 degrees with coastline recession of between 0.006 – 0.01 and 0.008 – 0.02 metres for the low and high estimates. This will amount to coastline recession ranging between 0.25 – 0.4 and

0.41 – 0.67 metres by year 2050, and between 0.55 - 0.91 and 0.92 – 1.5 metres by year 2100 for the low and high estimates. This is a distance of about 20km and the coastline is about 6km from the Eputu Town settlement and about 4km from the KM 35 Lekki-Epe expressway, See Map 4.2.

The highest coastline recession recorded in the Barrier coast includes areas along Tarqua Bay and the Bar Beach (see Map 4.3). In an 11.1 mm/yr. SLR, the coastline recession along these regions will be between 0.01 – 0.02 metre and 0.02 and 0.04 metre per year for the low and high estimates. This will amount to coastline recession of between 0.5 – 0.8 and 0.9 – 1.5 metres by 2050, while it will amount to a coastline recession of between 1.1 – 1.8 and 2.1 and 3.4 by year 2100 for the low and high estimates.

Figure 4.1: **Barrier Coast: Erosion extent for the high and low estimates of the SLR scenarios for year 2010**

Figure 4.2: Barrier Coast: Erosion extent for the high and low estimates of the SLR scenarios for year 2050
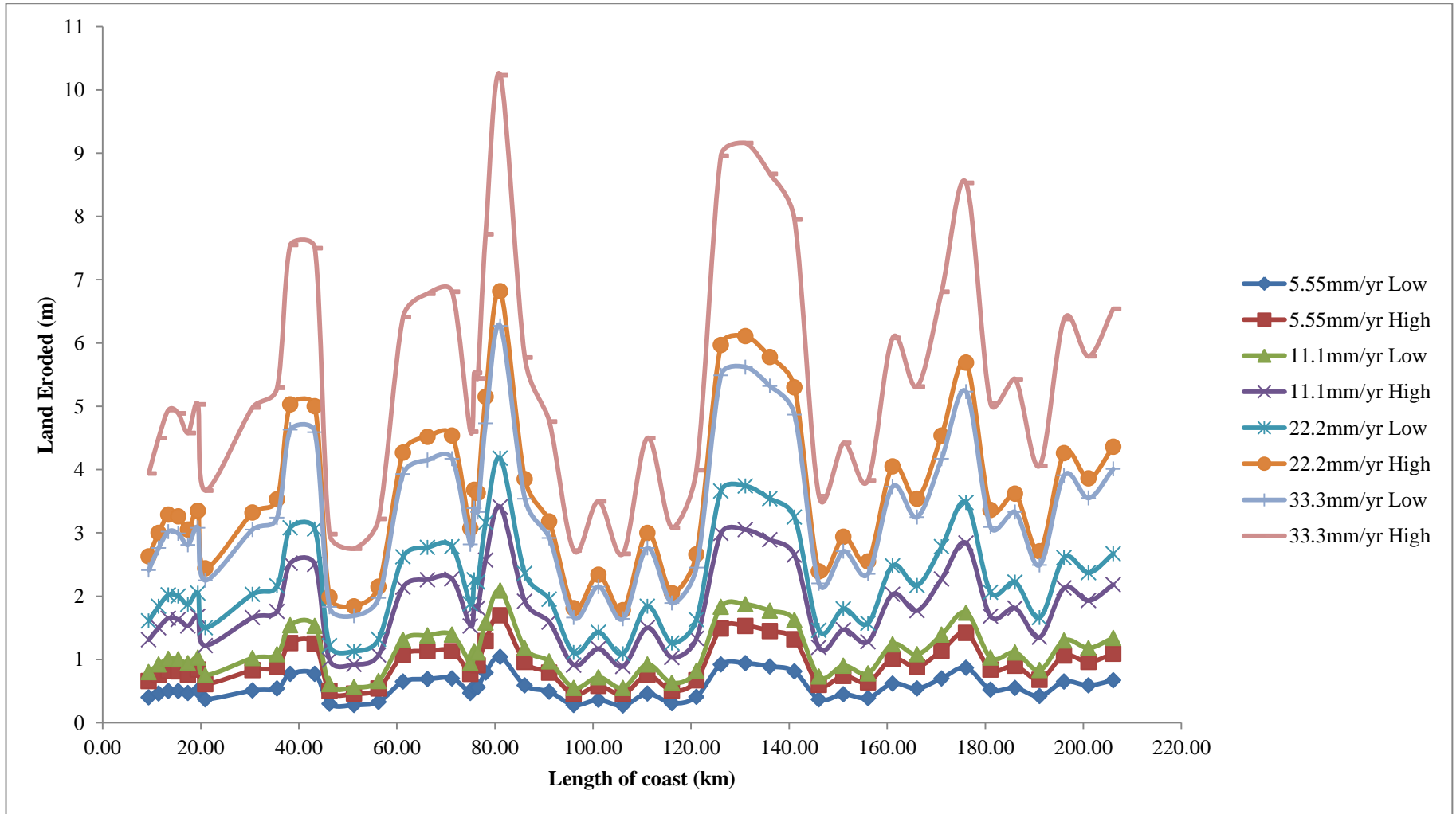
Figure 4.3: **Barrier Coast: Erosion extent for the high and low estimates of the SLR scenarios for year 2100**
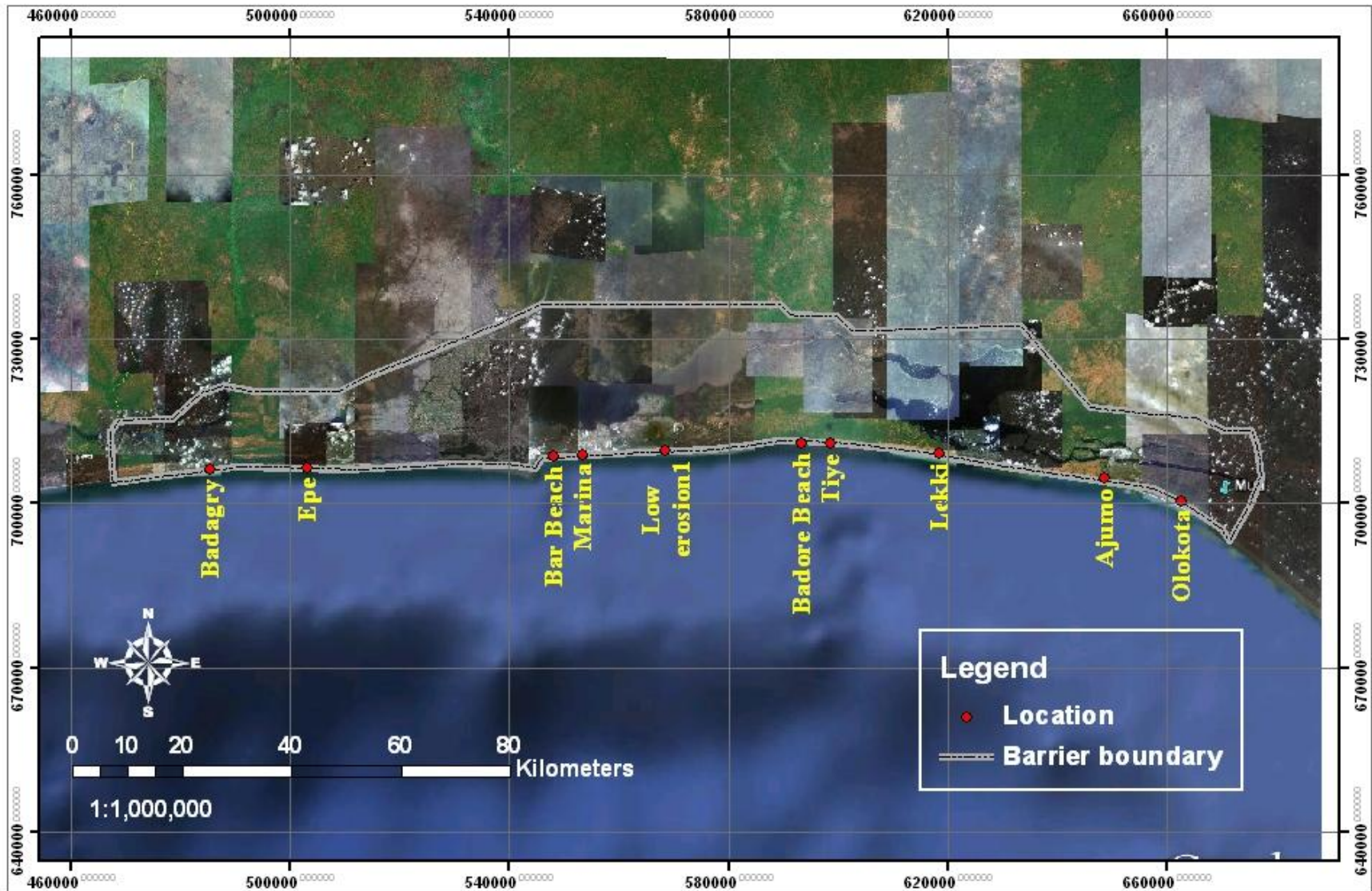
Map 4.1: Map depicting locations of low and high erosion along the Barrier coast, (Adapted from Google Earth)

Map 4.2: **Map showing the region of the lowest erosion in the Barrier coast, (Adapted from Google Earth)**

Other areas that will experience high erosion include the region around Badore beach, Lagos beach Tiye, Ikoti village, Lekki beach and Ebute Lekki area with recession amassing up to between 1.7 and 1.9 metres in a 1 m SLR by year 2100. In a continued accelerated sea level rise (i.e. 3 m by 2100), coastline recession in these areas could go inland in the range of 5.6 metres and 9.2 metres. For all the scenarios considered, the pattern of recession from one will be the same for the other for any period considered. However, this could change if other factors not included in the Bruun model occur along any part of the coast. Other factors that could cause a change in the pattern observed in the recession of coastline could also include changes in the variables that serve as input in the Bruun model at a particular location. These include high water mark, breaker wave height and depth of closure. Results shows that coastline recession will be more for the high estimates of sea level rise scenario of 2 m by 2100 than the

lower estimate of a 3 m scenario. The depth of closure plays a big role in determining

coastline recession.
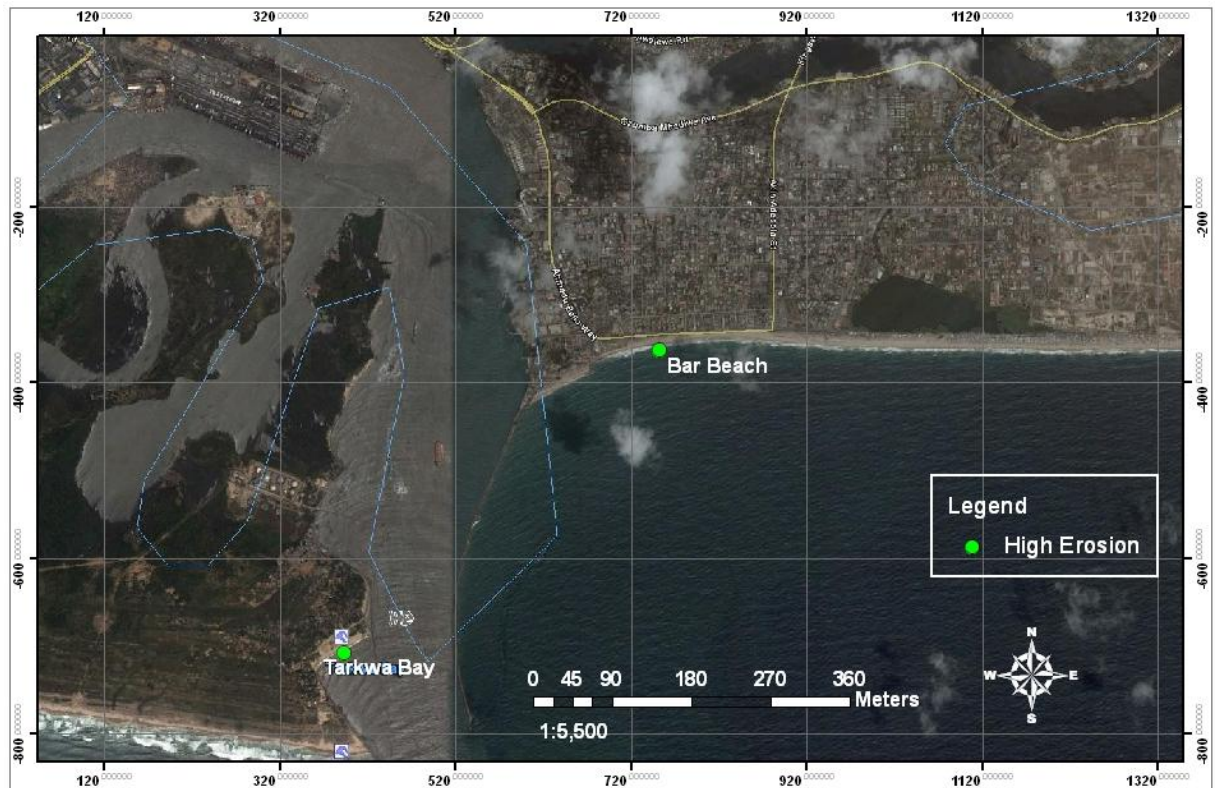
**Map 4.3:   Map showing the region of the highest erosion in the Barrier coast,
(Adapted from Google Earth)**

4.2.2   Delta Coast

The upper and lower estimates and the extent of recession in the Delta coast was

determined based on the data and the model employed. The length of the Delta coast

was estimated to be about 375 km. Coastline recession were projected for year 2050 and

2100 using the base year 2010 for SLR scenarios, 0.5, 1, 2, and 3 metres by year 2100.

The estimated values both for the low and high estimates are presented in Table 4.2.

Table 4.2:   Delta Coast: Projected Land Area Eroded (sq. km)

Scenarios of SLR (m)	Year		
	2010 (sq. km)	2050 (sq. km)	2100 (sq. km)
0.5 (5.55 mm/yr.)	0.005 - 0.008	0.19 - 0.30	0.42 - 0.69
1 (1.11 mm/yr.)	0.009 - 0.015	0.37 - 0.61	0.84 - 1.37
2 (2.22 mm/yr.)	0.019 - 0.030	0.75 - 1.22	1.68 - 2.74
3 (3.33 mm/yr.)	0.028 - 0.046	1.12 - 1.83	2.52 – 4.11

Result shows that at 5.5 mm SLR, between 0.005 and 0.008 square kilometres of the total area of the Delta coast was judged to erode in 2010. In a continued sea level rise until year 2100, the estimated coastline recession will be between 0.4 and 0.7 sq.km. However if there is an accelerated increase of 1 m by year 2100, recession could go as high as 1.4 sq.km.

Recession of the coastline because of sea level rise was estimated for the Delta coast for the four scenarios. This is presented in Figure 4.4 to Figure 4.6. Map 4.4 depicts the spatial locations with low and high erosion rate complement to Figures 4.4 to 4.6. The coastline recession estimates extends between 0.003 and 0.03 metres for the lower estimate and 0.005 and 0.05 metres for the upper estimate in a 0.5 metres SLR projection made for 2010. This could increase to between 0.11 and 1.2 metres for the lower estimates and between 0.2 and 1.9 metres by year 2050. In addition, between 0.25 and 2.6 metres for the lower estimates and between 0.4 and 4.2 metres for higher estimates for year 2100 could recede. If sea level rises by 11.1 mm/yr., then the erosion figures given previously could be doubled for the years considered.
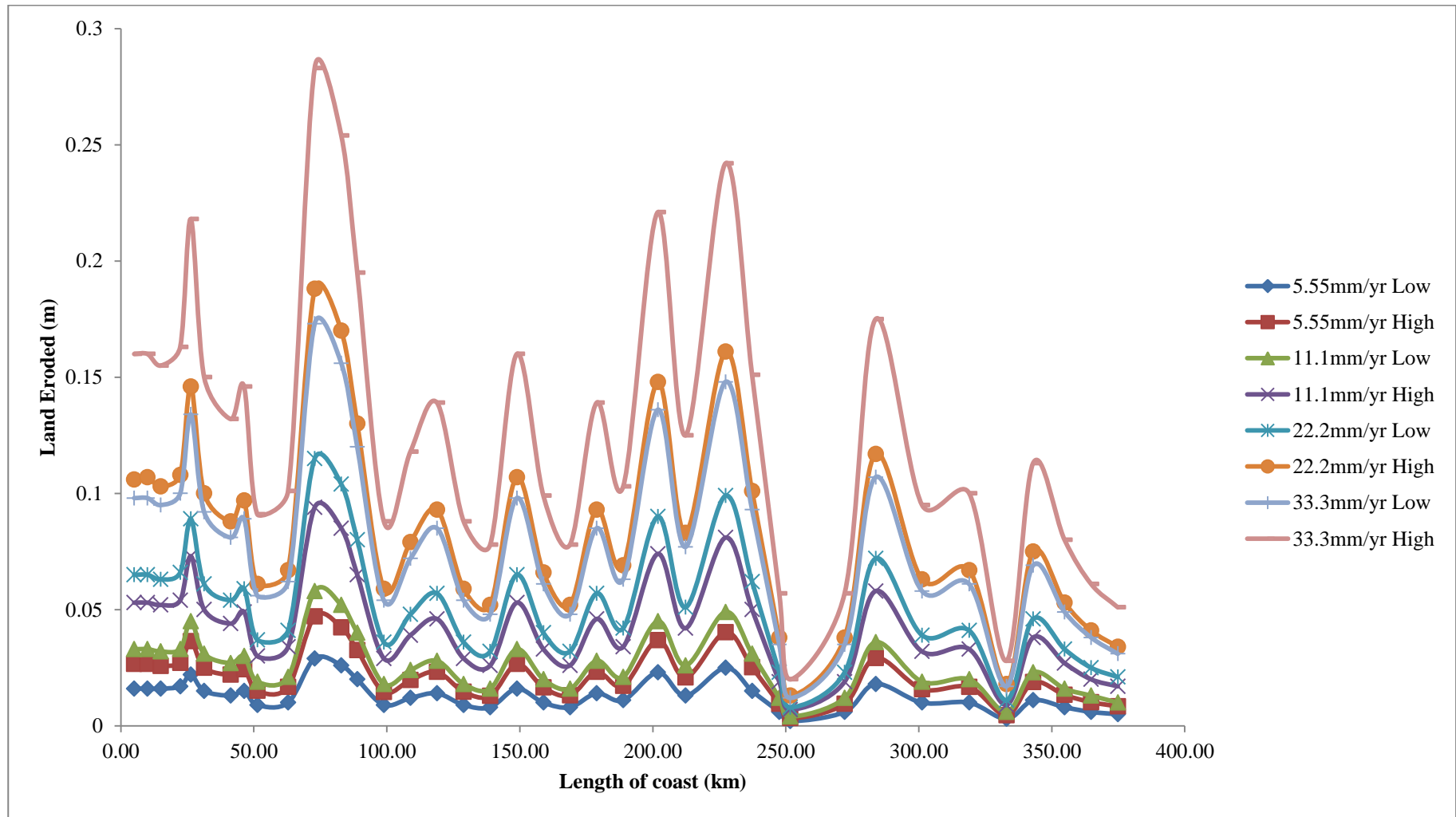
Figure 4.4: Delta Coast: Erosion extent for the high and low estimates of the SLR scenarios for year 2010
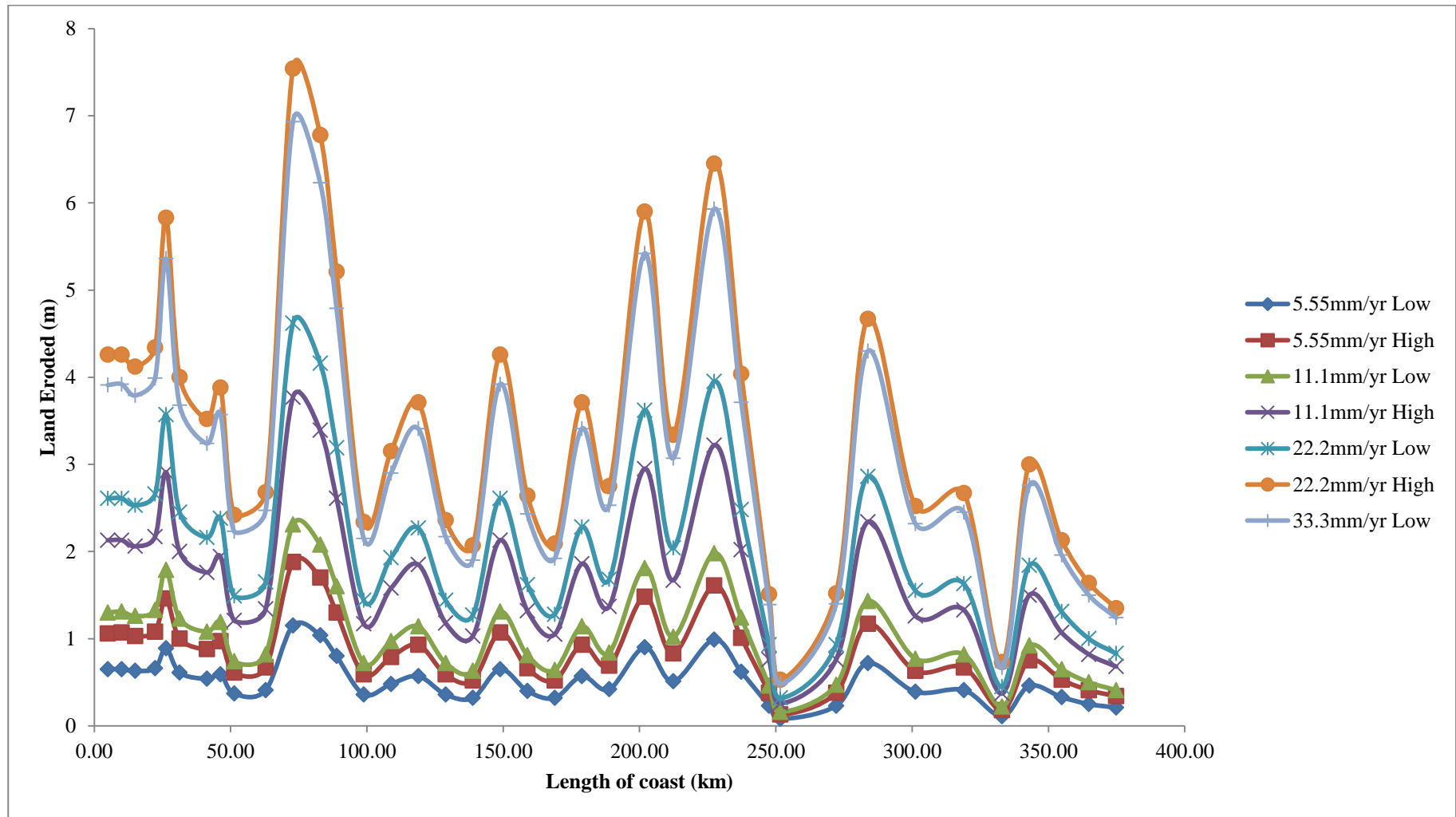
Figure 4.5: **Delta Coast: Erosion extent for the high and low estimates of the SLR scenarios for year 2050**
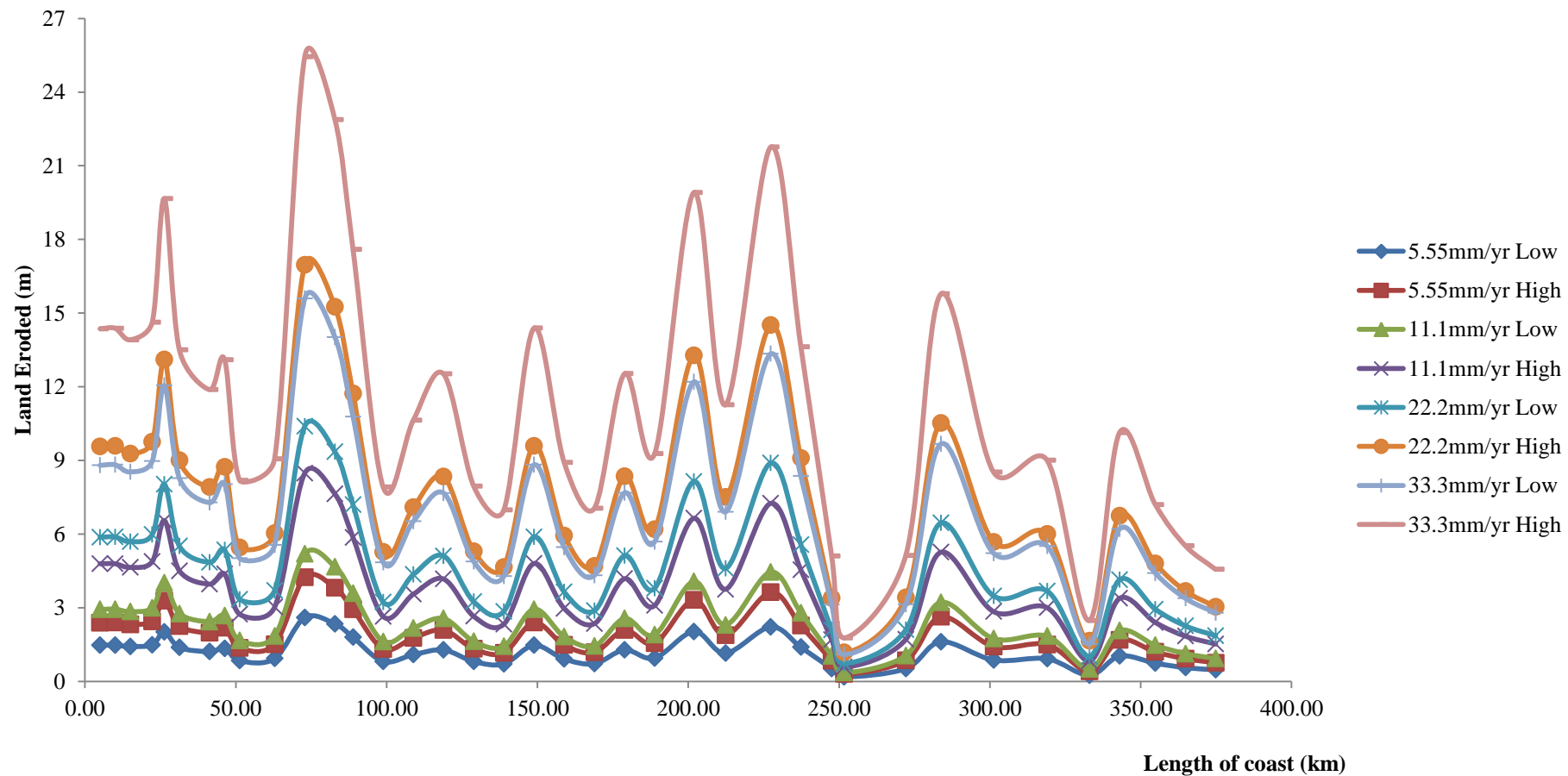
Figure 4.6:   Delta Coast: Erosion extent for the high and low estimates of the SLR scenarios for year 2100

Oke

Yokri Egbe

Odimodi

Ezeotu

Okumbiri/Akassa

Opikokiri

Abaji Okolo
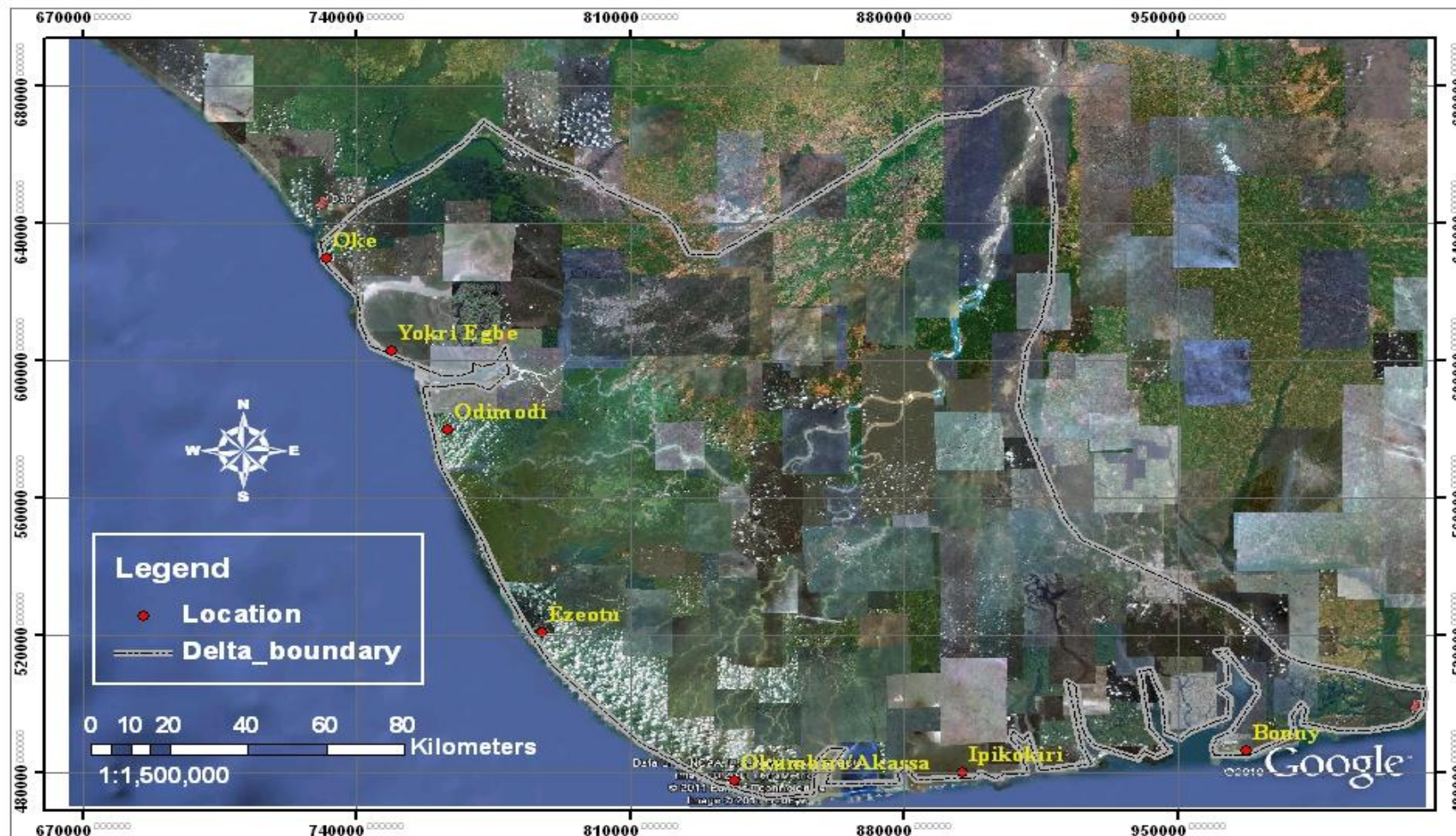
Map 4.4: Map depicting locations of low and high erosion along the Delta coast, (Adapted from Google Earth)

Projections made for a 1-metre SLR for 2100 reveals that the lowest erosion zone will be at around areas close to latitude 6.32 – 6.34 and longitude 6.54 – 6.71 degrees. The estimated coastline recession is between 0.4 and 1.1 metres for the low estimate and between 0.6 and 1.8 metres (see Map 4.5). The settlements around this region include Ipikokiri and Oyekiri. High recessions are recorded between latitude 4.35 and 4.28; and longitude 5.92 and 6.06. The settlement within this region extends from Okumbiri to Akassa. Estimated recession by year 2100 at 1 metre SLR is between 4.1 and 4.7metres for the low estimate and between 6.6 and 7.6 metres for the high estimate. High recession rates are also recorded for areas around Yokri Egbe, Kantu, and Burutu with low estimates ranging between 4.1 and 5.2 metres and high estimates ranging between 6.6 and 8.5 metres in a 1 m SLR by year 2100 (see map 4.6).
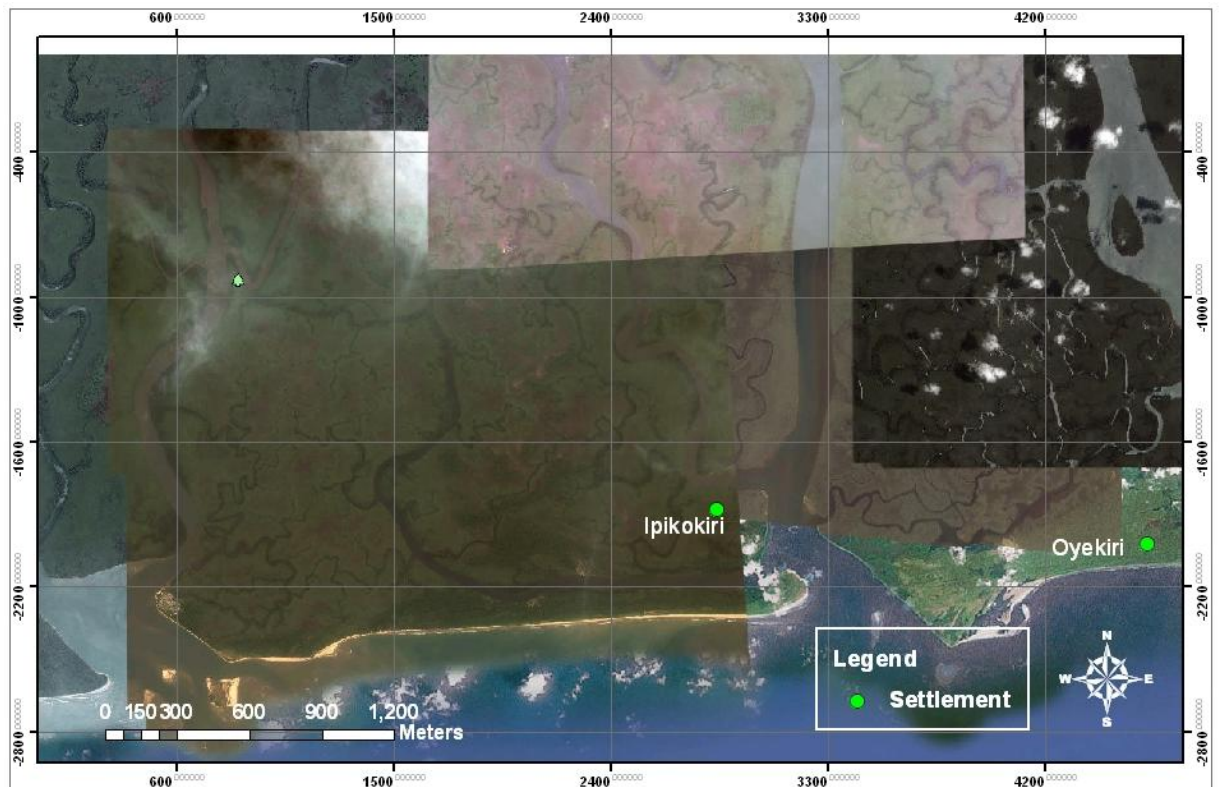
Map 4.5:   **Map showing the region of the lowest erosion in the Delta coast**
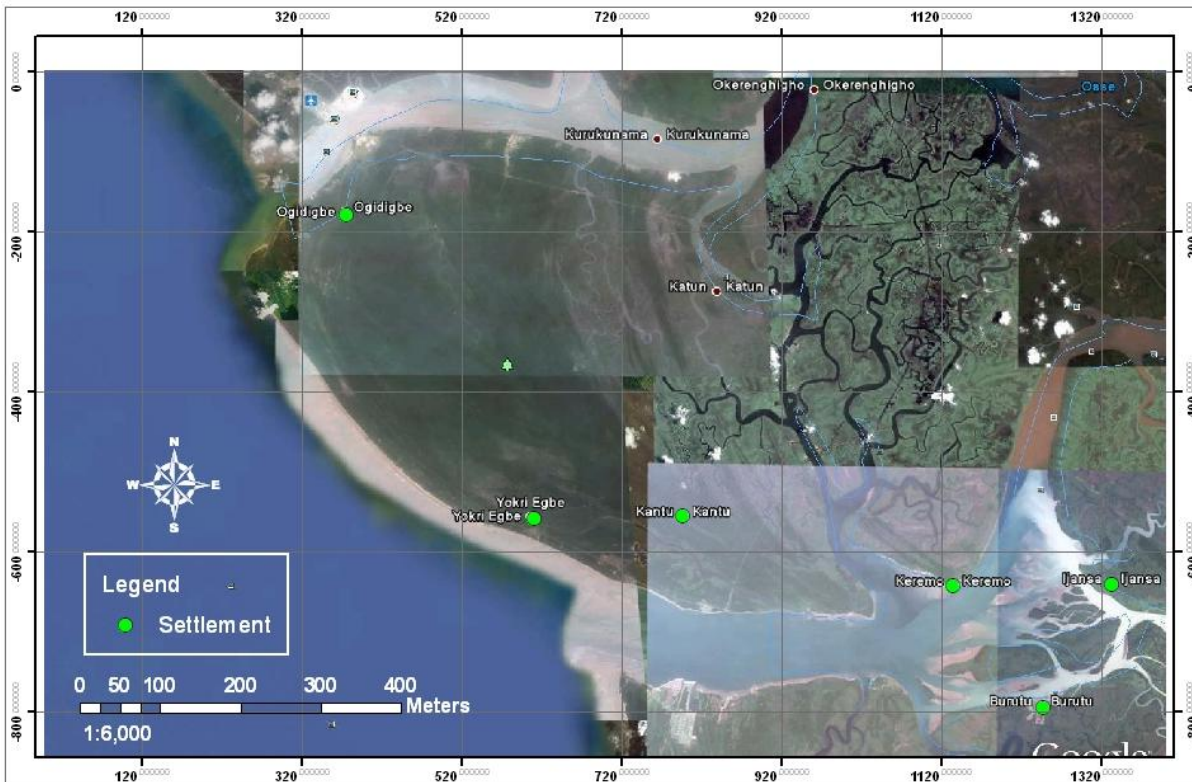
Map 4.6:   Map showing the region of highest erosion in the Delta coast, (Adapted from Google Earth)

4.2.3   Strand Coast

This section shows the computation of the upper and lower estimates of recession and the extent of erosion in the Strand coast. Erosion extent were projected for year 2050 and 2100 using the base year 2010 for SLR scenarios 0.5, 1, 2, and 3 metres by year 2100. The estimated values both for the low and high estimates are presented in Table 4.3. Result shows that at 0.5 SLR, between 0.002 and 0.003 square kilometres of the total area of the Strand coast was judged to erode in 2010. In a 1-metre scenario, the amount of land that will be eroded by year 2100 is between 0.32 and 0.52 square kilometres.

This research computed the recession of the coastline due to sea level rise for the Strand coast for the four scenarios.

Table 4.3:   Strand Coast: Projected Land Area Eroded

Scenarios of SLR (m)	Year		
	2010 (sq. km)	2050 (sq. km)	2100 (sq. km)
0.5 (5.55 mm/yr.)	0.002 - 0.003	0.07 - 0.11	0.16 - 0.26
1 (1.11 mm/yr.)	0.004 - 0.006	0.14 - 0.23	0.32 - 0.52
2 (2.22 mm/yr.)	0.007 - 0.011	0.28 - 0.46	0.63 – 1.03
3 (3.33 mm/yr.)	0.011 - 0.017	0.42 - 0.69	0.95 - 1.55

Figure 4.7 to Figure 4.9 shows the extent of erosion from the coastline for the low and high estimates for the four scenarios adopted in this Chapter. Map 4.7 depicts the spatial locations with low and high erosion rate. The map is a complement to Figures 4.7 to 4.9. The strand coast was noticed to have extremes in terms of coastline recession as there are regions where there seems to be no significant shoreline shift especially with the lower estimates and regions of extreme erosion. In numerical terms, the coastline recession estimates ranges between 0.001 and 0.003 metres for the lower estimate and 0.002 and 0.005 metres for the upper estimate in a 0.5 metres SLR projection made for 2010. Between 0.25 and 0.51 metres; and 0.41 and 0.83 metres were projected for the lower and higher estimates for year 2100 in a 1 m SLR. Projections made for a 1-metre SLR for 2100 reveals that the lowest erosion zone will be at areas close to Oron, and Calabar (see Map 4.8). However, there will be high erosion in areas close to Eket, in Akwa Ibom State in the Bight of Bonny. In this area is the Bell 412EP, Qua Ibo Terminal for helicopters. It is about 500 metres off the shoreline. Shoreline recession in this area will only be up to 6.9 metres from the shoreline in a 1 m SLR by 2100, hence, no significant impact.
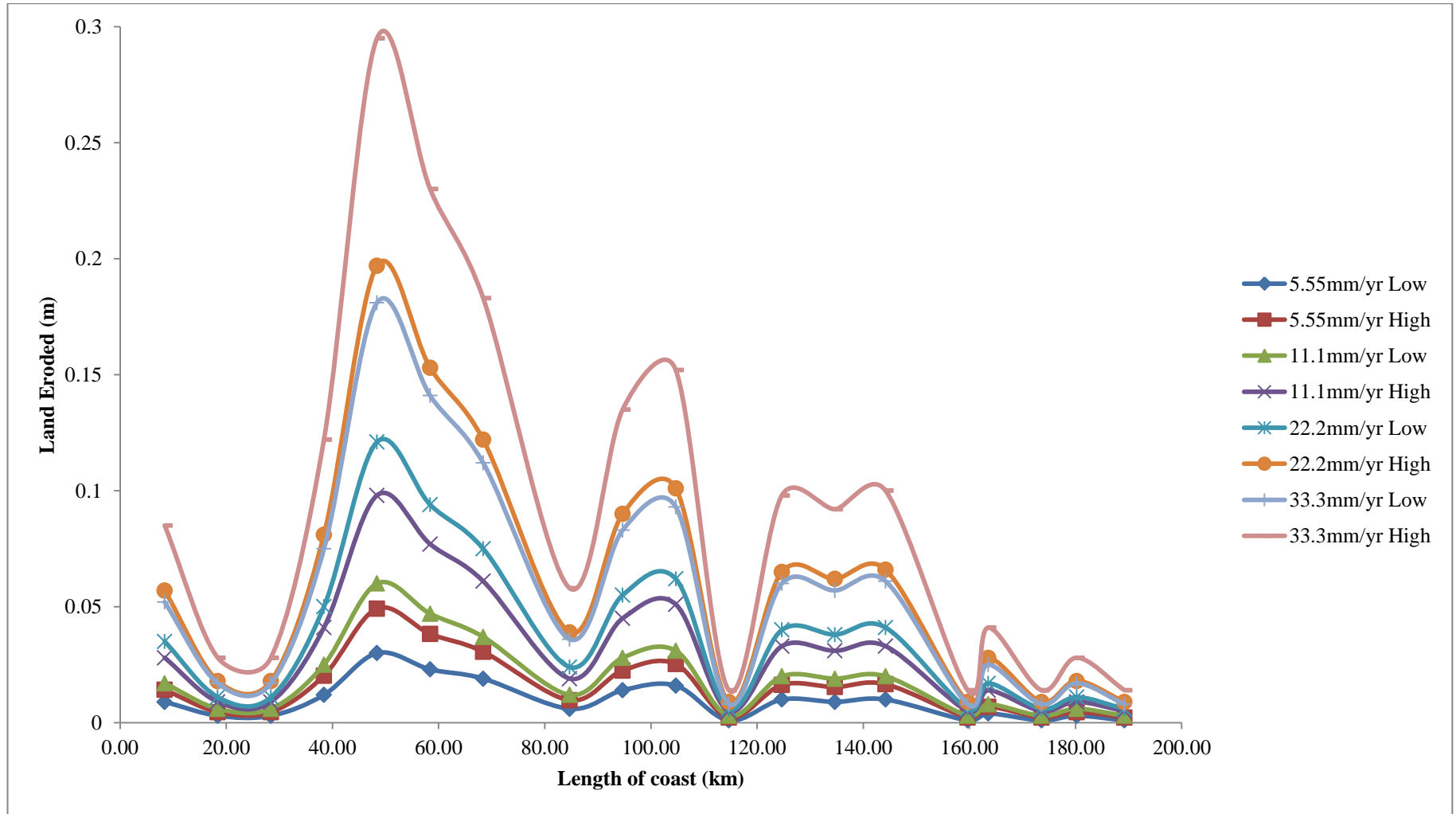
Figure 4.7: **Strand Coast: Erosion extent for the high and low estimates of the SLR scenarios for year 2010**
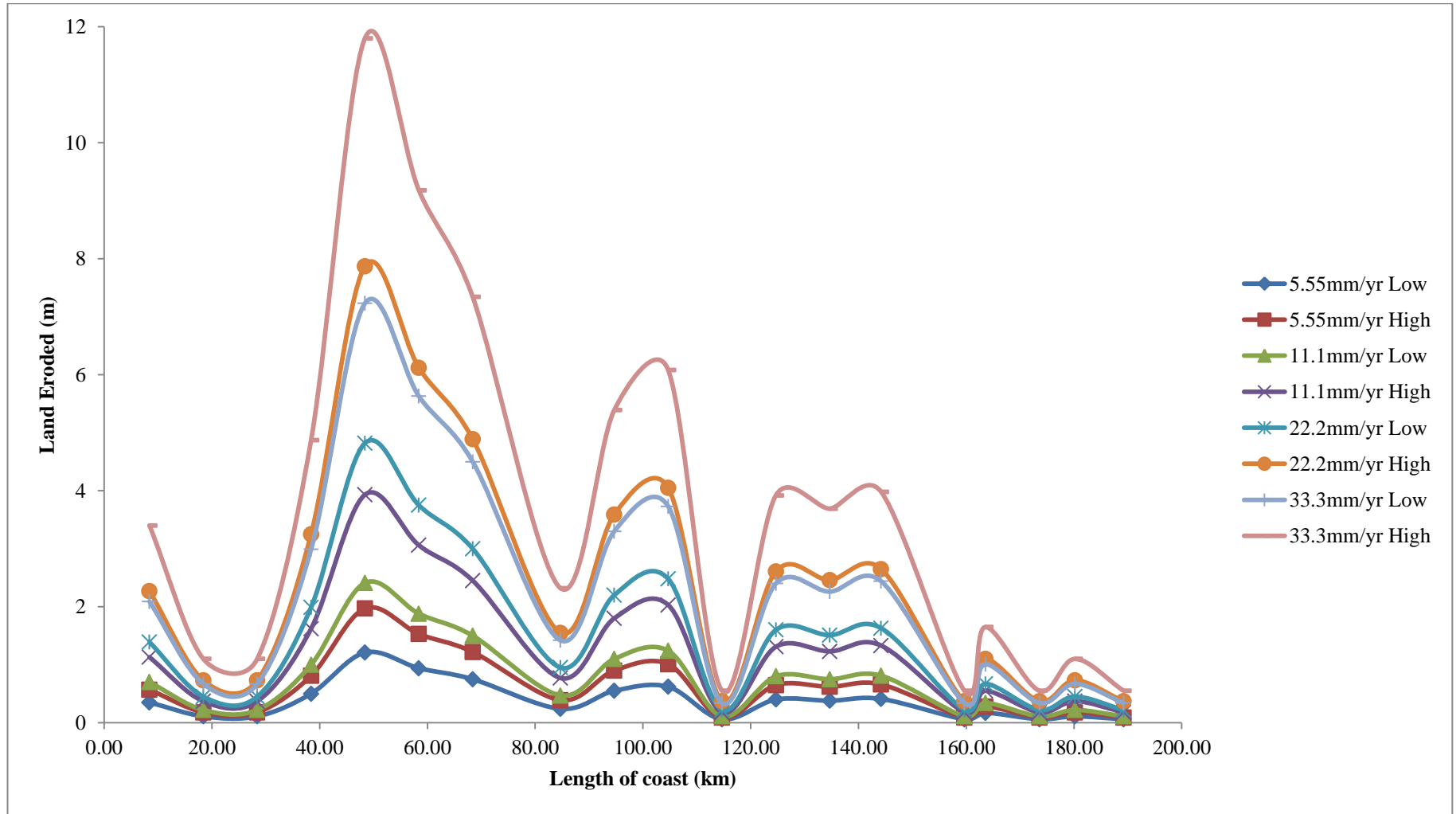
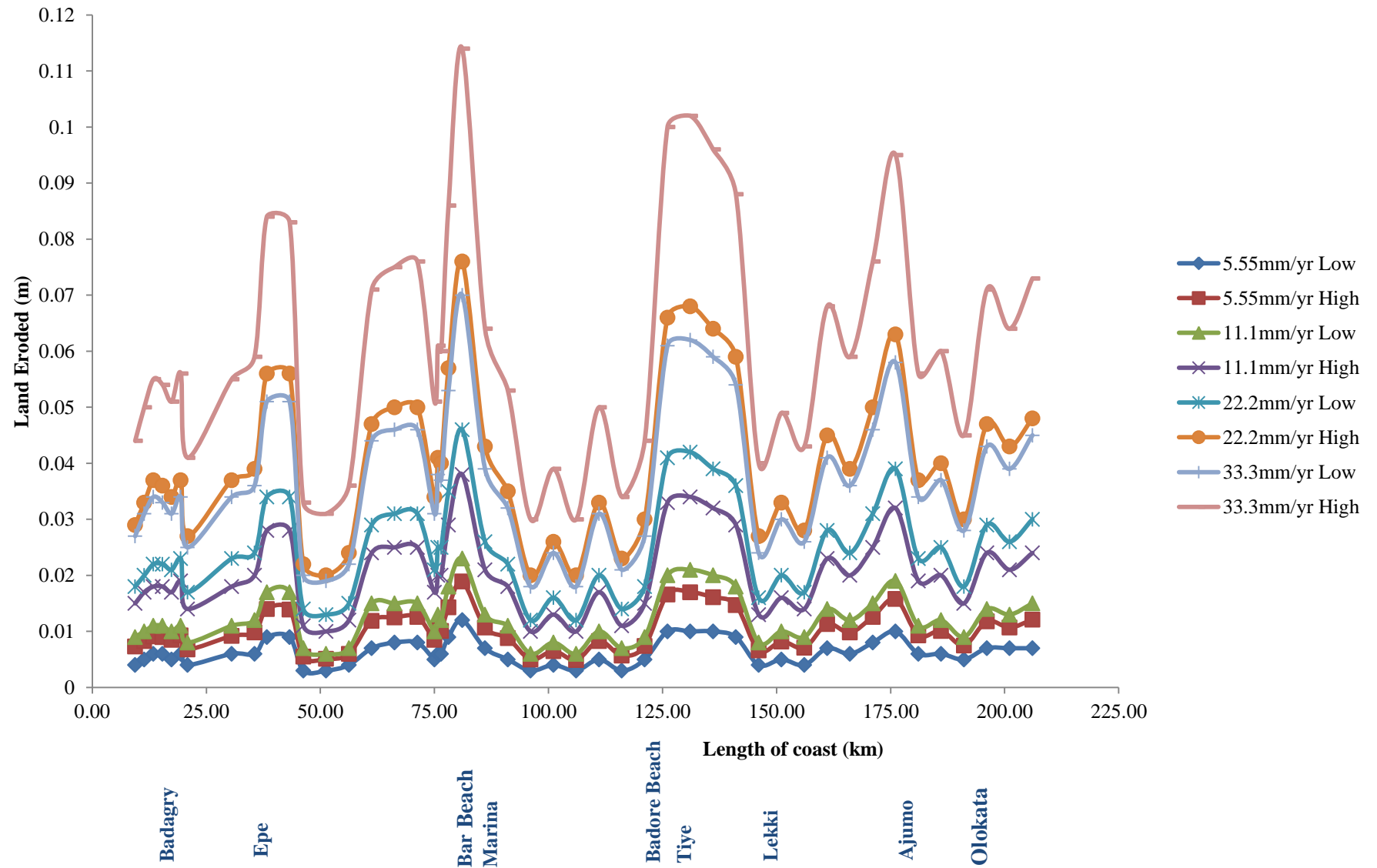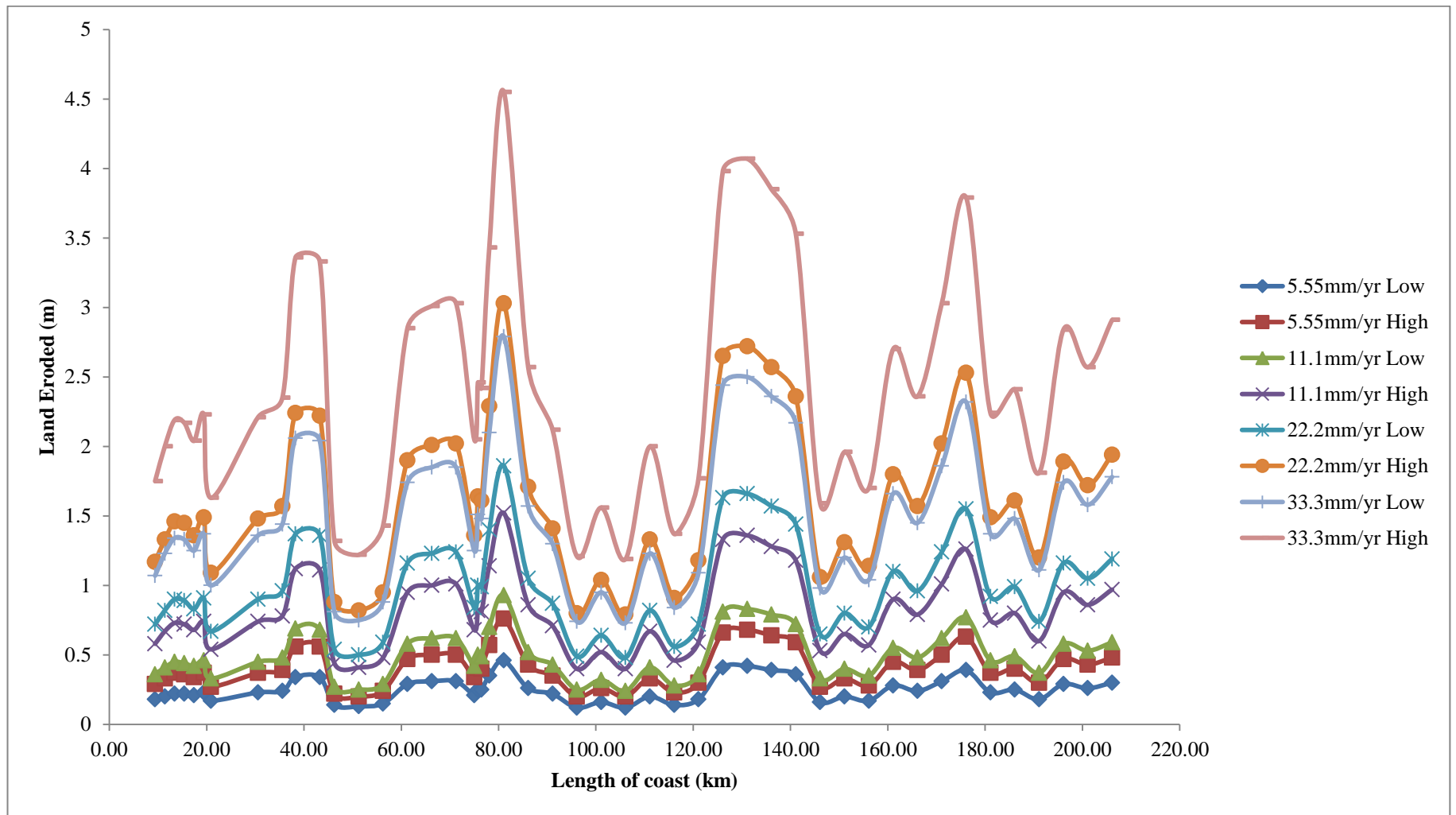**Figure 4.8:** **Strand Coast: Erosion extent for the high and low estimates of the SLR scenarios for year 2050**
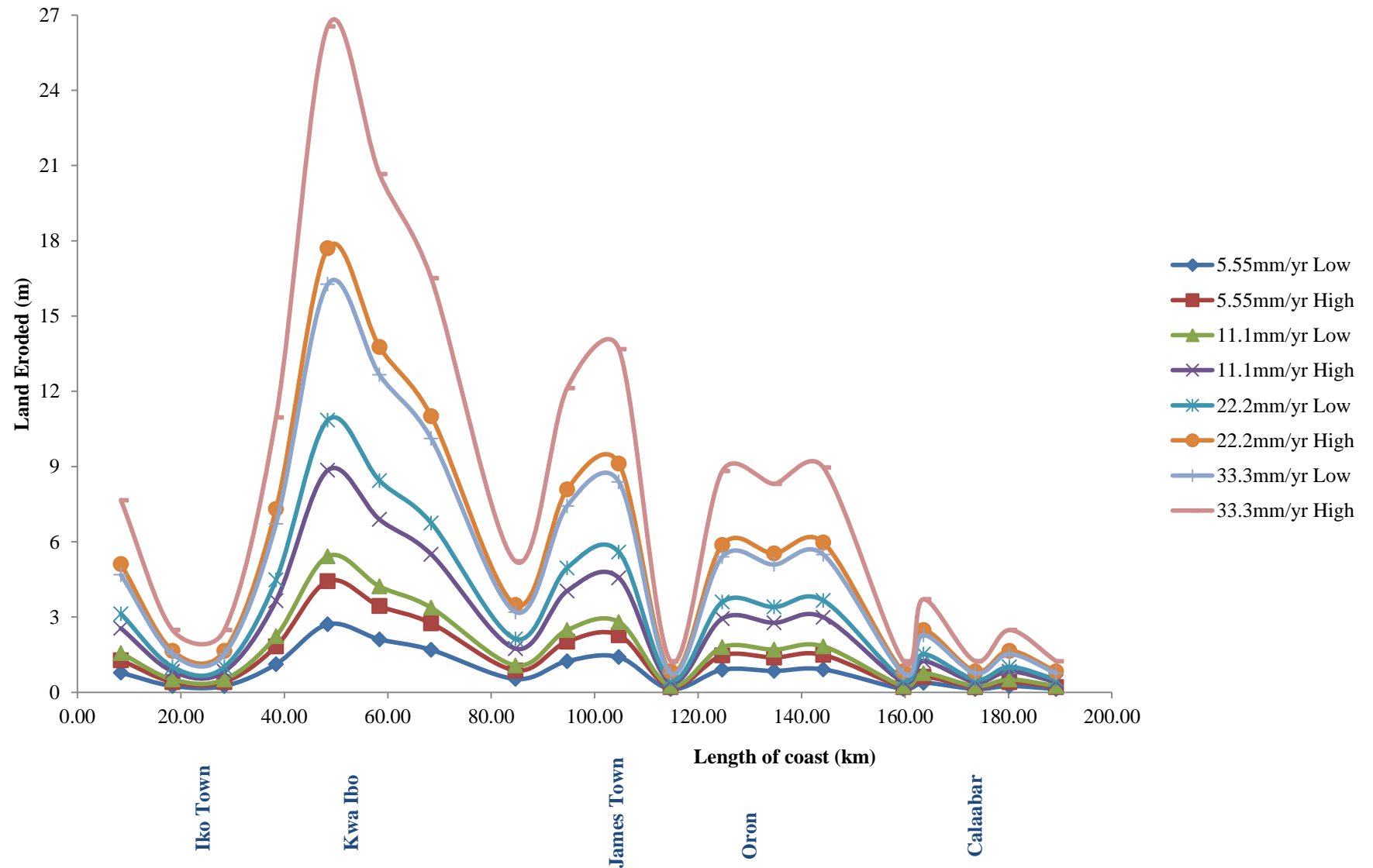
Figure 4.9: Strand Coast: Erosion extent for the high and low estimates of the SLR scenarios for year 2100

134
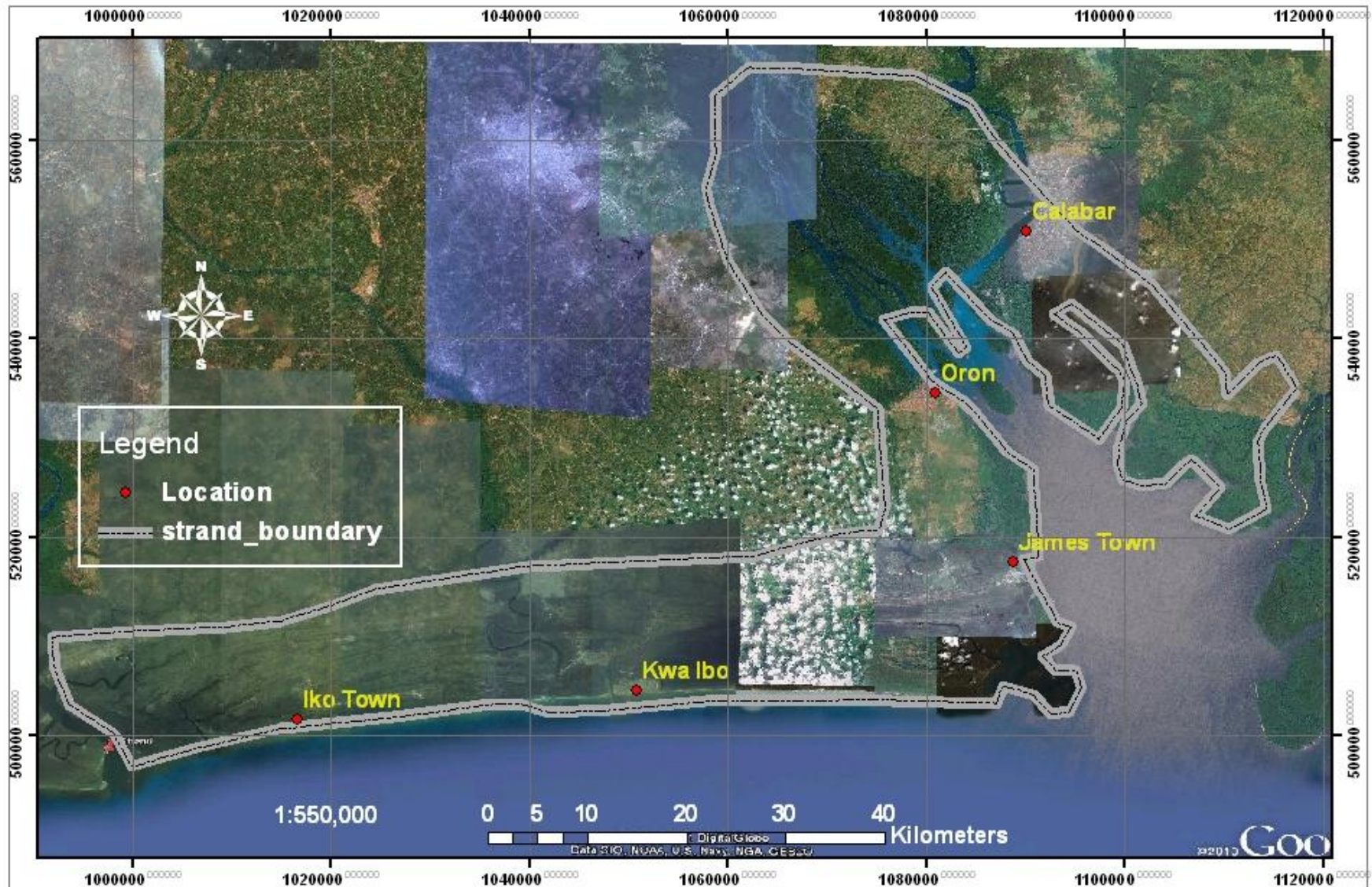
Map 4.7: **Map portraying locations of erosions along the Strand coast. (Adapted from Google Earth)**

135

Within this area, there is a residential area known as Kwa Ibo, which covers an area of approximately 3.5 sq. km. Kwa Ibo shares boundaries with the coastline and so with a significant increase in sea level rise, the zone might be at risk (sees Map 4.9). The trend in coastline recession across the coast increases sharply at the west and then drops considerably towards the east until it reach the Nigerian boundary with Cameroon.
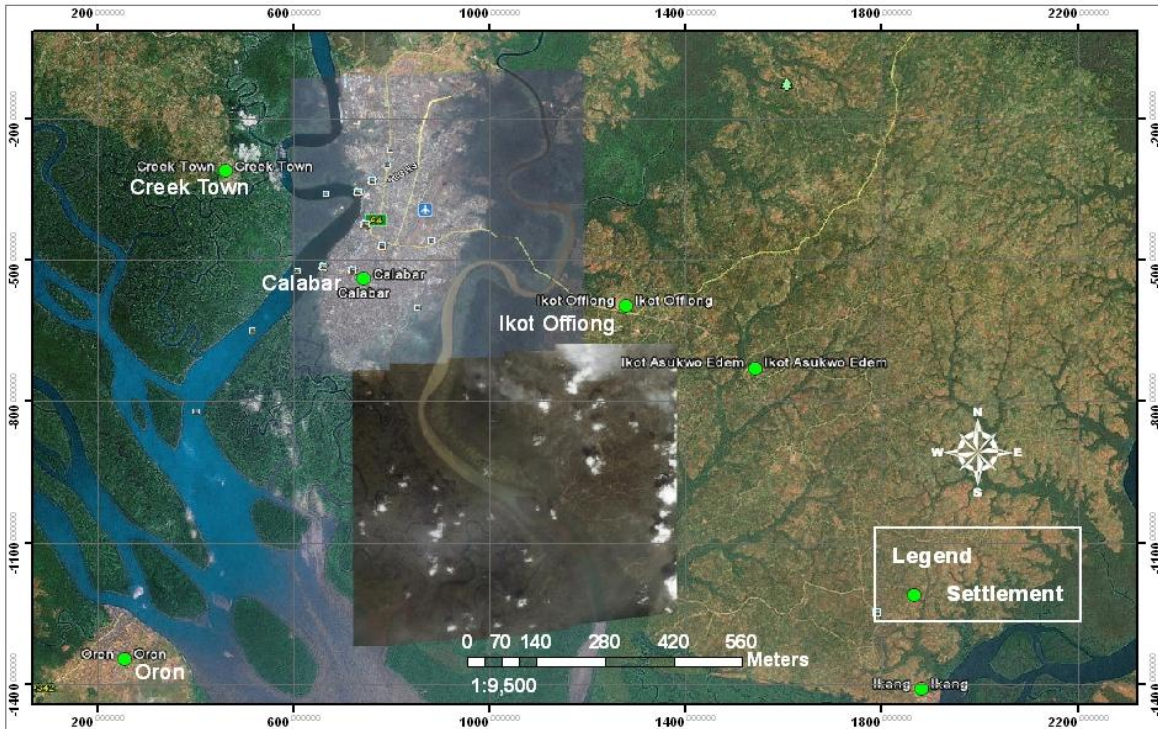
Map 4.8: **Map showing the region of low erosion in the Strand coast, (Adapted from Google Earth)**
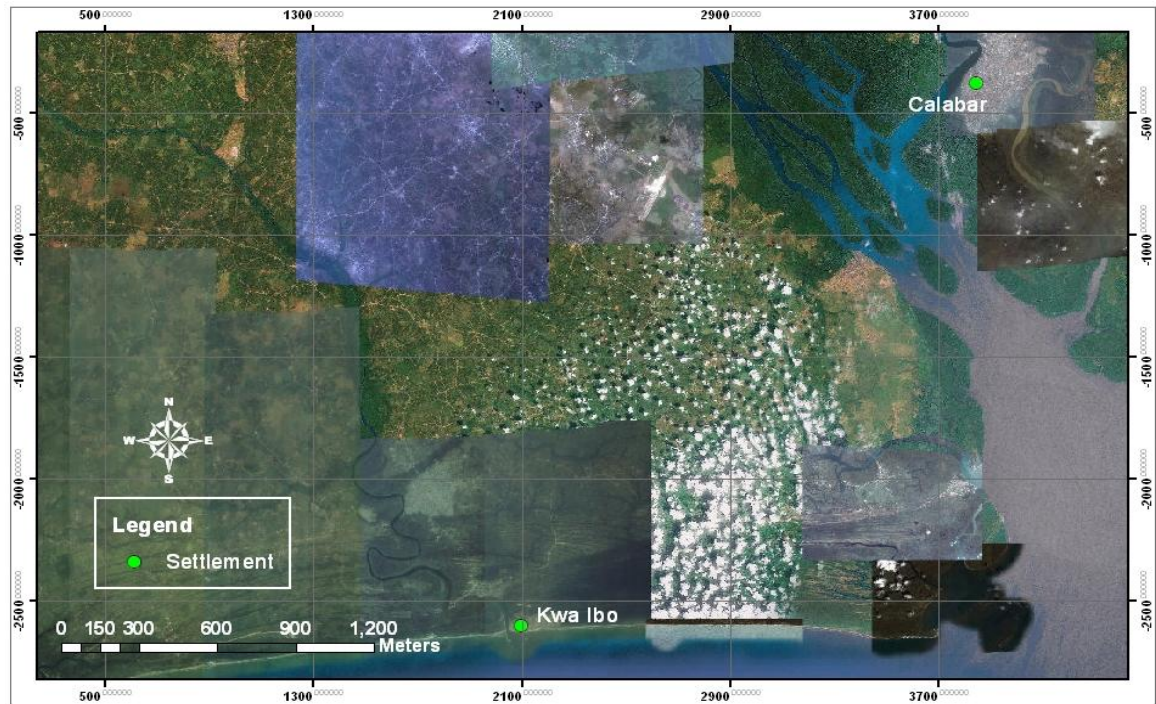
Map 4.9: **Map showing the region of high erosion in the Strand coast, (Adapted from Google Earth)**

4.3 Accounting for uncertainties in the Bruun Model

The parameters of the Bruun Model include the sea level rise, depth of closure, berm height and the width of shoreface. The uncertainty that relates to sea level rise has been explained in sections 2.2.1 and 2.2.2. For the depth of closure, the determining parameter is the significant wave height with the Hallermeier (1982) equation. Uncertainty in the significant wave height thus relates to how the wave data is collected and the degree of error associated with it. Significant wave height (H_s) is also a determining parameter for calculating the berm height. This is because significant wave height is part of the parameter needed to calculate the wave breaker height in the equation provided by Komar (1998), which is then subsumed in the equation provided by Takeda and Sunamura (1982) to calculate berm height (see section 3.4.3.1 for the equations). In addition, the wave period (T_w) forms part of the parameters of the berm height in that it is important in the estimation of the breaker height, which is subsequently, substituted into the berm height equation.

For the H_s and the T, the results are not absolute as there are uncertainties that underlie the calibration of each parameter. This thus necessitated a basic sensitivity analysis to test for the significance of the uncertainties. The first step was to determine the appropriateness and reliability of the wave data, which produces H_s and the T. The wave data from the BMT Fluid Mechanics is suitable for wave analysis. The metadata from the BMT Fluid Mechanics shows that wave observations were extracted from the Marine Databank UK for each area covered and were input into the NMIMET process for quality enhancing analysis and checking procedures. The NMIMET analysis is in three stages. (1) the derivation of coefficients for a parametric model relating wave height and wind speed statistics; (2) the use of the parametric model relating wave height statistics of enhanced reliability from input of all the available wind data; and (3) the generation of the joint probability distributions of wave heights and periods. The Global Wave Statistics which are based on visual observations has been collected under the auspices of and the guidance note prescribed by the World Meteorological Organisation (WMO) (BMT Fluid Mechanics, 2010). The advantages of the Global Wave Statistics database include wider coverage, increased number of observations and greater reliability through the NMIMET analysis program. Andrews *et al.*. (1983), Hogben *et al.*. (1983), Dachuna *et al.*. (1984) and Hogben and Dachuna (1985), compared the Global Wave Statistics data with other measured data on a worldwide basis and documented that the validity and the quality with the use of the NMIMET analysis.

The second step is the appropriateness and reliability of the raw data for the width of the shoreface profile. The measurement of this parameter is in accordance with the standard technique suggested by Andrade and Ferreira (2006). The technique is an alternative to the Emery (1961) method. This method is based on the physical principle of

communicating vessels, consisting of the sequential measurement of differential elevation as read on two graduated rods (Andrade and Ferreira, 2006). In terms of accuracy, this method compares favourably with standard topographic instruments and requires no correction for the earth's curvature with the added advantage of its significant low cost, higher portability and greater ease of use (Andrade and Ferreira, 2006). However, with the inability of this research to assess the whole of the Nigerian coastline, the Google Earth Satellite image was used as an alternative. The range of errors noticeable from the width of shoreface profile sample measured *in situ* to the Google Earth image is approximately +/- 5metres. The horizontal resolution for Google Earth Satellite Images on the global scale is about 15 metres, however high resolutions of less than 1m in Europe and the US (Google Earth, 2010). For the vertical resolution, it varies by country. The resolution of the Google Earth Image is a major source of uncertainty coupled with human errors in the measurement of the width of shoreface.

4.4   Sensitivity Analysis

The purpose of sea level rise sensitivity analysis is to quantify the consequences of the uncertainties in the raw data and their use in models on the derived answers eflecting the effects of rising sea levels. Hence, the uncertainties associated with all the parameters of the various sea level rise models are essential to test for the significance of the vulnerability. The Bruun model used in this study to estimate shoreline retreat along the Nigerian coast is dependent on the wave height, wave period and the width of the shoreface. Estimates from various wave data suggest that the H_s of Nigeria for each day varies between 1.2 and 1.4 metres (for example surf-forecast.com and Surfline/Wavetrak, Inc.). An all year forecast made by surf-forecast.com indicates that about 60% of the wave height at the Lighthouse Beach and the Tarqua Bay in Lagos is between 1.3 to 2 metres while less than 40% for wave heights between 0.5 and 1.3 metres. However, H_s refer to a third of the highest waves in a wave record, which is

within the range of 1.2 and 1.4 metres (Surfline/Wavetrak, Inc. 2011). This study uses the Global Wave Statistics database to estimate the significant wave height for Nigeria, which is on the average 1.55 metres for a whole year. One uncertainty involved with this database is that the wave data for Nigeria extends from Sierra Loane to Cameroon. This indicates that the same results of H_s will be obtainable from the countries that fall in this region. In conducting a basic sensitivity analysis, this research considered significant wave heights of 1.2, 1.3, 1.4 metres to reflect the range of H_s in Nigeria. 1.55 metres represents the computed H_s for this study and 1.7 and 1.8 metres are added scenarios. These scenarios are to assess what impact it will have in predicting shoreline retreat along the Nigerian coast and as well to be able to provide an account of the significance of these scenarios to the computed H_s.

The wave period determines the breaker height and subsequently the berm height. From the Global Wave Statistics, the computed wave period for Nigeria is 6.08 seconds. Typical wave period is about 4 and 10 seconds along coastlines that are dominated by locally generated wind waves and a swell dominated coastline respectively (Masselink and Hughes, 2003). To test for the significance of the uncertainty in the computed period T, This research uses scenarios of T that include 4, 5, 7, 8, 9 and 10 seconds in a sensitivity analysis.

For the width of shoreface (w) parameter, for each location, the uncertainty was established on the associated error from the *in situ* data for the samples collected and the Google Earth image measurement, which is +/- 5 metres. Therefore, w-5, w, w+ 5 and w + 10 metres represent variables considered for the sensitivity analysis. For example if the width of shoreface for a particular location is 50 metres, w-5 will be 45 metres, w+5 will be 55 metres and w+10 will be 60 metres. This research carried out a test of

significance to ascertain how the various levels of uncertainty differ from the measured width of shoreface.

4.4.1 Significant wave height (H_s)

The variables of the H_s parameter include 1.2, 1.3, 1.4, 1.7 and 1.8 metres, surrounding the computed H_s of 1.55 metres. The essence of the sensitivity analysis is to ascertain the extent the different H_s variables will contribute to shoreline retreat and the significant difference in the extent of the retreat of the shoreline generated by each variable of H_s to the computed H_s. Thus, the analysis determines if there is a relationship between H_s and shoreline retreat for all the sea level rise scenarios and the direction of the relationship as well as the significant relationship of each of the variables of H_s to the computed H_s. Therefore, the null hypothesis is as follows:

1   H_o: there is no significant difference between the H_s variables and the computed H_s in predicting shoreline retreat along the Nigerian coast.

2   H_o: there is no significant relationship between H_s and shoreline retreat for all sea level rise scenarios along the Nigerian coast.

In testing the hypothesis 1, this study carried out the t-test to test for the significant difference of H_s variables and the computed H_s, which produced the shoreline retreat results for the sea level rise scenarios of the three coasts. The *t*-test compares the actual difference between the means H_s variables and the computed H_s. The first step in this analysis is to present (Table 4.4) the extent of shoreline retreat that will be produced by each of the H_s variables for each sea level rise scenario and to indicate the extent of the retreat in a chart (Figures 4.10 - 4.12) showing the low and the high estimates.

The Bruun model advocates two calculations to encompass the depth of closure – the annual scale and the century scale which are referred to as the error estimate ultimately producing the high and estimate of shoreline retreat. The second step is to test the significant difference of the results.

Table 4.4: High and low estimates, based on the scales of depth of closure showing the extent of shoreline retreat (sq. km) for the three coasts with scenarios of sea level rise (m) varied with different significant wave heights (H_s)

SLR Scenarios (m)	H_s (m)					
	1.2	1.3	1.4	1.55	1.7	1.8
Barrier 0.5	0.12 - 0.21	0.12 - 0.2	0.12 - 0.2	0.12 - 0.19	0.11 - 0.18	0.11 - 0.18
Barrier 1	0.25 - 0.41	0.24 - 0.4	0.24 - 0.39	0.23 - 0.38	0.22 - 0.37	0.22 - 0.36
Barrier 2	0.5 - 0.82	0.49 - 0.8	0.48 - 0.79	0.46 - 0.76	0.45 - 0.74	0.44 - 0.72
Barrier 3	0.74 - 1.24	0.73 - 1.21	0.72 - 1.18	0.69 - 1.14	0.67 - 1.11	0.66 - 1.08
Delta 0.5	0.46 - 0.76	0.45 - 0.74	0.44 - 0.72	0.43 - 0.7	0.41 - 0.68	0.4 - 0.66
Delta 1	0.91 - 1.52	0.9 - 1.48	0.88 - 1.45	0.85 - 1.4	0.83 - 1.36	0.81 - 1.33
Delta 2	1.83 - 3.03	1.8 - 2.96	1.76 - 2.89	1.7 - 2.8	1.65 - 2.71	1.62 - 2.66
Delta 3	2.74 - 4.55	2.7 - 4.44	2.64 - 4.34	2.55 - 4.2	2.48 - 4.07	2.43 - 3.99
Strand 0.5	0.17 - 0.28	0.17 - 0.28	0.17 - 0.27	0.16 - 0.26	0.16 - 0.25	0.15 - 0.25
Strand 1	0.34 - 0.57	0.34 - 0.56	0.33 - 0.54	0.32 - 0.53	0.31 - 0.51	0.3 - 0.5
Strand 2	0.69-1.14	0.68-1.11	0.66-1.09	0.64-1.05	0.62-1.02	0.61-1
Strand 3	1.03-1.71	1.01-1.67	0.99-1.63	0.96-1.58	0.93-1.53	0.91-1.5

Figure 4.10: **Contribution of significant wave heights to shoreline retreat in the Barrier coast for the sea level rise scenarios. Results showing the high and low estimates based on the depth of closure scales.**
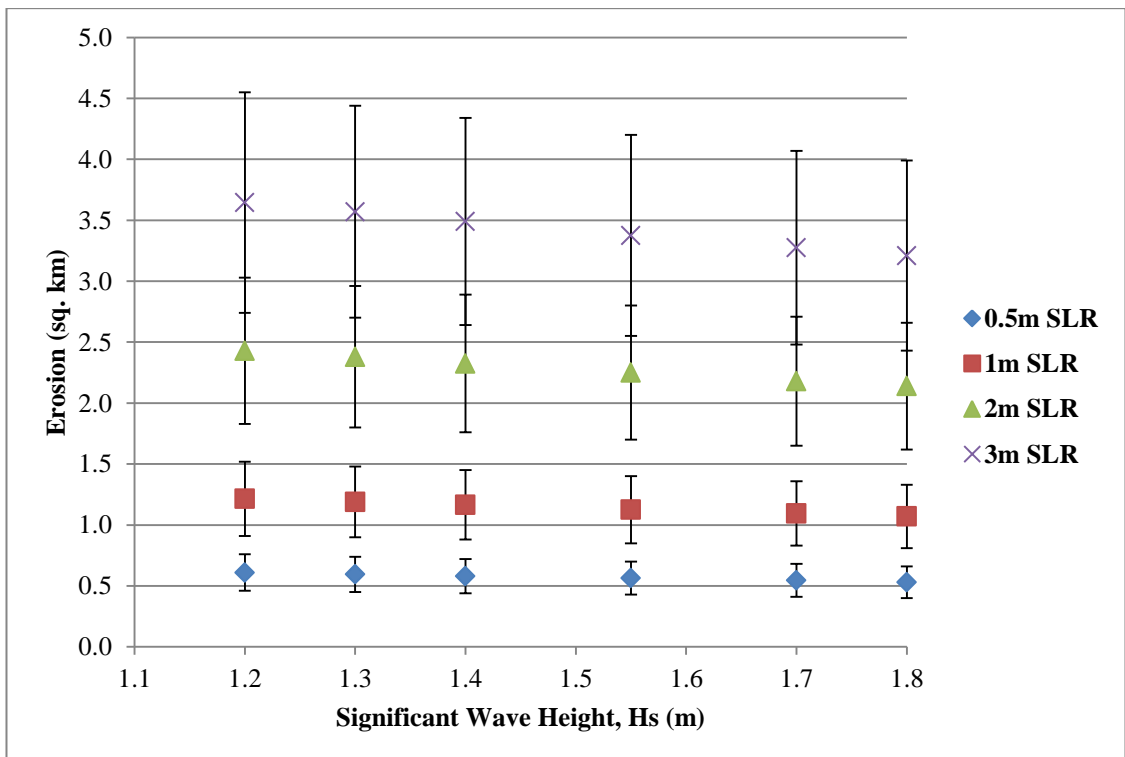
Figure 4.11: **Contribution of significant wave height to shoreline retreat in the Delta coast for the sea level rise scenarios. Results showing the high and low estimates based on the depth of closure scales.**
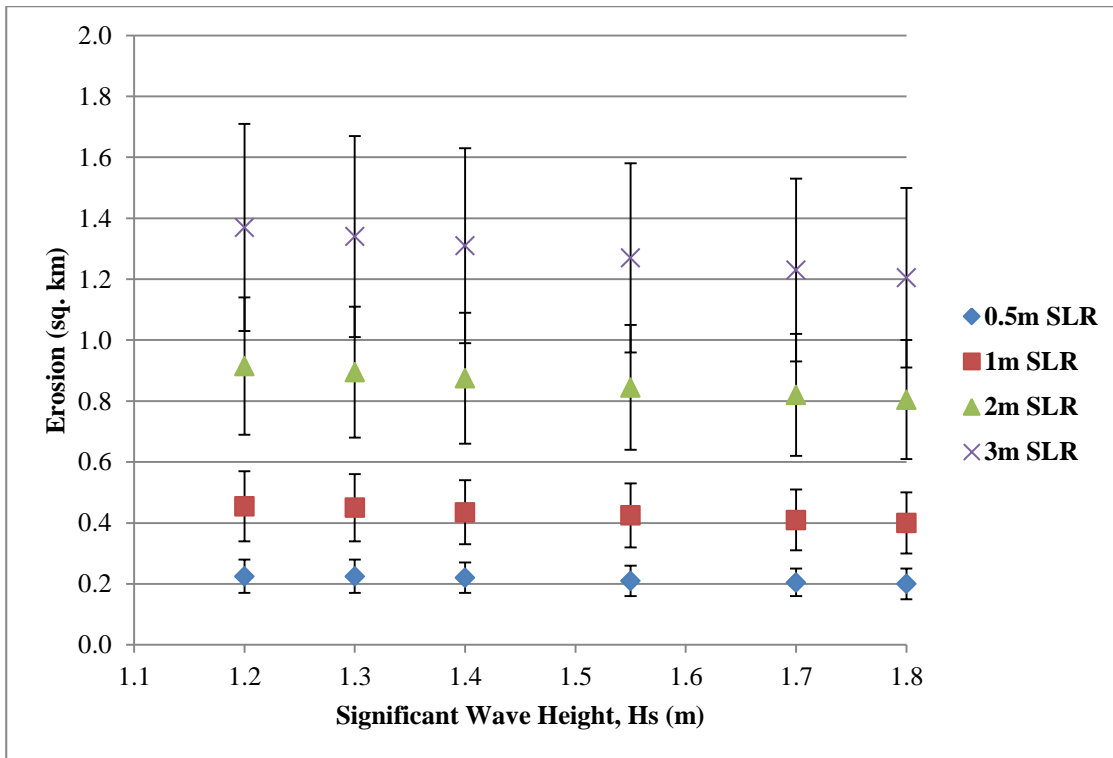
Figure 4.12: **Contribution of significant wave height to shoreline retreat in the Strand coast for the sea level rise scenarios. Results showing the high and low estimates based on the depth of closure scales.**

In testing hypothesis 1, a *t*-test was conducted to compare the means of the computed H_s and the H_s variables in effecting shoreline retreat. The result of the test i.e. the calculated *t*-value is in Table 4.5. The tabulated value of *t* at degree of freedom 22 and at 0.05 level of significance is 2.07 (0.05 significant level represents 95% probability of making a correct statement).

Table 4.5: **t-test calculated values of H_s variables against H_s computed**

H_s t-calculated (computed) 1.55m	Significant Wave Heights, H_s (metres)				
	1.2	**1.3**	**1.4**	**1.7**	**1.8**
t calculated (High)	0.84	0.89	0.93	0.94	0.89
t calculated (Low)	0.86	0.89	0.93	0.94	0.90

Verdict on hypothesis 1
Since, all the calculated H_s variables are lower than the tabulated *t*-values (2.07) at degree of freedom of 22 and at 0.05% significant value (*p*-value), there is no significant

144

difference in H_s variables and H_s computed in predicting shoreline retreat for all sea level rise scenarios on the Nigeria coast. Therefore, the H_o hypothesis is accepted.

Hypothesis 2 seeks to find if there is a relationship between H_s and shoreline retreat as well as the extent of its significance. In verifying if there is a relationship between H_s and shoreline retreat, a correlation analysis was conducted. Table 4.6 shows the correlation value for each sea level rise scenario.

Table 4.6: **Correlation values between Hs and shoreline retreat for the sea level rise scenarios (lower and upper estimates based on depth of closure scale) and analysis of their variance.**

SLR Scenarios (m)	R	R^2	F
Barrier 0.5	(-0.86) - (-0.98)	0.74 - 0.96	94
Barrier 1	(-0.98) – (-1.00)	0.96 - 0.99	614
Barrier 2	(-1.00) – (-1.00)	0.99 - 1.00	893
Barrier 3	(-0.99) - (-1.00)	0.99 - 1.00	1021
Delta 0.5	(-1.00) – (-1.00)	0.99 - 0.99	614
Delta 1	(-1.00) – (-1.00)	0.99 - 1.00	1275
Delta 2	(-1.00) – (-1.00)	1.00 - 1.00	1637
Delta 3	(-1.00) – (-1.00)	1.00 - 1.00	1678
Strand 0.5	(-0.93) - (-0.98)	0.86 - 0.96	95
Strand 1	(-0.99) - (-0.99)	0.98 - 0.99	329
Strand 2	(-1.00) – (-1.00)	0.99 - 1.00	1021
Strand 3	(-1.00) – (-1.00)	1.00 - 1.00	1660

Results indicate a strong correlation exists between the H_s and shoreline retreat for all the sea level rise scenarios along the Nigerian coast. Indeed perfect correlations exist

between the variables for some sea level rise scenarios which is indicated by a (-1) R-value and a (1) R^2-value. This study used the *t*-test to investigate the significance of the correlation value. Results indicate that t-test for the significance of the coefficient for all the variables at degree of freedom 10 and at 0.05 *p* value are not significant for all sea level rise scenarios as the t-test for the significant of the coefficient is as low as 8.83×10^{-8}. This study applied the regression analysis, which goes a step further than the correlation analysis by adding prediction capabilities. The R^2, which is the coefficient of determination, shows the proportion of variability by providing a measure of how well H_s predict erosion for all sea level rise scenario. For example, from Table 4.6, the lowest R^2 value is 0.74 to 0.96 for Barrier coast at 0.5m SLR by 2100. This result indicates that between 74 and 96% of the variance in H_s can be explained by the regression equation. Therefore, there is a strong relationship between H_s and shoreline retreat at 0.5m SLR in the Barrier coast. The analysis of variance was able to test for the significance of the relationship that exists between H_s and the erosion it predicts. For all sea level rise scenarios, the F-test, which is the equality of variances, indicates that the F calculated (hereafter regarded as F_{cal}) is greater than F tabulated or critical value (hereafter called F_{tab}) which is 6.16 at degree of freedom 6 and 4 and at 0.05 significant level. Therefore, the null hypothesis H_o is rejected.

Verdict on hypothesis 2
A simple linear regression was performed on a year's data of wave data to determine if there was a significant relationship between H_s and shoreline retreat for all sea level rise scenarios along the Nigerian coast. The F-statistics for all the scenarios were significant at the 0.05 critical alpha level. Thus, the null hypothesis is rejected. To conclude, there is a significant relationship between H_s and shoreline retreat. However, there is a negative correlation between the variables, which indicates that with increase in

significant wave height, less shoreline retreat is predicted according to the implementation of the Bruun model's parameters.

4.4.2 Wave Period (T_w)

The variables of the T parameter include 4, 5, 7, 8, 9 and 10 seconds, while the computed T_w is 6.08 seconds. The essence of the sensitivity analysis is to ascertain the extent the different T_w variables will contribute to shoreline retreat and the significant difference in the extent of the retreat of the shoreline generated by each variable of T_w to the computed T_w. Thus, the analysis determines if there is a relationship between T_w and shoreline retreat for all the sea level rise scenarios and the direction of the relationship as well as the significant relationship of each of the variables of T_w to the computed T_w. Therefore, the null hypothesis is as follows:

3   H_o: there is no significant difference between the T_w variables and the T_w computed in predicting shoreline retreat along the Nigerian coast.

4   H_o: there is no significant relationship between T_w and shoreline retreat for all sea level rise scenarios along the Nigerian coast.

In testing the hypothesis 3, the Student's *t*-test was carried out to test for the significant difference of T_w variables and the T_w computed which produced the shoreline retreat results for the sea level rise scenarios of the three coasts. The first step in this analysis is to present (Table 4.7) the extent of shoreline retreat that will be produced by each of the H_s variables for each sea level rise scenario and to indicate the extent of the retreat in a chart (Figures 4.13 – 4.15) showing the low and the high estimates. The second step is to test the significant difference of the results.

Table 4.7: High and low estimate, based on the scales of depth of closure showing the extent of shoreline retreat (sq. km) for the three coasts with the scenarios of sea level rise (m) varied with different wave periods (T_w)

SLR Scenarios (m)	Period, T (seconds)						
	4	5	6.08	7	8	9	10
Barrier 0.5	0.12 - 0.2	0.12 - 0.2	0.12 - 0.19	0.11 - 0.19	0.11 - 0.18	0.11 - 0.18	0.11 - 0.17
Barrier 1	0.24 – 0.4	0.23 - 0.39	0.23 - 0.38	0.23 - 0.37	0.23 - 0.37	0.22 - 0.36	0.22 - 0.35
Barrier 2	0.48 – 0.8	0.47 - 0.78	0.46 - 0.76	0.46 - 0.75	0.45 - 0.73	0.44 - 0.71	0.44 - 0.7
Barrier 3	0.72-1.2	0.7 - 1.17	0.69 - 1.14	0.69 - 1.12	0.68 - 1.1	0.67 - 1.07	0.66 - 1.05
Delta 0.5	0.44-0.74	0.43 - 0.72	0.43 - 0.7	0.42 - 0.69	0.42 - 0.67	0.41 - 0.66	0.4 - 0.64
Delta 1	0.88-1.47	0.86 - 1.44	0.85 - 1.4	0.84 - 1.37	0.83 - 1.34	0.82 - 1.31	0.81 - 1.28
Delta 2	1.76-2.95	1.73 - 2.87	1.7 - 2.8	1.68 - 2.74	1.66 - 2.69	1.64 - 2.62	1.61 - 2.57
Delta 3	2.63-4.42	2.59 - 4.31	2.55 - 4.2	2.52 - 4.11	2.49 - 4.03	2.45 - 3.93	2.42 - 3.85
Strand 0.5	0.16-0.28	0.16 - 0.27	0.16 - 0.26	0.16 - 0.26	0.16 - 0.25	0.15 - 0.25	0.15 - 0.24
Strand 1	0.33-0.55	0.32 - 0.54	0.32 - 0.53	0.32 - 0.52	0.31 - 0.51	0.31 - 0.49	0.3 - 0.48
Strand 2	0.66-1.11	0.65 - 1.08	0.64 - 1.05	0.63 - 1.03	0.62 - 1.01	0.61 - 0.99	0.61 - 0.96
Strand 3	0.99-1.66	0.97 - 1.62	0.96 - 1.58	0.95 - 1.55	0.94 - 1.52	0.92 - 1.48	0.91 - 1.45

Figure 4.13: Contribution of wave periods to shoreline retreat in the Barrier coast for the sea level rise scenarios. Results showing the high and low estimates based on the depth of closure scales.

Figure 4.14: Contribution of wave periods to shoreline retreat in the Delta coast for the sea level rise scenarios. Results showing the high and low estimates based on the depth of closure scales.
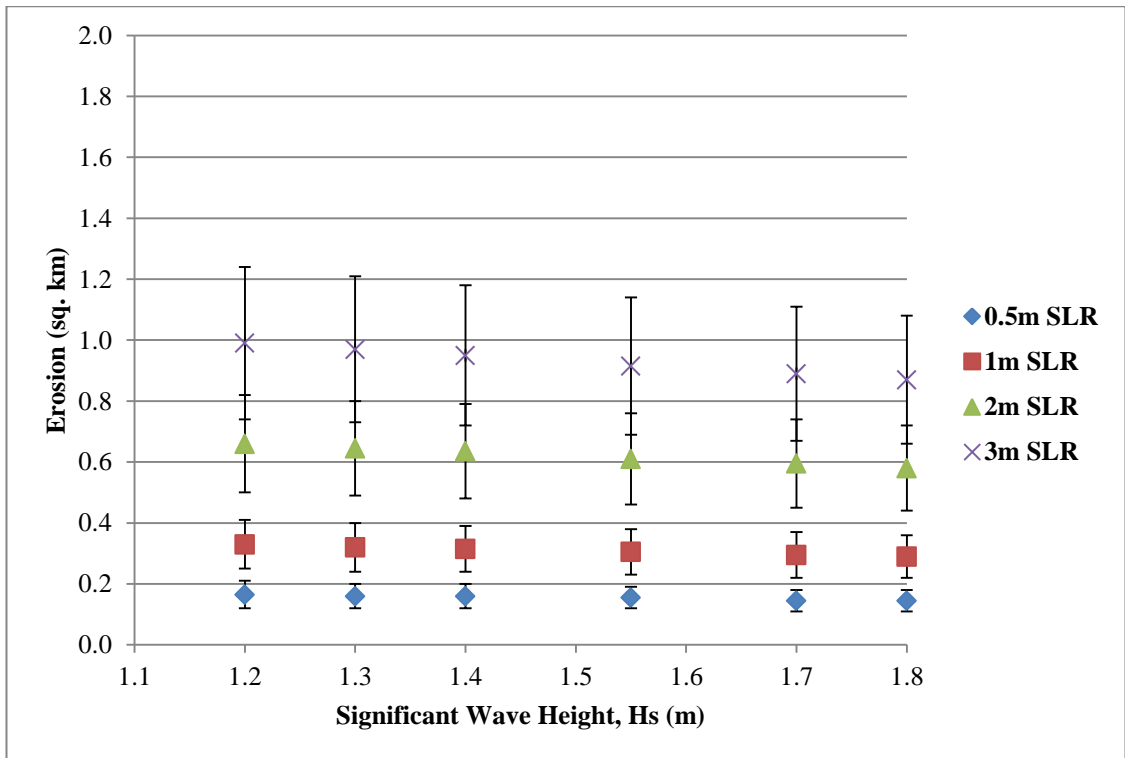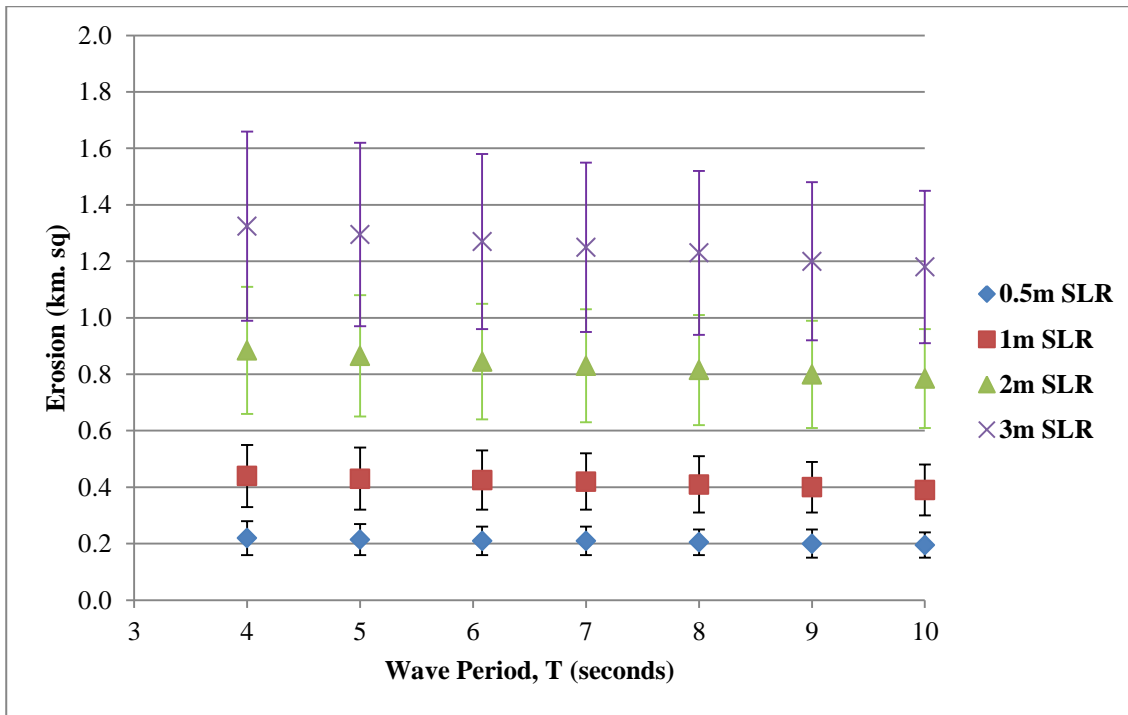
Figure 4.15: **Contribution of wave periods to shoreline retreat in the Strand coast for the sea level rise scenarios. Results showing the high and low estimates based on the depth of closure scales.**

Hypothesis 3, which is a null hypothesis, states, "There is no significant difference between the T_w variables and the T_w computed in predicting shoreline retreat along the Nigerian coast". A *t*-test was conducted to compare the means of the computed T_w and the T_w variables in effecting shoreline retreat. The calculated *t*-value is in Table 4.8. The tabulated value of *t* at degree of freedom 22 and at 0.05 level of significance is 2.07.

Table 4.8: **t-test calculated values of Tw variables against Tw computed**

T_w t-calculated	Wave Period, T_w (seconds)					
(computed) 6.08 seconds	4	5	7	8	9	10
t-calculated (High)	0.89	0.95	0.96	0.92	0.87	0.82
t-calculated (Low)	0.93	0.97	0.98	0.95	0.92	0.89

Verdict on hypothesis 3
Since, all the calculated T_w variables are lower than the tabulated *t*-values (2.07) at degree of freedom of 22 and at 0.05% significant value (*p*-value), there is no significant

difference in T_w variables and T_w computed in predicting shoreline retreat for all sea level rise scenarios on the Nigeria coast. Therefore, the H_o hypothesis is accepted.

Hypothesis 4 seeks to find if there is a relationship between T_w and shoreline retreat as well as the extent of its significance. In verifying if there is a relationship between T_w and shoreline retreat, a correlation analysis was conducted. Table 4.9 shows the correlation value for each sea level rise scenario.

Table 4.9: **Correlation values between T_w and shoreline retreat for the sea level rise scenarios (lower and upper estimates based on depth of closure scale) and analysis of their variance F calculated.**

SLR Scenarios (m)	R	R^2	F
Barrier 0.5	(-0.86) - (-0.97)	0.74 - 0.94	85.00
Barrier 1	(-0.90) – (-0.99)	0.80 - 0.98	213.80
Barrier 2	(-0.98) – (-1.00)	0.96 – 0.99	887.90
Barrier 3	(-0.98) - (-1.00)	0.96 - 1.00	1387.67
Delta 0.5	(-0.97) – (-1.00)	0.95 - 0.99	842.94
Delta 1	(-0.99) – (-1.00)	0.99 - 1.00	4017.32
Delta 2	(-1.00) – (-1.00)	0.99 - 1.00	1302.15
Delta 3	(-1.00) – (-1.00)	1.00 - 1.00	2144.98
Strand 0.5	(-0.79) - (-0.98)	0.62 - 0.95	105.25
Strand 1	(-0.95) - (-0.99)	0.90 - 0.99	344.97
Strand 2	(-0.99) – (-1.00)	0.98 – 0.99	915.54
Strand 3	(-0.99) – (-1.00)	0.99- 1.00	3072.12

Results indicate a strong correlation exists between the T_w and shoreline retreat for all the sea level rise scenarios along the Nigerian coast. Indeed perfect correlations exist between the variables for some SLR scenarios. This study applied the regression

analysis to predict the extent by which the variations in T_w can explain shoreline recession for all SLR scenarios and their significance. The R^2, which is the coefficient of determination, shows the proportion of variability by providing a measure of how well T_w predicts erosion for all sea level rise scenario. From Table 4.9, the lowest R^2 value is 0.62 - 0.95 for the Strand coast at 0.5m SLR by 2100. This result indicates that between 62 and 95% of the variance in T_w can be explained by the regression equation. In other words, the variability in the T_w accounts for between 62 and 95% of shoreline retreat at 0.5m SLR in the Barrier coast for the low and high estimate of the depth of closure. The analysis of variance (ANOVA) was able to test for the significance of the relationship that exists between T_w and the erosion it predicts. For all sea level rise scenarios, F-test, indicates that F_{cal} is greater than F_{tab} which is 4.88 at degree of freedom 7 and 5 and at 0.05 significant level. Therefore, the null hypothesis H_o is rejected.

Verdict on hypothesis 4
A simple linear regression was performed on a year's data of wave data to determine if there was a significant relationship between T_w and shoreline retreat for all sea level rise scenarios along the Nigerian coast. The F-statistics for all the scenarios were significant at the 0.05 critical alpha level. Thus, the null hypothesis is rejected. In conclusion, there is a significant relationship between T_w and shoreline retreat. However, a negative correlation exists between the variables, which indicate that with increase wave period, a less shoreline retreat is predicted.

4.4.3   Width of Shoreface (*w*)
The variables of the w parameter include w-5, w+5 and w+10 metres, while the computed or measured *w* is the width of shoreface. The essence of the sensitivity analysis is to ascertain the extent the different w variables will contribute to shoreline

retreat and the significant difference in the extent of the retreat of the shoreline generated by each variable of *w* to the measured *w*. Thus, the analysis determines if there is a relationship between *w* and shoreline retreat for all the sea level rise scenarios and the direction of the relationship as well as the significant relationship of each of the variables of *w* to the measured *w*. Therefore, the null hypothesis is as follows:

5   H_o: there is no significant difference between the *w* variables and the *w* measured in predicting shoreline retreat along the Nigerian coast.

6   H_o: there is no significant relationship between *w* and shoreline retreat for all sea level rise scenarios along the Nigerian coast.

This study used the Student's *t*-test to analyse hypothesis 5, for the significant difference of *w* variables and the *w* measured which produced the shoreline retreat results for the sea level rise scenarios of the three coasts. The first step in this analysis is to present (Table 4.10) the extent of shoreline retreat that will be produced by each of the *w* variables for each sea level rise scenario and to indicate the extent of the retreat in a chart (Figures 4.16 – 4.18) showing the low and the high estimates. The second step is to test the significant difference of the results.

Table 4.10: High and low estimate, based on the scales of depth of closure showing the extent of shoreline retreat (sq. km) for the three coasts with scenarios of sea level rise (m) varied with different width of shoreface (m)

SLR Scenarios (m)	Width of Shoreface (m)				R	R^2
	W-5	W	W+5	W+10		
Barrier 0.5	0.09 - 0.15	0.12 - 0.19	0.14 - 0.23	0.17 - 0.28	1.00	1.00
Barrier 1	0.18 - 0.29	0.23 - 0.38	0.28 - 0.47	0.34 - 0.55	1.00	1.00
Barrier 2	0.36 - 0.59	0.46 - 0.76	0.57 - 0.93	0.67 - 1.11	1.00	1.00
Barrier 3	0.54 - 0.88	0.69 - 1.14	0.85 - 1.4	1.01 - 1.66	1.00	1.00
Delta 0.5	0.38 - 0.62	0.43 - 0.7	0.47 - 0.78	0.52 - 0.86	1.00	1.00
Delta 1	0.76 - 1.25	0.85 - 1.4	0.95 - 1.56	1.04 - 1.71	1.00	1.00
Delta 2	1.51 - 2.49	1.7 - 2.8	1.89 - 3.11	2.08 - 3.42	1.00	1.00
Delta 3	2.27 - 3.74	2.55 - 4.2	2.84 - 4.67	3.12 - 5.13	1.00	1.00
Strand 0.5	0.14 - 0.22	0.16 - 0.26	0.18 - 0.3	0.21 - 0.34	1.00	1.00
Strand 1	0.27 - 0.45	0.32 - 0.53	0.37 - 0.61	0.42 - 0.69	1.00	1.00
Strand 2	0.55 - 0.9	0.64 - 1.05	0.74 - 1.21	0.83 - 1.37	1.00	1.00
Strand 3	0.82 - 1.35	0.96 - 1.58	1.1 - 1.82	1.25 - 2.06	1.00	1.00
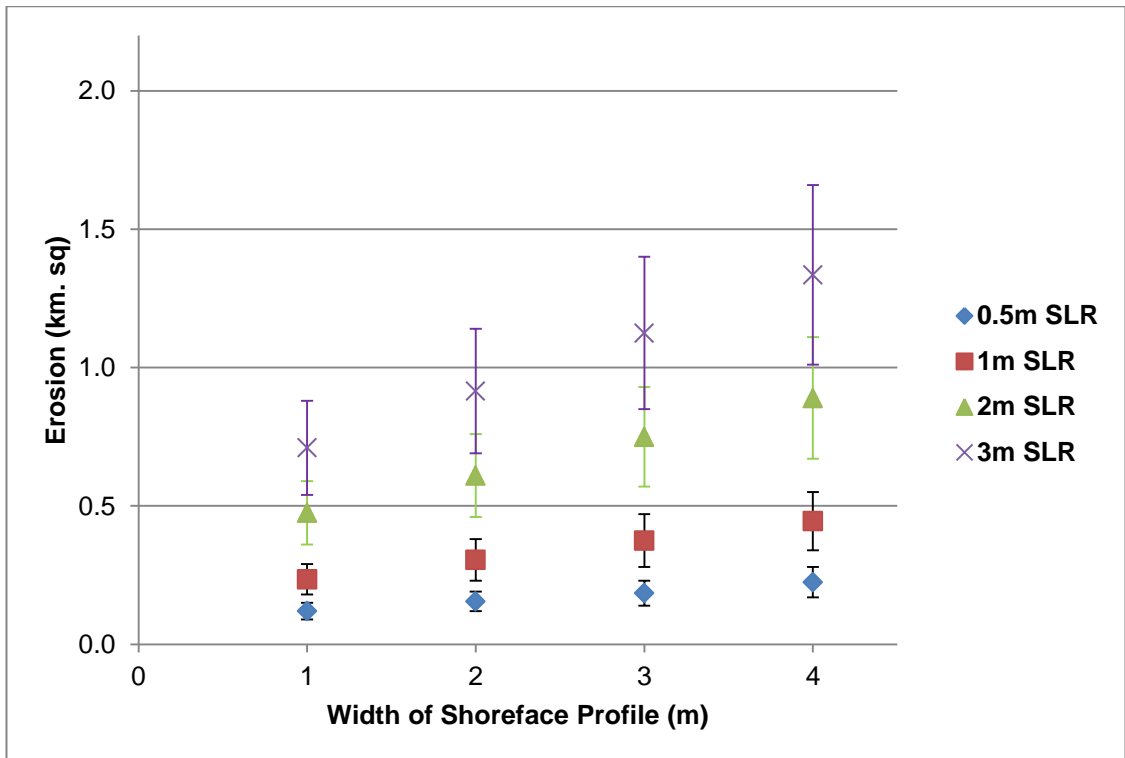
Figure 4.16: Contribution of width of shoreface to shoreline retreat in the Barrier coast for the sea level rise scenarios. Results showing the high and low estimates based on the depth of closure scales.
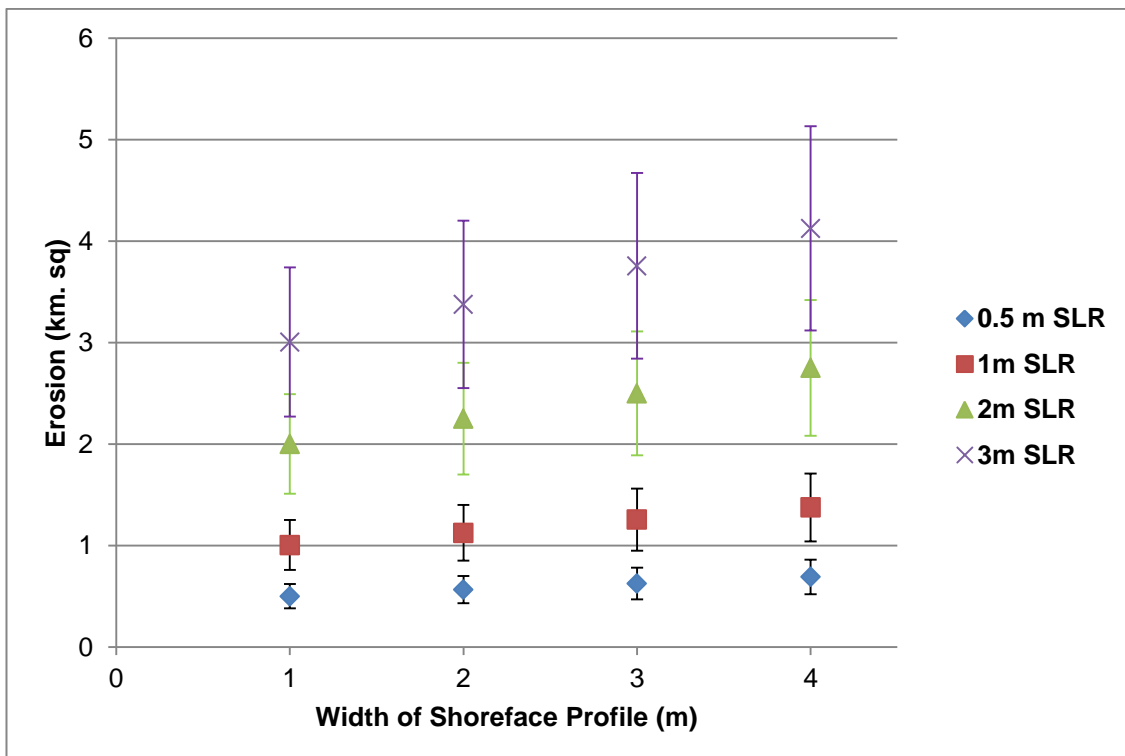
Figure 4.17: Contribution of width of shoreface to shoreline retreat in the Delta coast for the sea level rise scenarios. Results showing the high and low estimates based on the depth of closure scales.
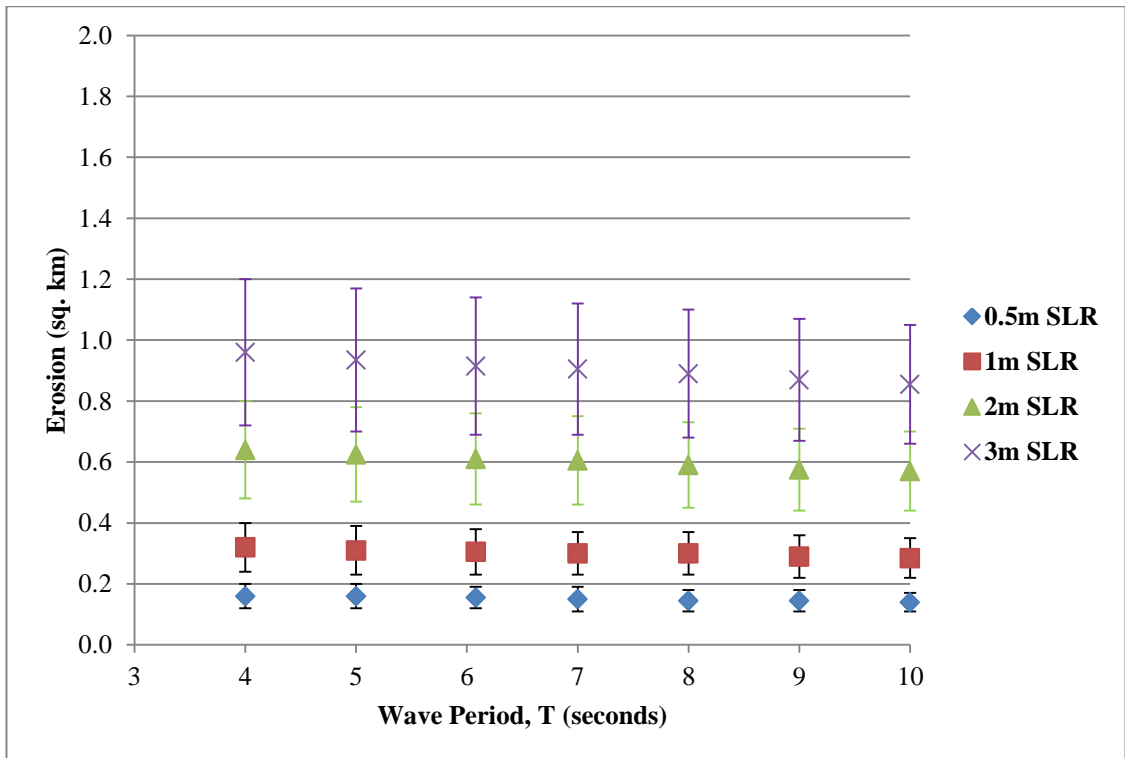
155
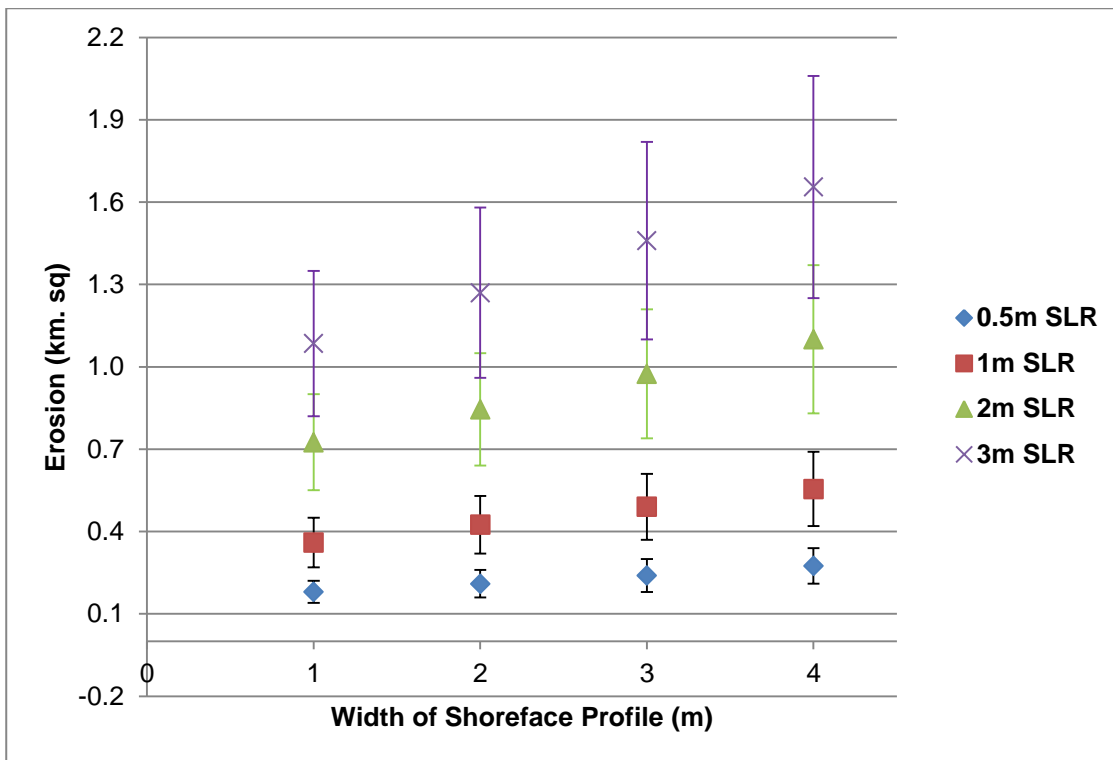
Figure 4.18: Contribution of width of shoreface to shoreline retreat in the Strand coast for the sea level rise scenarios. Results showing the high and low estimates based on the depth of closure scales.
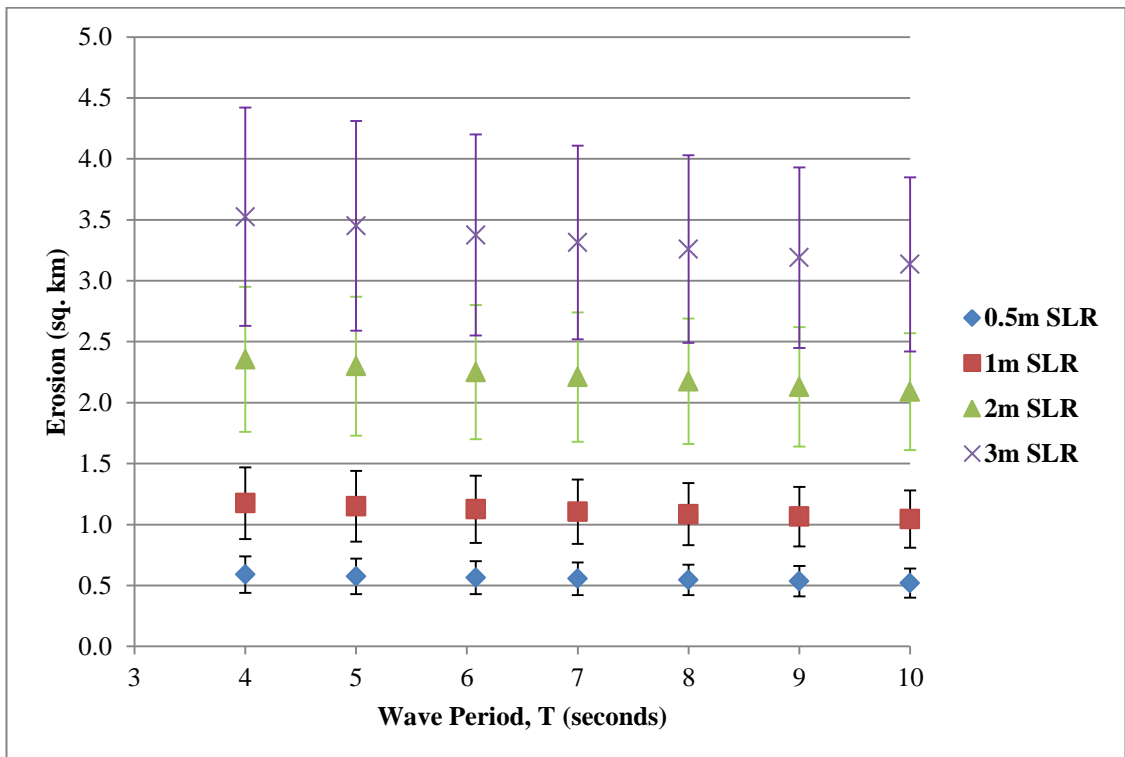
Hypothesis 5, which is a null hypothesis, states, "There is no significant difference between the w variables and the w measured in predicting shoreline retreat along the Nigerian coast". A t-test was conducted to compare the means of the measured w and the w variables in effecting shoreline retreat. The calculated t-value is in Table 4.11. The tabulated value of t at degree of freedom 22 and at 0.05 significant level is 2.07.

Table 4.11:   t-test calculated values of w variables against w measured

w t-calculated (measured)	Width of Shoreface, w (metres)		
	w-5	w+5	w+10
t-calculated (High)	0.71	0.73	0.52
t-calculated (Low)	0.71	0.73	0.52

The t-test calculated value for the high and low estimate of erosion due to the varying of the width of shoreface produces the same results. This shows that there is no difference

in the shoreline retreat produced by each scenario of width of shoreface between the high and low estimates of the depth of closure.

Verdict on hypothesis 5
Since, all the calculated w variables are lower than the tabulated t-values (2.07) at degree of freedom of 22 and at 0.05%, significant value (p-value), there is no significant difference in w variables and w measured in predicting shoreline retreat for all sea level rise scenarios on the Nigeria coast. Therefore, the H_o hypothesis is accepted.

Hypothesis 6 seeks to find if there is a relationship between w and shoreline retreat as well as the extent of its significance. In verifying if there is a relationship between w and shoreline retreat, a correlation analysis was conducted. Table 4.12 shows the correlation value for each sea level rise scenario.

Results indicate that there is perfect positive correlation between the w and shoreline retreat for all the sea level rise scenarios along the Nigerian coast. This study applied the regression analysis to predict the extent by which the variations in w can explain shoreline recession for all SLR scenarios and their significance. The R^2, which is the coefficient of determination, shows the proportion of variability by providing a measure of how well w predicts erosion for all sea level rise scenario. Results indicate that a 100% of the variance in w accounts for the shoreline retreat along the Nigerian coast for all SLR scenarios. The analysis of variance (ANOVA) was able to test for the significance of the relationship that exists between w and the erosion it predicts. For all sea level rise scenarios, F-test indicates that F_{cal} is greater than F_{tab}, which is 19.25 at degrees of freedom 4 and 2 and at 0.05 significant level. Therefore, the null hypothesis H_o is rejected.

Table 4.12: Correlation values between w and shoreline retreat for the sea level rise scenarios (lower and upper estimates based on depth of closure scale) and analysis of their variance F calculated.

SLR Scenarios (m)	R	R^2	F
Barrier 0.5	1.00	1.00	616
Barrier 1	1.00	1.00	2523
Barrier 2	1.00	1.00	9976
Barrier 3	1.00	1.00	1.27E+31
Delta 0.5	1.00	1.00	3.96E+31
Delta 1	1.00	1.00	11858
Delta 2	1.00	1.00	2.44E+31
Delta 3	1.00	1.00	107648
Strand 0.5	1.00	1.00	1.98E+31
Strand 1	1.00	1.00	7.92E+31
Strand 2	1.00	1.00	8216
Strand 3	1.00	1.00	18723

Verdict on hypothesis 6

A simple linear regression was performed to determine if there was a significant relationship between *w* and shoreline retreat for all sea level rise scenarios along the Nigerian coast. The F-statistics for all the scenarios were significant at the 0.05 critical alpha level. Thus, the null hypothesis is rejected. In conclusion, there is a positive and significant relationship between *w* and shoreline retreat.

4.5   Summary

This Chapter has been able to project the extent of erosion on three coastal systems (Barrier, Delta, and Strand) in Nigeria. This research did not make a computation and projection for erosion on the Mud coast because the Bruun model that was adopted did

not support its application on muddy coasts. From the results obtained, inference could be made that erosion problems will not be significant along the Nigerian coast as less than 8 kilometres square will be lost even in a 3m SLR by 2100. The areas that could be threatened by erosion in Lagos include the Nigerian Institute of Oceanography and Marine Research along Wilmot Point Close, the Nigerian Television Authority, and Ahmadu Bello Way among others but the recession of the coastline is marginal.

There will be mild erosion in the Delta coast. In a 1m SLR scenario, between 0.8 and 1.4 sq. km will be eroded in the Delta coast by year 2100. This is about 0.003% and 0.005% of the entire coast. When compared to the Barrier coast in terms of percentage of land eroded and land extent, it was deduced that land that will be eroded seem to be lower in the Delta coast than the Barrier as between 0.005% and 0.009% of the land area will be eroded. Coastline recession will also be mild on the Strand coast. Erosion is also mild within this coast as between 0.32 and 0.52 sq. km of land will be eroded in a 1m SLR scenario by year 2100. This will amount to between 0.01 and 0.02% of the land area of the coast that will be eroded.

The Strand coast will suffer more from coastline recession more than the other coasts in relation to the size of the coasts. The Strand coast also recorded the highest amount of recession, which ranges between 5 and 9 metres in a 1-metre SLR scenario by 2100 at some locations. Even though the extent of shoreline recession in the Barrier coast might not be as high as the other two coasts, the impact will be higher as there will be more loss in terms of the infrastructures and land value. This is because it is the most developed and urbanised of the coastline and because of the value attached to land in this zone. Quantifying in monetary terms the impact of loss is beyond the scope of this study but it will be a useful piece of research that can be embarked upon. It is the

opinion of this study that the impact of erosion will be more severe in the Barrier coast than the other coast. The impact of erosion due to sea level rise with the use of the Bruun rule indicates overall mild erosion along the Nigerian coast.

4.5.1 Account of Significance of uncertainties

The chapter has been able to complete a basic sensitivity analysis with the parameters involved in the Bruun model. The justification for the values employed for the sensitivity analysis revolves round the uncertainty that exists with each parameter. The parameters on which the Bruun model is constructed include the depth of closure, berm height, width of shoreface and sea level rise rates. Different scenarios of sea level rise has been analysed which shows the extent of shoreline retreat along the Nigerian coast. For each of the parameters of the Bruun model, uncertainties are evident within the sub-parameters. For depth of closure, the uncertainties are evident in the significant wave heights. For berm heights, uncertainties are present in the significant wave height and the wave period. Width of shoreface also is subject to uncertainties, which has to do with the method and the quality of the measurement of the shoreface profile. Lastly, there are many uncertainties with SLR rates and projections. A basic sensitivity analysis enabled this chapter to account for uncertainties on each of the parameters. In carrying out this analysis, the determinant sub-parameter for each of the Bruun's model parameters was analysed. They are the significant wave height, wave period and width of shoreface. Results indicate that with increased significant wave height less shoreline retreat is predicted if all other variables are held constant. Increase in the wave period indicates less shoreline retreat if all other variables remain constant while with increased value of width of shoreface and all other variables remain constant, increased shoreline retreat will ensue. Further analysis to test for the significance of these parameters prompted this research to formulate hypotheses to test for the significant difference in

the measured and the variable values of the sub-parameters in predicting shoreline retreat. Results show no significant difference between them. Furthermore, statistical tests were conducted to ascertain the level and direction of relationships that exists between the sub-parameters and the prediction of shoreline retreat. Strong but negative relationships exist between significant wave height and shoreline retreat; and between wave period and shoreline retreat. However, a perfect and positive relationship exists between the width of shoreface and shoreline retreat. For the three parameters, analysis carried out in this study found that their relationships in producing shoreline retreat are significant.

<center>**CHAPTER FIVE**</center>

5.0 Results: Impacts of Sea Level Rise Due to Inundation

5.1 Introduction

This Chapter presents results from the models developed to ascertain vulnerability of

the Nigerian coastal environment to inundation because of sea level rise. Subsection 5.2

states the results at national level for the Nigerian coast while subsection 5.3 focuses on

the regional zones delineated according to the four distinct geomorphologic units. The

study area refers to the four coastal zones considered in this study. Results of the study

area are referred to as National level results. The six indicators considered in this

analysis are land, population, economic activity expressed in Gross Domestic Product

(GDP), urban extent, agricultural extent, and wetlands. The sea level rise scenarios

employed for inundation are 1 to 3 metres. Maps and charts are used to depict the extent

of inundation. For all the elements considered in this Chapter and in the different coasts,

vulnerability at 1 m SLR map is used to highlight the extent of vulnerability except

where otherwise stated. Other scenarios may be chosen to compare the extent of the

inundation it will produce in contrast to a 1 m SLR scenario depending on the

importance of the information discussed.

5.2 National level results

This section presents the results of the analyses at the national level. The summary of

the results is presented in Table 5.1.

Land

The study area covers about 4.3% of the total area of Nigeria. Approximately 7.2%

(2869 sq. km) of the study area (land area) would be impacted by a 1-metre SLR. This

would increase to 12.3% (4,905 sq. km) in a 3 m SLR scenario. The extent of the impact

<center>162</center>

on the land area with 1 m and 3 m SLR is shown in Map 5.1. A significant amount of

land will be lost for each scenario of SLR.

Table 5.1: **Impacts of sea level rise: National Results**

	1 m	2 m	3 m
Land Area (Total = 39,890 sq. km)			
Impacted area	2,869	3,621	4,905
% of total area	7.20	9.08	12.30
Population (Total = 16,687,655)			
Impacted	1,168,448	1,629,091	2,124,486
% of total	7.00	9.76	12.73
GDP in Millions US$ (Total = 34,523 Million US$)			
Impacted GDP	626	798	1,089
% of total GDP	1.81	2.31	3.15
Urban Extent in square kilometres (Total = 1,425 sq. km)			
Impacted area	697	809	889
% of total area	48.91	56.74	62.39
Agricultural Extent in square kilometres (Total = 28,442 sq. km)			
Impacted area	4,299	5,787	7,466
% of total area	15.11	20.35	26.25
Wetlands Area in square kilometres (Total = 24,621 sq. km)			
Impacted area	8,287	10,412	12,320
% of total area	33.66	42.29	50

Population
The Nigerian population is approximately 146.9 million according to the computations

in this research. This value is slightly higher than the results of the population census of

2006, which put the Nigerian population at 140 million (National Population

Commission, 2011). Examining the population element, results indicates that at 1 m

SLR, about 1.2 million people (7% of the population) living in the study area will be

impacted.
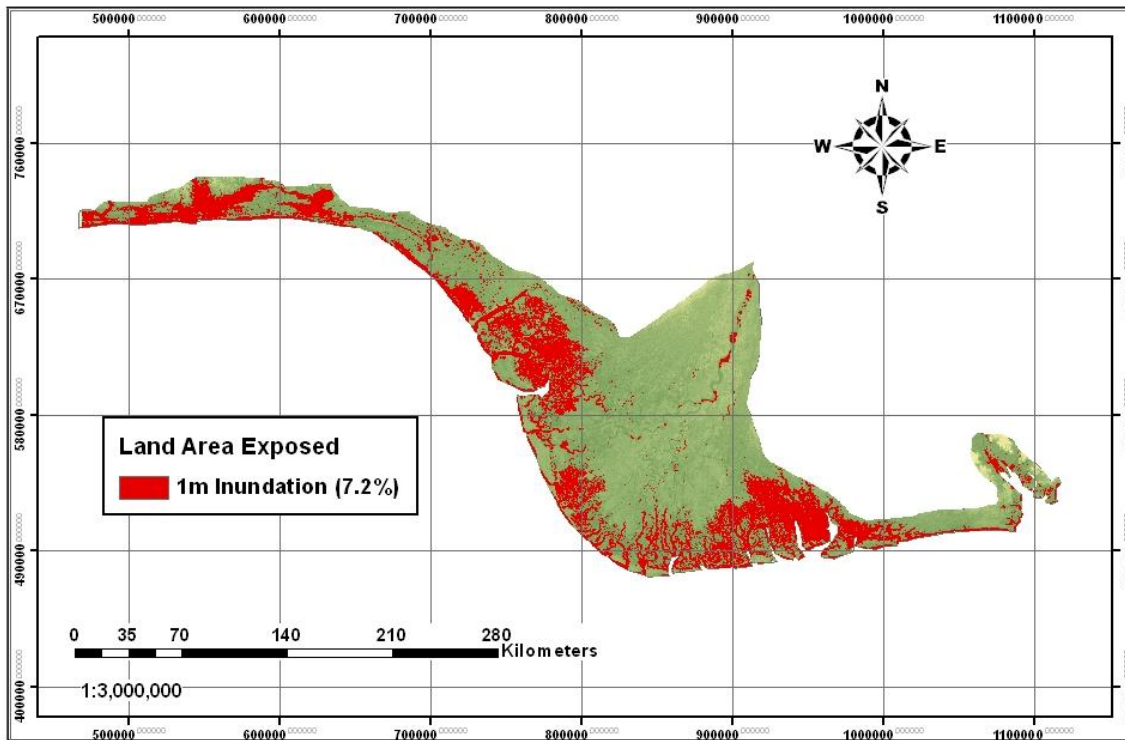
Map 5.1:   **Study Area - Land Extent Exposed in a 1 m SLR**

The regions within the Barrier coast will suffer more displacement as this area includes Lagos state that has the fastest population growth. However, for all the scenarios of SLR, there will be a lot of displacement in the vulnerable regions. The population displaced could bring about many social and economic problems to the settlement they move to except if there is government intervention, which could adopt a managed resettlement for the displaced populace. The coastal population vulnerable to a 1 m SLR is presented in Map 5.2.

The results presented are based on the current population as at the time of this research. Many studies (including this) have relied on fixed estimates of current population. Therefore, the results here are greatly underestimated in terms of the number of people that will be impacted if sea level rise is projected to 2100. With population estimates for Nigeria, which will be about 730 million people by 2100 (UN, 2011), the number of coastal dwellers will be about 88 million compared to 16.6 million under current estimates of this research.

164
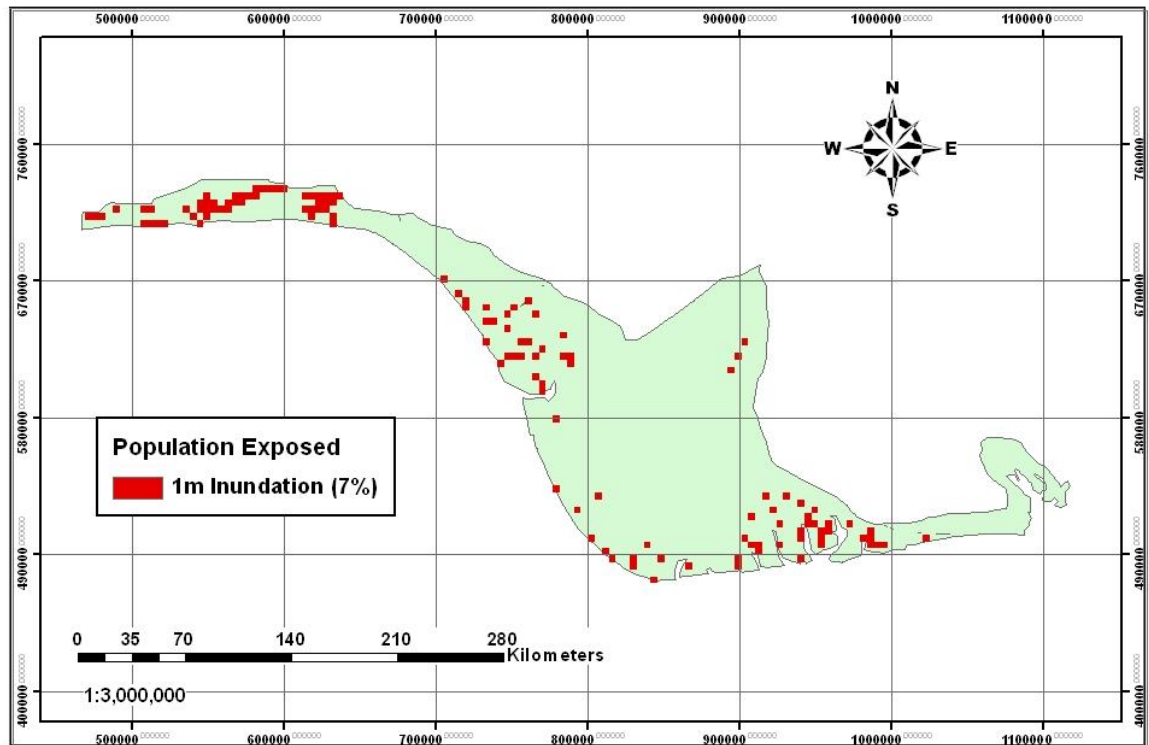
Map 5.2:   Study Area: Population Exposed in a 1 m SLR

With the land area of the Nigeria coastal zone estimated to almost 40,000 sq. km, the population density by 2100 will be 2,200 per square kilometre compared to the current 418 people per square kilometre. This is more than 500% increase of population in the Nigerian coast by year 2100. If the ratio of the population that will be displaced remains the same till the end of the century, then by simple mathematics inference can be made that about 6.2 million people could be displaced in a 1-metre sea level rise scenario, 8.6 and 11.2 million people in a 2 and 3 metre SLR scenarios respectively. This indicates that just about 19% of the population will be displaced by year 2100 if there are no measures put in place to prepare for sea level rise. Since sea level rise is a long-term process, the impacts on the population might not be significant over a whole century if there is adequate coastal management and as adaptation plan in place. However, the foregoing predictions are likely to come true if there are no adaptation plans put in place by the various environmental and governmental units in Nigeria. With the recent awareness that is being propagated by climate scientists, it is expected that coastal

165

planners with the various governments should embark on mitigation and adaptation plans based on good science, which technically should reduce the disturbance because of sea level rise. In a report by the US Today (2005), which estimated that about 44% of Nigeria's population is younger than 15 while just 3% is older than 65, it means that Nigeria will experience a rapid increase in population over the next two decades.

An increasing population will bring about its own problems, which will include the need for development and supporting infrastructure. There will be millions of young people to educate and employ in Nigeria, and there will be a need for huge investments to provide for the growing population. Coupled with the effects of sea level rise, the situation could be catastrophic hence, the need for adaptation plans. Therefore, any increase in sea level rise will have a significant effect on the Nigerian coastal population either if a 1-metre SLR is achieved in the next 10 years or in the next 90 years. An increase from a 1 to 2 metres SLR with the current circumstances in Nigeria regarding coastal management and adaptation plans will ensure an increased level of impacts. (Correspondingly, refer to section 7.2.2).

GDP
The country's total GDP computed is 129 billion US dollars. The study area accounts for 34.5 billion US Dollars, which is about 26.8% of the country's GDP. There were regions of 'no data' for the GDP; as a result, inundation estimates cannot be computed for the regions. This means that the results of GDP are underestimated especially for the Delta and Strand coasts. The impact of SLR on GDP seems to be the lowest proportion compared to all the other critical elements. At 1 m SLR, 1.8% GDP will be lost. These figures remain relatively small in percentage terms, in absolute figures, about 626 million USD and 1.1 billion USD will be lost under the 1 m and 3 m SLR scenarios respectively. Map 5.3 shows the regions that are vulnerable to loss in terms of GDP.
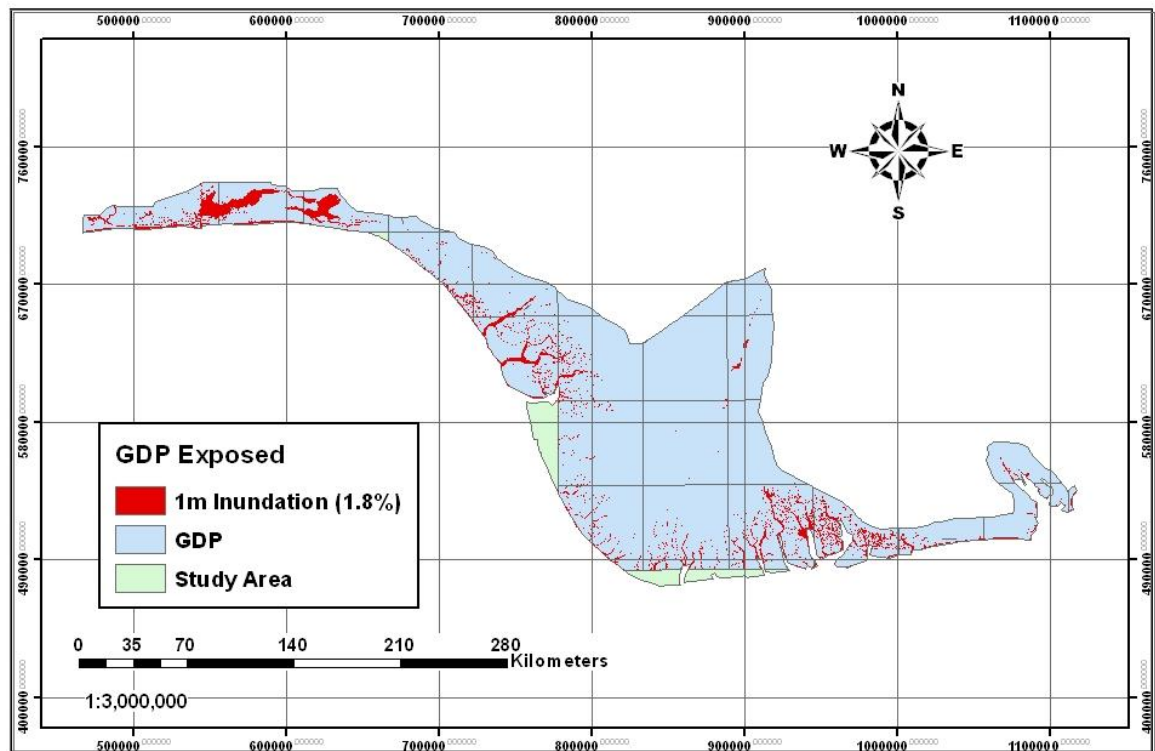
Map 5.3:   **Study Area - Economic Activity (GDP) Exposed in a 1 m SLR**

The significance of sea level rise to trends in GDP is an important discussion. Nigeria's GDP growth rate was about 6.9% in 2011. This indicates that the Nigerian economy is expanding which will lead to growth in businesses, jobs and personal income. If the sea level continues to rise such that it brings about inundation, then the economic growth drivers in the country will be hampered. There will be loss of natural capital, which includes land – which matters for economic production. Loss of land will produce negative consequences of output (Hallegatte, 2011) which will have an impact on GDP. The physical capital, which includes infrastructure, housing and other building, and production equipment, will be affected thereby having a negative impact on GDP. SLR is a slow process and the impacts are usually significant in the long term. The scientific community has proposed that sea level rise vulnerability assessments should be projected to 2100 (Gesch *et al*., 2009). For any sea level rise, analysis to assess its impact on GDP by 2100 will have the need of the economic growth rate projection for year 2100. Due to the unavailability of such data, this research did not delve into

providing such estimates. However, with the latest reforms in Nigeria which include market oriented reforms, modernisation of the banking system, reduction in the rate of inflation through stalling excessive wage demands and more importantly, settling disputes over the distribution of earnings from the oil industry, all have ensured a surge in GDP between 2007 and 2010 (CIA, 2011). Disputes emerged in the Niger Delta over the distribution of revenue from the oil sector that reduced oil production from about 2.2 million to 1.3 million barrels per day. Various governments have failed in the attempt to resolve the dispute until 2009 when the Nigerian government successfully resolved the dispute through an amnesty programme for the Niger Delta militants. Therefore, with production now back to full capacity, there is tendency for increased GDP in Nigeria. If sea level rises, it will have significant impact on oil production especially on the installations onshore subsequently affecting the GDP negatively. Increased level of sea level rise will amount to significant impacts on the GDP.

Urban Extent
This study used the Global Rural Urban Mapping Project to overlay land use onto the SRTM elevation model and the outcome is vulnerable urban areas with different sea level rise scenarios. The urban extent is about 1425 sq. km, representing about 3.6% of the study area. Results indicate that there will be a significant impact to urban extent for all SLR scenarios. Up to 49% of the urban land use will be inundated in a 1 metre SLR and the impact becomes more significant in a 2 and 3-metre SLR scenario as about 57% and 62% of urban area will be inundated. Increased, sea level rise will cause submergence of urban areas and the vulnerable urban amenities and there will be loss of urban facilities. Many urban facilities in the Nigerian coast are installed on low grounds, which will make them to be vulnerable to the effects of sea level rise. Up until now, construction and installation activities within the Nigerian coast have not yet considered the prospects of sea level rise in their building designs. Map 5.4 shows the degree of

vulnerability of the urban extent to SLR for 1 m and 3 m scenarios. Areas classified as urban is more on the western part of the Nigerian coast. It consists of Lagos state which Lagos represents more 90% of the Barrier coast. If sea levels rises from 1 m to 2 m, the significance of the impact will increase considerably as up to 57% of the urban extent in the Nigerian coast will be affected. In Lagos, there are still on-going developments which include buildings and estates. Some of these include the low cost housing estate at Ikota (The Guardian, 2011). Other schemes include Oba Akran Garden Scheme, Badagry, Suntan Beach Scheme, Badagry, Iya-Afin Residential Scheme, Arewa Court Scheme, Lekki Sub-region, Ibeju Lekki Coastal city, Ehingbeti Water Front Scheme among others (AllAfrica, 2011). Many of the schemes are within elevation of between 0 − 3 metres. An increase in sea levels will result to a lot of disturbance within these areas thereby increasing the significance of its impacts.

Agricultural and Wetland Extent
For the agricultural extent, the various agricultural elements within the study area were verified. Table 3.2 showed the classification for the spatial dataset that was employed. The details of their vulnerability to SLR are shown in Map 5.5. Wetlands would also experience significant impact of SLR. Concerning the wetland elements that will be inundated, Map 5.6 highlights the extent of inundation.
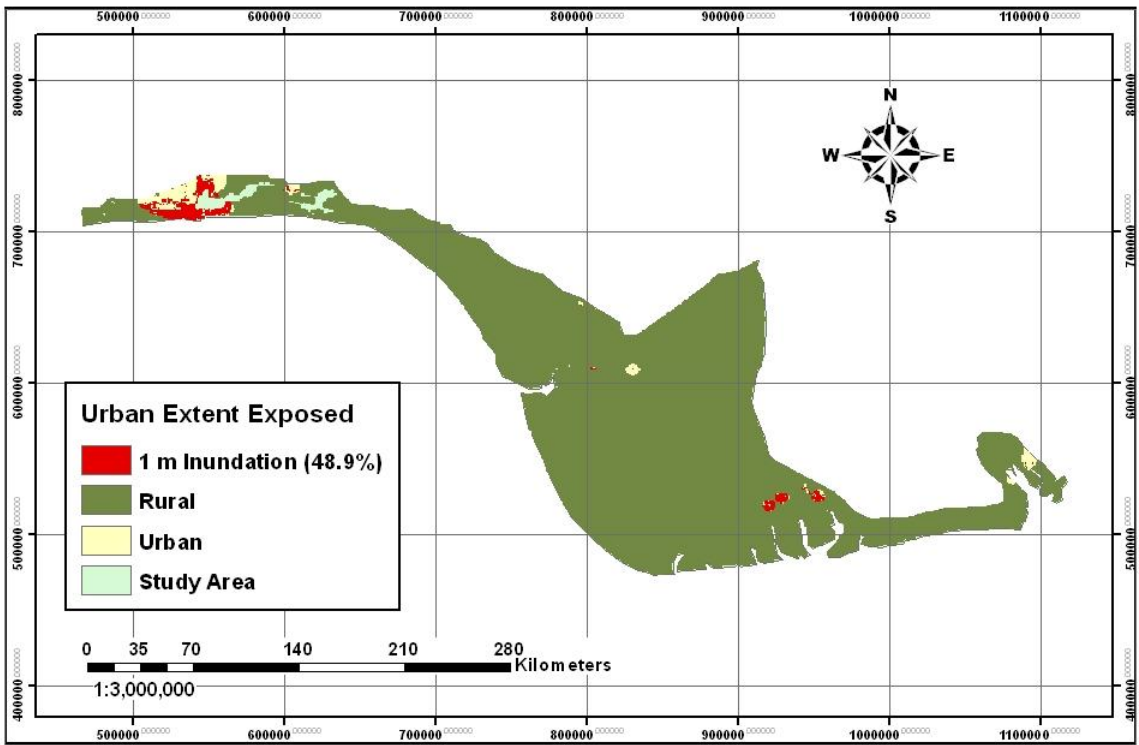
Map 5.4:   Study Area - Urban Extent Exposed in a 1 m SLR
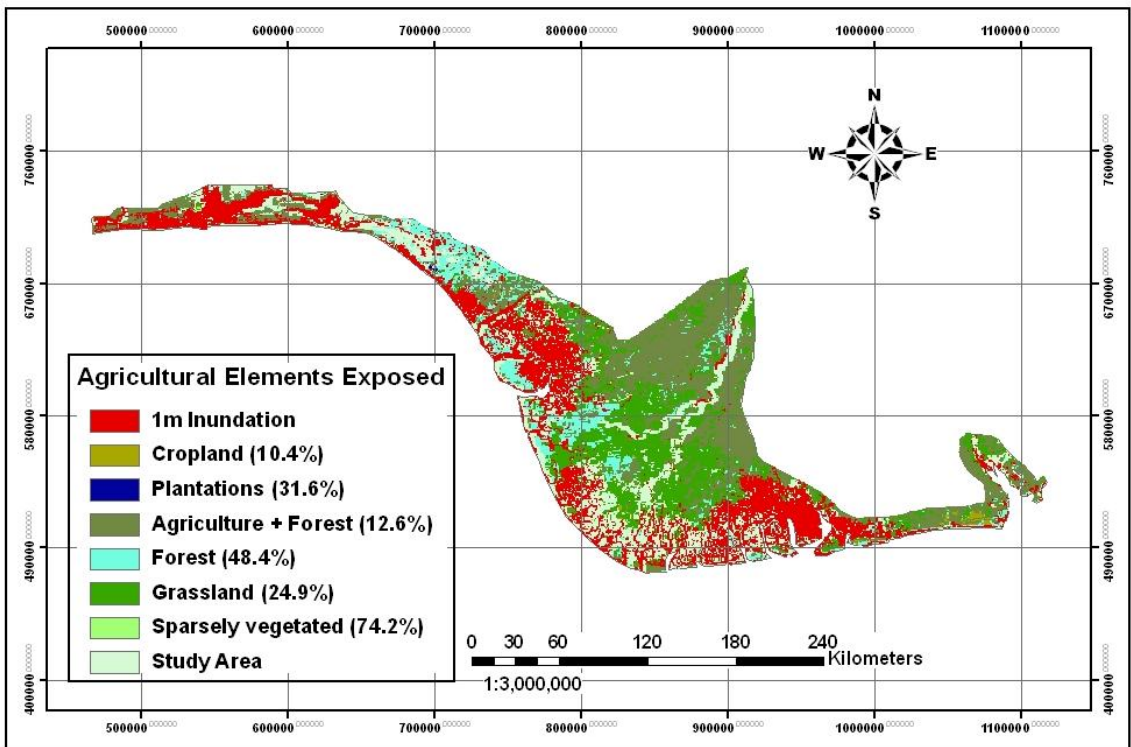
Map 5.5:   Study Area - Agricultural Elements Exposed in a 1 m SLR

Wetland Elements Exposed

- 1m Inundation
- Lake (83.4%)
- River (51.3%)
- Freshwater/Floodplain (43.1%)
- Swamp/Flooded Forest (6.4%)
- Coastal Wetland (52%)
- Study Area
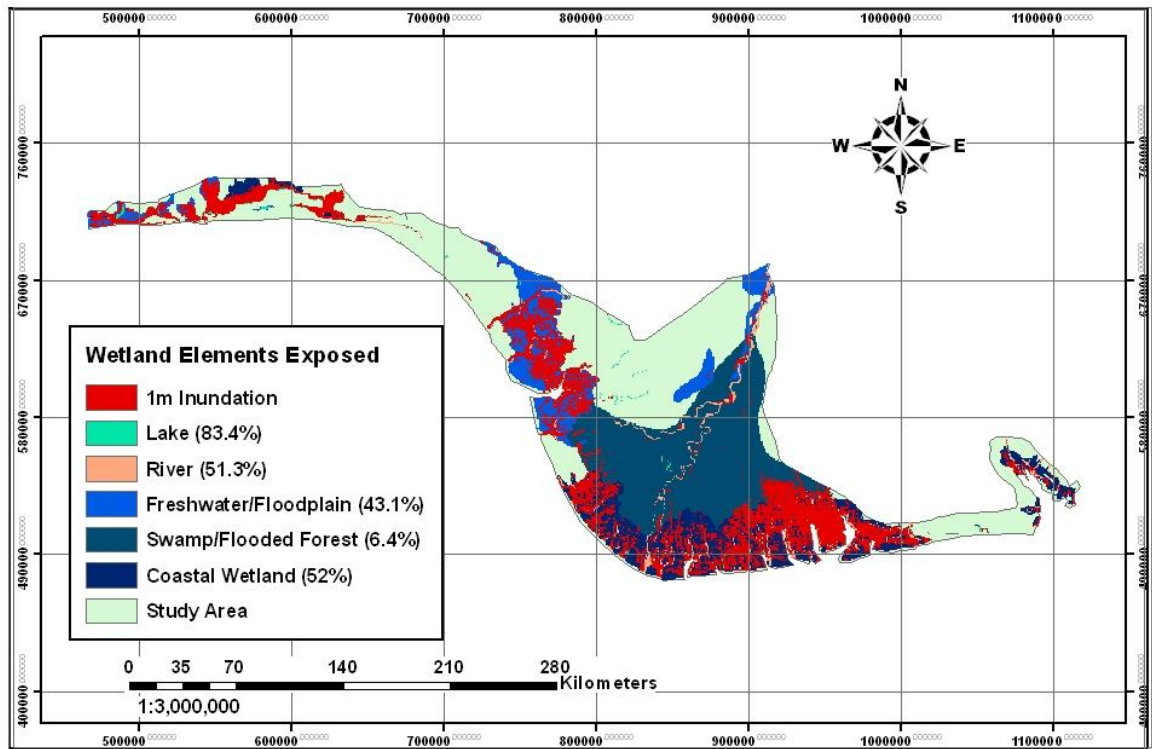
Map 5.6:   Study Area - Wetland Elements Exposed in a 1 m SLR

The impacts presented however are not consistently spread across the four geomorphologic (coasts) units, but are more severe in some and less in the other. This form the basis of section 5.3 as it examines the level of impact of sea level in terms of inundation on the four coasts. To the knowledge of this research, no other study has considered a GIS-based sea level rise investigation for the four geomorphic units of Nigeria.

Having discussed the impact and its significance of the scenarios of sea level rise on the Nigerian coast at the national level, the next section will focus on presenting the results of the assessment on the four coasts used in this study with a case study approach.

5.3   Regional Results

In this subsection, the results for the geomorphologic zones are examined. The Coasts

are Barrier, Mud, Delta, and Strand. Results are presented concerning the total impact of

scenario rise in sea level within the extent of the specific coast.

5.3.1   Barrier Coast

The analyses conducted to determine the impact of scenarios of SLR on the Barrier

coast delivered the results in Table 5.2.

Table 5.2:   Impacts of Sea Level Rise: Barrier Coast

	1 m	2 m	3 m
Land Area (Total = 4,247 sq. km) (10.7%)			
Impacted area	973	1,080	1,219
% of zone extent	22.92	25.43	28.71
Population (Total = 6,430,062) (38.53%)			
Impacted Population	897,165	1,268,233	1,526,362
% of zone extent	13.95	19.72	23.74
GDP (Total = 9,106 Million US$) (7.05%)			
Impacted GDP	224	248	280
% of zone extent	2.46	2.73	3.08
Urban Extent (Total = 1,070 sq. km) (75.09%)			
Impacted area	549	637	686
% of zone extent	51.03	59.16	63.74
Agricultural Extent (Total = 2,435 sq. km) (9.13%)			
Impacted area	1,202	1,399	1,591
% of zone extent	49.38	57.45	65.36
Wetlands Area (Total = 1,984 sq. km)			
Impacted area	1,370	1,510	1,618
% of zone extent	69	76.11	81.56

Land Area

This study estimated the land area for the Barrier coast to be about 10.7% of the study

area. A 1 m SLR will have significant impact on the extent on land affecting nearly a

quarter (23%) of its extent. Further rises will increase the land loss and pressure on the

system. With a rise of 3 m, the loss rises to about 29%. Nevertheless, any action taken would be better reacting to more than a metre inundation.

Map 5.7 showcases the areas of the Barrier coast that will be inundated under 1 m SLR scenario. The information regarding the extent of land that will be impacted by SLR is important to be considered as land extent could include agriculture, barren land, developed land, forest, grassland, and wetland.
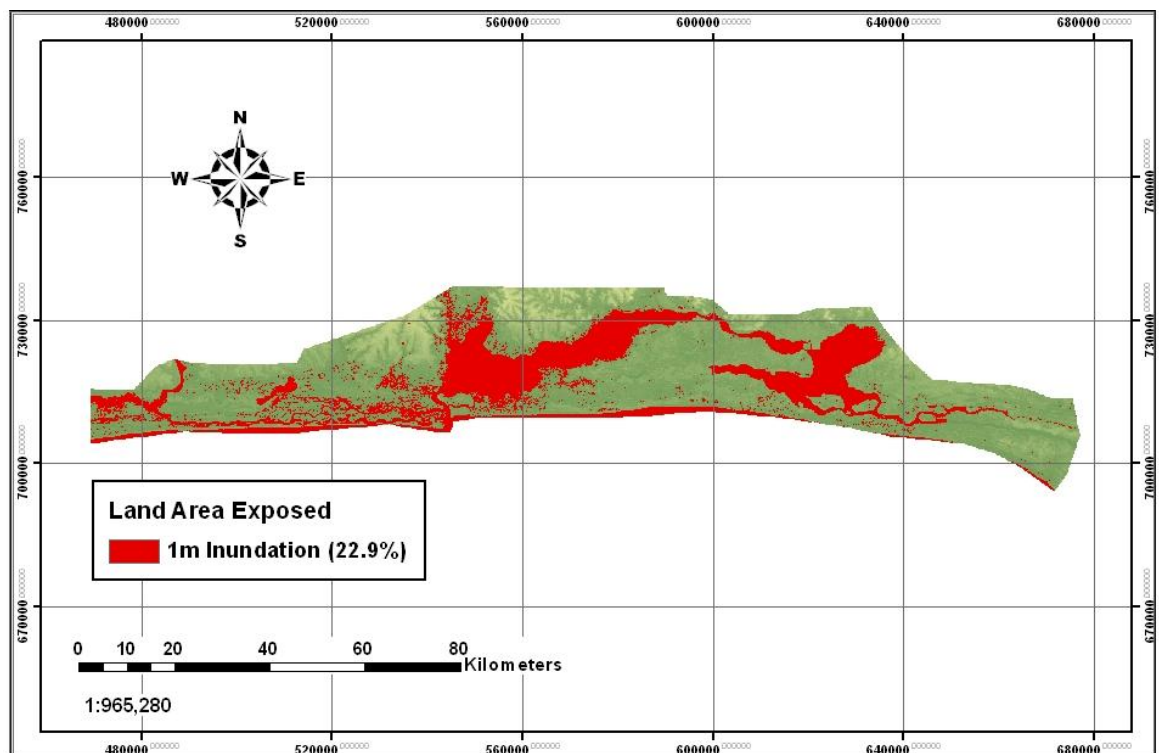
Map 5.7:   Barrier Coast: Vulnerability of Land Area in a 1 m SLR

Population
The coastal population will also be severely affected as with even a 1 m SLR will result to the displacement of about 14% of the Barrier coast population, which could mean up to 900,000 coastal dwellers in the barrier coast impacted. The approximate population of the Barrier coast is 6.4 million which accounts for about 38.5% of the population of the whole study area. At 1 m SLR, 13.9% of population of the Barrier coast will be affected which will then increase to 24% at 3 m SLR. Results indicate that not all the

Barrier coastal populace live in a low-lying area and might not be at risk to the effects of SLR. Map 5.8 depicts the portion of the population most vulnerable to scenarios of SLR at 1 m.

Economic Activity (Gross Domestic Product)

GDP impacted in terms of percentage does not seem high just like the national results in section 5.2 but a 1 m SLR would mean that the Barrier coast would lose 224 million US Dollars. This loss amount to about 2.5% of the total GDP generated in the Barrier coast and 0.2% of the country's total GDP. This will then amount to nearly 280 (3.1%) million US Dollars at 3 m SLR. An estimate of 9.1 billion US Dollars makes up the GDP of the Barrier coast, which is approximately 7% of the country's total GDP and 26.4% of the GDP of the study area. Map 5.9 shows GDP vulnerability to SLR.
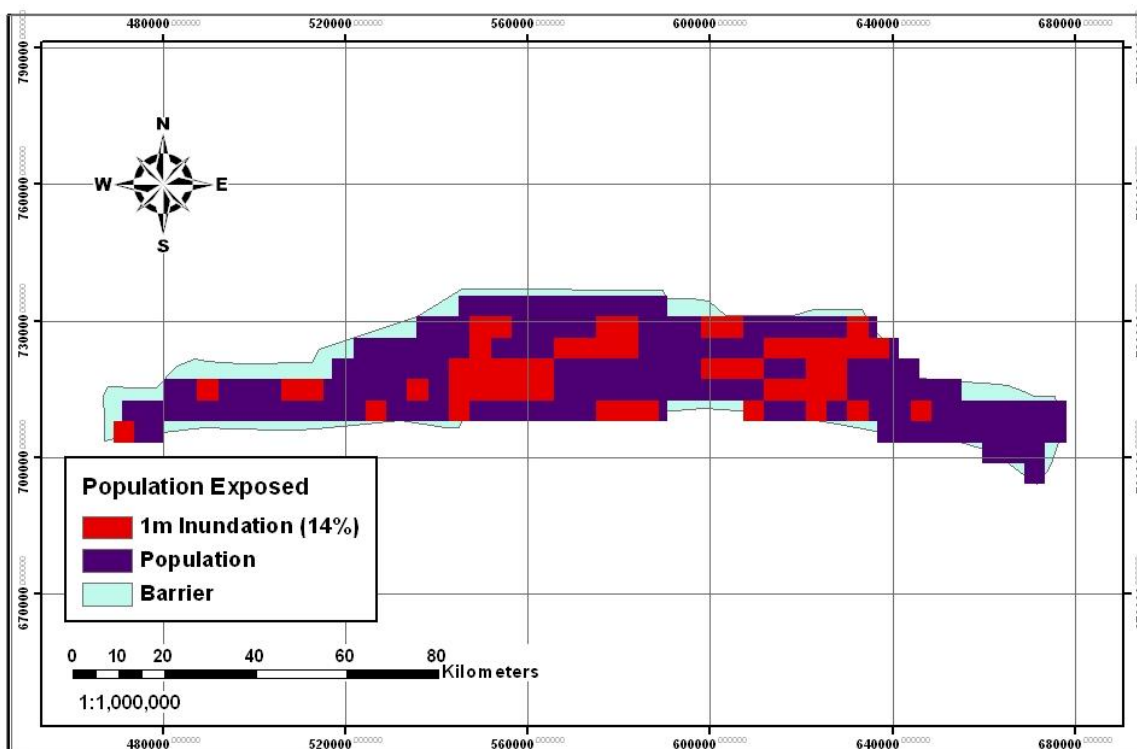
Map 5.8: **Barrier Coast: Vulnerability of Population in a 1 m SLR**
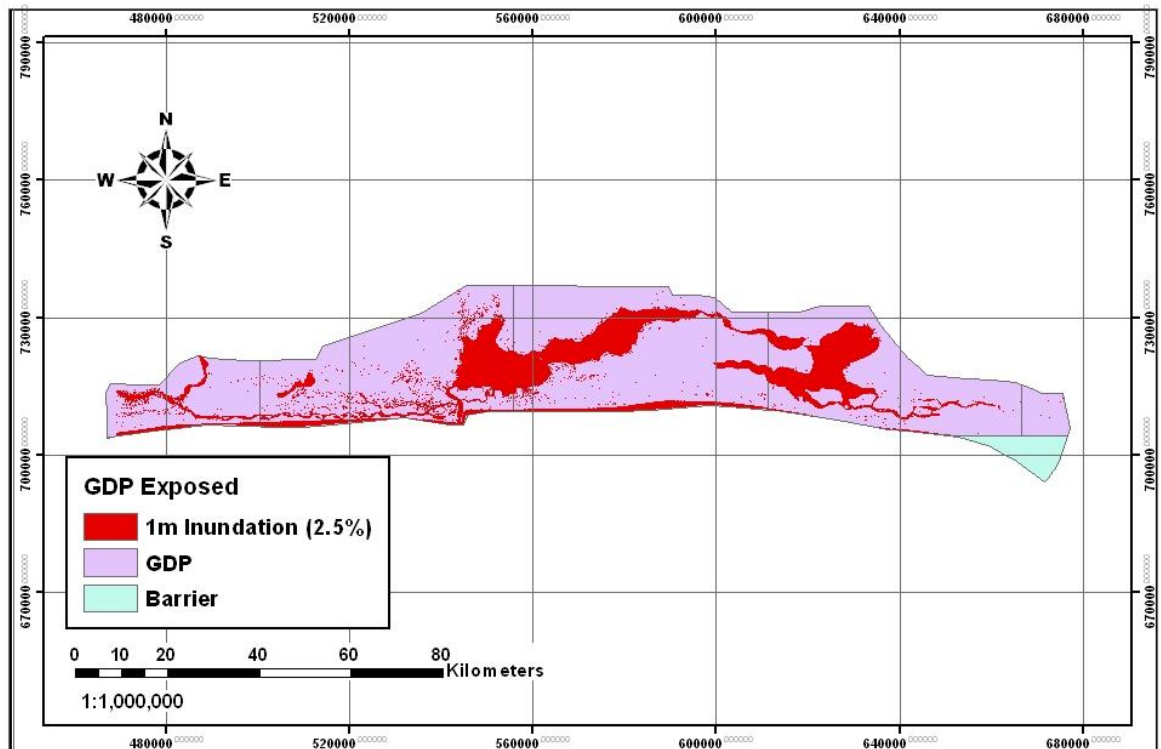
Map 5.9:   **Barrier Coast: Vulnerability of GDP in a 1 m SLR**

Urban Extent

The Barrier urban extent is about 75% of the urban extent for the study area, which indicates that a larger percentage of urban areas are in the Barrier coast. Results also indicate that within the Barrier coast urban extent covers about 25% its extent. These results indicate that the Barrier coast is the most urbanised and developed in terms of infrastructures. A larger percentage (more than 80%) of the Barrier coast consists of Lagos state, which is the most, urbanised and industrialised state in Nigeria. In a 1 m SLR scenario, about 51% of the total urban land will be inundated. This will include all facilities and infrastructure located on the vulnerable urban land. The urban land in Lagos metropolis will be severely impacted, as there are numerous urban facilities located in the area. Notable areas that will suffer inundation include the urban facilities in Lekki, Victoria Island, large parts of Apapa, a considerable amount of Ikoyi and many others. These regions are heavily developed with numerous industries, office space, business centres, market place, and other form of commercial installations. Map

175

5.10 reveals the actual areas of the urban extent that will be exposed to 1 m SLR scenario.

Agricultural Extent

In the event of increasing SLR, agriculture will be subjected to inundation. Results of this study show that 43.9% of agricultural extent will be inundated at 1 m SLR while 59.3% will be inundated at 3 m SLR. Map 5.11 highlights the vulnerable zones within the agricultural elements for a 1 m SLR.
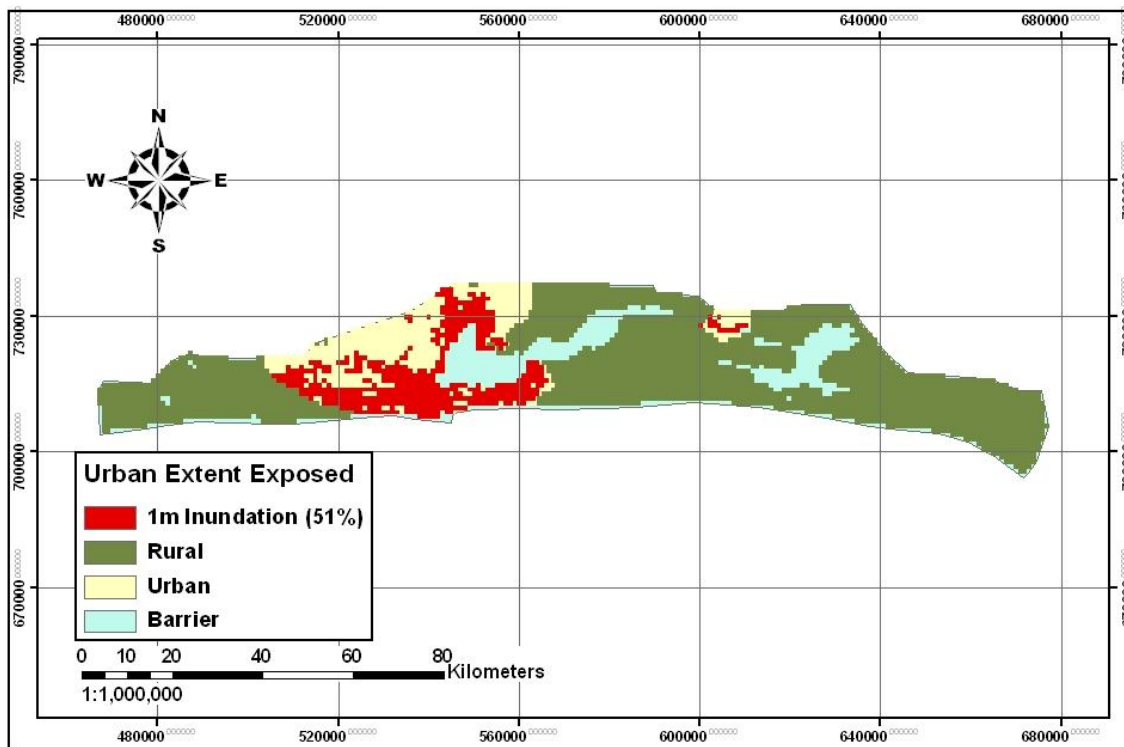
Map 5.10: **Barrier Coast: Vulnerability of Urban Extent in a 1 m SLR**
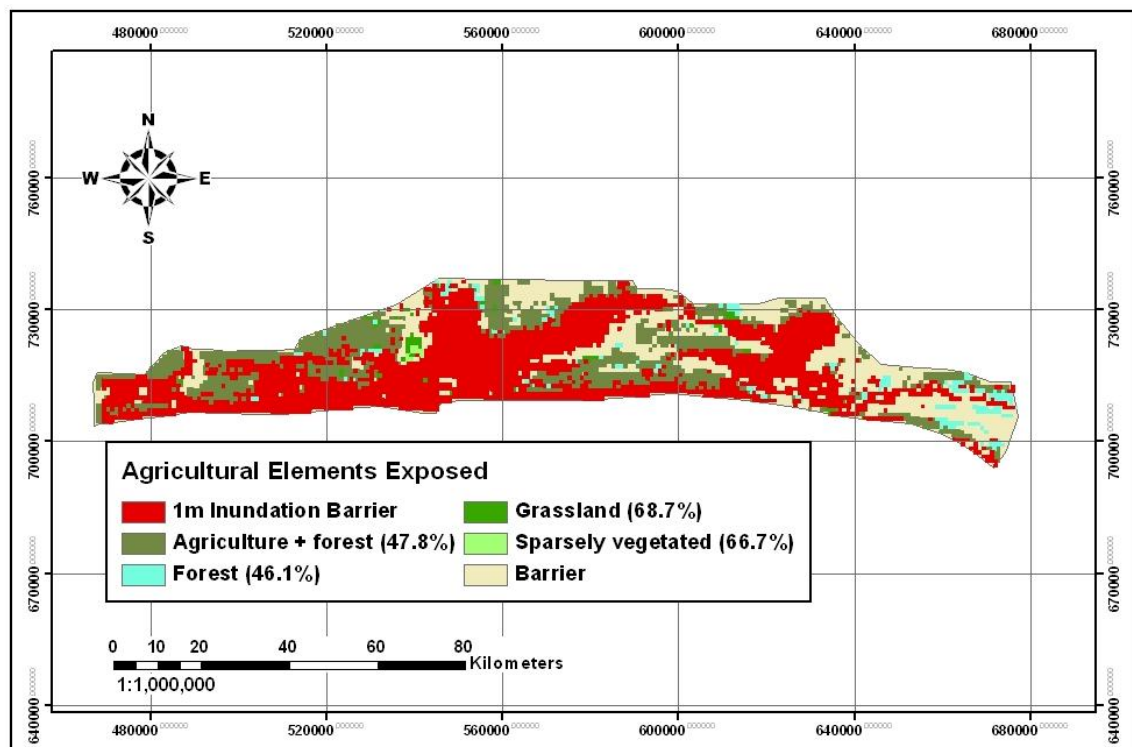
Map 5.11:   Barrier Coast: Vulnerability of Agricultural Extent in a 1 m SLR

Wetland

The extent of wetlands that will be impacted is stated in Table 5.2. Based on the classification of the spatial dataset used in this assessment (see Table 3.3), four classification of wetland relates to the Barrier coast. These were examined to verify the extent of inundation to the scenarios of SLR in the Barrier coast and they are lake, river, freshwater marsh and floodplain, and coastal wetland. Map 5.12 indicates which portion of the wetlands will be inundated in a 1 m and 3 m SLR. Results indicate that the lake classification would suffer the greater amount of impact. The lake actually signifies two distinct lagoons in the Barrier coast. The first to the west is the Lagos Lagoon while the other is the Lekki Lagoon. The length of the Lagos Lagoon is approximately 70 km and its width varies from 3 to 13 km and has an approximate area of 375 sq. km. A long sand spit of about 2 - 5 km wide separates it from the Atlantic Ocean. Both Lagoons consists of mangroves (although many of them have been cleared and exploited for fuel-

wood and other purposes), fish species (79 species already identified by Ramsar), and

they are both used as waterways for passengers and cargoes.
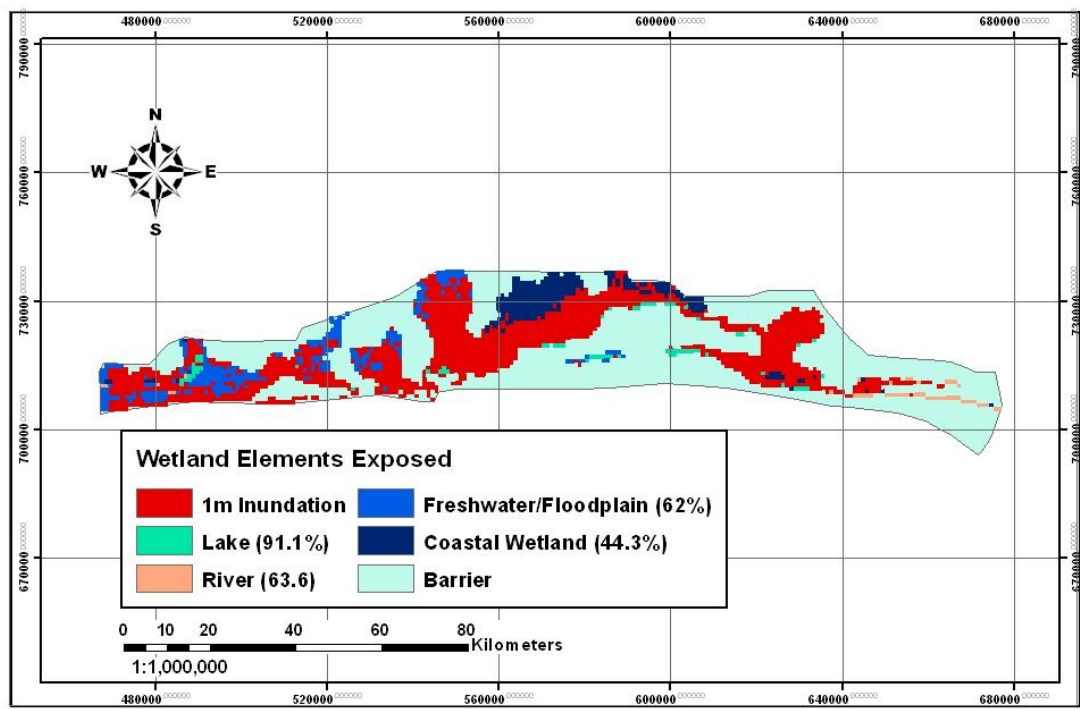
Map 5.12:   Barrier Coast: Vulnerability of Wetland Extent in a 1 m SLR

5.3.2   Mud Coast

The analysis conducted revealed that the area of the Mud coast is approximately 3,308

sq. km, which is 8.29% of the total study area. The population of the Mud coast was

estimated to be about 413,000, which accounts for 2.5% of the population in the study

area. GDP in the coast is just above 1 billion US$ which is about 2.9% of the total GDP

in the study area and 0.78% of the country's GDP. Based on the classification of the

spatial data used in the analysis, there are no urban extents in the Mud coast.

Agriculture covers an area of about 2,977 sq. km while the area covered by wetlands is

approximately 581 sq. km (17.6%). The aforementioned results show the state of the

Mud Coast if there is no rise in sea level. The analysis progressed to project using

scenarios of SLR the impact levels of rise of the sea on the coast. Table 5.3 reveals the

present state of the six indicators and the impact scenarios of SLR will have on them.

Table 5.3   Impact of sea level rise: Mud

	1 m	2 m	3 m
Land Area (Total = 3,307.71 sq. km) (8.29%)			
Impacted area	199	322	458
% of zone extent	6.02	9.72	13.86
Population (Total = 412,764) (2.47%)			
Impacted Population	9316	16,454	37,067
% of zone extent	2.26	3.99	8.98
GDP (Total = 1,009 Million US$) (0.78%)			
Impacted GDP	33	60	88
% of zone extent	3.27	5.92	8.74
Agricultural Extent (Total = 2,449 sq. km) (7.85%)			
Impacted area	492	694	910
% of zone extent	20.08	28.33	37.16
Wetlands Area (Total = 580.52 sq. km) (2.36%)			
Impacted area	131	145	165
% of zone extent	22.58	25	28.48

Land Extent
Results of the impact of scenarios of SLR on the extent of land indicate that at 1 m SLR, 6% of the land area of the Mud coast will be inundated. Map 5.13 reveals the specific area that will be inundated with the scenarios of SLR.

Population
Increase in sea level rise will result in inundation, which will affect the coastal populace living in the Mud coast. Results indicates that with a 1 m SLR, 2.3% of the population will be impacted which represents more than nine thousand people which will rise to about thirty-seven people that will be displaced in a 3 m SLR. Map 5.14 displays the location of the population that will be vulnerable to SLR with the scenarios considered.
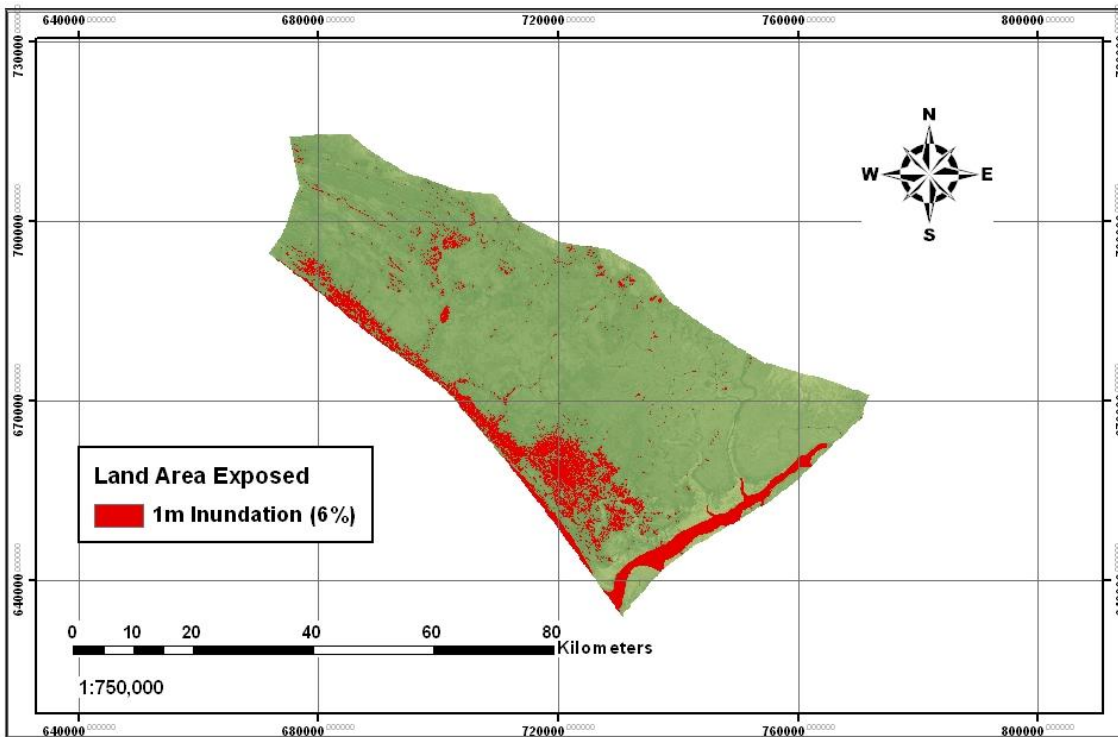
Map 5.13:   Barrier Coast: Vulnerability of Land Area in a 1 m SLR
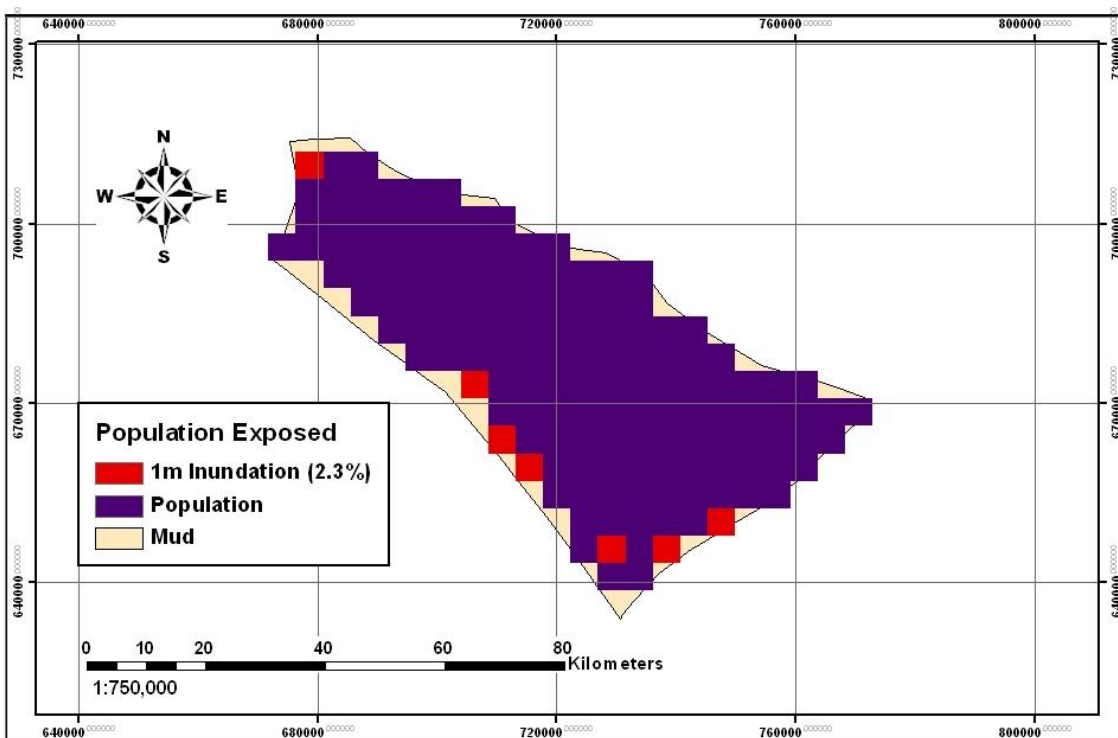
Map 5.14:   Barrier Coast: Vulnerability of Population in a 1 m SLR

Economic Activity (Gross Domestic Product)

The total GDP for the coast is approximately 1.01 billion US$. Out of the four coasts,

the Mud coast generates the lowest GDP. The impact SLR on the GDP within the coast

for the SLR scenarios would be severe to its economic activity. At 1 m SLR, 33 million

US$ will be lost which represents 3.3% of the total GDP in the coast and 0.03% of GDP of the whole country. Map 5.15 shows the vulnerability of the Mud coast to scenarios of SLR.

Agricultural Extent

Results indicate that agricultural extent of the Mud coast is approximately 2977 sq. km. At 1 m SLR, approximately 596 sq. km (20%) will be inundated which will then rise to about 1121 sq. km (37.7%) in a 3 m SLR. Map 5.16 depicts the extent of vulnerability of the agricultural elements to SLR for 1 m scenario.
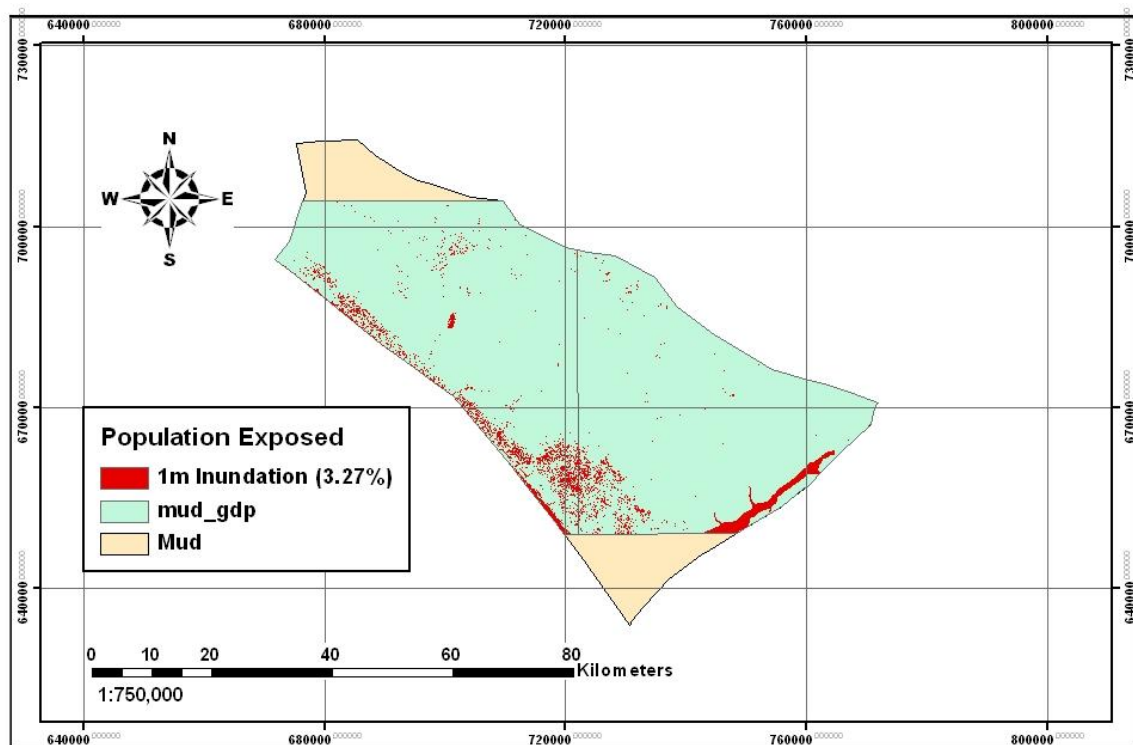
Map 5.15:   Mud Coast: Vulnerability of GDP to in a 1 m SLR

Wetlands

Wetlands within the Mud coast were also noticed to experience some degree of impact in terms of inundation with rise in sea levels. The scenarios considered reveal different degrees of impact. Nearly 71 sq. km (12.3%) of wetland will be inundated in a 1 m SLR scenario. There seems to be little significant impact between the scenarios as only an addition of about 1.1% of wetlands will be inundated even in a 3 m SLR.

181
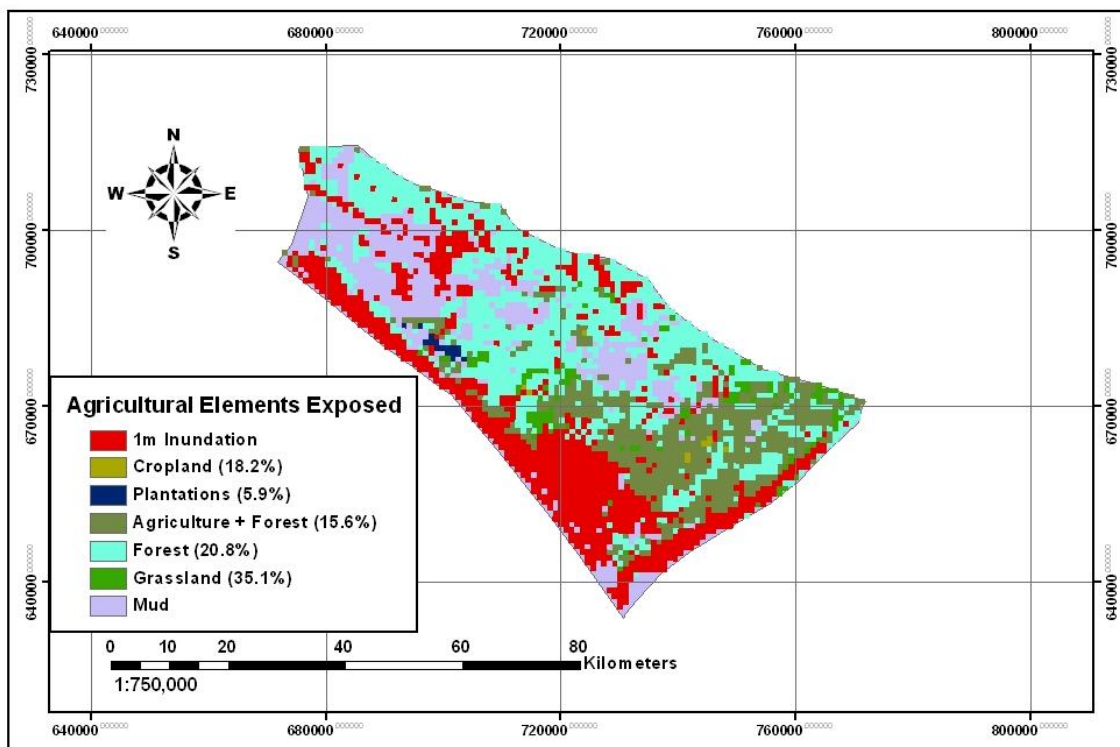
Map 5.16:   Mud Coast: Vulnerability of Agriculture in a 1 m SLR

Further analysis reveals the extent of inundation expected in the wetland elements in the coast. Lake was estimated to cover an area of approximately 10.6 sq. km, which is 1.82% of the total wetland extent of the Mud coast. At 1 m SLR, 41.7% of the lake will be inundated. The river extent in the Mud coast covers an area of about 92.4 sq. km, which is about 15.9% of the total wetland in the Mud coast area. It was established that out of the four-wetland classification, the river would be most severely impacted with about 75.2% affected at 1 m. Freshwater marsh and floodplain is the wetland that covers much extent compared to other wetlands in the Mud coast. It covers an approximate extent of 473 sq. km, which is about 81.5% of the total wetland in the coast, an approximate of 12% will be inundated at 1 m SLR. No impact was recorded for the 4.4 sq. km extent of the coastal wetlands in the Mud coast impact to SLR. Map 5.17 shows the extent of vulnerability of the wetlands in the Mud coast.
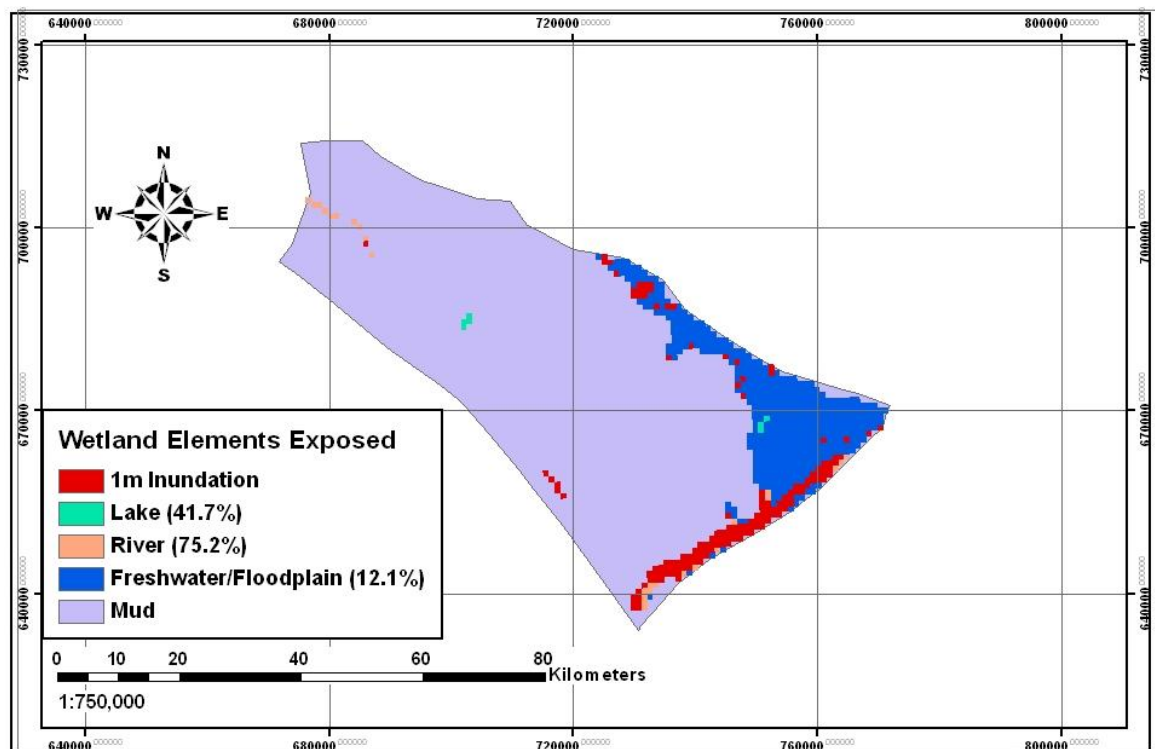
Map 5.17: **Mud Coast: Vulnerability of Wetland in a 1 m SLR**

5.3.3   Delta Coast

Deltas have been recognised as areas that are highly vulnerable to sea level rise (Nicholls *et al.,* 2007). As reported by Ogba and Utang, (2010) subsidence has been found to occur in most deltas which made the rates of sea level to rise above the global average. This research computed the area of Delta coast to be approximately 29,767 sq. km. It is the largest of the four coasts, and account for about 75% of the whole study area. However, in terms of the area of the country, it only amounts to 3.2% of its area. Population is dense for the region as over 9 million people reside there. According to the United Nations (2008), the average population for Nigeria is 164 per sq. km but analysis in this study have been able to estimate that the population density for the Delta coast is 282 per sq. km. The UN based their estimate on the whole of Nigeria while this study is focused on the Delta coast. It is therefore normal for the difference in the population density because more population usually lives in the coastal regions. The Delta also generates the largest income to the Nigerian government. There are oil fields in the Delta coast, which have been the main income and export generating resource of

183

the country. This study was able to ascertain that the revenue from the Delta coast is about 20.1 billion US$ which is 54% of the country's total GDP. The Urban extent in the coast is not as much as that of the Barrier coast. It covers an area of about 229 sq. km. The Urban centres in the coast are in major cities such as Port Harcourt in Rivers state and Warri in Delta state. Most of the Niger Delta is rural areas with creeks and other wetlands. The wetland in the Delta coast is more than 21000 sq. km, which is about 86.5% of the total wetland in the study area. The wetland consists of rivers, tributaries that branch off River Niger, swamp, and fresh water.

This section examines the impact the scenarios considered in this study will have on the critical elements in the Delta coast. Table 5.4 is a summary of the impacts. Percentage of total area refers to percentage within the study area except for GDP, which mirrors the percentage impacted for the whole country while percentage of zone extent refers to the percentage that will be impacted within the coast.

Land Extent

A significant amount of the land area in the Delta coast will be lost to inundation for all the scenarios of SLR considered in this analysis. This loss will be severe, as water will cover the low-lying areas, which could mean that houses, and constructions within the level the sea rise to will suffer damage. Area meant for agriculture and other installations especially oil fields will be flooded which will hamper the economic life of the coastal inhabitants as well as their social lives. Map 5.18 depicts the actual land areas that will be vulnerable to 1 m sea level rise.

Table 5.4   Impacts of sea level rise: Delta

	1 m	2 m	3 m
Land Area (Total = 29767 sq. km) (74.62%)			
Impacted area	1,618	2,120	3,097
% of zone extent	5.43	7.12	10.41
Population (Total = 8,404,138) (54.06%)			
Impacted Population	509,777	629,384	783,541
% of zone extent	6.07	7.49	9.32
GDP (Total = 20,106 Million US$) (15.58%)			
Impacted GDP	326	434	649
% of zone extent	1.62	2.16	3.23
Urban Extent (Total = 229.37 sq. km) (16.09%)			
Impacted area	147	156	159
% of zone extent	62.93	66.81	68.10
Agricultural Extent (Total = 21,057 sq. km) (78.06%)			
Impacted area	2,458	3,417	5,430
% of zone extent	11.67	16.23	25.79
Wetlands Area (Total = 21316.62 sq. km) (86.58%)			
Impacted area	6,620	8,485	10,129
% of zone extent	31.05	39.81	47.52

Population

The Delta coast is densely populated and an accelerated rise in sea level will have severe impact on the lives of the coastal dwellers. This will lead to displacement of hundreds of thousands of people and congestion in the nearby hinterland as the displaced residents will seek to dwell there as temporary migrants which will lead to competition for goods and services and the resources of the nearby settlements.

In comparison to the other three coasts considered in this study, the Barrier and the Strand coasts have more population density although the area covered by the Delta coast is considerably more than all the other coasts.
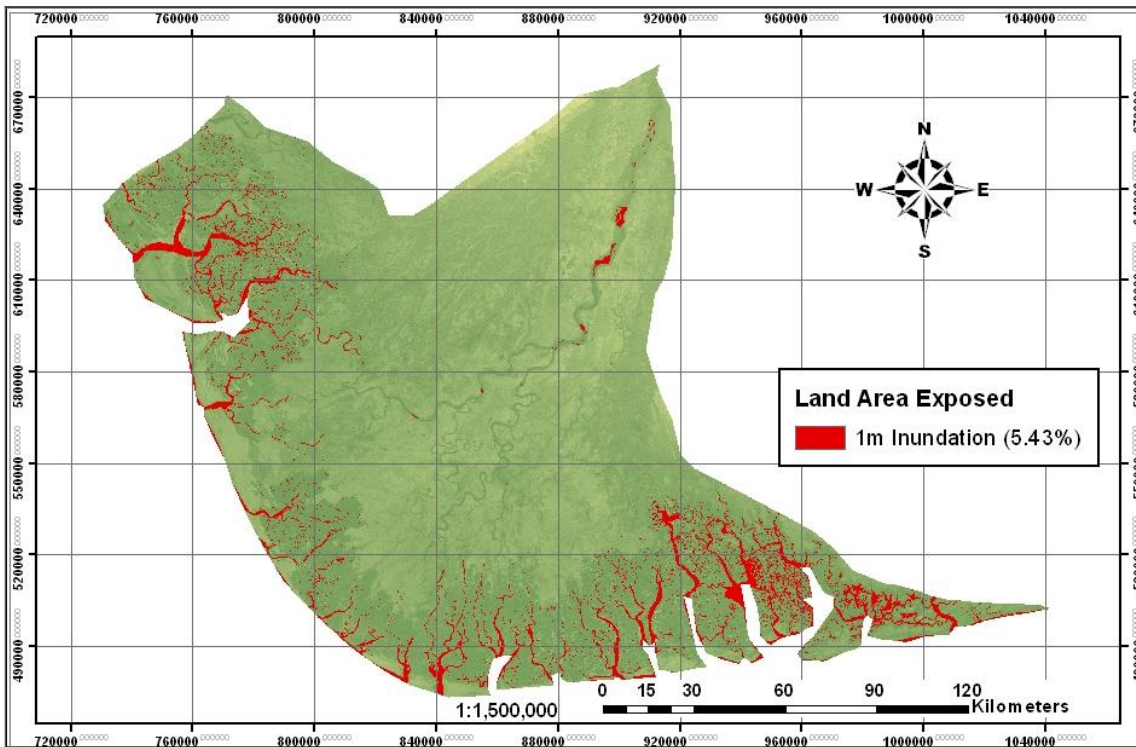
Map 5.18:   Delta Coast: Vulnerability of Land Extent to in a 1 m SLR

If the sea rises by 1 m, more than 509 thousand people will be severely impacted. This figure represents 6.1% of the total population within the Delta coast, which could rise to over 783 thousand (9.3%) that will be displaced in a 3 m SLR scenario. These figures show that the impact of rising sea will be highly severe and as sea level rises, the impact on the Delta coast's population becomes more significant. Map 5.19 illustrates the particular location where the impact of SLR rise will be severe in a 1 m SLR scenario.

Economic Activity (Gross Domestic Product)
The Delta coast, which is a subset of the Niger Delta, is a major source of oil and gas production and a supplier of large exports to the United States. The major oils companies especially the Shell Petroleum Development Company has flared the most amount of gas thus making Nigeria a major source of greenhouse gas emissions in the world. Greenhouse gas will thus allow for increased temperature and rise in sea level.
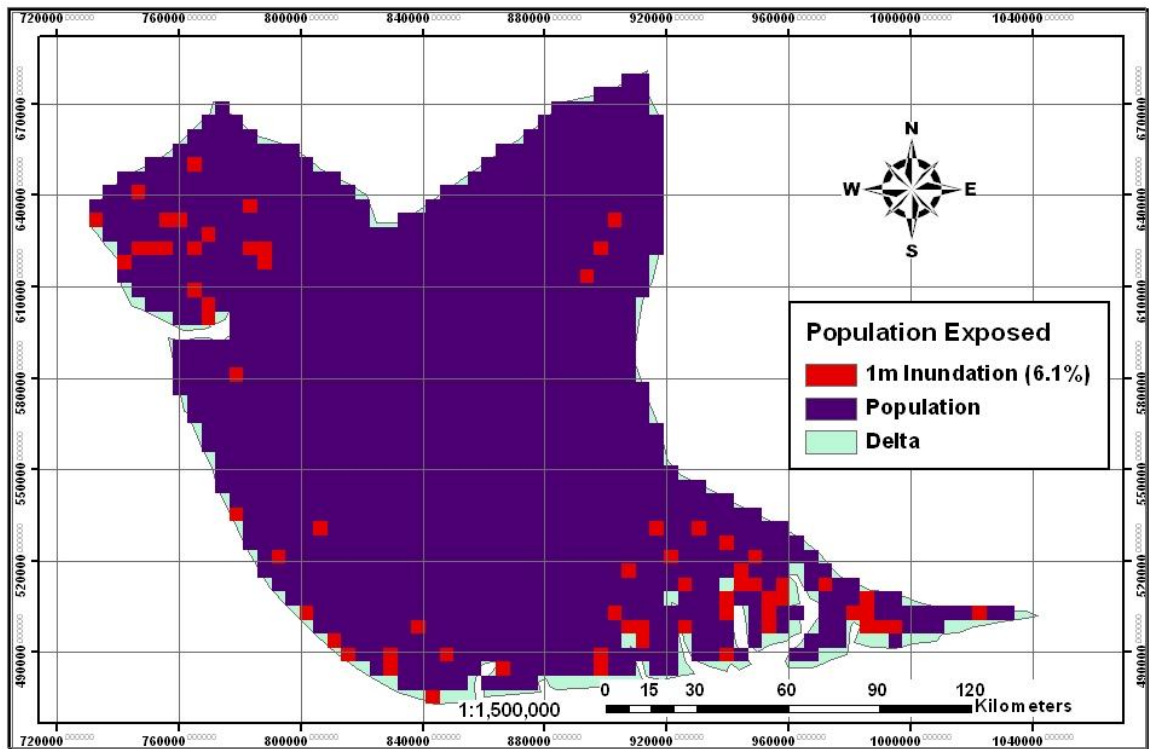
Map 5.19: Delta Coast: Vulnerability of Population in a 1 m SLR

In the event of accelerated sea level rise, the Delta coast and the country as a whole will be severely impacted in terms of GDP among other forms of impacts that will be experienced. The task in this study is to estimate how much GDP will be vulnerable as the sea level rises. The Delta coast's GDP is about 16% of the country's total earnings. In a 1 m SLR, US$ 325.8 million will be lost. This amount to 1.6% of the total GDP within the coast and 0.3% of the country's total earning. The percentage of GDP seems to be low compared to other critical elements presented in this study. Map 5.20 displays locations where GDP will be impacted in a 1 m SLR.

Urban Extent
The Delta coast urban area is a low-lying coast. Urbanisation, land subsidence and climate change has been observed to enhance the vulnerability of the low-lying areas (De Graaf, 2008). A sizeable amount of the urban extent in the Delta coast is less than 3 m above sea level.
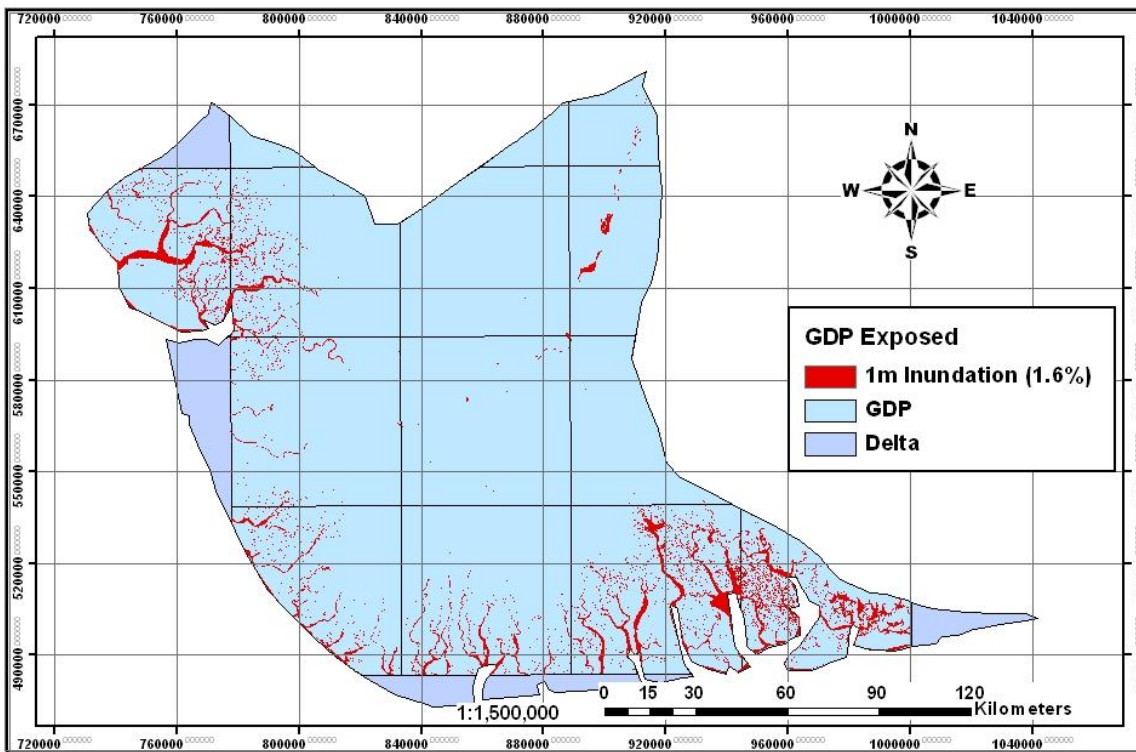
Map 5.20:   Delta Coast: Vulnerability of GDP in a 1 m SLR

The Delta coast is composed of wetlands, coastal plains and river plains that are exposed to flooding and it was said by De Graaf (2008) that these are the regions where urbanisation predominantly takes place. It is thus essential to ascertain the extent of the vulnerability of the urban extent in the Delta coast, which could then be a springboard on which mitigation and adaptation plans to safeguard the urban extent, can be based. The Delta coast consists of not too large an urban extent (229 sq. km) and 63% of it will be lost in a 1 m SLR. The urban extent will be extremely vulnerable to increased sea level rise as many installations, constructions, buildings, oil wells, infrastructure, and other amenities are within elevation levels of 0 to 3 m above sea level. The cost of rebuilding could be enormous as well as the cost it will have on the coastal dwellers. Map 5.21 shows the urban areas that will be vulnerable to a 1 m SLR.
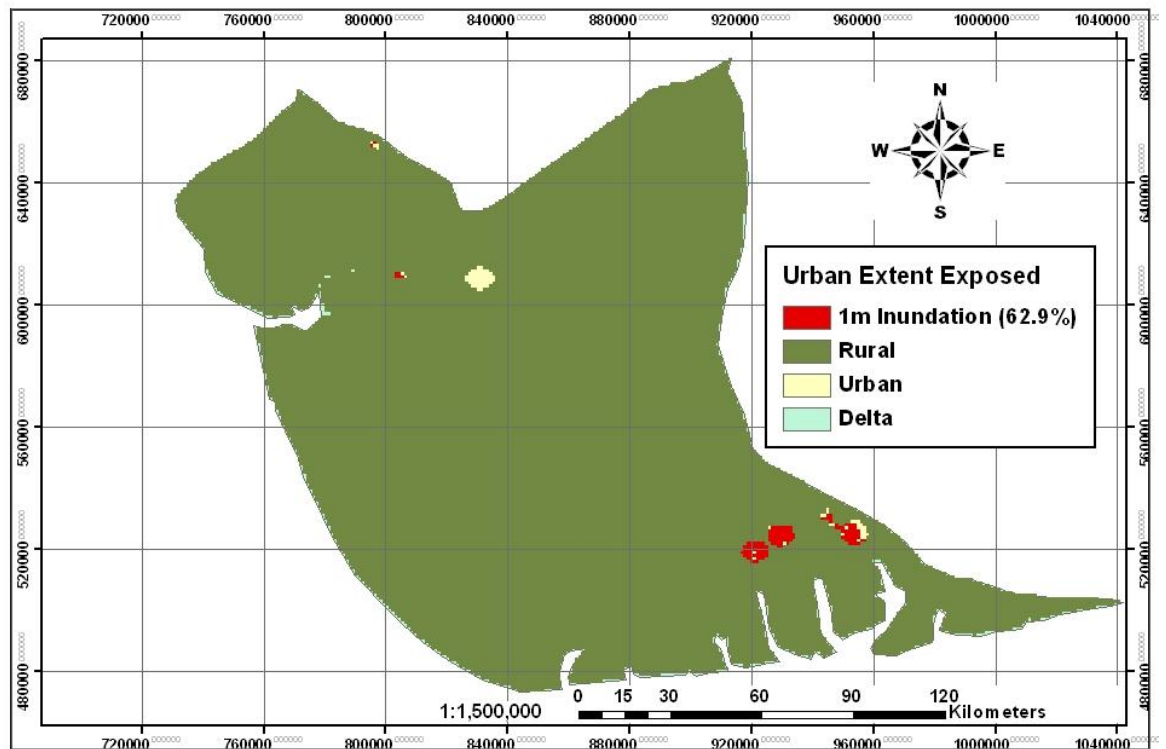
Map 5.21:   Delta Coast: Vulnerability of Urban Extent in a 1 m SLR

Agricultural Extent

The Delta coast provides a diverse range of natural resources and favourable conditions for social and economic development (fisheries, aquaculture, agriculture, tourism etc.). However, these ecosystems are also highly vulnerable, due to coastal hazards, which include human activities such as mangrove extraction, crude oil extraction, and sea level rise related to global climate change. Agriculture in the Delta coast will face severe impacts not only from sea level rise but also from pollution because of oil extraction in the region, gas flaring, and oil spills that occurs frequently during petroleum operations within the coast. For this study, other impacts were not considered but the impact from rising sea levels. In an attempt to estimate the extent by which agriculture will be affected because of sea level rise, the area covered by agriculture in the coast was examined to find out its vulnerability to rising sea levels. Results show that if the sea rises by 1 m, about 12% of the total area covered by agriculture in the Delta coast will be inundated and in a 3 m SLR, the loss could be as high as 26%. Agricultural elements will be affected with increase in sea level rise. Forest area will suffer inundation of

189

31.1%, in a 1 m, SLR scenarios and grassland element, as more than 11% of its area in a 1 m SLR scenario. Map 5.22 indicates the extent of vulnerability of the each of the agricultural elements to rise in sea level.
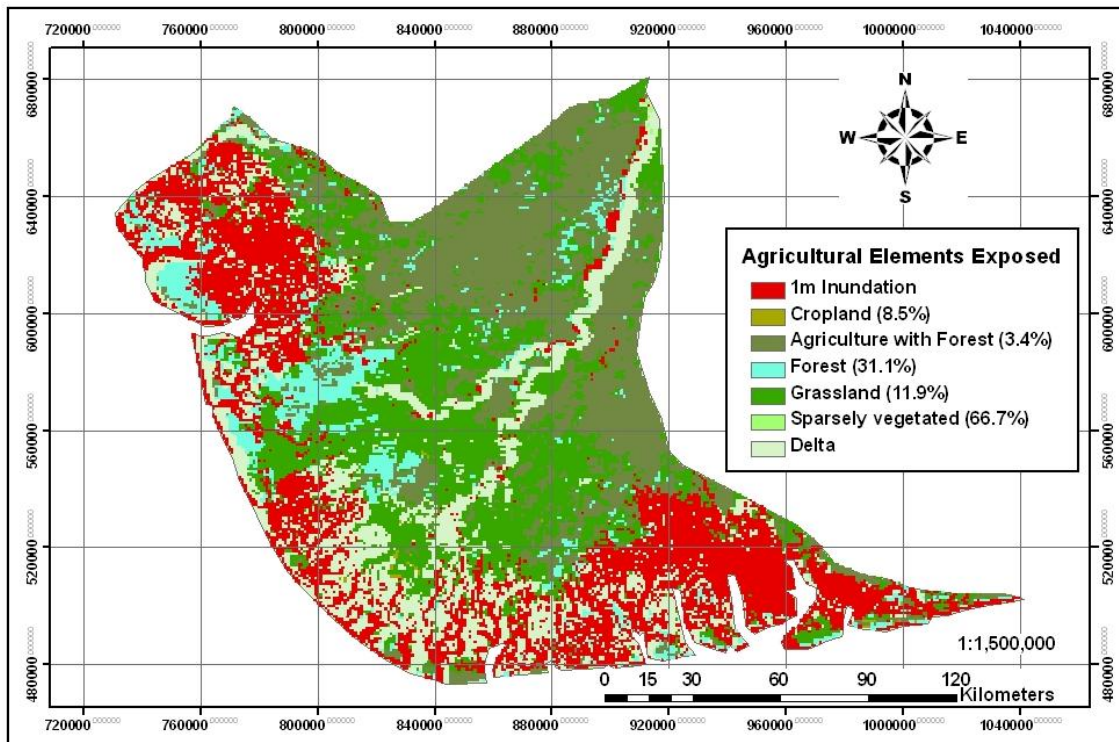
Map 5.22:   Delta Coast: Vulnerability of Agricultural Extent in a 1 m SLR

Wetland
Degrees of inundation will be seen in the wetland extent in the Delta coast. The coast consists of large wetlands, which include rivers and tributaries, lake, swamp, freshwater etc. These elements will be severely impacted with inundation if sea rises. Results indicate that in a 1 m SLR scenario, the total wetland area that will be inundated is 1,396 sq. km, which amount to 6.6% of the total wetland in the coast. The two wetlands of international importance according to the Ramsar classification are Apoi Creek Forests in Bayelsa State, which covers an area of 292 sq. km, and the Upper Orashi Forests in Rivers State, which covers an area of 252 sq. km, seems not to suffer from inundation if sea rises. However, if sea rise up to 3 metres a minor part of the Apoi creek might be affected, this is because elevation levels aound the creek ranges from 3

m to 8m above sea level. The case of the Upper Orashi Forest is more optimistic as the lowest elevation levels recorded is 15 m above sea level. No further analysis will be presented as regards the extent of inundation on the Ramsar sites as the study does not intend to examine specific locations within the coast. Based on the classification of the data explored, five wetland elements will be impacted with rising sea levels. Coastal wetland will be more severely impacted at 1 m (54.4%). The degree of impact will continue to rise as sea level increases. Map 5.23 depicts the regions where these wetlands will be vulnerable.
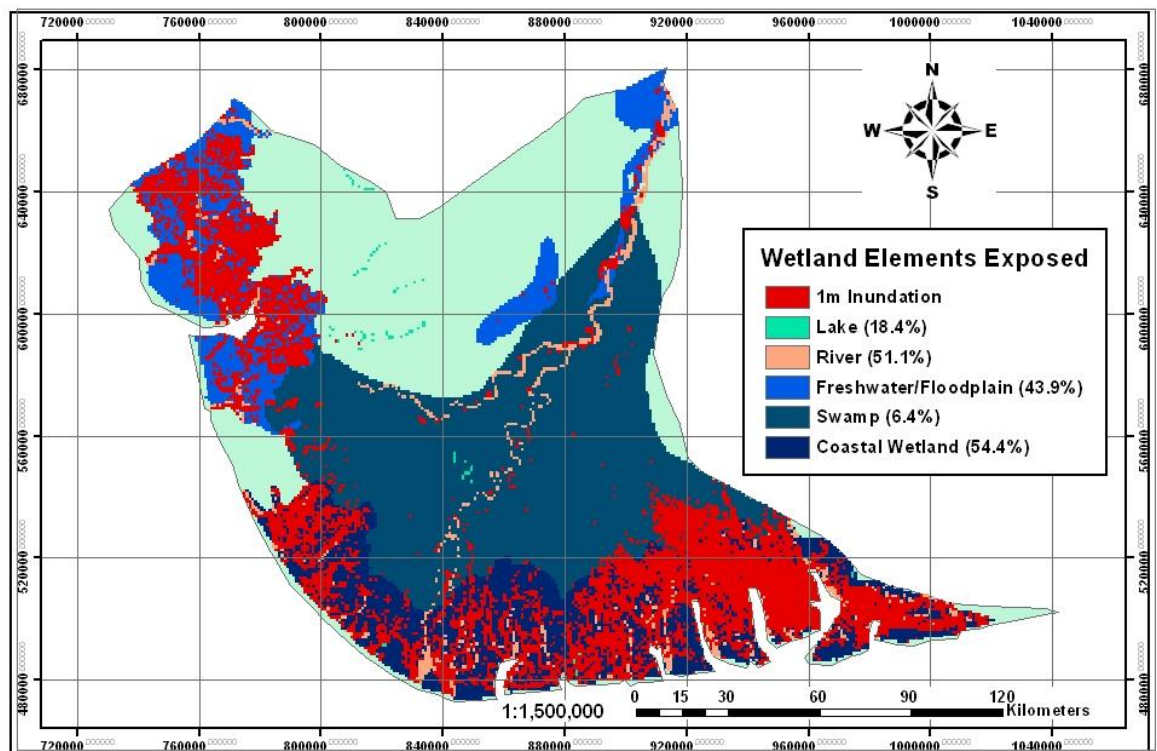
Map 5.23:   **Delta Coast: Vulnerability of Wetland Extent in a 1 m SLR**

5.3.4   Strand Coast

The Strand coast is the smallest in term of land extent. Analysis shows that it covers an area of about 2518 sq. km, which is about 6.3% of the total extent of the study area. Population was estimated to be 902,520. The population in the coast is dense as the population density per sq. km is 358. This figure is more than double the population density per sq. km for Nigeria. GDP was estimated to be 4.3 billion US$ this is on

average 1.7 million US$ per sq. km for the coast. GDP in the Strand coast is considerably more than the GDP generated averagely in the country but far less than the GDP generated in both Barrier and Delta coasts. Urban land area in the Strand coast is approximately 101 sq. km, which is about 7.1% of the total urban extent in the study area and 4% of the total land area within the Strand coast. The extent covered by agriculture amounts to 2371 sq. km (6.35% of total agricultural area in the study area). Wetland covers an area of 644 sq. km. Table 5.5 gives a detailed summary of the impacts of scenarios of sea level rise on the six critical elements in the Strand coast.

Table 5.5   Impacts of sea level rise: Strand

	1 m	2 m	3 m
Land Area (Total = 2518.18 sq. km) (6.31%)			
Impacted area	73	94	124
% of zone extent	2.90	3.71	4.93
Population (Total = 902,520) (5.41%)			
Impacted Population	4943	4943	24773
% of zone extent	0.55	0.55	2.74
GDP (Total = 4, 302 Million US$) (3.33%)			
Impacted GDP	17	22	29
% of zone extent	0.40	0.51	0.68
Urban Extent (Total = 101.61 sq. km) (7.13%)			
Impacted area	5	23	35
% of zone extent	4.9	22.55	34.31
Agricultural Extent (Total = 2,349 sq. km) (6.35%)			
Impacted area	189	498	498
% of zone extent	8.04	21.21	21.21
Wetlands Area (Total = 643.85 sq. km) (2.61%)			
Impacted area	128	235	337
% of zone extent	19.95	36.48	52.32

Land Extent
Less than 3% and 5% of the total land area will be lost in a 1 m and 3 m SLR respectively. This represents the lowest impact when compared to other coasts. The

main reason for this is that elevation is higher in the Strand coast more than the other coasts that have been examined in this Chapter. Therefore, it could be expected that lower inundation will occur in this coast in virtually all the critical elements considered compared to what will be experienced in the other coasts. Map 5.24 depicts the actual land areas that will be vulnerable in a 1 m sea level rise.
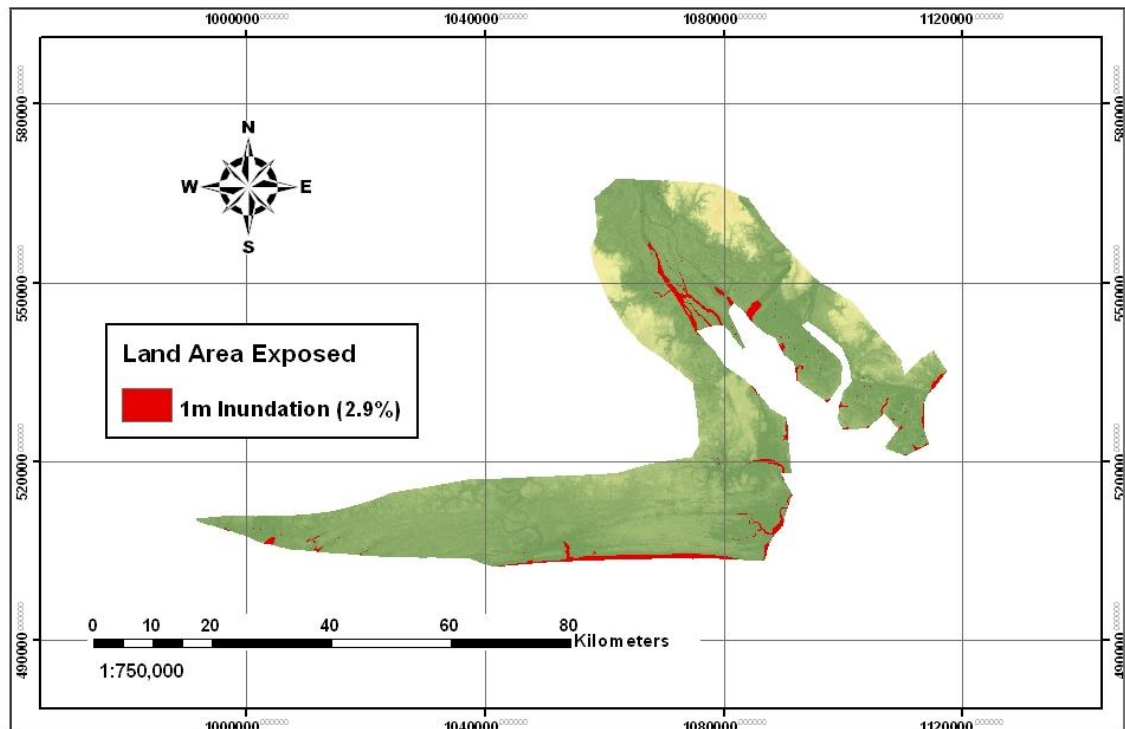
Map 5.24:   Strand Coast: Vulnerability of Land Extent in a 1 m SLR

Population
It was estimated that the population density within the Strand coast is 358 persons per sq. km. This is more than double the average population density of Nigeria. This could signify that if there is a major hazard in the coast a lot of coastal resident will be severely affected. In a 1 m SLR scenario, almost five thousand (0.6%) coastal inhabitants will be affected. They might be rendered homeless, their properties might be lost, and they might need to seek for temporary or even permanent residency in the nearby settlements or cities. Interestingly, the situation will not be worse in a 2 m scenario as the same impact in a 1 m SLR will be felt in a 2 m SLR scenario. Elevation

of the locations where people reside is a contributing factor to this. It could be inferred that no coastal inhabitants resides in area in which the elevations are greater than 1 m and less than or equal to 2 m. Indeed elevations within this range are rare along the coast. Furthermore, inference could be drawn that the coastal populace resides in locations that are more than 2 m as results clearly shows that the resident will suffer the consequence of SLR for 3 metres SLR. In fact, there will be a sharp increase for residents that will be affected in a 3 m SLR compared to a 1 m and 2 m SLR. Map 5.25 illustrates the location of the coastal residents that will be displaced in a 1 m and 3 m SLR scenario. It is observed in comparison to the three other coasts already discussed that the population of the Strand coast will be less impacted in the event of rising sea level.
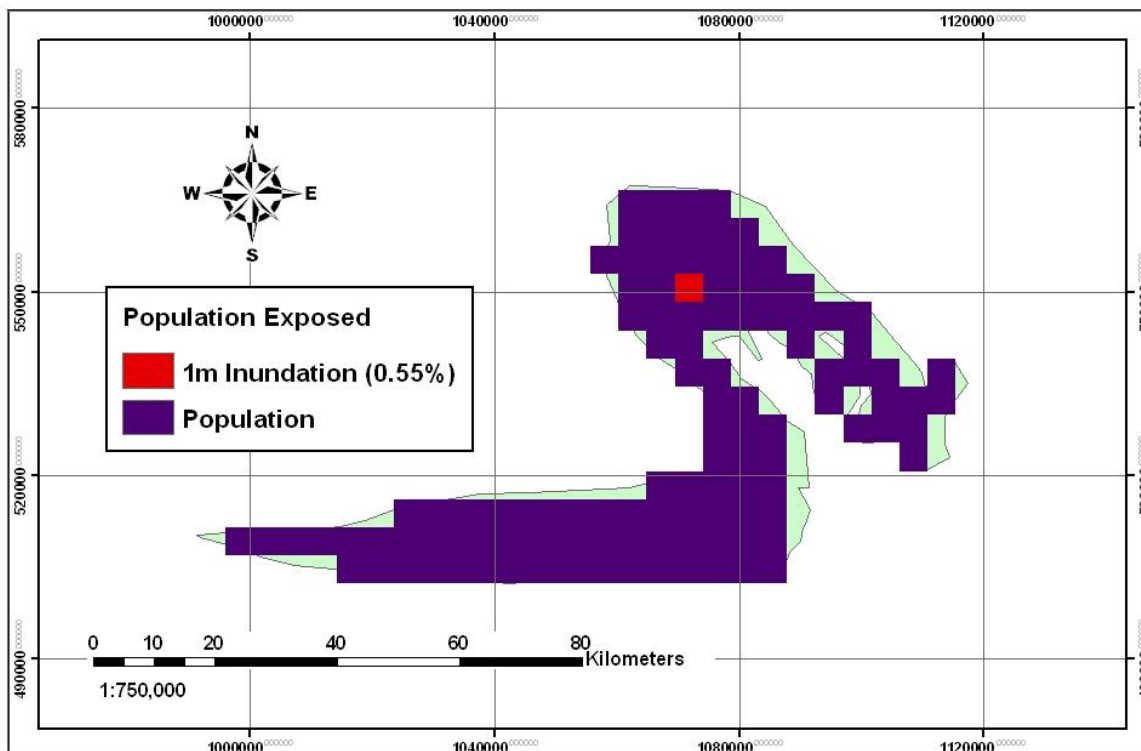
Map 5.25:   Strand Coast: Vulnerability of Population in a 1 m SLR

Economic Activity (Gross Domestic Product)
This study went ahead to ascertain the GDP that will be lost in the Strand coast. While the Mud coast in relation to the GDP produce will bear the highest impact, the Strand

194

coast will put up with the lowest amount of impact at all levels of SLR. With regards to the amount of GDP contributed to the country's economy, the Strand coast have more than the Mud coast which contributes the lowest amount of GDP to the country. The total GDP in the coast in relation to the country is about 3.3%. In a 1 m SLR, 17.4 million US$ will be lost while US$29 million will be lost in a 3 m SLR. Map 5.26 shows the vulnerability of the GDP to sea level rise for 1 m.
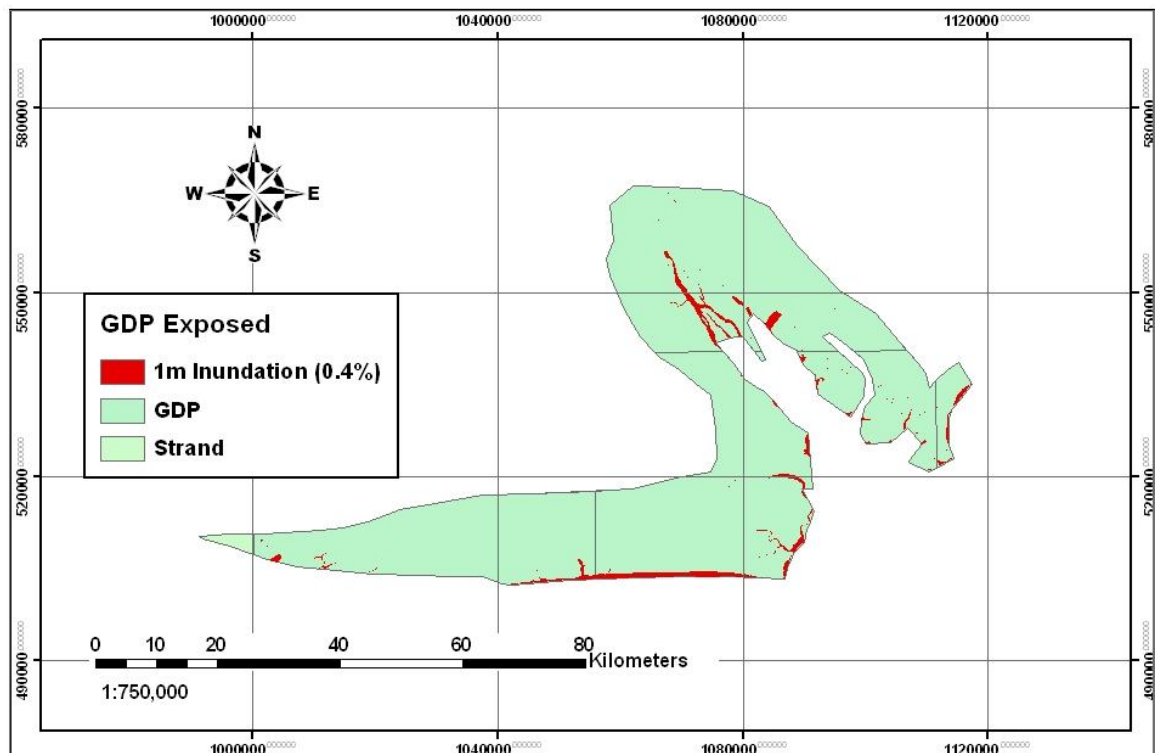
Map 5.26:   Strand Coast: Vulnerability of GDP in a 1 m SLR

Urban Extent
The effect on urban amenity (4.9%) will not be significant in a 1 m sea level rise in comparison to a 2 or 3 m SLR situation. This is because most of the elevations in the Strand coast are more than 1 m above sea level. However, other factors may cause inundation at 1 m SLR. This could include land subsidence, coastline morphology etc. but these factors are outside the scope of this research. About 23% will be inundated in 2 m and 34% in a 3 m SLR scenario. Map 5.27 shows the urban extent in the Strand coast that is vulnerable to increase in sea level rise.
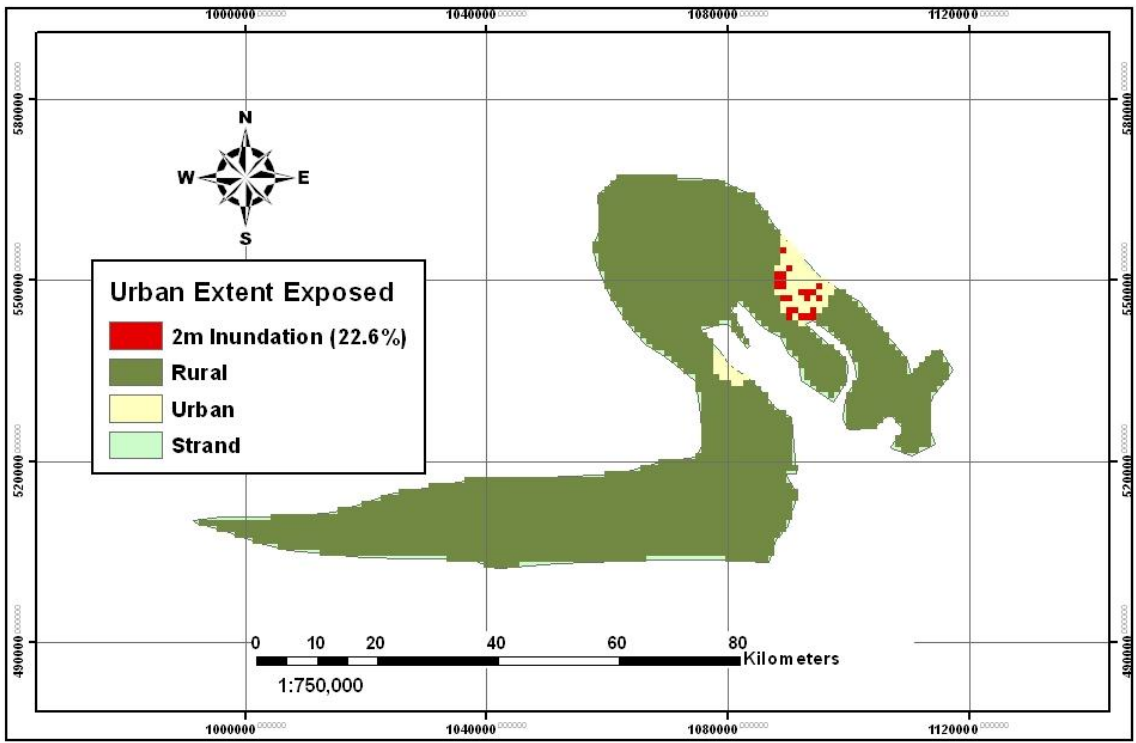
Map 5.27:   Strand Coast: Vulnerability of Urban Extent in a 2 m SLR

Agricultural Extent

Approximately 8% of agricultural extent will be inundated in a 1 m SLR, which will increase to about 21% in 2 m and 3 m SLR situations. Breaking down the agricultural extent into agricultural elements in the coast, it was observed that no large extent of the agricultural elements will be inundated at 1 m SLR. However, inundation in 'forest' could be up to 37.9% of its extent in a 1 m SLR scenario. Map 5.28 shows the actual agricultural elements that will be impacted and its extent in a 1 m scenario.
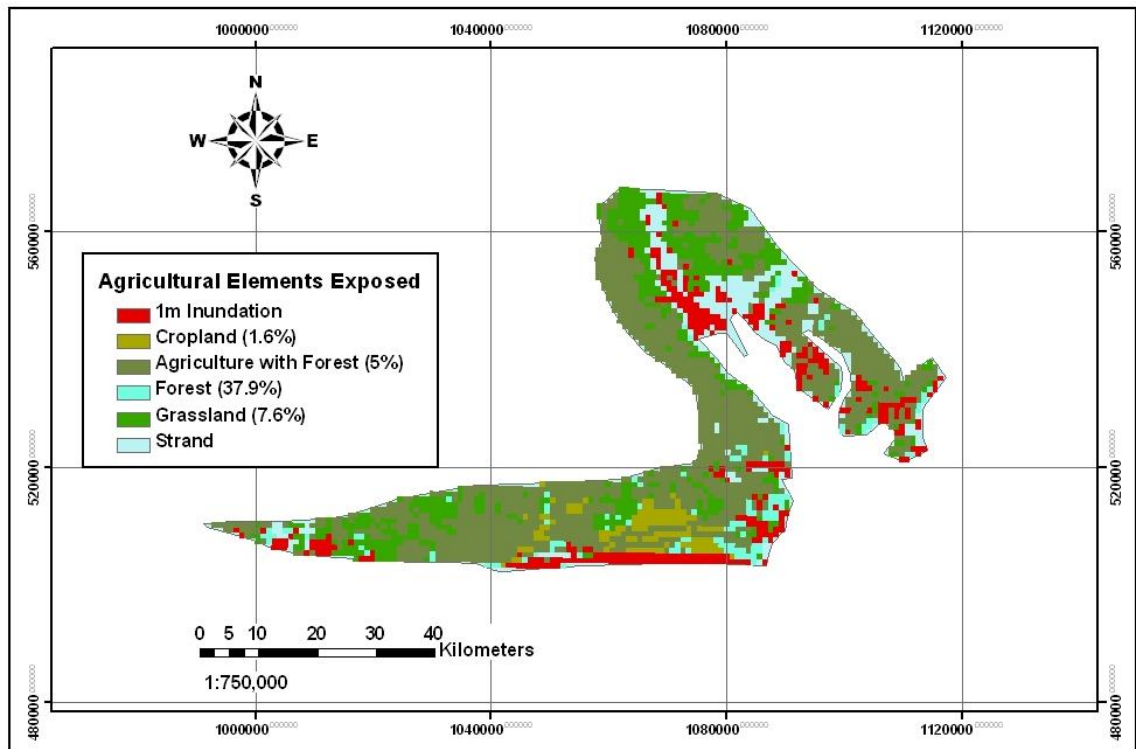
Map 5.28:   Strand Coast: Vulnerability of Agricultural Elements in a 1 m SLR

Wetland Extent

This research projected that wetlands in the Strand coast will suffer impacts with increase in sea level rise, as up to 3.7% of the total extent of the wetland will be inundated in a 1 m SLR scenario. The wetland elements that suffer the impacts are lake, river and coastal wetland. Lake covers about 10 sq. km; river is about 108 sq. km, while coastal wetland is 525 sq. km. In a 1 m scenario, it is the coastal wetland element that is more inundated as 20.8% of its extent will be under water. However, in terms of element extent, coastal wetland suffers more. Map 5.29 detailed the actual locations of the wetlands that will be vulnerable in a 1 m SLR.
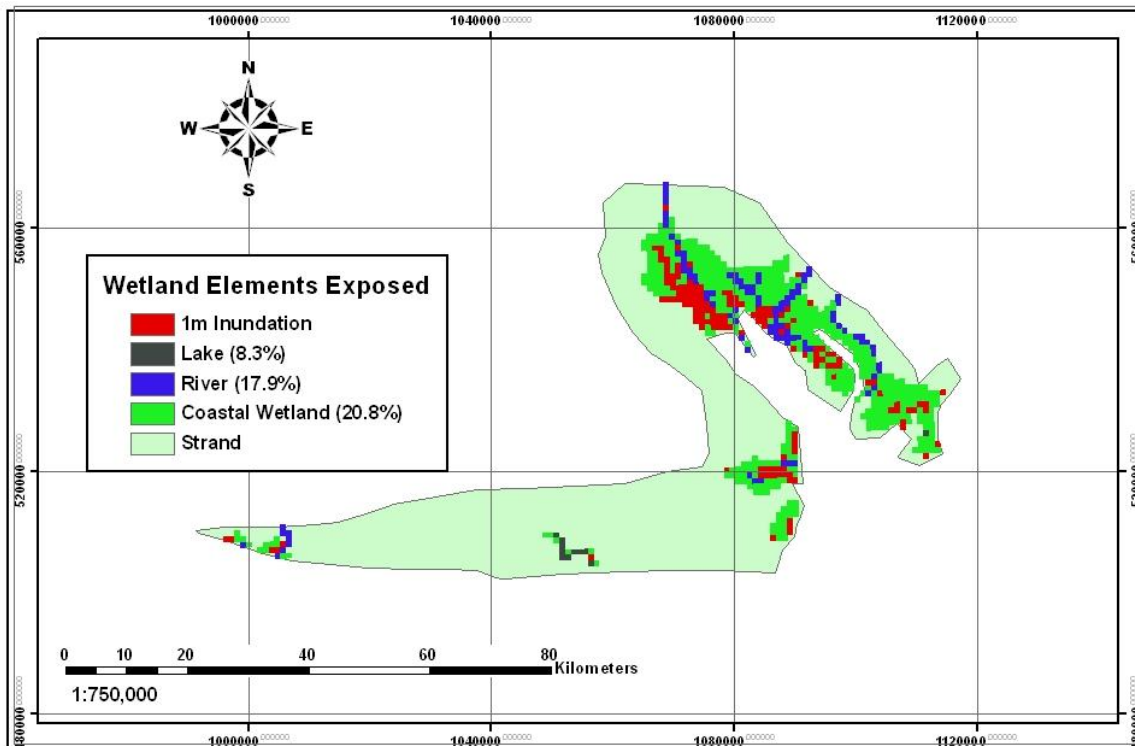
Map 5.29:   Strand Coast: Vulnerability of Wetland Elements in a 1 m SLR

5.4   Accounting for Uncertainty in Inundation analysis

Elevation plays a significant role in the development of the inundation models for the

sea level rise scenarios because topography is a key parameter that influences many of

the processes involved in coastal change (Gesch, 2009). Various sea level rise

vulnerability assessments have produced maps and statistical summaries that fascinate

the decision-makers, planners and coastal managers to formulate mitigating and

adaption policies (Gesch *et al.*, 2009). This study has produced maps and statistical

summaries of the potential risk involved in various scenarios of SLR, derived from the

Shuttle Radar Topographic Mission (SRTM) elevation model digital elevation model.

Limitations of the model serve as the uncertainties, which include the horizontal and

vertical accuracy. With regard the vertical accuracy, the DEM is quantised to 1m

increments, which make it impossible to adequately predict from the DEM SLR

scenarios that are not whole integers. The vertical accuracy is +/- 6.13 metres at 95%

confidence level (CIAT, 2005). The method for accounting for uncertainty is adding the vertical accuracy to the projected sea level rise scenarios, which will add more area to the inundation zone delineation, which represents a spatial representation of uncertainty.

For this study, scenarios 1, 2 and 3m sea level rise were used. Figure 5.1 shows how the three sea level rise scenarios is mapped onto the land surface using the SRTM elevation model with vertical accuracy of +/- 6.13 metres at 95% confidence level. Putting the vertical accuracy into consideration, the uncertainty range for each of the scenarios will be very high. For example, in a 1 metre SLR scenario, the additional area that will be included in the delineation is as high as 7.13 metres indicating that a 1-metre SLR may actually fall within this range given the statistical uncertainty of the original elevation measurement. However, for this study, it is impossible to account for the uncertainty in the inundation analysis because the SRTM elevation data is quantised to 1m intervals. This ensures that sub-metre increments are not possible within this assessment. Mapping of sub-metre increments of sea level rise is highly questionable if the elevation data used have a vertical accuracy of a metre or more at the 95% confidence level (Gesch, 2009). Considering the range of impacted area for the SLR scenarios, it is clear that SRTM elevation data is poorly suited for detailed inundation mapping. Hence, there is the need of high-resolution elevation data with high vertical accuracy.
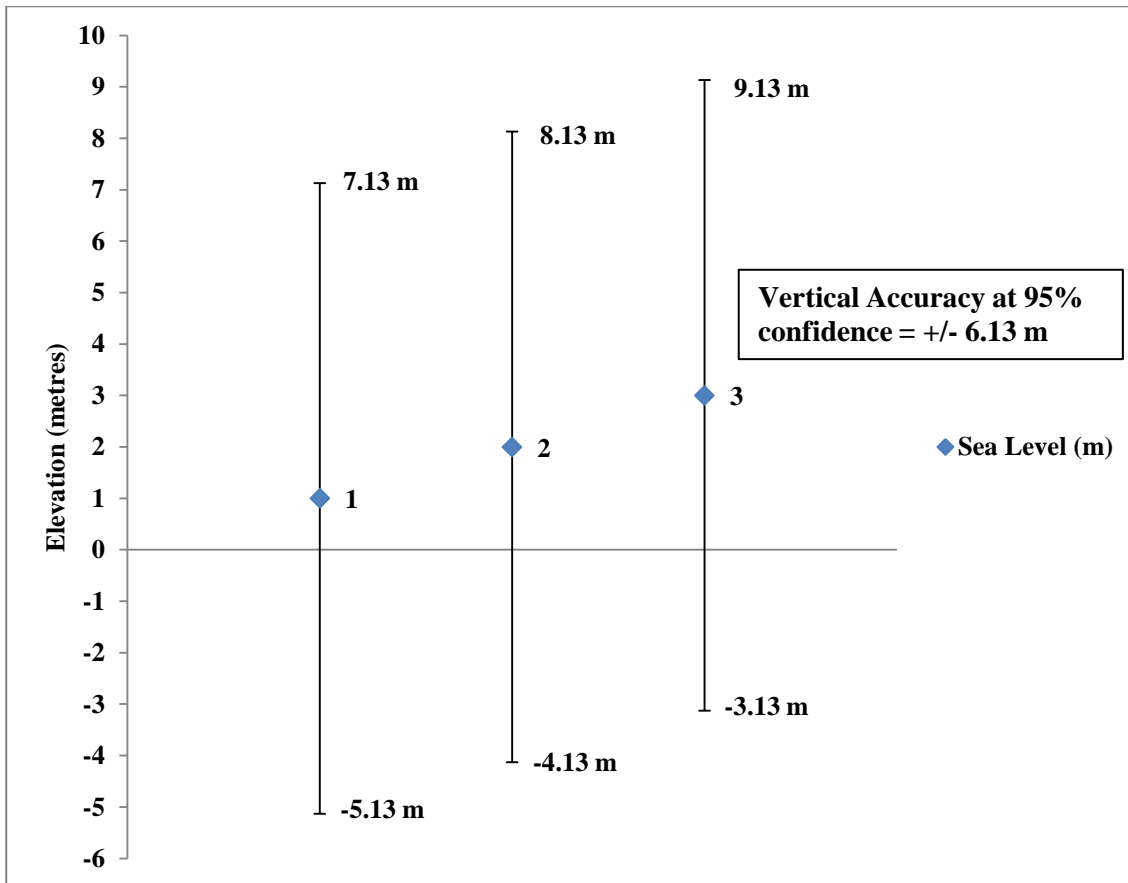
Figure 5.1: Sea level rise scenarios mapped onto land surface using SRTM elevation model.

5.5 Summary of results

This is a comparative analysis between the four coasts to evaluate the extent of impacts to inundation. Overall, the Barrier coast will experience the largest percentage of impacts from SLR. The Delta coast will suffer the highest amount of land loss, as it will account for approximately 56% of the total inundation in the study area. Inundation that will occur in the Barrier coast will be more than a third (34%) of the inundation for the whole study area in a 1 m SLR. In an assessment to find the proportion of land loss in the Barrier and Delta coasts to the study area in a 2 m and 3 m SLR, the Barrier coast will account for about 30% and 25% respectively while the Delta coast will account for approximately 59% and 63% respectively. There will be a significant increase in land area affected by inundation as sea level rises on the Delta coast, whereas for the Barrier coast the proportion is less. The Mud coast will lose more land with each increase in sea

level rise in relation to the total inundation that will occur in the study area. For the Strand coast, the proportion of land that will be lost will be within the same range (2.5%) as sea level rises in proportion to the total area of land that will be lost in the study area. For example, the Delta coast will lose approximately 502 sq. km (1.7%) of land if SLR increases from 1 m to 2 m and 1,479 sq. km (5%) in an increase of 1 m to 3 m. Even though the land area that will be lost as sea level rises will be greater in the Delta and Mud coasts, the Barrier coast will still suffer more impacts relative to its total land area.

The amount of coastal populace that will be displaced will be enormous across the coast. The Barrier coast will be more severely affected because the coastal population in the coast is denser (i.e. about 1514 people per sq.km) than the other coasts even though the population in the Delta coast (282 people per sq. km) is more.

The impact on GDP in the Mud coast will be more severe in terms of percentage. Both Barrier and Delta coasts generate more GDP than the Mud coast as it accounts for only US$33 million in comparison to Barrier coast accounting for US$224 million and the Delta coast accounting for US$325 million that will be lost in a 1 m SLR. GDP that will be affected because of inundation was observed to be low compared to all other elements. GDP is a measure of the overall earnings of a country or a region or the overall amount spent expressed in US Dollars. Loss of GDP will definitely have a large impact on everyone within the economy which could bring about high unemployment, decrease in wage, lower profits for companies and lower stock prices (Investopedia, 2011). The Delta coast will lose more GDP followed by the Barrier coast. The Mud and Strand coast will lose a considerable amount of GDP but not significant compared to the loss that will be experienced by both Barrier and Delta coast because they do not generate large GDP in themselves.

The urban extent is another element in which the Barrier coast will not suffer the highest impact. Urban area impact is larger in the Delta coast for all SLR scenarios. There is no urban area in the Mud coast. However, urban area extent in the Barrier coast (1070 sq. km) is about five times that of the Delta coast (229 sq. km). More urban lands will be inundated in the Barrier coast more than any other coast. Comparing the indicators on the national level, urban area will be the most impacted as up to 49% and 64% could be inundated in a 1 m and 3 m SLR for the whole study area. Severe impacts are expected also within the agricultural elements, as about 15% of agricultural lands will be inundated in a 1 m SLR. More impacts will occur in the Barrier coast but the Delta coast will lose more agricultural land. For example in a 1 m SLR, agricultural land that will be lost in the Delta coast will be about 2,458 sq. km whereas the Barrier coast will lose approximately 1,202 sq.km.

Wetlands will suffer inundation, as up to third will be lost in a 1 m sea level rise. Delta coast will lose more wetlands (6,620 sq. km) but the impacts will be more severe in the Barrier coast.

Table 5.6 shows the extent of impact that due to inundation by each coast and the study area. It is a comparison of the significance of sea level rise on the different coasts. Figure 5.2 and 5.3 established the impacts for each critical element considered for 1 m and 3 m SLR scenarios respectively for the four coasts and for the whole study area.

Conclusive remark
For all the results presented in this chapter, uncertainties exist within each result, which is very significant. As discussed in section 5.4 the uncertainty surrounding the elevation model used in this research is +/- 6.13 metres, which will increase the amount of

vulnerability of the critical element considered. Therefore, further studies need elevation data with high vertical accuracies.

Table 5.6   Summary of Impacts of sea level rise on the Nigerian coast

	Study Area	Barrier	Mud	Delta	Strand
Indicators	**1 m SLR**				
Land	7.2	22.9	6.0	5.4	2.9
Population	7.0	13.9	2.3	6.1	0.6
GDP	1.8	2.5	3.3	1.6	0.4
Urban Extent	48.9	51.3	0.0	62.9	4.9
Agricultural Area	15.1	49.4	20.1	11.7	8.0
Wetland Extent	33.7	69	22.6	31.1	19.9
	3 m SLR				
Land	12.3	28.7	13.9	10.4	4.9
Population	12.7	23.7	9.0	9.3	2.7
GDP	3.2	3.1	8.7	3.2	0.7
Urban Extent	62.4	63.7	0.0	68.1	34.3
Agricultural Area	26.3	65.4	37.2	25.8	21.2
Wetland Extent	50	81.6	28.5	47.5	52.3
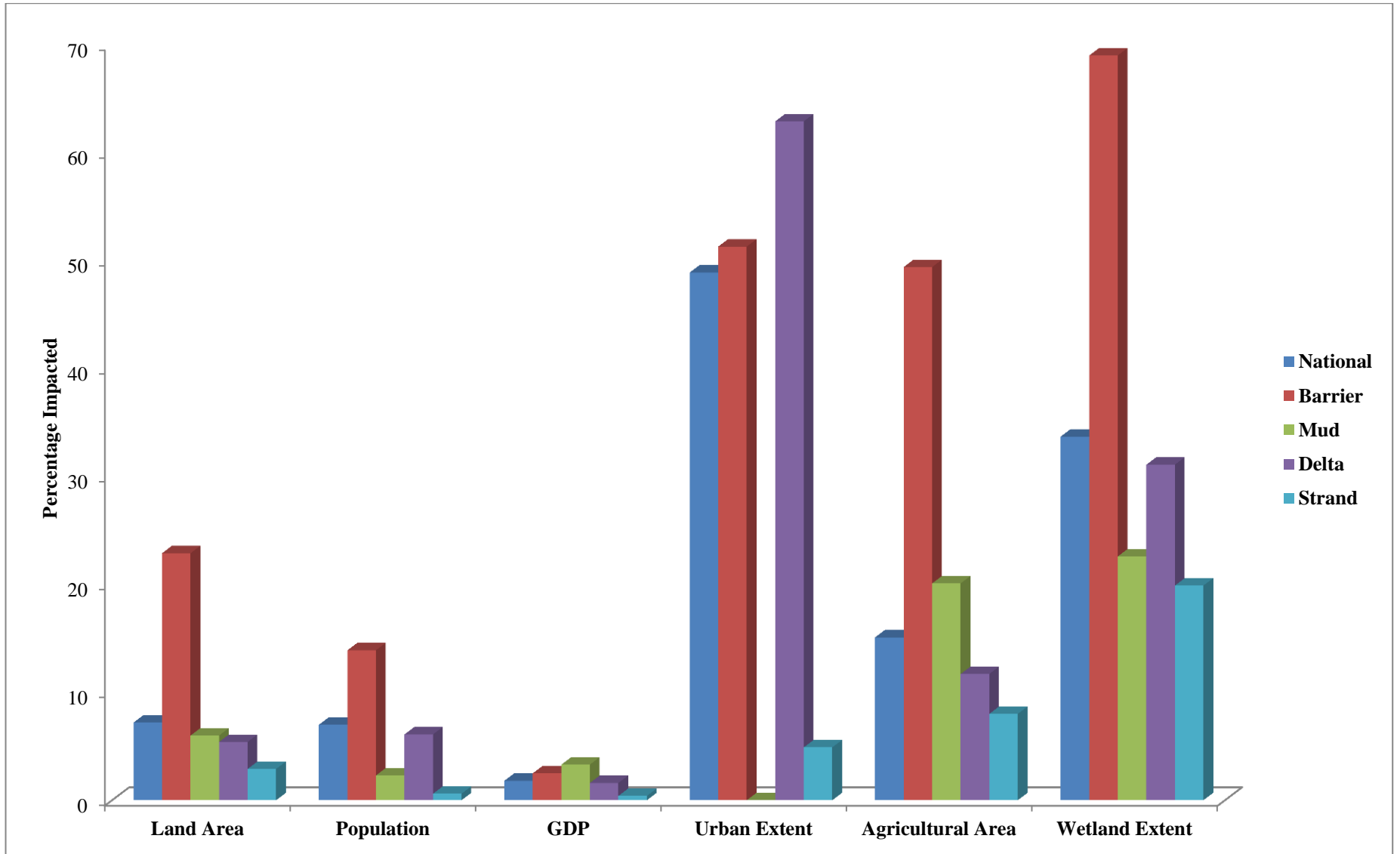
Figure 5.2: The extent of impact for each critical element in a one metre sea level rise for the Nigerian coast
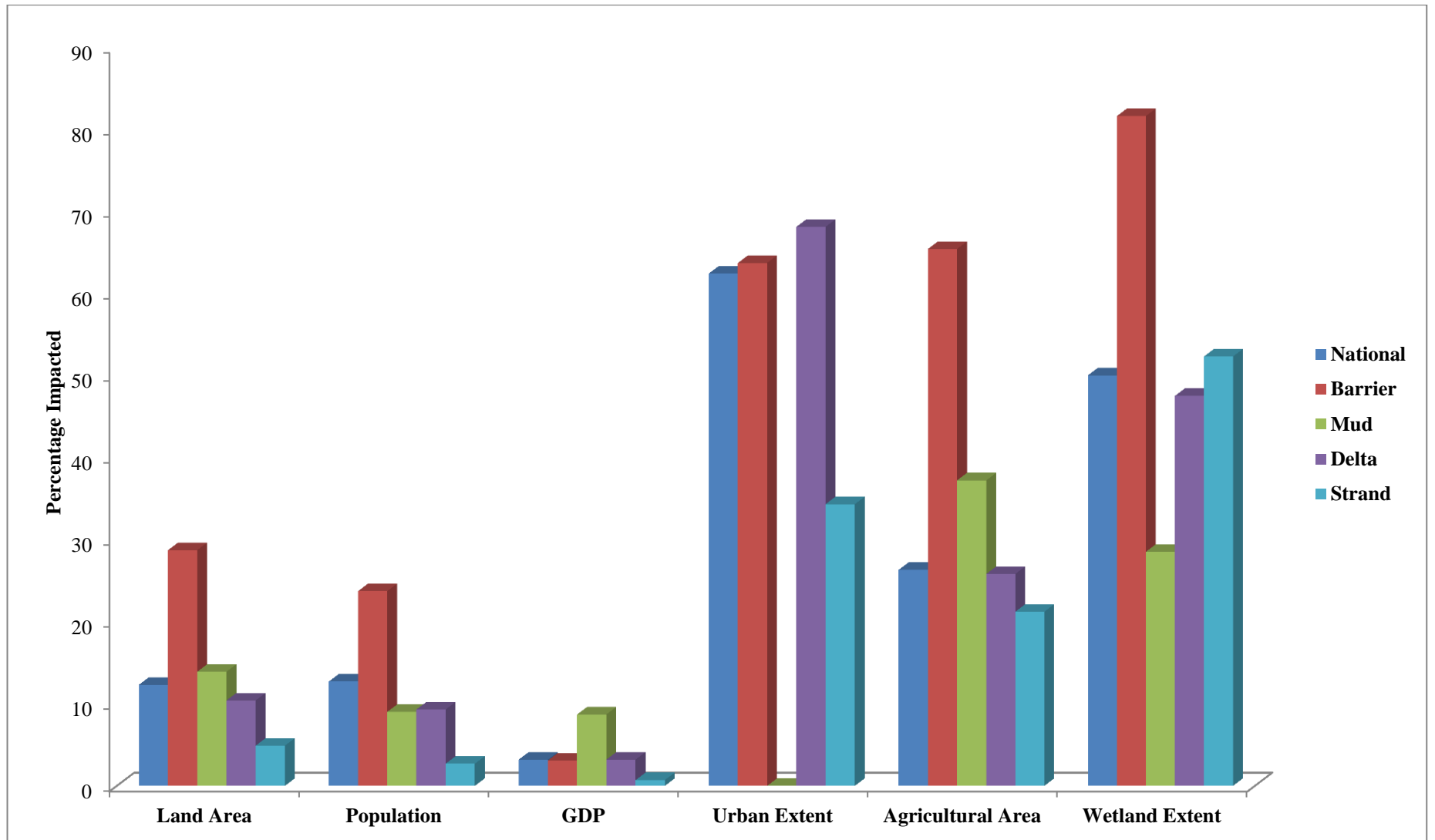
Figure 5.3: The extent of impact for each critical element in a three-metre sea level rise for the Nigerian coast

CHAPTER SIX

6.0   Sustainability Assessment of Coastal Management Initiatives

6.1   Introduction

This Chapter presents the results and analysis of the sustainability assessments carried out with the aid of the Coastal Sustainability Standard (CoSS) model with four case studies. The case studies selected for this research are organisations, which work in the coastal environment. These organisations (coastal partnerships) have a voluntary or statutory role. The selection process for these is described in Section 3.5.1. This Chapter evaluates the performance of the CPs towards a sustainable coast using the key principles identified in Gallagher's (2006) CoSS. The principles are:

- Planning

- Participation

- Communication

- Integration

- Responsibility

- Balance

The CoSS consists of the principles, criteria and performance indicators (PIs). The PIs are in the form of a guidance note, which serve as an aid to the scoring for each criterion for the sustainability principles. In order to evaluate the performance of Coastal Partnerships (CPs), the research involved interviewing their officers. Their responses to these questions, including direct quotes and comments, and evidence such as relevant documentation of the partnership and publications form the basis of the appraisal. Each principle was specifically analysed for each case study and a concluding assessment undertaken to bring the data together. Section 6.4 compares and contrasts the analytical assessment of the four case studies.

6.2　　　　Case Studies

6.2.1　　　　Pro-Natura International (PNIN)

6.2.1.1　　　　Overview

Pro-Natural International (PNI) started in Brazil in 1985. The basis of its operation is a non-statutory principle of voluntary coordination aimed at tackling the social, economic and environmental problems that face rural communities in the developing world. It operates through voluntary and coordinated participatory processes by facilitating the involvement of local people in development. PNI advocates that the participatory process is the only viable vehicle for sustainable development, conflict resolution and economic improvement for poor and marginalised communities. There are four key areas in which PNI works which are: the poverty amelioration, agriculture, biodiversity management, and climate change (PNI, 2009).

Pro-Natural International Nigeria (PNIN) is an offshoot of PNI. PNIN drives home the vision of PNI in Nigeria. It advocates top-down support for bottom-up development and puts effort into identifing practical ways in which people can be empowered to steer their own development in the coastal environment (PNIN, 2011a). The mission of PNIN is to reduce poverty by increasing institutional capacities for sustainable development in the coastal zones. Intrinsic to the aim of the PNIN is to manage the coast and ensure a participatory and holistic process is in place to guide decisions. The objectives for achieving this are:

1. To promote community-led development: through a holistic participatory development planning;

2. To establish community development foundations (CDF) to act as support to holistic development planning;

3. To develop and establish the Institute for Sustainable Development (ISD) for research purposes by supporting individual and institutional capacity for participatory community development, good governance and creating partnerships; and

4. To create partnerships for the enhancement of **i**mproved linkages between the communities, government, civil society and the private sector (PNIN, 2011a).

A major project of PNIN is institutional development and capacity building in Akassa, through the CDF Coastal Development Model Initiative, which empowers communities to take control of their own development. Akassa is a remote sand-barrier island community located on the Atlantic coast. As a result of its success in achieving development objectives, this research found out that it has been replicated in other coastal towns along the Nigeria coast which include Eastern Obolo, Opobo-Nkoro, Oron, Esit Eket, Eket, Kolo Creek and Egi (PNIN, 2011b).

The CDF initiative started in Akassa in May 2004 as the Coastal Development Initiative (PNIN, 2005) and it is referred to as the Akassa Development Foundation (ADF). The ADF model is being facilitated by PNIN to increase local participation in decision making, strengthening institutional capacities and building skills in coastal management, reducing conflict, demonstrating how principles of good governance are applied, and improving links between communities and the local government (PNIN, 2008b) for the purpose of providing an efficient coast.

The task of PNIN is to facilitate an agreed development plan by the CDF by assisting the management committees to ensure the implementation of the projects and to ensure that accurate documentation in the form of records and reports of all expenditure are

available and will be communicated to the wider community and project donors (PNIN, 2005). The 'Living University', which is a centre of learning, stems from the CDF. Through this community members teach each other what they have learnt with regards to various issues and how best to manage the coast. This involves participants working in a fully integrated, community led development programme, which supports coastal management. Participants are inspired to replicate the success of the CDF in their own communities spreading an effective working model based on the principle of community participation (PNIN, 2005).

Many organisations actively support the CDFs of the PNIN. They include: Statoil Hydro; Elf Petroleum Nigeria Limited; Frontier Oil/Gulf of Guinea Energy; Nexen; The British Foreign and Commonwealth Office in Nigeria; Voluntary Service Overseas; the Embassy of France in Nigeria; and the World Bank (PNIN, 2005).

In conclusion, PNIN contributes significantly to the development of the coastal area of Nigeria. Though the term 'integrated coastal zone management', is not a common or popular term in Nigeria, a number of the management activities of PNIN, indicate an integrated form of coastal management. Proper planning, which is the hallmark of PNIN, ensures that retrofitting of projects is not the norm while integrated management is. This they do with the involvement of all the necessary stakeholders, and by communicating the appropriate information to the stakeholders through meetings, a community forum and informally. Planning for activities is undertaken in an iterative way, which generally leads to the implementation of agreed projects that benefit all participants involved (PNIN, 2011a), (Personal Communication, 2008b)

6.2.2   Niger Delta Wetland Centre (NDWC)

6.2.2.1   Overview

The NDWC is dedicated to the study, conservation and management of the natural resources of the Niger Delta and the coast (NDWC, 2007). NDWC uses participatory approaches to involve local people in evaluating their resources and in planning for their use and management in ways that focus on sustainability. The vision of NDWC is to implement goal-directed projects for community-driven development actions to improve the quality of life and alleviate poverty in the Niger Delta and a balanced coast. The objectives to achieve this goal include:

1. To research into sustainable coastal resource use and habitat biodiversity;

2. To undertake conservation and resource management by conducting EIAs and embarking on integrated management planning;

3. To alleviate poverty through participatory rural appraisals, community development projects, feasibility studies, environmental education, awareness building, functional literacy and skills acquisition training; and

4. To enable institutional development (capacity building) by consulting and recruiting management and field staff, project-specific consultants and resource persons. (NDWC, 2007)

NDWC have their main office in Yenogoa, Bayelsa State which is the NDWC Development Complex. The main objective of NDWC's Development Complex is to promote development of the human and natural resources of the Niger Delta through participatory development and training. Feasibility studies were carried out by the experts at NDWC in conjunction with Nigeria Liquefied Natural Gas (NLNG) on areas within and outside Bonny Island where social and natural resources' conditions were considered.

Using, remote sensing imagery, this showed that the forest and waterway resouces of the entire Niger Delta were under threat of irrecoverable damage. Based on the critical need for protecting the integrity of the coastal beaches and forests, recommendations were made that the site at Bonny Island be developed as a Nature Park (NDWC, 2008).

6.2.3   Niger Delta Development Commission (NDDC)

6.2.3.1   Overview

The Federal Government (FG) established the NDDC as a FG agency in year 2000 with the mission of developing the Niger Delta Region (NDDC, 2007). There has been a high level of neglect of the NDR making the region highly underdeveloped, coupled with an alarming rate of poverty and pollution of farms, water bodies, and the whole environment (NDDC, 2007). This has made the NDR a very volatile area and an area of conflict, as the locals demand an immediate intervention in their lives and environment. There are confrontations with the state governments and oil companies as well as with other communities by the locals. The violent acts have resulted in loss of lives and property. Oil production has been constrained as disaffected youths or organisations deliberately disrupt oil operations in attempts to effect change. These disruptions have been extremely costly to the Nigerian oil industry. The FG established NDDC to attend to the demands of the Delta's restive population and to allow for uninterrupted extraction operations,

6.2.3.2   NDDC Mandate

The mission of NDDC involves facilitating "the rapid, even and sustainable development of the Niger Delta into a region that is economically prosperous, socially stable, ecologically regenerative and politically peaceful" (NDDC, 2007). The vision is to offer a lasting solution to the socio-economic difficulties of the Niger Delta. The objectives of the NDDC is as follows:

- To formulate policies and guidelines for the development of the NDR;

- To conceive, plan and implement in accordance with set rules and regulations for the sustainable development of the NDR

- To survey the NDR in order to ascertain measures, which are necessary to promote its physical and social economic development;

- To prepare master plans and schemes designed to promote the physical development of the NDR and the estimates of the costs of implementing such master plans and schemes;

- To tackle ecological and environmental problems that arise from the exploration of oil mineral in the NDR and advise the FG and the member states on the prevention and control of oil spillages, gas flaring and environmental pollution;

- To Liaise with the various oil mineral and gas prospecting and producing companies on all matters of pollution, prevention and control;

- To execute and perform other functions, which are required for the sustainable development of the Niger Delta region and its people.

Source: (NDDC, 2007)

NDDC employed relevant projects to realise its mandate; they are conceptualized, designed, and executed based on extensive consultation with locals, input from interested parties and critical analysis by experts with the sole purpose on its ability to give maximum impact to the local region. Some of their recent achievements include the demography and baseline study and the Niger Delta Regional Development Master Plan. The demographic and baseline study have two-fold objectives. These are:

- collecting baseline socio-economic and demographic data;

- and interpreting datasets to give to give a picture of demographic trends and factors integral to the regional development plan (NDDC, 2005).

The NDDC Master Plan is based on a comprehensive analysis of life, development imperatives, challenges and opportunities in the NDR (NDDC, 2006). Within the NDDC, there is no acronym known as ICZM but it is implicit as the environmental management section of the Commission undertakes the activities of managing the coast (NDDC, 2006). The aim of the Master Plan is to achieve an economic vitality, ecological integrity and social equity in the region (NDDC, 2006). This is in line with the purpose of sustainable development. Other indices that have been enshrined in the purpose of the master plan include community involvement and responsibility, cultural vitality, strong and effective community-based institutions, democratic decision-making processes and consensus-building and adaptive management (NDDC, 2006).

6.2.4   Flood Erosion and Coastal Zone Management, State Ministry of Environment, Rivers State (FECOZM)

6.2.4.1:   Overview

FECOZM unlike PNIN and NDWC is a government establishment with a clear legal basis. It is an arm of the State Ministry of Environment in Rivers State. A Commissioner heads the State Ministry of Environment while the head of FECOZM is the Executive Director who reports to the Commissioner. The goal of FECOZM is to minimize coastal erosion and other forms of coastal degradation. The objectives include:

- The appropriate and effective use of control measures in affected areas;

- To ensure EIA/technical audits are carried out before any form of construction;

- To ensure good monitoring and controlling activities;

- To ensure safe and sustainable ways of handling runoff;

- To encourage appropriate indigenous marginal land practices; and

- To promote awareness of the danger of misuse of coastal zone.

In meeting these objectives, routine inspections are in operation in the coastal environment of Rivers State. Sand filling and re-vegetation are activities carried out if required. FECOZM believes the task of managing the coast is multi-disciplinary in nature and therefore liaises with other ministries such as the Ministry of Works, the Ministry of Agriculture and the Forestry Department (Federal Ministry of Environment, 2005a). FECOZM employs experts and resource persons in the field of coastal management for effective management (Personal Communication, 2008c). The overall goal of the Ministry of Environment forms the basis of the activities of FECOZM. The goal is to protect the environment from degradation, loss of productive land and negative impacts of flood and the objectives for achieving the aim include

- Maintenance of the integrity of the coastline through appropriate effective control measures; and

- Implementation of ICZM

These are broad objectives but the ministry exists such that different arms are made available to ensure a well-balanced coastal environment. The arms include the coastal zone management department, flood control and water conservation, watershed management, the Erosion and Flood Control-Management Support System and the Monitoring and Evaluation Department. In Rivers State all these department are under the FECOZM (Federal Ministry of Environment, 2005b).

6.3   Sustainability Principles and Assessment
This section makes a critical analysis of the four case studies to assess their performance against the sustainability principles and criteria used in this research. For each of the principles the scoring criteria is as follows: A score of 0-2 means failure and requirement for corrective action, 3 is the threshold for constructive management, 4-6

means evidence of some constructive management in operation, a score of 7 is the standard achievement mark, and 8-10 represents evidence of exceptional and well-developed management technique.

6.3.1 Planning

The planning criteria are in Table 6.1. Figure 6.1 shows the planning criteria performance score obtained from the case studies based on detailed interviews and reviews of published documents.

Results indicate that PNIN performs better than the other case studies. Despite scoring higher, it did not meet the standard achievement mark. According to the coastal sustainability standard, the performance score for each criteria and the whole principle must achieve the mark of 7 for it to pass the assessment. This could not be achieved in any of the case studies.

Two striking criteria within the planning principle are criteria 1 and 2 which relate to the management areas being clearly and spatially defined in relation to natural processes and cultural contexts. None of the case studies could achieve the standard achievement mark for the two criteria. For the CPs to achieve evidence of exceptional and well-developed management technique mark, the spatial area has to be clearly defined and there must be maps for the management area. With regards to management systems consistent with nature and scale of the coastal area, there must be maps clearly defined with respect to all natural processes which include ecosystems and habitats, fish feeding and nursery grounds, bird nesting and roosting areas, catchment areas, sediment dynamics and coastal processes.

Table 6.1:   Planning Criteria

Number	Criterion
1	Map for the management area showing explicit references to natural processes
2	Map for the management area showing explicit references to cultural aspects
3	Management structure showing responsibilities of individuals and organizations
4	Management operates on the basis of a clear and detailed understanding of the area and with reference to appropriate baselines
5	The management system takes a farsighted view
6	The management system contains short-term and long-term objectives
7	Objectives are focused on the most significant issues facing coastal sustainability
8	Operational procedures and methodology to meet objectives
9	Procedures are in place for measuring performance relative to objective
10	The management plan is clearly linked to a system of feedback and iterative reflection on past actions and consequences
11	The management process is adaptive
12	The management system is effectively audited on a regular and periodic basis
13	The management system has a commitment to continually improve in the light of sustainability
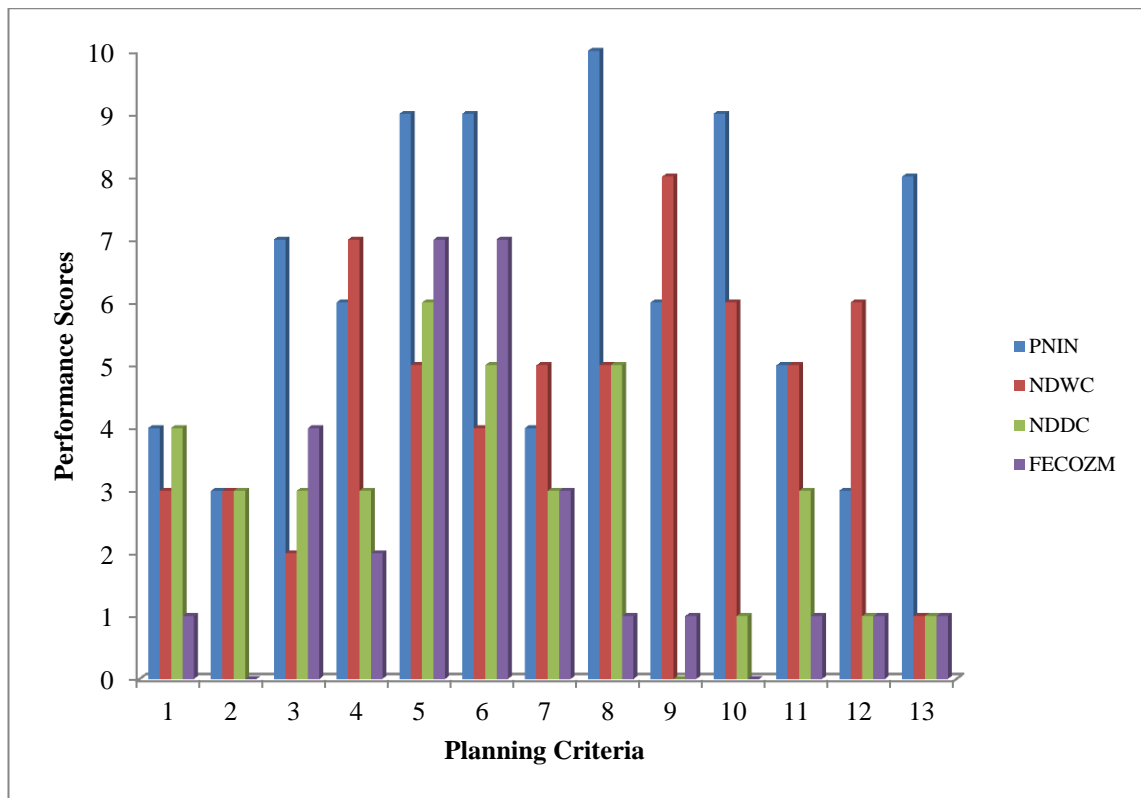
Figure 6.1: Planning criteria performance scores

Also, the map must show the linkage between the land and the sea. With regards management systems consistent with cultural context, the maps must include political areas, coastal settlements and other specific communities, it must show cultural heritages, ports, archaeological sites and other cultural heritages (Gallagher, 2006). In the case studies, the spatial area is not clearly defined and they are not fully relevant to all natural processes and cultural context. It is evident from, the interview conducted and also from their website, that the CPs have not considered to a great extent the need to have these types of maps. It was noted that generally maps were produced on demand. Indeed FECOZM do not have maps essesntial for monitoring coastal activities and processes. The maps available in some CPs are old, not updated and not geographically referenced. They conduct inspections on the ground and without reference to appropriate maps.

Another striking criterion relates to operational procedures and methodology being clearly stated and appropriate to meet objectives. In this criterion, PNIN was able to achieve 'evidence of an exceptional and well-developed management technique'. This is because the procedures, methodology and the responsibility for action are clearly and explicitly stated with regard to each of its stated objectives. Evidence of this is in PNIN's annual report. For the other case studies, this is not the situation. In relation to this criterion are two criteria. The first relates to procedures (monitoring, coordination and evaluation) being in place for measuring performance relative to objectives while the second is "the management plan is clearly linked to a system of feedback and iterative reflection on past actions and consequences". These two criteria are important in the planning process, as this will give the opportunity to be able to reflect on past actions in accordance with defined goals to bring about a progressive change.

With regards the first, the rationality of assessment is based on the availability of procedures, which must be clearly stated (in either the management plan or annual reports) for the methodologies by which performance in each objective can be assessed. In the course of the interview, questions were posed on: the efficacy of the procedures, the clarity of their statement and the detail and value of the information gathered to aid assessment. Apart from PNIN and NDWC, which show some evidence of constructive management, the other two CPs are in need for corrective action.

The second is concerned with the overall operation of the management system. It seeks to identify the ability of the planning system to consider past performance and to be reflective. In the course of the interview, this research seeks to know if and how reflection has been clearly and transparently linked into the management plan and if it occurs on a regular and periodic basis. Just like the previous criterion, only PNIN and

NDWC performed well. Indeed, there was evidence of exceptional and well-developed management technique in the two CPs as the reflective nature of the management system is evidenced in their practices. These include feedback being linked to the management plan and objectives through meetings and annual reports, was made available during the course of the interview. FECOZM have no system of feedback and iterative reflection on past actions and consequence while a little exists at NDDC.

FECOZM performed worst out of the four CPs. It has an average score of 2.0 under the principle of planning which shows that there is need for an immediate corrective action within the management system. However, the standard achievement mark was attainable by FECOZM in one criterion. The management system contains explicitly stated short term and long term aims, which is an indication that it takes a farsighted view.

Despite failing the standard, PNIN performed better than the other CPs under the principle. Some of the reasons as obtained from the interview why PNIN performed better is that PNIN has been able to take farsighted views and identify objectives in a systematic way in relation to their significance. PNIN has also been able to set up operational procedures and methodologies to meet the objectives, have a very good system of feedback and review, which has enabled them to consider past performance and be reflective on a regular basis. In addition, there is a great commitment to improve performance on a continual basis. NDWC shares some belief system with PNIN. The difference is that PNIN has developed over many years of experience and has shifted much more than NDWC from the government and oil company practice of community development and coastal management, in which a 'quick fix' solution is the norm, yet offers no real solution to the coastal areas. PNIN has also developed a process of

institutional development and capacity building that is integral to the sustainable development of their management area.

6.3.2   Participation

The participation criteria are in Table 6.2. Figure 6.2 shows the participation criteria performance score obtained from the case studies based on detailed interviews and reviews of published documents.

Table 6.2   Participation Criteria

Number	Criterion
1	An appropriate range and diversity of stakeholders participate actively in the management process
2	Stakeholders understand their role and responsibility within the management process
3	The system of planning and decision-making is transparent
4	There is a participatory process of conflict resolution
5	Good working relationships between the statutory empowered regulators and other stakeholder groups
6	There is an active system of stakeholder review and feedback
7	Decision-makers are accountable for their actions

Results from the assessment conducted show that PNIN performed better than all the other CPs within the principle of participation. Indeed, on average there is evidence of constructive management in operation as it was able to score above the standard achievement mark. NDWC shows elements of some constructive management in the system (with an average score of 5.4). However, for NDDC and FECOZM, there was failure and so the need for corrective action.

Noteworthy among the criteria representing the principle of participation is the criterion that deals with the active participation of an appropriate range and diversity of stakeholders in the management process in which both PNIN and NDWC performed exceptionally well.
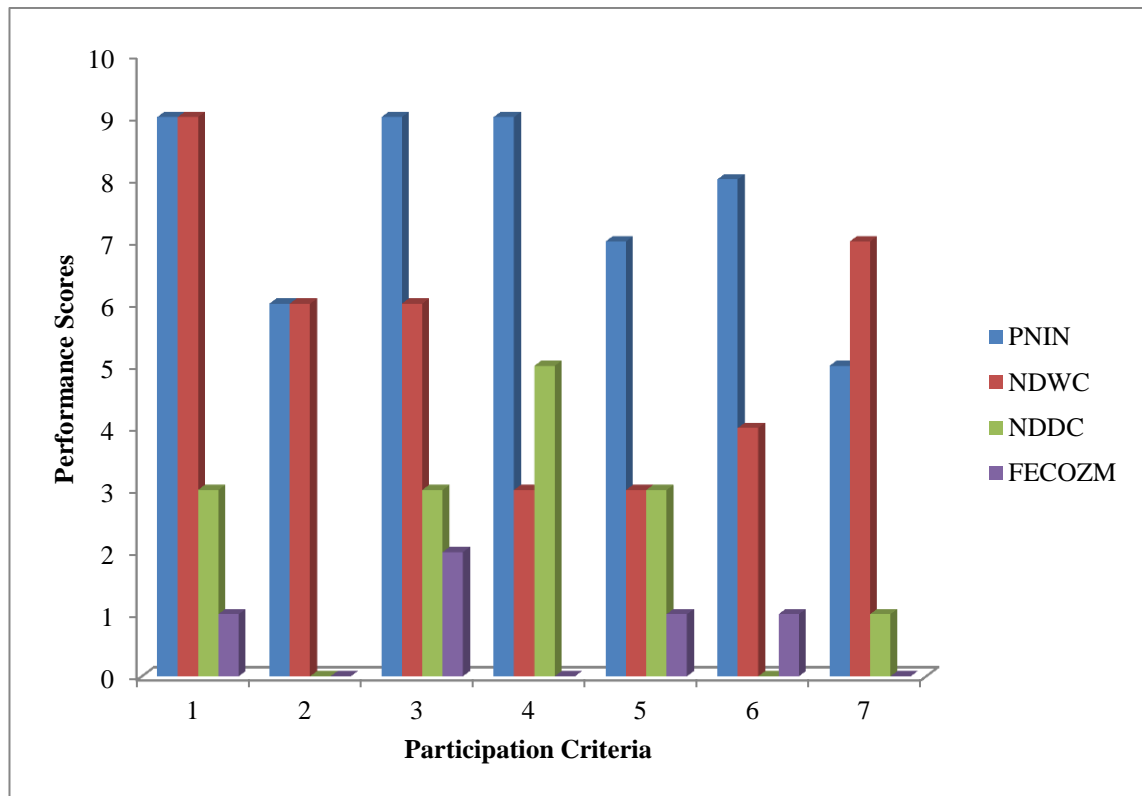
Figure 6.2: **Participation criteria performance scores**

In assessing this criterion, there should be the participation of key stakeholders (i.e. organisations that have a statutory responsibility that affect the management area or represent a principal user of the area) and the general public. The criterion also tries to assess the level at which these individuals, representatives and organisations participate in the process. The indicators of this include active contribution through dialogues and negotiations, making suggestions, provision of monitoring information or data, stakeholders leading on particular actions and contribution of particular logistical resources. In NDDC, only a few of the stakeholders are represented in the management process. The Partners for Sustainable Development (PSD) is a forum set up by NDDC

for bringing other stakeholders to collaborate, harmonise and pursue the development of the NDR. The researcher's assessment is that the level of success of the PSD is low in comparison to the purpose for which it was created.

Another criterion that is important within the principle of participation deals with the transparency of the planning and decision-making system of the CPs. This actually relates to a clear of statement evidence that shows all stakeholders understand planning and decision-making within the management system. The assessment was based on clear statements in the form of specific comment being made in either meetings, through specific communication tools such as the website, newsletter, or annual reviews, and the importance to the management system on this criterion in terms of awareness and its consideration. In PNIN, there is a high level of transparency of the planning and decision-making process and they are easily understandable to almost all the stakeholders. With NDWC, only the key stakeholders understand the planning and decision-making process. There have been some attempts at enabling transparency to the key stakeholders within the NDDC management system whereas in FECOZM, this is done on an ad-hoc basis and has not been an effective practice.

This research tried to ascertain the extent of an active system of stakeholder review and feedback. Only PNIN achieves the standard in this criterion. Indeed, there are evidences of exceptional and well-developed management techniques in PNIN, which indicates that there is an active system of stakeholder review and feedback. Apart from NDWC that was able to show some evidence of constructive management, other CPs performed very poorly.

The criterion that deals with the participatory process of conflict resolution is also worthy of mentioning. This criterion is in full operation in PNIN which established a participatory development forum by which conflict is resolved in Akassa (the model project area). The mechanism has been tested and is appropriate for conflict resolution (PNIN, 2005). Evidence gathered during the interview indicates that the mechanisms have been replicated in other project areas. Among the objectives of the NDDC is to develop a programme to foster empathy and understanding to reduce conflicts in the NDR. A set of procedures have been developed towards achieving this. Committees for peace and security have been put in place; likewise, there is the involvement of partners for a sustainable network. However, there has not been a sustained success despite the attempts. Accountability by the decision-makers is an important issue in ICZM. It involves transparent attempts that have been made by decision-makers to detail, explain and justify management outcomes. The assessment conducted shows that only NDWC achieve the standard achievement mark in this criterion.

Overall, PNIN performed best with an average score of 7.6. This is because PNIN is involved in facilitating trusted and transparent community foundations. PNIN has been able to involve all stakeholders in the management process. They help communities to lead their own development process by building institutions, capacity, trust and confidence within the community. NDWC has an average score of 5.4. NDDC score 2.1 while FECOZM score 0.7. Obviously, there is evidence of exceptional constructive management going on at PNIN with some evidence of constructive management in operation at NDWC. Both NDDC and FECOZM are in need for corrective actions to improve the management systems in terms of coastal sustainability.

6.3.3　Communication

The communication criteria are in Table 6.3. Figure 6.3 shows the communication criteria performance score obtained from the case studies based on detailed interviews and reviews of published documents.

Table 6.3　　Communication Criteria

Number	Criterion
1	Stakeholders and the community at large have easy access and opportunity to relevant coastal information and education
2	Information presented through the dissemination system is easily understood and interpreted correctly by different cultural (occupation, advocacy etc.) groups
3	The general public are fully aware of the management process and understand its relevance
4	A comprehensive range of stakeholders are fully aware of issues pertaining to coastal sustainability
5	Indicators or integrated surrogate variables are used for presenting and interpreting information on environmental quality to a comprehensive range of stakeholders
6	An outreach system of coastal sustainability education operates effectively
7	Communication is seen and operated as a two-way process
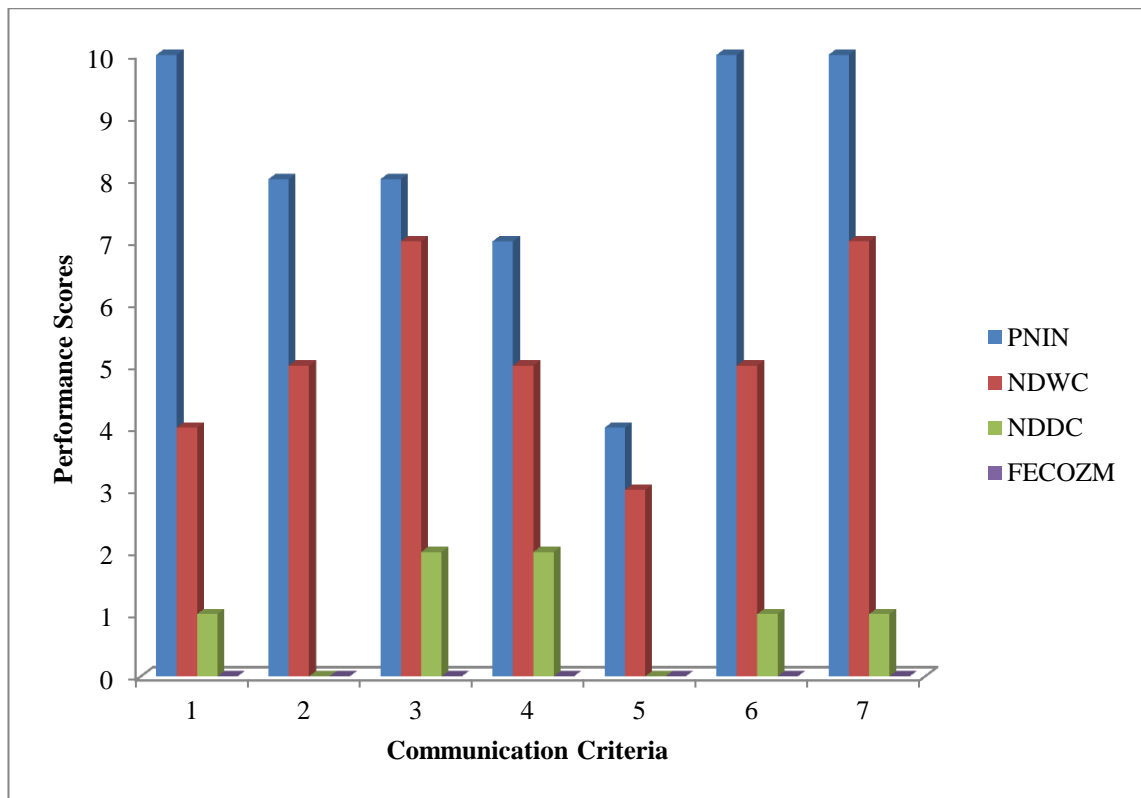
Figure 6.3: **Communication criteria performance scores**

Communication as a principle seeks to impart coastal information to the stakeholders by improving understanding, behaviour, attitudes and practices to achieve coastal sustainability. From the interviews and assessments made on the CPs, this research was able to obtain varying results. PNIN score very high in all the criteria except for the criteria that relates to the use of sustainability indicators in disseminating information. Despite the fact many indicators of sustainability are already in use in PNIN, there exist no formal or detailed suite of indicators. Criterion 1 relates to access to relevant coastal information and education by the stakeholders and the community at large. PNIN show evidence of exceptional constructive management in this criteria. Within PNIN, there exists a formal system of dissemination using both low and hi technology methods which address all stakeholders. The formal system is also functioning effectively. The low technology information dissemination mechanism that is in use in PNIN include posters and leaflets. Also, the community members are being educated through the

Institute of Sustainable Development and the "iving university". The high tech dissemination method employed in PNIN include the website which contains thorough and comprehensive reports of meetings and other information. For NDWC, there is the dissemination of information, although this is done on an ad-hoc basis through newsletters and giving of talks to schools and university students. In NDDC and FECOZM, very little is done in disseminating coastal information. There is no use of either low or high technology means of disseminating coastal information except for adverts in the newspapers, which is only on an ad-hoc basis.

In a question to ascertain the extent by which the public are aware of the management process and the understanding of its relevance, PNIN and NDWC, have scores which indicate evidence of exceptional management technique for PNIN and attaining the standard achievement mark by NDWC. Table 6.4 shows the scoring of the four CPs under this criterion.

Criterion 6 seeks to ascertain the extent of the effectiveness of the operation of an outreach system of coastal sustainability education. Operating a formal education system requires that there are specific statements of this as part of the management goals or objectives. Methods of outreach might include newsletters, education wardens, visitor centres and different forms of interpretation such as in-situ notice boards. Ad-hoc approaches may be employed with talks to schools and colleges. Table 6.5 presents the scores and comments from the assessment made with the CPs.

This research determines if the flow of information is seen and operated as a two-way process. The criterion relates to the ethos of the CPs in terms of how it views the value of holding a two-way communication with both key stakeholders and the public at large. Both PNIN and NDWC score high, NDDC score very low, while FECOZM has no

score. Part of the philosophy of PNIN and NDWC is to disseminate information in a comprehensive way. With PNIN, there exists an effective means of receiving information from stakeholders and members of the public, which helps in responding to individual enquiries, whereas with NDWC, this process is not yet in place.

For all the criteria, FECOZM did not have any score. There is no system of information dissemination in operation. An ad-hoc system exists through another body - the National Emergency Management Agency (NEMA). No system of check and feedback is in place. Also from the stakeholders and public's view, FECOZM is not communicating any information to them about coastal management. There is lack of concern about anything the government does because they have not gained the confidence of the populace. The public are not even aware that there is a management system for ICZM at FECOZM and there is no mechanism in place to ensure they are aware of the general issues relating to coastal sustainability.

It is uncertain how coastal information is collected and if they are, there is no communication of it to the public. The department has also not embarked on educating the public on coastal sustainability either by formal education or on ad-hoc basis. No formal outreach system exists where the members of the public can be educated on coastal information. It is therefore not surprising that there is no two-way communication between FECOZM and the stakeholders as well the members of the public.

The assessment outcome for the principle of communication is that only PNIN was able to achieve the standard achievement mark.

Table 6.4:   Criterion 3 scores and comments for the Coastal Partnerships

Criterion 3: The general public are fully aware of the management process and understand its relevance			
0 - The public are not aware of the management system. 3 – The public are aware there is a management process at work but not specifically what it does, how it operates or what it tries to achieve. 7 – The public are aware there is a management process at work and what it is trying to achieve. 10 – The public fully understand the management process and what it is trying to achieve and are fully supportive of its work.	Coastal Partnerships	Comments and Evidence	Score
	PNIN	PNIN is open to the public. There has been a lot of work and activities to ensure that they are aware of the management system, its role and its relevance particularly to the overall development of the area including coastal issues. Through the facilitation team, PNIN is widely presented with good communication skills, which made events well attended. They are also very supportive to the cause of PNIN	8
	NDWC	NDWC in its activities have always involved the community and the stakeholders. Therefore, there is a degree of awareness by them. This is seen in the Finima Park, and the capacity building and youth empowerment programme	7
	NDDC	The general public are aware there is a management system process at work within the NDDC but not specifically what it does, nor how it operates but a little on what it wants to achieve	2
	FECOZM	The general public are not aware of the management system	0

Table 6.5: Criterion 6 scores and comments for the Coastal Partnerships

Criterion 6: An outreach system of coastal sustainability education operates effectively			
0 - There is no attempt to educate on matters of coastal sustainability. 3 – Management offers an informal educational input into relevant groups and organizations. 7 – Management operates a formal education input into a range of relevant groups and organizations. 10 – Management actively seeks to develop educational material, operates its own educational mechanisms and feeds formally into a range of relevant groups and organizations, and the community at large.	**Coastal Partnerships**	**Comments and Evidence**	**Score**
	PNIN	The stakeholders are educated about the community development management and coastal sustainability in a formal outreach system. This is evident in the establishment of the Institute of Sustainable Development and the 'Living University' at Akassa. Informal education also comes about through meetings with relevant organizations. The website is also a useful resource for informal education. Evidence clearly shows that there exists proactive input and a clear intention to progress	10
	NDWC	Formal training courses are being organized for staff, students, organizations and the members of the community on taxonomy and preservation of botanical specimens	5
	NDDC	There is nothing to suggest there is a formal outreach system of coastal sustainability education, but there is a plan for it in the future	1
	FECOZM	There has not been an attempt to educate the stakeholders or the general public on coastal sustainability either by formal education or on ad-hoc basis	0

Indeed, the average score of 8.1 indicates that there is evidence of exceptional management technique as regards coastal sustainability. NDWC could not attain the standard achievement mark but with a score of 5.1, there is some evidence of constructive management in operation. Both NDDC and FECOZM (with average scores of 1.0 and 0) failed the standard and so the need for corrective actions.

6.3.4 Integration

The integration criteria are in Table 6.6. Figure 6.4 shows the integration criteria performance score obtained from the case studies based on detailed interviews and reviews of published documents.

Table 6.6   Integration Criteria

Number	Criterion
1	Interactive, problem-solving techniques are employed in the analysis of relevant issues
2	The management of the coast takes into account the impact of decision-making on its exogenous boundaries
3	Vertical policy components fully accord with one another
4	Horizontal policy components fully accord with one another
5	The coastal management process shows evident moves to develop a perceived and inherent equality between relevant disciplines
6	Science directed and is playing an effective role in achieving coastal sustainability
7	Resources are focused on facilitating greater integration
8	There are continued improvements in integration
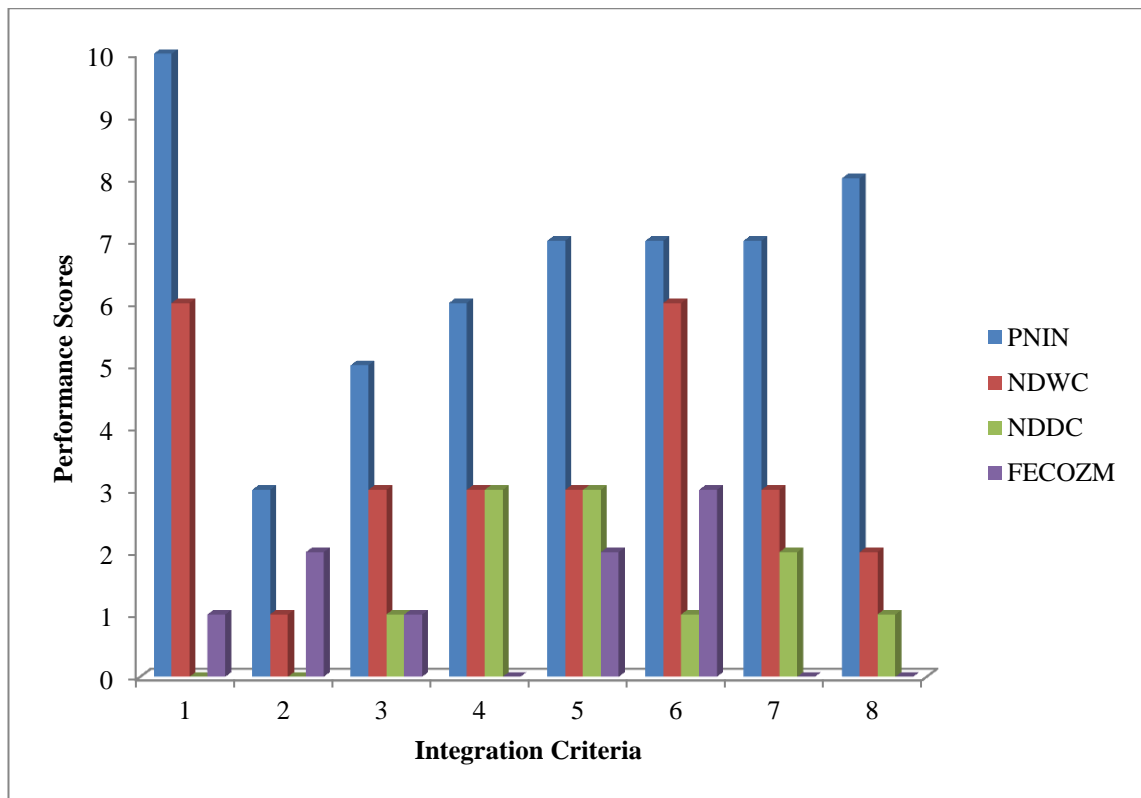
Figure 6.4:   Integration criteria performance scores

Integration as discussed in depth in section 2.5.1 is an attempt to avoid fragmentation. It is also an approach to operate a more holistic, systems-based approach to management. Eight criteria were used to assess the CPs within the principle of integration. Criterion 1 relates to the use of interactive and problem solving techniques in analyzing coastal sustainability issues. The techniques considered are those which can be in form of events that put people together with identifiable problems such as the focus groups, workshops, brainstorming events and the likes. The essence of this is to generate communication in the overall system either formally or informally as this represents ways by which problems can be solved. Table 6.7 shows the result of the assessment made on the four CPs.

Criterion 2 seeks to know if the management of the coast takes into account the impact of policies and decision-making on its boundaries. As stated in the guidance note

(Gallagher, 2006), the criterion is concerned with the relationship between the defined management area and the surrounding environs. It relates to the impact policies and decisions will have on areas outside the management system and as well as the impact other areas outside the management system in terms of policies and decisions will have on the management system. This is essential given the nature of environmental processes, there is the likelihood that clear links will exist between external decision-making and policies and the quality of the management system and vice versa (Gallagher, 2006). For all the CPs assessed, only PNIN understands the need to take into account and review the impact of policies and decisions across its spatial boundaries. However, the understanding is implicit and little evidence suggests that this is carried out. For the other CPs, they could not attain the threshold for constructive management.

In a question to find out if there is a transparent and strategic attempt to operate equality between different management units and disciplines, only PNIN was able to achieve the standard achievement mark. This is because there is evidence of sectoral understanding allowing a proactive and synergistic policy development to take place. In PNIN, different units and disciplines are considered within the management process and there are some transparent actions to synchronise their work towards meeting combined objectives. A relatively good score with PNIN is not surprising because the main aim of the ICZM initiative is to enhance sectoral integration. NDWC and NDDC attained the threshold for constructive management, while there is a need for corrective actions for FECOZM. The criterion relates to the synchronization of different sectors into achieving management objectives. The understanding of sectoral views, which enables constructive and co-operative working through consultation, workshops, meetings and focus group are essential in operating equality among disciplines.

Table 6.7:   Integration: Criterion 1 scores and comments for the Coastal Partnerships

Criterion 1: Interactive, problem-solving techniques are employed in the analysis of relevant issues			
0 - No analytical problem solving techniques have been considered or employed.	**Coastal Partnerships**	**Comments and Evidence**	**Score**
	PNIN	PNIN has been able to organize events that put people together with regard to identifiable problems. There have been workshops, brainstorming events, seminars, formal and informal education for the public, stakeholders and government agencies. This research gathered that there has been great communication, interaction and involvement between those that are relevant to the questions posed.	10
3 – Formative analytical techniques have been considered as a means of enabling problem solving.			
7 – Formative analytical techniques have been employed with regards some problem solving.	NDWC	Workshops and seminars are sometimes being organised. This brings the stakeholders and representative of the community together to discuss and to interact on the issues regarding maintaining and preserving the coastal environment	6
10 – Comprehensive analytical techniques are employed in all problem solving.	NDDC	There is no evidence to show that analytical problem solving techniques have been employed. The level of interaction between and involvement between NDDC, the stakeholders and the general public cannot be ascertained.	0
	FECOZM	It does not exist now but a need for it was been expressed	1

In assessing if resources are focussed on facilitating greater integration, the points considered as stated in Gallagher's (2006) guidance note includes the following. With the nature of ICZM, any partnership or organisation willing to achieve it will have resources focused on facilitating greater integration. The assessment of this criterion is based on assessing how resources and funding enable the core objectives to be met or how decisions are made. The recorded success in achieving greater integration is value-added to the assessment. Table 6.8 presents the findings of this criterion.

This research identified that integration is a core focus of PNIN and there is evidence of improvements in integration. PNIN has been able to bring individuals and organizations together to meet their purpose. They have been involved in a community development foundation and community-led development programmes, the Institute for Sustainable Development, conflict resolution and environmental research and protection. They have been able to incorporate all these into their project. In PNIN, there exists a close relationship with partner organisations and international agencies through formal and informal meetings where scientific ideas and funding are sought. For all the other CPs assessed, there is no constructive evidence in place towards improvements in integration.

The assessment outcome for the principle of integration shows that none of the CPs could attain the standard achievement mark. PNIN scored highest with an average score of 6.6 followed by NDWC (average score 3.4) that was able to attain the threshold of constructive management. Both NDDC and FECOZM with average scores of 1.4 and 1.1 failed the standard and so the need for corrective actions.

Table 6.8: Integration: Criterion 7 scores and comments for the Coastal Partnerships

Criterion 7: Resources are focused on facilitating greater Integration			
0 - There is no evidence of resources being allocated to enable greater integration. 3 – Resource allocation has not operated explicitly to enable further integration but some enhancement has occurred. 7 – Resource allocation has taken some explicit and transparent steps to enhance integration. 10 – Resource allocation is explicitly focused on the enhancement of integration in all areas.	**Coastal Partnerships**	**Comments and Evidence**	**Score**
	PNIN	PNIN is geared to facilitate greater integration. PNIN has been able to have funding available in achieving their objectives. This is through donor agencies, which include the McAuthur Foundation, the Leventis Foundation, international agencies such as the Commission of the European Community (which sponsored the Micro Project Programme) and the United Nations' programme. With regards to how decisions are made and problems are solved, a participatory and transparent approach is always applied.	8
	NDWC	The issue of integration has not been a major priority at NDWC but some of their actions suggest that this is accepted as necessary. Decisions are made to some extent in a participatory and transparent way. In addition, they receive funding to meet their goals in the Finima project from NLNG.	3
	NDDC	There is the allocation of resources to a regional master plan for the Niger Delta, but it is evident that issues of coastal sustainability and ICZM have been neglected. The NDDC has been highly funded by the Federal, State and Local governments, NGOs, and International Development Agencies. More integration is being solicited which is hoped will bring in more positive results to the Niger Delta	1
	FECOZM	There is no evidence to show that resources are allocated to enable greater integration	0

6.3.5 Responsibility

The responsibility criteria are in Table 6.9. Figure 6.5 shows the responsibility criteria performance score obtained from the case studies based on detailed interviews and reviews of published documents.

Table 6.9   Responsibility Criteria

Number	Criterion
1	The management system has a clear legal basis
2	The coastal environment is regulated effectively
3	Organizations and institutions involved in coastal management promote the stewardship and efficiency of use of natural resources
4	The coastal management system uses the best practicable means which to achieve its objectives
5	The management system evidently employs a 'precautionary approach'
6	The management system evidently applies the 'polluter pay principle'
7	The risks to sustainability associated with coastal management policies and decision-making is as low as reasonably practicable
8	The management system gives due consideration to the life cycle and impact of coastal activities
9	There is a sufficient budget for the management system to operate successfully
10	Management adopts an ecosystem approach to operating
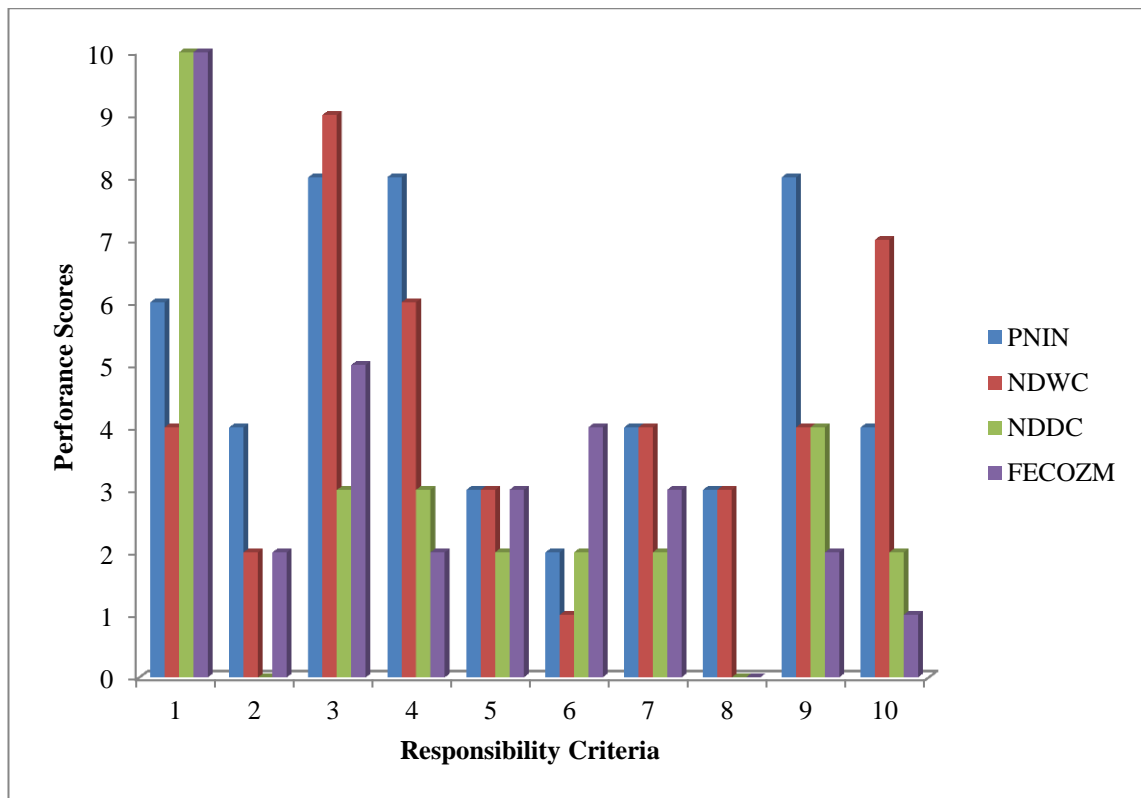
Figure 6.5: **Responsibility criteria performance scores**

This principle deals with the application of due care on the coast with the use of best practicable means. (See section 2.6.5.5). An interesting criterion in this principle relates to the management system having a clear legal basis. The assessment is based on the premise that the greater the degree of legal powers afforded to the management system the better in terms of dealing with complex issues facing the coast (Gallagher, 2006). Therefore, a legally defined entity represents a beneficial step forward for ICZM. NDDC and FECOZM are legal entities with statutory powers and they can deal with issues relating to the coast within their area of jurisdiction. In addition, their activities do not preclude the responsibilities of the federal, state, and local government's development programmes and local initiatives and vice-versa. PNIN scored highly on a clear legal basis. This is not because it is operating as a statutory body but it is actively creating legally responsible and accountable community based organisations in all the local governments they are involved in by which development interventions can be

237

channelled. They also bring together organisations with statutory responsibilities. NDWC also carry out this activity like PNIN, but not at the scale of PNIN. On effective regulation of the coast all the CPs scored low except for PNIN which was able to show some evidence of constructive management in operation such as best practices, codes of conduct and information. The extent of information available is important in this criterion as well the value or the significance of the information. Concerning 'promoting the stewardship and efficiency of natural resources' in the operation of the CPs, the assessment is based on the availability of best practice or codes of conduct, and the development of monitoring, indicators and targets with defined timescale. Table 6.10 reveals the comments and the score for each CP within the criterion.

Another important criterion in the principle of responsibility deals with the application of a precautionary approach in the absence of insufficient information. As stated in the guidance notes in Gallagher (2006), it involves taking thoughtful action in advance of scientific proof, not extracting resources even though they are there for the taking, care in management and the duty of care on all actions. The approach enables active participation in situations where there are unknown consequences of actions. The assessment measurement includes the availability of specific codes of conduct concerning resource use; the action of the management system with regard to proposed developments; the consideration of precaution in policy and decision-making; and the establishment of procedures for achieving the principle concerning all relevant issues. Three out of the four CPs, have the precautionary principle as an implied principle of the management process. Evidence of this is the precaution that has been taken with regards to the Nypa-palm, which was mentioned by the three CPs. NDDC though claimed that precaution is always taken before any action is taken however there is no evidence to show that this has been applied.

Table 6.10:   Responsibility: Criterion 3 scores and comments for the Coastal Partnerships

Criterion 3: Organizations and institutions involved in coastal management promote the stewardship and efficiency of use of natural resources			
Scoring Criteria	**Coastal Partnerships**	**Comments and Evidence**	**Score**
0 - Resource efficiency is not agreed as a driving principle behind the management process and there is no evidence to show its promotion. 3 – Resource efficiency is an implied principle of the management process. There is some limited evidence of its operation. 7 – Resource efficiency is agreed to as a driving principle of the management process and there is some evidence of its operation. 10 – Resource efficiency is agreed to as a driving principle of the management process and there is comprehensive and transparent evidence of its operation.	PNIN	PNIN makes use of best practices. Codes of conducts are available. The management system carries out monitoring of the environment periodically. PNIN does not import materials but they encourage the stakeholders with the use of local and natural resources in efficient ways.	8
	NDWC	This is a driving principle at NDWC. Conservation and resource management activities are being carried out. These include EIAs, feasibility of establishment of protected areas, Community Resource Protection and Integrated Management Planning, Local language databases on resources and Renewable Energy Technologies (RETs) especially solar and wind.	9
	NDDC	There is insignificant evidence to show that resource efficiency is being promoted. Codes of conducts are available.	3
	FECOZM	There is evidence of resource efficiency being promoted in the case of Nypa-Palm and dredging activities, which lead to cost and environmental benefits. Codes of conducts exist and some evidence indicates that they are in operation (although partially).	5

In the application of practicable means to ensure there is due care to the coast, comes practices such as the 'polluter pay principle' (PPP), risk assessment, life cycle analysis (LCA) and the use of ecosystem approach. No CPs performed well on these criteria. For example, PNIN considered the application of the PPP to be outside the scope of the management system but it is involved in ensuring stakeholders are aware of the consequences of polluting the environment. LCA is more or less an implied principle in PNIN and NDWC but not in operation in NDDC and FECOZM. Regarding ecosystem approach, NDWC was able to achieve the standard achievement mark. The convention on Biological Diversity describes the ecosystem approach as a "strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way" (Convention on Biological Diversity, 1992). A management enables the capacity of ecosystems to produce food, revenue, employment, services and livelihood despite its variability, uncertainty and likely natural changes in the ecosystem. The management is not about manipulating ecosystem processes but is concerned more with ensuring that management decisions do not adversely affect those processes. Table 6.11 details the comments and score as regards the application of the ecosystem approach.

The assessment outcome for the principle of responsibility shows that none of the CPs could attain the standard achievement mark. PNIN scored highest with an average score of 5.0 followed by NDWC. These two show some evidences of constructive management going on within the management system for sustaining the coast. Both NDDC and FECOZM did not perform well despite the fact that they operate as legal entities. There is therefore a need for corrective actions. Some of the obvious reasons why the uptake of these tools and techniques relevant to coastal management is low include lack of resources (funding), and lack of awareness, knowledge or skills amongst coastal managers.

Table 6.11:   Responsibility: Criterion 10 scores and comments for the Coastal Partnerships

Scoring Criteria	Coastal Partnerships	Comments and Evidence	Score
Criterion 10: Management adopts an ecosystem approach to operating			
0 - The ecosystem approach has not been considered in relation to the coastal area.	PNI	There is an attempt to adopt the ecosystem approach to management. This is evident through meetings but not explicitly stated in the visions or the management plan of the organization but some progress has been achieved in this regard e.g. fishing resource, sea turtles etc.	5
3 – The ecosystem approach is being viewed in a constructive manner but with no evidence of its practicable employment. 7 – The ecosystem approach is being viewed in a constructive manner.	NDWC	The ecosystem approach is viewed in a constructive manner. Evidence includes the Finima Park, which is a habitat to various species of animals and plants, which produce food, employment, and revenue generation.	7
There is some evidence of its practicable employment.	NDDC	There is a plan to adopt the ecosystem approach. Evidence of this is in the popular version of the Niger Delta Development Master Plan.	2
10 – The ecosystem approach is being operated in a comprehensive manner.	FECOZM	There is claim that the ecosystem approach is been considered but there is no evidence of its practicality.	1

Figure 6.6:   Performance criteria performance scores

The principle of balance deals with maintaining integrity between the three pillars of sustainability i.e. the natural environment, economic prosperity and an equal opportunity for all people to benefit from a better quality of life. Nine criteria represent this principle according to the coastal sustainability standard. This research tries to find out the extent by which the management system conserves, protects and restores the health and integrity of coastal biodiversity. In carrying out the assessment, the objective is focused on habitat species conservation. The guidance note used in this assessment reveals that commitment to conserving biodiversity could identify it as one of the key issues facing the management system. Evidence of its operation should include specific aims, objectives and targets relating to such conservation. Responses and evidence seen from the CPs were assessed to ascertain the extent by which the health and integrity of coastal biodiversity is being maintained. Table 6.13 reveals the comments from responses and evidence obtained.

6.3.6 Balance

The balance criteria are in Table 6.12. Figure 6.6 shows the balance criteria performance score obtained from the case studies based on detailed interviews and reviews of published documents.

Table 6.12   Balance Criteria

Number	Criterion
1	Coastal management conserves, protects and restores the health and integrity of coastal biodiversity
2	Environmental and economic policies and decision-making take into account social 'fairness'
3	Coastal management protects and enhances optimum environmental quality with regard to its impact upon employment, income and wealth generation
4	Coastal management conserves and maintains cultural heritage
5	Coastal management improves the equity of coastal communities and maintains development options and opportunities for generations to follow
6	Coastal management optimises the 'quality of life'
7	Temporal variations in the coastal system are effectively managed
8	Policies and decisions are made through negotiation with due consideration being given to the relative importance of environmental, social and economic interests
9	Stakeholders representing environmental, social and economic interests consider trade-offs to be appropriate

Table 6.13:   Balance: Criterion 1 scores and comments for the Coastal Partnerships

Criterion 1: Coastal management conserves, protects and restores the health and integrity of coastal biodiversity			
Scoring Criteria	**Coastal Partnerships**	**Comments and Evidence**	**Score**
0 - Coastal management has no commitment to the conservation of biodiversity. 3 – Coastal management has an implicit commitment to the conservation of biodiversity. There is some limited evidence of success in its operation. 7 – Coastal management has an explicit commitment to the conservation of biodiversity. Procedures exists which can be used to implement this and some evidence of success in its operation. 10 – Coastal management has an explicit commitment to the conservation of biodiversity. Procedures exist which can be used to implement this, with comprehensive evidence of enacting this commitment and success in its outcomes.	PNIN	The tasks of PNIN involve facilitating people and make them aware of their rights to have an influence on their environment. Conserving, protecting and restoring the health and integrity of coastal biodiversity is inherent but not stated as the driving principle for the organization	4
	NDWC	There is an explicit commitment stated in the mission statement and objectives for the conservation of biodiversity. There are a lot of work going on in the preservation of the fauna and flora, insects and arthropods in the Finima park. Reforestation activities is on as well as herpetology (amphibians and reptiles) and ornithology (birds) studies	7
	NDDC	There are attempts in conjunction with the federal government for the establishment of protected/conservation areas, forest reserves, wildlife sanctuaries, and conservation of traditional areas. However, weak and/or non-existence of appropriate institutional frameworks and capacities are obstacles to achieving this.	5
	FECOZM	The effort to conserve, protect and restore the health and integrity of coastal biodiversity has just started, it is not adequate and it is not been done appropriately	2

This research seeks to ascertain if the CPs have a commitment for environmental and economic decisions to take into account 'social fairness'. Results of respondents indicate that only PNIN attains the standard achievement mark, while there is evidence of constructive management in NDWC. Social fairness is explicitly stated in PNI vision and procedures for realising the vision. This is clearly revealed in the way the community and all stakeholders have been involved in all environmental and economic decision-making, and passing information regarding access issues, livelihoods and land use across to them. Operational procedures for example, valuation techniques used in environmental economics exist in ensuring social fairness though not used on a periodical basis. NDWC shows an implied commitment to this criterion with evidences such as promoting and educating on the livelihood of the coastal community. Both FECOZM and NDDC show no real commitment to social fairness as there is yet to be an establishment of an operating mechanism to ensure its appropriate consideration in environmental and economic decision-making.

There was the need to ascertain if the management system improves the equity of coastal communities and maintains development options and opportunities for generations to follow. This is an important criterion as far as sustainability is concerned. Evidence with respect to this criterion as obtained from the guidance note would include the nature of the management system in terms of its role in protecting a common asset. There should be an explicit declaration of this as a system objective, specific mechanisms allowing such considerations to be discussed and the evidence of actions aiming to improve equity. Table 6.14 shows the comments scores for criterion 5.

Policies and decisions taken by the decision-making bodies with regards the importance of environmental, social and economic interests is important in this research.

Sustainability involves the three aspects and it depends on the type of sustainability that decision-makers are willing to achieve that will determine if a weak or a strong sustainability will be achieved or if there is going to be trade-offs among the three pillars of sustainability. The coastal sustainability standard seeks to find out if CPs considers and negotiates the consequent costs and benefits for the three pillars. None of the four CPs performed well in this criterion.

The assessment outcome for the principle of balance shows that none of the CPs could attain the standard achievement mark. PNIN scored highest with an average score of 4.3 followed by NDWC (average score 4.1). These two show some evidences of constructive management going on within the management system in the principle of balance for sustaining the coast. Both NDDC and FECOZM with average scores of 3.1 and 1.7 failed the standard. There is therefore a need for corrective actions.

Table 6.14:   Balance: Criterion 5 scores and comments for the Coastal Partnerships

Criterion 5: Coastal management improves the equity of coastal communities and maintains development options and opportunities for generations to follow			
Scoring Criteria	**Coastal Partnerships**	**Comments and Evidence**	**Score**
0 - Coastal management does not consider or accept a commitment to improve social equity. 3 – Coastal management has an implicit commitment to both intra and inter-generational social equity. 7 – Coastal management has an explicit commitment to both intra and inter-generational social equity. Procedures exist which can be used to implement this and some evidence of its operation and success. 10 – Coastal management has an explicit commitment to both intra and inter-generational social equity. Procedures and measures exist which can be used to implement this, with comprehensive evidence of enacting this commitment effectively.	PNIN	Has been involved in empowering the community members to improve the equity by facilitating and encouraging them to protect the common asset and ensuring the community is vibrant. In addition, the participatory community development practiced in PNIN ensures the equitable distribution of benefits directed towards communities. However, there are no explicitly stated actions directed towards equity	5
	NDWC	NDWC has the task of ensuring the coastal environment is vibrant. Although there is no direct statement of intra and intergenerational equity but there is a commitment to preserve the common assets in the coastal environment	4
	NDDC	There is only an implicit effort to maintain and improve intra and intergenerational equity. No explicit statement has been made as regards the protection of a common asset and there is no explicit declaration that it is one of the objectives of the CP.	2
	FECOZM	Consideration is given to this criterion but there is no commitment towards achieving equity	1

6.4   Summary of Results

6.4.1   Introduction

This segment is a comparative review of the principles and the CPs. It is meant to identify some degree of commonality and differences between the CPs. Table 6.15 shows the summary of the assessment of the various organisations in line with sustainability principles involved in management of the coast in Rivers State with the aid of the CoSS.

Table 6.15:   Average scores along principles and CPs

	PNIN	NDWC	NDDC	FECOZM	Average
Planning	6.4	4.5	2.9	2.0	**4.0**
Participation	7.6	5.4	2.1	0.7	**4.0**
Communication	8.1	5.1	1.0	0.0	**3.6**
Integration	6.6	3.4	1.4	1.1	**3.1**
Responsibility	5.0	4.3	2.8	3.2	**3.8**
Balance	4.3	4.1	3.1	1.7	**3.3**
Average	**6.3**	**4.5**	**2.2**	**1.5**	**3.6**

On the total, there are 54 criteria for the six principles. From the assessment made based on the guidance notes obtained from Gallagher (2006), scores were awarded to each criterion based on the performance of the CPs. For example PNIN have an average score of 6.4 under the principle of planning, while NDDC has an average score of 2.8 under the principle of responsibility. Figure 6.7 illustrates scores along the six principles for the CPs.

The next segment is a review of these assessments. In doing this, the scores are viewed and interpreted from the perspective of both the principles, and the variation that is

evident in the performance levels between them and the CPs. Also, the corresponding variation in performance demonstrated between the organisations were reviewed.

6.4.2 Assessment of the principles

According to the CoSS, the organisations must score at least 7 in all the principles and on the average for it to pass the assessment. From the test carried out none of the organisations could achieve the standard achievement mark. On the average the principles score very low but they were able to achieve the threshold of constructive management. The principle of integration scored the lowest with an average score of 3. The principle of planning and participation scored highest (4.0) followed by the principle responsibility with average score of 3.8.

Putting the four coastal partnerships, into consideration in the principles of participation and communication, results indicate that they did not perform well but with evidence of constructive management. The principles record a score of 4.0 and 3.6 respectively. There are obviously varying degrees in the performance of the CPs against the CoSS. PNIN scored the highest in both principles having a score of 7.6 and 8.1 respectively.

These scores are above the standard achievement mark of seven, which show evidence of exceptional and well-developed management technique. For the other case studies, none of them could achieve the standard achievement mark. Indeed only one (NDWC) was able to score above the threshold of constructive management with scores of 5.4 and 5.1 respectively. Noteworthy is FECOZM who could not record any score for the principle of communication. On why the other CPs performed poorly, it is because these CPs have not considered the principle of participation or communication in their activities on the coast (Personal Communication, 2008a).

	Planning	Participation	Communication	Integration	Responsibility	Balance
PNIN	6.4	7.6	8.1	6.6	5.0	4.3
NDWC	4.5	5.4	5.1	3.4	4.3	4.1
NDDC	2.9	2.1	1.0	1.4	2.8	3.1
FECOZM	2.0	0.7	0.0	1.1	3.2	1.7
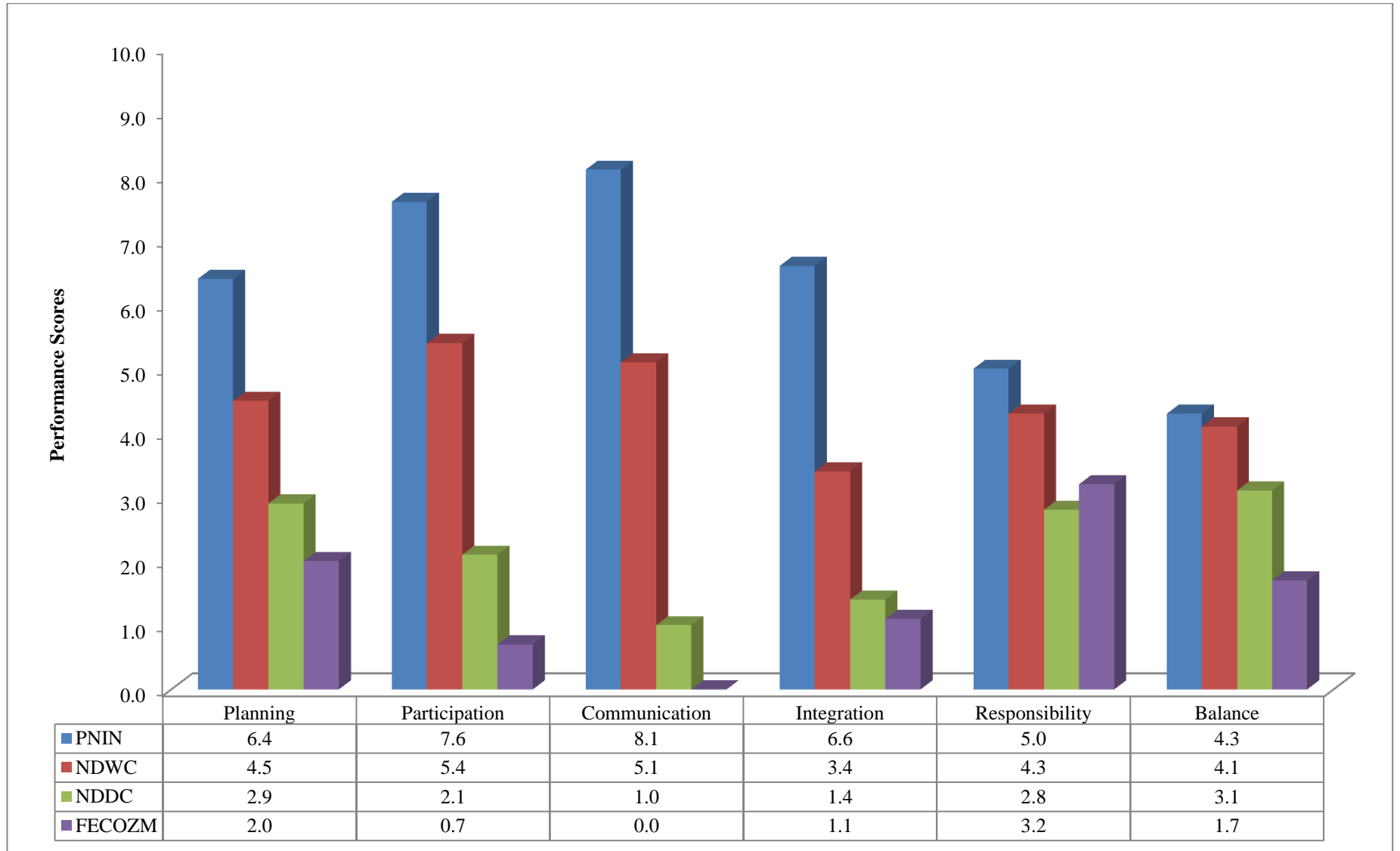
Figure 6.7   Scores for the Coastal Partnerships

Most of the projects and contracts awarded are politically controlled and members of the community are not carried along with the management system (Personal Communication, 2008a). Very often, the CPs communicates decisions taken to some representatives of the members of the public not for allowing them to contribute but just for them to be aware that a project will be carried out. This is a top-down approach to community development as opposed to the top-down support for bottom-up approach. In a bottom-up approach, the people initiate their own projects and the government establishment gives support and help to the aspirations of the people. PNIN is fully involved in this approach. They facilitate programmes and enable a participatory process where people are empowered to determine and manage their own development. The community members are also encouraged to participate actively in decision-making. This is evident in all the CDFs. NDWC shows some constructive management is in operation in the principles of participation and communication. It has also advanced participatory rural considerations and environmental education.

On average, the principle of balance has a score of 3.3. Three of the CPs (PNIN, NDDC, and NDWC) individually score above the threshold while FECOZM score very low. This research found out that there is no adequate awareness and knowledge regarding various criteria considered in this assessment. An example of these is the criterion that relates to the effective management of temporal variations in the coastal management systems of the CPs. In the mission statement of PNIN and NDWC, issues of improving the quality of life of the people are stated and evidence shows that these are well considered. A correlation exists between this and criterion 3, which consider the 'protection and enhancement of optimum environmental quality with regards to its impact on employment income and wealth generation'. In improving the quality of life of the community members, both PNIN and NDWC has enabled economic activities

251

that have increased the diversity of the resources in ways by which compromise of environmental quality is not supported. These include agriculture for the provision of food, sea turtles preservation, and fishery, mariculture for the provision of periwinkles, prawns, and oysters. It is however not the case with equity which is at best been implicit across all the CPs.

Integration scored the least out of all the principles. This is because there is no incorporation of the art and science of coordinating, harmonizing, and integrating the disparate elements of coastal zone management. Initiatives of one establishment in achieving ICZM are very different from the other. There are noticeable clashes of interest among these bodies who are supposed to have the same aim to manage the coast in a sustainable way. None of the CPs was able to achieve the standard achievement mark but there is some evidence of constructive management in PNIN and NDWC. Evidence of constructive management of PNIN within the principle of integration includes:

- Organizing events that put people together with regard to identifiable problems which has brought about communication, interaction and involvement and as well integrating ideas;
- The upholding of close links with individuals, partner organisations, government agencies and educational institutes through formal and informal meetings where scientific information as well as funding is sourced;
- Facilitating community-led development programmes
- The establishment of the Institute for Sustainable Development, and
- Participatory process of conflict resolution

6.4.3 Assessment according to case studies

On average, PNIN score highest with 6.3. Although it did not achieve the standard achievement mark, there are indications to show that on the overall there are evidences of constructive management. In the principles of participation and communication, PNIN performs exceptionally well. PNIN ensures there is community involvement in all decision-making and the appropriate communication of information to the community members as well receiving information from them. PNIN however performed low on the principles of responsibility and balance. PNIN considers some criteria such as the 'polluter pays' to be outside the scope of the organisation, likewise LCA, the precautionary principle, temporal variations, and equity.

NDWC did not achieve the standard mark. However, it maintained the status of 'evidence of some constructive management in operation' throughout the principles with an average score of 4.5. Like PNIN, NDWC score highest on the principles of participation and communication. This is in contrast to the government establishments that attach less emphasis on these principles. NDWC uses participatory approaches to involve local people in evaluating their resources and in planning for their use and management in ways that focus on sustainability (NDWC, 2007). NDWC score poorly on the principle of integration because this has not been the priority at NDWC. The principle of responsibility performed better than integration.

FECOZM performed very poorly against the CoSS but performs high in the principle of responsibility because it operates as a legal entity. The scores lift the average score of the principle against the CoSS. The only other criteria that shows some evidence of constructive management is criterion 3 which relates to the promotion of efficient use of natural resources in carrying out the management actions. There is the Nypa-Palm project that FECOZM embarked on with the aim of preserving it. The nature of the plant is that it spreads out and makes use of the available space without producing or

253

serving any useful purpose (Personal Communication, 2008c). There were attempts to cut down and destroy the plant but then FECOZM decided to conduct a research in conjunction with the Rivers State Ministry of Environment to ascertain benefits of the plant (Personal Communication, 2008c). Results of their findings show that the plant is however beneficial in some aspects, which include the provision of food (the young shoots are edible). In addition, the petals of the flower are good for brewing aromatic tea. FECOZM have also been able to realise that the dried fronds are useful to thatch and woven into mats, baskets and other household items. The plant is also good for ornamental purposes (Personal Communication, 2008c). FECOZM has already started deriving optimum value from the plant.

FECOZM performed exceptionally low in the principles of participation and communication. Indeed, it has a score of zero in the principle of communication. This is because it has not considered it necessary to communicate what the management system is doing concerning ICZM to the public. The stakeholders and the community members have not been adequately involved in decision-making as far as ICZM process is concerned within the CP. One of the major reasons why the community members are not involved in decision-making is that almost all of the projects within the management have political motive (Personal Communication, 2008). Many private individuals benefit from the circumstances of the coastal environment. There are stake by politicians, village chiefs and contractors in getting varying types of contracts from FECOZM, the State and the Federal Government without delivering a reasonable outcome. The target is to make as much profit without doing the tasks in the proper way. This always leads to awarding and re-awarding contracts repeatedly without any meaningful success coming out of them. FECOZM on their part has not been able to operate mechanisms to inspect and make sure that there is proper accountability of the

contracts awarded. Certainly, there is no transparency in the operations of the establishment and the extent of corrupt practices has hindered the success of coastal management initiatives. Another factor of note is that the level of awareness and understanding of the importance of ICZM in enabling sustainability is very low. The right set of technology is not in place and very few individuals have the necessary skill to operate the available technology. The main reason for the poor performance is that ICZM is still a new phenomenon and in an early developmental phase as regards ICZM.

NDDC also performed poorly against the standard with an average score of 2.3. This score is less than the threshold of constructive management. Many of the issues that relate with FECOZM are also noticeable with NDDC. These include corrupt practices, less consideration given to community involvement in decision-making, inadequate communication to the various stakeholders and the members of the public as regards issues relating to ICZM. A major difference is that ICZM is not an explicit aim of NDDC. It is expected that NDDC will be actively involved in coastal management but up till the time of this research there is yet to be seen any form of progress. Indeed, the Niger Delta Regional Development Master Plan is silent on pertinent issues of ICZM. According to the officers interviewed, they were able to say that ICZM is now starting to gain recognition as an important tool in achieving sustainability in the Niger Delta Region and that NDDC will spearhead this in a comprehensive manner in the nearest future although many coastal management initiatives are already in place.

6.5   Conclusion

This Chapter has been able to apply the CoSS to the assessment of coastal partnerships in Rivers State, Nigeria. These CPs are seen as voluntary organisations and government establishments who have the interest and the wellbeing of the coast in Rivers State. The

assessment made has been able to confirm that ICZM is at its lowest ebb in Rivers State. Out of the four CPs assessed, none was able to achieve the standard achievement mark. However two were able to score more than the threshold of constructive management. These are the PNIN and NDWC. PNIN performed more better with an average score of 6.3. From this score it can be concluded that some criteria are lacking to meet the standard. A comparative analysis was attempted to assess commonalities and peculiarity between the CPs. It is the view of this research that if the CPs could achieve the standard achievement mark of the sustainability assessment, then a sustainable coast could be achieved. Various measures have been in place to mitigate and adapt to climate change related problems such as sea level rise. It is the firm belief of this research that an ICZM could offer a sustainable solution to these hazards as it has the capacity to integrate policies and institutions to ensure proper mitigation and adaptation measures are in place without duplication of efforts and conflicts of interest among CPs. However, there would be need for adequate funding, provision of the necessary resources, creation of awareness as regards the significance of ICZM, communicating coastal information to all stakeholders, educating staffs and stakeholders to improve technical know-how, and ensuring that there is transparency in decision-making as well as fight against corrupt practices.

CHAPTER SEVEN

7.0   An Evaluation of the Sea Level Rise Models and the Sustainability Assessment Model

7.1   Introduction

Section 1.1 clearly gives an overview of what the coast is. It is essential that there should be proper planning with the aim of protecting and sustaining the coastal environment. In order to do this, appropriate information should be available to highlight the present state of the coast and as well predict what the situation will be in the near future.

This research acknowledges that this is not the first time sea level rise assessment will be conducted in Nigeria. French *et al.* (1995) conducted the first assessment using the Aerial Videotape Vulnerability Assessment (AVVA) in 1995. The result of this assessment has been in use up until now. The AVVA technique is old and since it was done at a very large scale, it is insufficiently detailed. The basis of this research is to use a different approach to predict the effects of sea level rise for the Nigerian coast to improve, update and provide a more detailed description of the likely impacts.

Various valid constants and equations were integrated and computed which forms the parameters of the Bruun model. Regarding inundation, this research uses the Geographic Information System (GIS) technique to assess impacts of sea level rise along the Nigerian coast. This method as highlighted in section 2.4 has been used to examine the impacts of sea level rise on developing countries, Nigeria inclusive (Dasgupta *et al.,* 2007). This Chapter integrates the key findings of this research and supplements it with depicting and validating the models employed in determining vulnerable regions along the Nigerian coast. It also evaluates the sustainability model used to assess the integrated coastal zone management initiatives (ICZM) in Nigeria. It

also seeks to make a judgement as regards the results of this study and other previous studies with regards effects of sea level rise in Nigeria. The structure of the Chapter is in two main parts. The first part focuses on the vulnerable regions from erosion and inundation. The second part focuses on adopting and operating a suite of coastal sustainability indices to ascertain sustainability levels in use by various coastal management initiatives along the coast.

7.2   Erosion Analysis

The Bruun model for shoreline change was employed to estimate erosion along the Nigerian coast because that is the only model that can be applied on long stretches of coastlines to give an estimated result of the extent of erosion. Indeed there has not been up till now a developed universally applicable model of shoreline retreat when subjected to sea level rise (Cooper and Pilkey, 2004). Other models could be more accurate for specific locations along the coast. The limitations in applying the Bruun model which was discussed in section 2.3, have been the subject of debate together with the parameters used in calibrating shoreline changes (Cooper and Pilkey, 2004); (Thieler et al., 2000). The major cause of concern for this research was finding an applicable model to predict shoreline erosion over a long stretch of coast with different characteristics. It was a substantial task and there was no other model, which could serve the purpose of this research. The crosscutting themes considered in estimating erosion in this study includes the criticisms against the model and more importantly its applications, which is discussed in section 7.2.1.

7.2.1   Salient Issues in erosion analysis

Examining the variables and parameters of the model as used in this research and comparing to how it has been employed in other work that estimated erosion along the

Nigerian coast, the depth of closure (section 3.4.3.1) seems not to agree with what was used in the work by French *et al.*, (1995). The depth of closure is important for its numerous applications which include estimation of coastal budgets, numerical models of coastal change, beach nourishment design and the disposal of dredged material (Masselink and Hughes, 2003). Equation 2 ($h_c = 2\hat{H}_S + 11\delta$) as presented in section 3.4.3.1 was used to predict the depth of closure. The Bruun model advocates two calculations for the depth of closure. They are $d_{L,1}$ (annual scale) determined from the annual exceeded wave height in a twelve hour period and $d_{L,100}$ (century scale) estimated as 1.75 $d_{L,1}$. The coefficient 1.75 is based on Hands (1983). These two estimates have been considered to provide the low and high estimates of the likely erosional response of the shoreline to sea level rise. Based on equation 2 the depth of closure $d_{L,1}$ and 1.75 $d_{L,1}$ for Nigeria was computed to be 10.11 and 17.69 metres respectively. In validating this assertion, this research considered the various range of techniques used in estimating the depth of closure. Among them include the grain size trends and the orientation of offshore contours as postulated by Hallermeier (1981). However, the best technique is the wave-based approach because it relates to time scale; and the depth of closure is time scale dependent: the longer the time period considered, the larger the depth of closure (Hands, 1983, Stive *et al.,* 1992).

From the wave database used for this study, the significant wave height, $\hat{H}_S$, was computed to be 1.55 metres with a standard deviation of 0.637. In the work of French et.al (1995) $d_{L,1}$ was estimated to be 5.4 metres which is low compared to the result of this analysis. It is not explicit how the depth of closure was determined in French *et al.* (1995). The only statement relating to the determination of the depth of closure is that linear interpolation was used to determine the position of the high estimate depth of closure contour and the low estimates was assumed as 25% of the value of the high

estimate. Factors that could be responsible for the difference in the prediction of the depth of closure include the quality of the wave data, the beach and the wave characteristics, and slope which was put into consideration in the equilibrium profile theory which has been operated in Larson and Wise (1998) and Walton and Dean (2007), among many other authors.

Apart from the depth of closure, the other parameter operated is the berm height. The equation 3 in section 3.4.3.1 gave the prediction of berm height to be $Z_{berm} = 0.125H_b^{5/8}(gT^2)^{3/8}$. Estimating H_b, which is the breaker height, posed a challenge because no easily available dataset exists for its calculation. With the equation provided by Komar (1998) as presented in equation 5, the wave breaker height of Nigeria was estimated to be 1.8 metres. In coastal constructions, breaking wave heights are important influencing factors. Therefore conservative estimates should be guarded against to avoid uneconomical projections, structural failure and high maintenance cost (Vincent *et.al.*, (2002) The maximum values of horizontal water particle velocities are reached at the wave breakpoint ensuring that the coarsest sediments are brought into suspension on the sea floor beneath the breaker zone (Le Roux, 2007). Wide coastal swath is affected because the breaker zone is migratory with tides and variations in the wave climate; hence, the need for the accurate determination of the breaker zone as a function of the sea floor slope (Le Roux, 2007). Beach slope, wavelength, and period all contribute to the breaker height (Brown *et al.,* 1999). Period T was computed from the Global Wave Statistics database for Nigeria, which yields a result of 6.08 seconds. Putting all these into equation 3, berm height was estimated to be 1.64 metres for Nigeria. The research acknowledges that the berm height along the Nigerian coastline will not be the same value throughout. A detailed study might indicate that berm heights are lower or higher for some locations. However, this estimate was employed

throughout the coastline in this research. Equation 1, which was expanded in equation 11, was used to estimate shoreline recession along the Nigerian coast.

Results of the erosion analysis conducted in this research indicate that erosion will not be severe for the sea level rise scenarios considered. Land at risk in a one-metre sea level rise by 2100 will be less than 2 sq. km for each of the coastal units. A comprehensive computation of the shoreline recession analysis detailed the extent of recession along the Nigerian coast using the Bruun rule. For example, this research computed coastline recession in a stretch of coastline 5km eastward from the Eko Atlantic City Exhibition Office (latitude 6.42N, longitude 3.42 – 3.46E) in the Barrier coast. With the computations made, the beach width is 23.33 metres; the berm height is 1.64 metres; the depth of closure is 10.11 metres and with sea level rise scenarios of 1 m projected for year 2100, the total shoreline recession in this coastline stretch will be equal to 9.93 x 10^{-3} sq. km. In a 2 m SLR by 2100, it will be up to 1.99 x 10^{-2} and 2.98 x 10^{-2} in a 3 m SLR scenario. The addition of all the coastal divisions as made by this study produced the results for each coastal unit. The result of this study is thus validated based on the Bruun model and the quality of the data employed for this study. However, a contrary view to the results presented in this study has been reported. This contrary view is the analysis carried out by French *et al.* (1995) in which their results indicate a considerable amount of land loss due to erosion. Table 7.1 and 7.2 compare the results of this study and that of French *et al.* (1995) that used the AVVA Technique.

Two obvious reasons could be attributable to the difference in the two assessments. Firstly, it has to do with the generation of the width profile. As used by (Mwakumanya *et al.,* 2009), standard beach measurement should be taken during the low spring tide period twice a month to obtain monthly average. From this, monthly beach widths

should be obtained for one year and then the calculation of the mean monthly beach width change.

Table 7.1: Land loss due to erosion by coast type (sq. km): This research

Coast	Sea level rise (metres)			
	0.5	1	2	3
Barrier (km)	0.1-0.2	0.2–0.4	0.5-0.8	0.7–1.1
Delta (km)	0.4-0.7	0.8–1.4	1.7–2.7	2.5–4.1
Strand (km)	0.2–0.3	0.3–0.5	0.6–1.0	1.0–1.6

Table 7.2: Land loss due to erosion by coast type (sq. km): French et al. (1995) estimates

	Sea level rise scenarios (metres)		
	0.5	1	2
Barrier (km)	4-9	8-26	15-52
Delta (km)	65-112	129-332	258-663
Strand (km)	9-24	19-70	38-140

This change can be established by summing the highest and the lowest values of the monthly mean changes divided by the number of categories established. For this study, there was no time nor finance to conduct a whole year measurement along the Nigerian coast. In addition, the coast in many parts of the Mud, Delta and Strand coast are high-risk areas due to the Niger Delta crisis, which involves militants against any suspected expatriate or government worker. This situation necessitated that an alternative method of estimating the width of shoreface which was explained in section 3.4.2.1. Measurement of the Nigerian coastline with the aid of Google Earth involves dividing the coastline into a segment of 5km, 10km and other lengths depending on the attribute of a specific segment of the coastline. Within each segment, three measurements were

taken at three sites, which were then averaged to give the beach width for each coastal segment. In validating the beach width, three sites were measured on a segment of the Barrier coast (Eko Atlantic City Exhibition Office) in the course of the fieldwork and the average width gives a value of 43.09 metres and 23.17 towards the eastside of the stretch. However, using the Google Earth image an average beach width measured is 41.32 and 22.33 metres respectively. Results might not be accurate since data was not collected over a period of one year on a monthly basis. For the AVVA technique, 14 beach profiles along the coastline were surveyed and they serve as representative for the whole coast. In addition, horizontal error especially in the Delta coast is up to 10km. With these, the results will lack sufficient details.

Secondly, the estimation of the depth of closure may be a reason for the difference in results as discussed earlier in this section. This study is based on sound scientific philosophy, which employed the best available wave data in the absence of high-quality repetitive morphological surveys in computing significant wave heights, which was used in the computation of the depth of closure. The wave data obtained has its own downside, as it did not give wave data for specific locations in Nigeria (see section 3.4.1.1).

The AVVA technique used by French *et al.* (1995) is not free from errors. The philosophy of the AVVA technique was basically a reconnaissance survey which was used to select occasional ground truth stations and then extrapolate the information obtained along large distances of coastlines (Leatherman *et al.,* 1995). The AVVA technique is inappropriate for detailed analysis. This study is more detailed in its approach as it measures the beach width in ranges of between 5 to 15 km coast length

segments. This is in contrast to the AVVA technique whose estimates are based on extrapolation of results with the use of 14 representative beach profiles.

With regards the assumptions of the Bruun model, a major assumption is that equilibrium exists on coastal profiles. However, a significant finding of this study suggests that there might not be equilibrium in a significant part of the Nigerian coast. Where or where not equilibrium exists cannot be ascertained in this research because of lack of detailed wave data for specific locations. The depth of closure according to the Bruun model plays a significant role in shoreline recession. Indeed, it is assumed from the model that the larger the depth of closure the flatter the overall beach and the greater the projected erosion (Nicholls *et al.,* 1995). Contrary to expectations, this research found out that the $d_{L,100}$ large-wave associated depth of closure predicts less recession than the smaller (annual) $d_{L,1}$. This sort of result in which the $d_{L,100}$ predicts less recession than $d_{L,1}$ has been reported in three case studies (Dennis et al., 1995a, Dennis et al., 1995b) and (Volonte and Arismendi, 1995). The shape of the shoreface is the influencing factor and as construed by Nichols *et al.* (1995), it is an evidence which demonstrates that there is no profile equilibrium. It indicates the assumption of, and presence of an equilibrium profile in the Nigerian coast is subject to debate.

Apart from computing the total area that will be at risk due to erosion for different sea level rise scenarios, this research embarked on determining how far inland the coastline will shift. The area that will be mostly eroded is the Kwa Ibo in the Strand coast and this is followed by the Odimodi area in the Delta coast with the coastline receding by about 9 metres and below 27 metres following a sea level rise of 1 m and 3 m by year 2100 respectively. In the Barrier coast, the Bar Beach area will be the most eroded with the shoreline receding by 3.4 metres and 10.2 metres following a 1 m and 3 m sea level rise

by year 2100. This implies that erosion will be a mild phenomenon along the Nigerian coastline. There are claims that the Bar beach could erode up to 30 metres per year (French *et al.,* 1995) and likewise some locations in the mud coast recede up to 110 metres per year (Ibe, 1988). Historical data were not available to verify this assertion. This research conducted some survey on the 6km section of Bar Beach and came up with some valid judgement. If this stretch of the Bar Beach has been eroding by about 25-30 metres per year since 1995, then in 2011, the Bar Beach would have eroded inland between 400 and 480 metres. However, in showing that erosion has not been as high as predicted along the Nigerian coast, historical data obtained from Google Incorporated was viewed to see how far the coastline has receded. The earliest historical data was in January 2000 and the latest in January 2011. Therefore, the assessment was based on an 11-year period. Within this period, it is expected that the coastline would have receded as much as 275 to 330 metres but there is no indication that the Bar Beach section has receded as far as this amount between these years. Map 7.1 displays shoreline recession along the 6km stretch of the Bar Beach indicating the extent the shoreline would have receded if erosion rate per year were 30 metres from year 2000 to 2011 and shoreline recession in a 3 m SLR by year 2100.

Erosion rate of about 30 metres per year along this stretch of beach will ensure that major parts adjoining the land areas will have eroded. All of Bishop Oluwole Street, Ahmadu Bello Way, Wilmont Point Close, Water Corporation Road and its surrounding land would have been eroded (see Map 7.2). A significant land extent in, Olugbosi Close, Amodu Ojikutu, Ologun Agbeje Street, Akin Adesola Street, Tiamiyu Savage Street up to the Kuramo Waters would have suffered from coastline recession due to erosion. Observation from the survey conducted for this research indicates that these areas mentioned have not suffered from erosion as it was suggested they might. These

areas are densely populated and they contain industrial and office complexes as well as residential buildings. So there is need to re-compute what the erosion rates are within this stretch of land, which also applies, to the whole of the Nigerian coastline as undertaken by this study.

7.2.1.1 Uncertainties and limitations of the Bruun model

This study applied the Bruun model to estimate shoreline retreat along the Nigerian coast. The Bruun rule assumes that any rise in the mean sea level will result in the retreat of unprotected coastlines (Bruun, 1962). There has been debate in its usefulness as a predictive tool (Pilkey and Cooper 2004; Nicholls and Stive 2004; Nicholls *et al.* 2007; Cooper and Pilkey 2004). The Bruun rule has used in this study has not been able to satisfy the criteria needed for any predictive tool. The model in the first place is not widely applicable and does not have the capabilities to produce accurate and reliable predictions. This is due to high level of uncertainties within its parameters. The parameters of the model include sea level rise, width of shoreface, depth of closure and berm height. For all these parameters there are uncertainties attached to them.

For sea level rise, recent studies have shown that there may be an unprecedented rise in global average sea levels in the twenty-first century (Leuliette *et al.*. 2004; Beckley *et al.*. 2007). With the latest projections, global sea level rise could range between 0.18 m and 1.4 m (IPCC 2007; Rahmstorf 2007). This uncertainty alone would produce recession estimates of about 700% (Ranasinghe and Stive, 2009). Depth of closure has been estimated based on empirical equations in the absence of data.
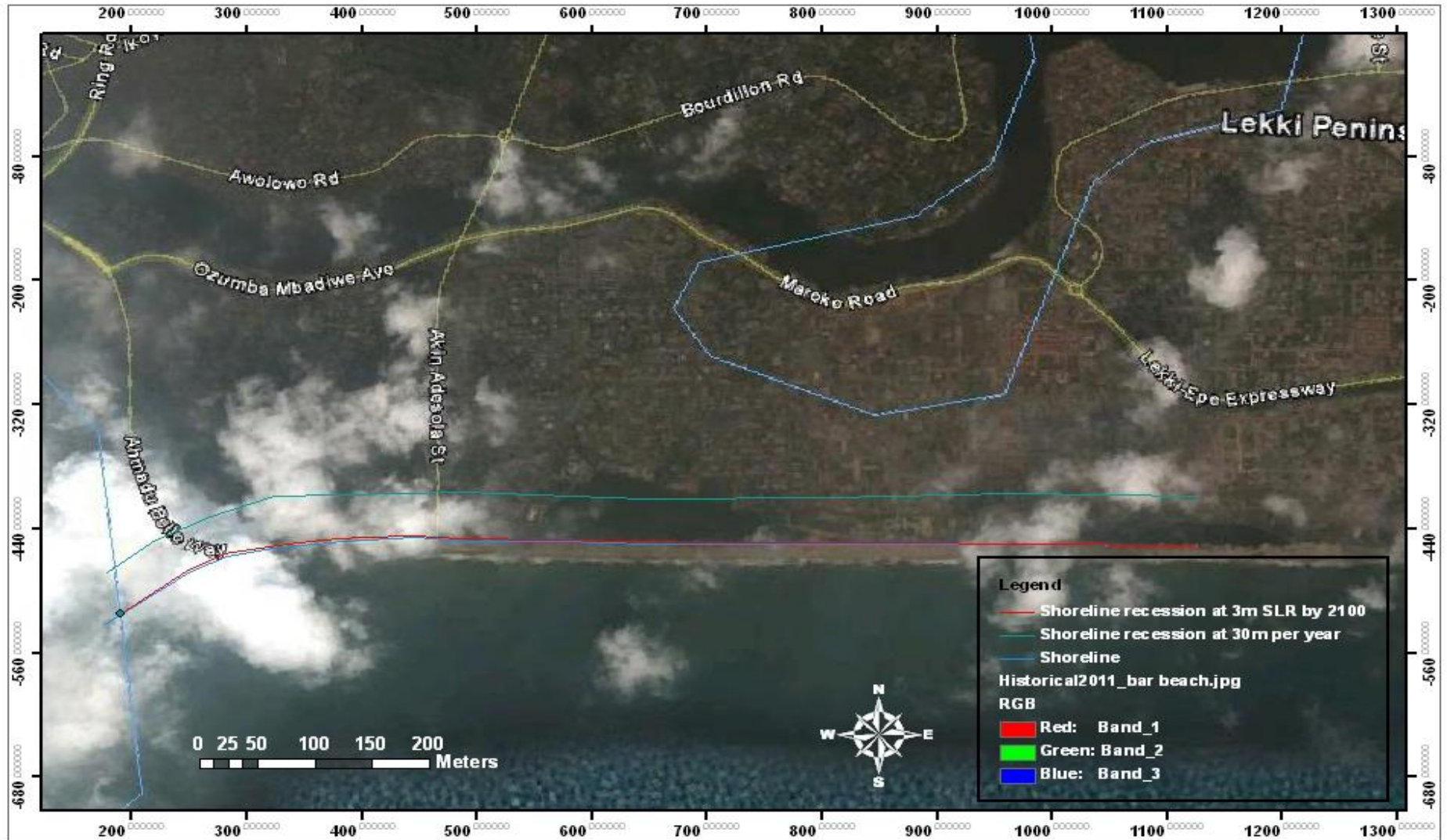
Map 7.1:   A comparison made to highlight shoreline recession along the 6km stretch of the Bar Beach
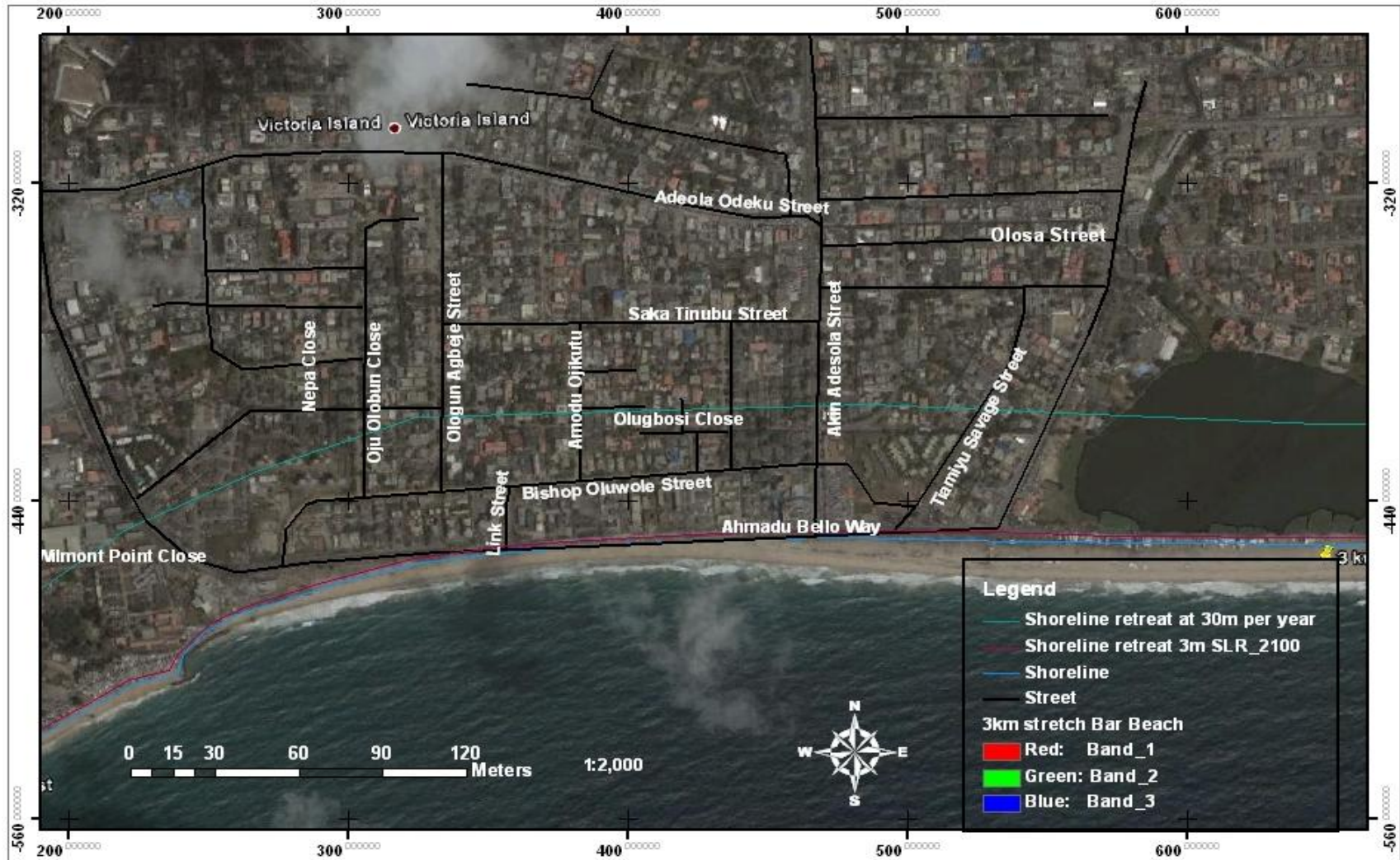
Map 7.2: Map showing the regions that will be eroded if erosion rate per year is 30 metres between 2000 and 2011 in a 3km stretch of the Bar Beach

For example, from the study carried out by Ranasinghe *et al.* (2007), uncertainties in depth of closure and berm height in predicting shoreline recession estimates could be up to 500%, and the combination of these uncertainties - both for SLR and for depth of closure and berm height could be up to 4000% in shoreline recession prediction. The high-level uncertainty brings about substantial concern regarding the quantitative precision and strength of the Bruun model predictions. Therefore, the predictions are indicative and are evidence of the requirement for higher resolution, and higher accuracy dataset.

A basic sensitivity analysis was conducted in this study to establish the ability of each of the Bruun's model parameters in predicting shoreline recession and how significantly different the variables of the parameters prediction to the observed parameter. The significant wave height H_s for this study was compted. Based on the various empirical formulas that was used to estimate depth of closure and berm height, this study found that with increased H_s, less shoreline retreat is predicted. This result is directly opposite of what is expected because larger wave heights are expected to generate more coastal recession. The explanations that could be given to this include that the waves have reached equilibrium with land and have eroded the coast so much to form a beach. However, this is not the case for most of the Nigerian coastline.

The other explanation could be that the equation for the depth of closure and the berm height needs to be re-examined. For example, the Hallermeier (1982) equation (section 3.4.3.1), with increased significant wave height, a larger depth of closure is produced, ultimately leading to a lower erosion rate. This type of equation needs more in-depth analysis to find out if it is useful in the Bruun model. Bruun did not provide any rigorous mathematical derivation of the equation for the depth of closure, which has

brought about confusion in the coastal research community (Zhang *et al.*, 2004). The results of the wave period in predicting shoreline recession is expected as there will be more wave action on the coastline with decreased wave period. The width of the shoreface parameter also indicates that as it increases shoreline recession increases. The sensitivity analysis conducted in this study with the variables considered for each of the Bruun model's parameter revealed that there is no significant difference in the variables and the observed values of the parameters in predicting shoreline retreat. However, a significant relationship exists between the parameters and shoreline retreat.

7.2.2 Inundation Analysis

Inundation will be severe along the Nigerian coastline. Out of the six critical elements, the urban land extent will experience the highest impact, as about half of the total urban area in the study area will be inundated in a 1 m SLR scenario. The impact in terms of GDP lost will be the lowest compared to the other elements, as only about 1.8% of GDP in the Study Area will be lost. When viewed as a nation, the total GDP that will be lost will be 1.4% of the total GDP in a 1 m SLR. In the analysis carried out by Dasgupta *et al.* (2007), the average GDP lost in a 1 m SLR is 1.3% and 0.2% for 84 developing countries and for the Sub-Saharan Africa respectively. Going by the results of the analysis conducted in this study, GDP will be severely impacted in Nigeria.

A comparative analysis of the four coasts revealed that the Delta coast would be more impacted in terms of land loss to inundation. In a 1-metre SLR, land loss in the Delta coast accounts for about 4.1% of the total land area in the Study Area. Regarding population, the Barrier coast will face a more severe displacement if sea rises by 1 metre. This is obvious as more than six million people are accounted to live in the Barrier coast with a population density of 1514 per sq. km on the average. The Delta coast will be the most severely impacted in terms of GDP in a 1 m SLR scenario. The reason is down to

the oil extraction activity that goes on in the coast. Indeed Nigeria derives more than 80% of its foreign exchange from its oil reserves. However, the impact that will be experienced in the Barrier coast is also high and similar to that of the Delta coast. The high rate of economic activity in the Barrier coast is responsible for this despite the fact that oil exploration activities are not extensive on this coast. For urban extent, the Barrier coast will be the most severely affected. Indeed, the proportion of urban land area (39%) that will be inundated in a 1-metre SLR is about four times that which will be inundated in the Delta coast (10.3%). No urban land area in the Mud coast and the Strand coast will only be impacted up to about 0.4%.

The results of the agricultural extent in this study should not be taken too seriously, as the spatial dataset's classification is subject to criticism. This is because the total agricultural extent for the area accounts for about 28, 442 sq. km whereas the total land area is just a little short of 40,000 sq. km. From the other analysis conducted, urban extent itself is approximately 1,425 sq. km, and the wetlands extent is approximately 24,621 sq. km. These add up to more than a 100% and so it is impossible for agricultural extent to cover as much as the dataset suggests. Much of the land area that the dataset described as agricultural land are occupied with urban facilities, houses, industries, cities, towns and many other small settlements. For the wetland elements, there is a suspicion that the dataset might have overestimated their extents. This is because the areas covered by swamp and coastal wetland, especially in the Delta coast are occupied by humans, buildings and other rural and urban facilities. However, since wetlands are not necessarily wet all the year round it could be agreed that humans live on these fragile lands. Therefore, there is an explanation why the total amount of land occupied by wetland extent, agricultural extent and urban extent add more than 100%. Regarding wetlands, the Delta coast will be the most severely impacted. The regions

that will be most affected include the outskirts of Port Harcourt, the southern part of Rivers State, nearly half the total wetlands in Bayelsa State and parts of the Delta State.

Inundation analysis due to sea level rise assessment in Nigeria was first carried out in Nigeria by French *et al.* (1995) with the use of the AVVA technique to estimate land loss and population displaced. This research adopted a different technique (GIS) for the assessment by assessing impacts on land, population, GDP, urban extent, agricultural extent and wetland extent. This methodology has been used by Dasgusta *et al.* (2007) to estimate impacts on 84 countries. The difference in this research is that there is focus on the four coastal zones along the Nigerian coastline. This enables a detailed comparative assessment on the effect of sea level rise on the four coasts using GIS.

French *et al.* (1995) made a study to estimate land loss due to inundation for some sea level rise scenarios using the AVVA technique. In comparing the results of the AVVA technique and the results of this study, discussion is made in relation to the Nigerian extent to make value judgements. Comparing this result with the AVVA technique, total land loss to inundation was estimated to be 17,968 sq. km (about 1.9% of the total land area in Nigeria) in a 1 m SLR rise scenario, which is greater than the results of this study. A comparison was made with the study carried out by Dasgupta *et al.* (2007) which estimated the total land that will be lost as a result of inundation in Nigeria to be less than 1% even in a 5 metres sea level rise scenario. The Dasgupta *et al.* approach did not state categorically the impacts of sea level rise on Nigeria, but inference can be drawn from the charts produced that less than 1% of land area in Nigeria will be lost in a 5 m SLR. The Dasgupta *et al.* (2007) result agrees more with the result of this research in that at 1 and 3 metres SLR, only about 0.3% and 0.5% respectively of the total land area will be inundated which when projected to a 5 m SLR scenario, only a

total of 0.9% of the total land area will be inundated. The verdict here is that the AVVA technique overestimated the extent of impact of sea level rise on land because there were large uncertainties with the data used.

Concerning population that will be displaced in the event of accelerated sea level rise, the results of this analysis do not tally with that of the AVVA technique. In a 1 m SLR scenario, the AVVA technique estimates that about 3.6% of the total residents in Nigeria will be displaced in a 1 m SLR. This study on the other hand estimated that only about 0.8% and 1.5% of the total residents in Nigeria would be displaced in a 1 and 3 metres SLR scenario respectively. This is not a case of the AVVA technique to be wrong but a factor that could influence the result is the population dataset that was used. The AVVA technique uses the National population census figures of 1991, which computes the Nigeria population to be 88.5 million. Whereas the population dataset for this research was based on the Gridded Population of the World, which is a projection, made by the United Nations for Nigeria. The computation made put the Nigerian population to be 146.9 million as at 2005. This figure is slightly higher than the population results of the Nigerian census in 2006 (140 million). However, analysing in absolute numbers the total population that the AVVA technique estimated to be displaced in a 1 m SLR scenario was 3.2 million, and the amount that this study estimates to be displaced was approximately 1.2 million, it could be inferred that there is a significant difference in the two estimates. The AVVA technology's estimate was produced prior to 1995 using the 1991 census estimates but population has increased since then, indeed more than 63% of increase was documented for the 2006 census. It is expected that population estimates that will be displaced would have increased. The opposite is the case. This indicates that is not just a matter of different dataset employed that determines the outcome of the AVVA technique estimate. A detailed assessment of

the AVVA technique shows that there are great levels of uncertainties in the tools and the dataset employed. Indeed, the video record could not obtain enough information in the Nigerian coast especially in the Delta coast because of the low gradient of the Nigerian coast. The horizontal accuracy was estimated to be within 100 to 500 metres and the horizontal error in the inundation contours is up to 10km (French *et al.,* 1995).

From the Dasgupta *et al.* (2007) study, it was found that the percentage of the population that will be displaced in Nigeria is less than 1% in a 1 m SLR and less than 2.5% in a 3 metres scenario. This result is closer to the results obtained in this study, hence providing some validity to this research. This research is of the opinion that the AVVA technique overestimated the impact to population in the event of sea level rise, as less people will be displaced. Even though this study predicts less displacement for the sea level rise scenarios, impacts will still be enormous

With increasing population in Nigeria and its coast, the event of accelerated rise in sea levels will have enormous effects on the coastal populace. In terms of the significance of the effects of increasing sea level rise, if sea levels rise to 1 m in the next 2 years compared to the next 10 years, the significance of the effect will be high over the two-year period. This is due to a higher rate of acceleration over the two-year period (about 50 cm per year) than the 10-year period (about 10 cm per year) coupled with increased population. Although population in 10 years' time is expected to be more than in two years' time, a gradual increase in sea levels will give time for the government units and the various stakeholders to prepare for a 1 m SLR in 10 years than if it happens in two years. Presently, most coastal regions are managed under the premise that sea level rise is not significant and in Nigeria, there has not been any formal management to plan for the potentials of rising sea. A one-metre increase in two years will be a shock to the

Nigerian populace since there is virtually no management plan in place to adapt to the potential of rising sea. If the sea levels increased by 1 metre over 10 years, the impact will be less with good management plans, the coastal populace will be able to adapt better than if it happens over a period of two years. However, population will not be stagnant, as it will keep increasing. More population will be at risk over the years as sea levels rises.

The GDP estimates for this study are slightly lower compared to the study carried out by Dasgupta et al (2007). Assessing impacts reveals that about 0.8% of the Nigerian GDP will be inundated in a 3 m SLR. The reasons might be related to the delineation, which was focused on the geomorphologic units along the coastline. It is possible that regions outside of this delineation will be subject to loss of GDP in the event of sea level rise.

For the Urban extent, the urban centres that will be vulnerable to inundation include the Buguma, Abonnema towns in the Delta coast. The suburbs of Port Harcourt will suffer some degree of inundation as those areas are within 1-3 metres elevation. A large amount of urban land will be subjected to inundation in the Barrier coast, as most of the land is low-lying and with heavy rainfalls throughout the month of May and September, which usually results in flooding.

The results of the agricultural extent will be taken lightly in this research, as the data available is inadequate to accurately quantify the land area that agriculture will cover. The spatial data seem to overestimate the extent agriculture cover for the Nigerian coast as virtually the whole (94%) of study area is covered with agricultural elements. The total land area for the Study Area is 39,980 sq. km. From the results of the analysis

conducted, urban land area cover approximately 1,425 sq. km, while the wetland extent is 24, 621 sq. km. The addition of these two elements will mean that the area covered will be 26,046 sq. km and this amounts to about 65% of the total land area in the Study Area. What this indicates that the area that can be covered by agricultural land will be greatly less than 35% of the Study Area. This is because rural areas though not computed in this research occupy more land area than the urban centres. Indeed, the urban centres' land area is about 3.8% of the rural area extent. This will then leave only about 566 sq. km for agriculture for the Nigerian coast. Wetlands will also suffer adverse consequences, as nearly 10% will be inundated in a 1 m SLR scenario.

Some important issues that were taken into consideration in this research include:

- The assessment of sea level rise effects using existing population, socio-economic circumstances and pattern of land use. Impact of sea level rise is not predicted for future states of population. With the rapid increase of population in Nigeria, and more especially in the coastal area, the results here underestimate the future impacts of sea level rise for example when projected to year 2100.

- This case also applies to the GDP because growth rate has been on the increase in recent years. As computed by the Central Intelligence Agency (2011), GDP growth rate increased from 6% in 2008 to 7% in 2009 and to 8.4% in 2010. If this trend continues, then the results of this study will have underestimated the potential impacts to GDP in an accelerated sea level rise for future years.

It is the view of this research that comprehensive baseline estimates of SLR have been provided and validated which will be helpful for the Nigerian government, policy-makers and international development institutions to make plan and allocate resources to adapt to the prospect of sea level rise in Nigeria.

7.2.2.1   Uncertainties of the Inundation model

This study has quantified uncertainties in the elevation data for sea level rise inundation analysis. The understanding of the accuracies of the elevation data is necessary for proper quantitative use (Gesch *et al.,* 2009). This study used the Shuttle Radar Topographic Mission (SRTM) elevation model for its sea level rise assessment. SRTM elevation data was preferred to GTOPO30 in this study because of its broad area coverage and higher resolution. Sea level rise issues have generated wide interest from the public and therefore, there is the need for sea level rise impacts to be communicated with adequate acknowledgement of uncertainties with the data that is being used. This research presented maps and statistical summaries based on the SRTM elevation data.

One of the limitations of the SRTM elevation data is that it has a low resolution and poor vertical accuracy that are poorly suited for detailed inundation mapping. Therefore, the results generated in this study are for general depictions of low elevation zones. Because the SRTM has a relatively coarse spatial detail, it cannot be endorsed for use for production of detailed vulnerability maps. The vertical accuracy of SRTM is low which will not be suitable for detailed analysis. For better accuracy, lidar (light detection and ranging) data are better. Lidar datasets are not available on the global scale and not for Nigeria; this necessitated the use of SRTM elevation data. Lidar elevation data have high resolution with vertical errors of about 15 cm (RMSE) and about 30 cm for standard resolution (ASPRS, 2004). In a comparison between SRTM with vertical accuracy of +/- 6.13 metres used in this study and a standard lidar elevation data with vertical accuracy of +/- 0.3 metres at 95% confidence level shows that the lidar elevation data is far more accurate than the SRTM for all the SLR scenarios. Figure 7.1 shows a graphical representation of SRTM and lidar vertical accuracy using error bars around specified elevations.
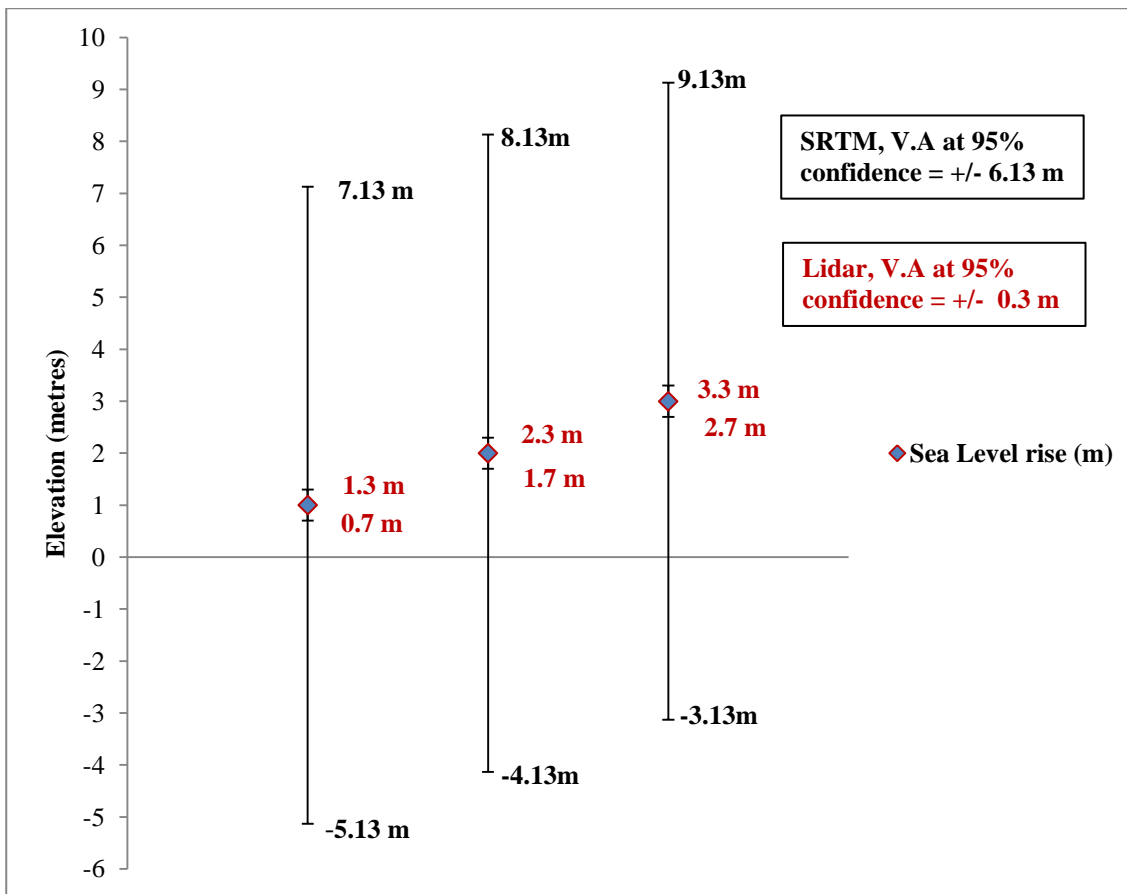
Figure 7.1: Sea level rise scenarios mapped onto land surface using SRTM and lidar elevation models for vertical accuracy (V.A) testing

The lidar elevation model locates the 1-metre elevation to within +/- 0.3 m at 95% confidence meaning that the true elevation falls within the range of 0.7 to 1.3 m whereas the SRTM elevation model with +/- 6.13 m at 95% confidence locates the 1-metre elevation within a range of 0 to 7.13 m. Therefore, for the SRTM elevation dataset, the delineation of potential inundation areas is very large and uncertain in comparison to areas delineated from lidar elevation models. Map 7.3 is an example that shows the land area that will be inundated in a 1m inundation considering the +/- 6.13 metres vertical accuracy of the SRTM dataset. The range for a 1m SLR is 0 to 7.13, but Map 7.3 (can be compared with Map 5.1) can only show inundation area for range 0 to 7 because it vertical intervals is rounded up to whole integers (in this case 1 m increments).
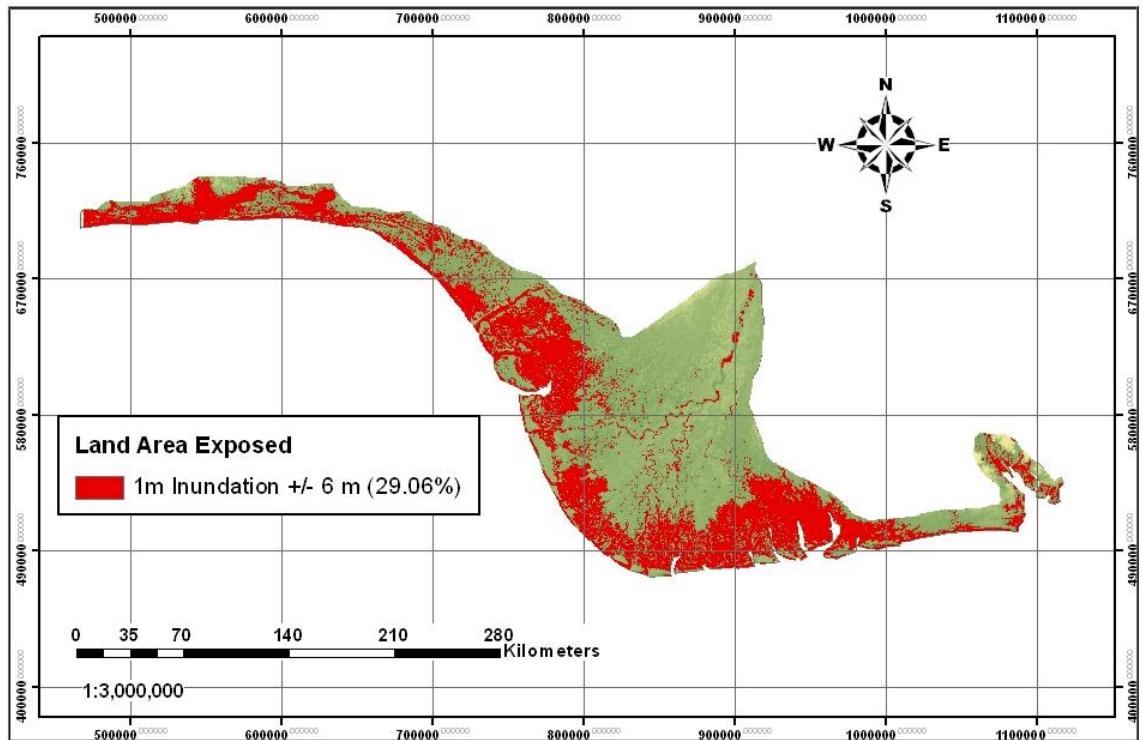
Map 7.3:   **Land Area Extent Exposed in a 1 m (+/-6 m) SLR**

Table 7.3 represents the low and high estimates of a 1m SLR when the SRTM

uncertainty is included.

Table 7.3   Low and High estimate of a 1 m SLR on Land area

Land	Impacted area in a 1 m SLR no uncertainty included	Impacted area in a 1 m SLR when uncertainty of +/- 6 metres is included		% Increase in Vulnerable Area when Elevation Uncertainty is Included
		Low Estimate	High Estimate	
Impacted Area (sq. km)	2,869	2,468	11,593	369%
% of total area	7.2	6.2	29.1	

Another limitation of SRTM elevation data is that it is quantised only to 1m intervals, and therefore sub-metre sea level rise scenario intervals that has been predicted in this century cannot be modelled.

7.3   Coastal Sustainability Evaluation

Communicating coastal information is vital to achieving a sustainable coast. Section 7.2 has adequately dealt with providing information with regards to potential sea level rise on the Nigerian coast and as well validated the results and presented the models employed and the methods used in assessing coastal vulnerability to both erosion and inundation. The coast is a dynamic environment, which therefore needs to integrate the many coastal uses and to develop them in harmony with the environment (Masalu, 2008). This research identified Integrated Coastal Zone Management (ICZM) as a measure to achieve a balanced and sustainable coast. In achieving coastal sustainability, coastal data and information are essential. The need to ensure there is sustainability of the coast usually requires coastal initiatives. However, assessment of many coastal initiatives found they are not even near sustainability in terms of their activities. In the UK, an assessment of three coastal partnerships was carried out to ascertain progress towards sustainability in the coast; none of the coastal partnership were able to achieve the standard achievement mark but they all show evidence of constructive management practices (Gallagher, 2010). The suite of coastal sustainability index termed the 'coastal sustainability standard' (CoSS) developed by Gallagher (2006) was employed for the assessment. This research adopts this same suite of coastal sustainability index (see section 2.6.4). With the numerous coastal problems that exist on the Nigerian coast which also include the potential rise in sea level, it is essential to assess the management practices of the organisations involved or are supposed to be involved in coastal management in the light of coastal sustainability. This will be a starting point in

ensuring coastal sustainability and making advance plans for the inevitable sea level rise situations in the future.

From the various suites of coastal sustainability indicators, this research favoured the systems sustainability assessment for ICZM. The other sets of indicators mentioned in section 2.6.4 are subject to criticism from a number of perspectives, which include their reductionist nature. The coast has been argued to be a unique example where problems should be addressed by systems analysis (Van Der Weide, 1993), therefore the CoSS lends itself to both ICZM and the consideration of coastal sustainability (Gallagher, 2006). Four coastal partnerships (CPs) were examined using this system approach. None of the CPs achieves the standard achievement mark, which might indicate achievement of sustainability according to the standard. There could be many reasons why none could achieve the standard. The argument could be that the CoSS has not been able to reflect accurately ICZM and its aim of achieving sustainable development. The concept of sustainable development has actually been a well debated one and has been termed as a notoriously difficult, slippery and elusive concept (Williams and Millington, 2004). The geographical nature of the concept even though it contains common themes has made it difficult to develop a standard global definition. (O'Riordan, 2000). No matter what the argument against sustainability, it has been seen as an acceptable concept that has surpassed the values of the traditional Environmental Impact Assessment (EIA) and the Strategic Environmental Assessment (SEA) (see section 2.6.3). Since the Rio Declaration, ICZM has received the blueprint in achieving sustainable development in the coast. Sustainability indicators could be said to be a realistic and reasonable approach to measure sustainability. If sustainability has principles that guide it, then it is logical that whatever guides ICZM must be sustainability principles.

An in-depth assessment of the coastal management initiatives in Nigeria suggests that ICZM has not been embraced even though some of the CPs interviewed accept that ICZM is the measure by which coastal sustainability can be achieved. It is surprising to find out that Nigeria, which is one of the countries that ratified the protocols of the Abidjan convention in 1981, is yet to develop a formal ICZM initiative in the country. What are the reasons why Nigeria has not been able to develop an ICZM for the coast? The answer could be diverse and ranging from inadequate laws, policies, political interests, etc. However, some CPs realised the need to sustain the coastal environment, and have structured their goals towards achieving sustainability without specifically declaring their management practices as ICZM. Interviews conducted found out that many of the principles of sustainability are already in operation in the CPs, such as communication of coastal information, and stakeholder participation in decision-making. Indeed PNIN performed well above the standard achievement mark for these two principles in the evaluation conducted.

For the principles adopted in this research, it could be argued that they are specifically derived from a national survey of UK coastal managers and that they are based on the sound normative principles of a geographically specific location. A thorough analysis of the CoSS show that the principles and criteria used are sufficient and proffer themes that represent a thorough appraisal system for sustainable development. Since there is no suite of indicators to assess sustainability in the Nigerian coast, this research adopts the CoSS as a litmus test for the coastal management initiatives in Nigeria. This research is not about developing suites of coastal sustainability indicators for Nigeria. It is about using the best available suite of indicators to evaluate the coastal management initiatives with the view to realise how far the Nigerian initiatives have gone in achieving progress towards coastal sustainability. In addition, the result of this

evaluation could serve as an indication of the lapses in the Nigerian coastal management initiative, allows for the development of corrective measures, and identification of research needs to develop sound normative principles of a geographically specific location for assessing coastal sustainability.

There is a lot to learn from the CoSS. This includes broadly the scoring mechanism of the principles and criteria. There has not been any agreed weighting index incorporated into the criteria therefore all the criteria were judged equal in value just as it was operated in the UK (Gallagher, 2006). Operating the system is an objective of this research. However, there are pertinent issues, which have to do with the accuracy of its operation and how subjective the evaluation is. Gallagher (2006) argued that for any standard used in management appraisal, subjectivity could be an inherent attribute since judgements are based on interpretations of both information and the range of activities. To this end, guidelines to minimise the degree of subjectivity for the purpose of enhancing interpretation of information which were produced for the CoSS were fully adopted. The guidelines include terminologies, examples of the information that could be used to make scoring judgments; its objectivity and transparency also allows for a comparative assessment (Gallagher, 2006).

The results of the assessment indicate that PNIN performed better than all the other CPs on all the principles. PNIN is a non-governmental organisation focused on facilitating participatory development aimed at improving sustainability in the coast. Other areas where PNIN did well include

- creating coastal partnerships,
- creating community development foundations that supports holistic and development planning,

- communicating coastal information,

- ensuring accountability and organising events with regard to identifiable problems which has brought about communication, interaction, involvement and integrating ideas.

These they do efficiently and it distinguishes them from the other CPs. This is evident in their high scores especially in the principle of participation and communication in which it has an average score that shows there is an exceptionally constructive management technique in operation. A major difference to the other CPs is that PNIN started in Brazil as opposed the others that have an indigenous origin. Their voluntary and participatory process approach, which forms the hallmark and is intrinsic to their goal stands out as the propelling force towards their success in the sustainability assessment. Although ICZM is not the basis of its establishment, PNIN has been able to demonstrate with various effort and management practices to achieving a sustainable development for the Nigerian coast. Even in the principles that PNIN was unable to achieve the standard, there was evidence of constructive management going on. This relates more especially to the principle of planning and integration as they nearly achieved the standard. The two criteria that need more immediate actions within the principle of planning include maps that show explicit reference to both natural processes and cultural aspects. The maps are important as it helps with identifying the relevant natural processes and enclosing them at appropriate scales into a management area. According to the 'scale matching' principle (2) of the Lisbon Principles (Costanza *et al.,* 1998), this requirement is seen as an important one.

PNIN and NDWC operate as non-statutory bodies. A legally defined entity should be able to bring more benefit to progressing ICZM because of the powers afforded them to

deal with complex issues like managing the coast. Even though NDDC and FECOZM operate as legal entities, they have not been able to use these powers to the full benefit of the coast. This is noticeable in their failure to regulate the coast effectively (i.e. in terms of the information available, what the information is depicting, how the information is organised and monitored) and the failure to use mechanisms and tools that can deliver action and desired outcomes such as developing Coastal Partnerships. Although, NDDC established the Partners for Sustainable Development, it is clear from the assessment made in this research that it is operating sub-optimally. The reasons are not difficult to identify. Communication is lacking, and participation of all the stakeholders has not been evident in the process.

Neither NDDC nor FECOZM have operated the precautionary approach to a satisfactory level in the absence of scientific proof. There is no explicit statement regarding not using up resources and they have not demonstrated the duty of care on all actions which might be expected. Although FECOZM has applied this principle to the Nypa-Palm project, however for other resources, there is no evidence that the principle is operated. PNIN and NDWC are disadvantaged in the 'polluter pays principle' criterion because they do not have the legal powers to enforce the principle. FECOZM and NDDC should be able to enforce the principle effectively, as gathered in this research but they have not been able to carry out this task to a reasonable level. This is because of corrupt practices that still go on within the "corridors of power" that allows defaulters to go unpunished on several occasions (Personal Communication, 2009). In addition, the lack of vision and adequate planning as regards attaining a sustainable coast has contributed to the poor results of the two CPs in the sustainability assessment. The implication of these in the event of sea level rise is that there will not be adequate mechanisms to adapt which will lead to loss of lives, properties and economic power.

7.4   Conclusion

This Chapter has been able to assess the models used and developed in this research. It begins with validating the parameters of the Bruun model used to ascertain the extent of shoreline shift due to erosion. It then went ahead to validate the methodology used as well as the results which indicate a mild erosion along the Nigerian coast. The research also validated the results of the inundation analysis by comparing it with the results of two previous studies. Impacts of inundation will be significant along the Nigerian coast and could result in very substantial problems in the future. The sustainability assessment was undertaken to ascertain the extent by which CPs in Nigeria have gone towards achieving a sustainable coast and their preparedness for future challenges. The finding is that there is need for corrective actions on many of the management practices within the CPs.

It is thus the view of this research that operating the CoSS as a test in Nigeria could be a stepping-stone into developing the necessary suite of indicators that can be used to routinely assess sustainability in the coast and support the determination of adaptations, which will be required in the future. The standard clearly reflects the relationship between ICZM and sustainable development. Developed countries like the UK have passed through many stages in the development of its coastal management system. As a developing country, it will not be appropriate for Nigeria to undergo all the processes and stages that other developed countries have undergone in the past because of lack of resources and the immediacy of the challenges associated with sea level rise. The better idea is to learn from the experiences of these countries, evaluate them and adopt the best practices they have employed to ensure a sustainable coast and to develop the research base to be able to make available and communicate coastal information more accurately.

In the UK, marine spatial planning (MSP), which will integrate with ICZM and terrestrial planning, has been introduced through the Marine and Coastal Access Act 2009 (DEFRA, 2011). The aim of this is to enable proactive forward planning which integrates economic, social and environmental objectives into a framework that will contribute to sustainable development of the UK's coasts. It has taken decades to reach this point; its implementation has required the creation of a new executive, non-departmental public body, the Marine Management Organisation (MMO). It will be at least 10 years before the first set of plans are complete (DEFRA, 2011). There is a great deal of research on going in many institutions and universities with regards a sustainable coast and marine environment in the UK and even then a key concern of the MMO is whether sufficient information is available (Almada-Villela, 2011).

There has not been tangible research carried out in the coastal zones of Nigeria due to lack of up-to-date technology and there is a reliance on repackaging data and information produced about twenty years ago or more when the technology that was in vogue then which obviously to make decisions on the coastal environment are out-dated. The database of Nigeria is poor and they do not have the resources to obtain them. The sparse data that are available are usually with companies who are not willing to release them for public consumption. This has limited research and meaningful decisions on appropriate interventions in many sectors of Nigeria and on the coastal environment. Resources (financial, expertise etc.) are inadequate which limits the opportunities to acquire relevant technological and managerial capacity especially in the highly skilled sectors. Up-to-date information with appropriate methodology and technology are to be incorporated into a system of ICZM if a sustainable coast is to be achieved along the Nigerian coast in the light of rising sea levels.

CHAPTER EIGHT

8.0 Conclusion

8.1 Introduction

This Chapter reviews the aim and objectives in terms of the findings. It will draw conclusions on the extent of vulnerability of the Nigerian coast to erosion and inundation, the models employed to predict vulnerability, and on the sustainability assessment, which evaluates four case studies. The Chapter will proceed to make recommendations concerning the findings of this study, the contribution to knowledge and noting the area for potential research.

8.2 Conclusions

About the models used for sea level rise assessment and sustainability appraisal, these conclusions can be drawn from the research:

8.2.1 Sea Level Rise

- The Bruun model is not adequate for predicting shoreline erosion; however, it gives an estimate that can be used to plan for the eventualities of erosion pending the availability of an appropriate model.

- With the use of the Bruun model, results indicate that the impact of erosion in response to sea level rise will not be severe along the Nigerian coastline for the sea level rise scenarios considered.

- The Bruun model's parameters have associated uncertainties, which could lead to range of modelled results.

- A Geographic Information System (GIS) has been useful in the sea level rise analysis to ascertain inundation zones for the critical elements considered in this study. This method overcomes the several shortcomings of previous sea level rise analyses in Nigeria. GIS was used to delineate the areas that have the potential to be inundated, to calculate total land area of the potentially inundated zones, to estimate the population at risk, and to estimate the gross domestic product that will be lost in the inundation zones. In addition, the method aids in assessing sub-areas, which include urban land, agricultural land, and wetlands that have the potential to be inundated along the Nigerian coast. With the aid of GIS, inundation maps were produced to display the zones that are vulnerable to inundation.

- Elevation data are fundamental to the inundation analysis in this study. The analysis in this study was performed with the best datasets available for Nigeria. This research used GIS to perform geoprocessing activities on the datasets to develop inundation models. GIS as used in this study helped to automate workflow, share geoprocessing knowledge, and ensures that proper records of workflow and methodology is well documented. In addition, the models serve as a technique in which the geoprocessing activities of this research were validated.

- This research acknowledges that greenhouse gas (GHG), thermal expansion and deglaciation could raise sea levels more than the nearly 1 metre proposed by IPCC. Indeed sea levels could rise to 3 metres by the end of this century (Dasgupta *et al.,* 2007), which will lead to high magnitudes of inundation in coastal areas. This necessitated that this research consider higher sea level rise

scenarios. Therefore, there is the need for adequate planning for adaptation to minimise the effects of sea level rise.

- The SRTM elevation model has a wide range of uncertainty thereby producing a large range of results.

8.2.2 Coastal Sustainability Assessment

Section 8.1 demonstrated the vulnerability of Nigeria, its population, land area and businesses reflected in terms of GDP to sea level rise. To tackle this, there must be a formal management mechanism, which can be an Integrated Coastal Zone Management (ICZM) approach. This research views ICZM as the best way to manage the coast and ensure its sustainability. ICZM involves integrating issues and processes of the land and sea, and harmonising policies and decision-making structures to encourage purposeful and concentrated action through a well-detailed course and alternative courses of actions to achieve detailed ends. This research accepts that ICZM is a valuable approach to coastal sustainability. This approach includes all necessary institutions and policies so that in the case of a natural hazard just like sea level rise, the coastal dwellers will be able to adapt.

- The research did not probe into developing an ICZM plan, but assessed organisations and/or coastal partnerships (CPs) in Nigeria concerned with management practices towards achieving the goal of ICZM. The litmus test employed is a systems sustainability appraisal known as the coastal sustainability standard.

- The study found that there has not been concerted action to progress ICZM in Nigeria despite it being one of the few countries that ratified the protocols of the Abidjan Convention in 1981. Piecemeal approaches exist for managing the coast but these approaches do not ensure sustainability. Various government bodies were set up to deal with coastal issues, but most of these organisations are not aware of the best way to manage the coast. Indeed, there is duplication of duties and conflicting responsibilities among the organisations.

- The result of the sustainability appraisal shows that none of the case studies could achieve the standard achievement mark. Despite failing the sustainability assessment, two of the case studies, which are voluntary organisations, performed better than the two government organisations. The performance of the CPs in terms of failing the assessment was expected, as there is limited coordinated or joint responsibility, or collective liability and there is inadequate desire especially for the government establishments to adopt the principles of sustainability in their management practices.

- As described in section 7.3, the management practices in the Coastal Partnerships are in need of attention and corrective measures. Nigeria has not formally embraced ICZM, and the Coastal Partnerships do not have the necessary guidance as regards to their operations to achieve sustainability in the coast. However, whilst the concept of sustainability is fuzzy the aim of the coastal zone management initiative in Nigeria is to attain a sustainable coast.

8.3   Contribution of this research to knowledge

Research into assessing the vulnerability of the Nigerian coastal zone to sea level rise is sparse. This study has been able to compute the impact that erosion and inundation will have on the extent of Nigerian coast, with verifiable data with regards its uncertainties. With the aid of the Bruun rule, this research demonstrates that consequences of erosion would be mild across the Nigerian coast, which is contrary to previous results because of large errors and uncertainties with the data. However, the impacts of inundation will be severe. This research has been able to identify the regions that will experience high and low erosion, as well as inundation, along the Nigerian coast with the aid of charts and maps. In addition, the inundation models developed in this study with the aid of GIS aid the workflow and documents all the processes undertaken. This methodology will be useful for users to simulate sea level rise scenarios in the future to produce vulnerability maps for the phenomena of interest. Uncertainties in the parameters of the Bruun model were accounted for likewise for the elevation dataset which were represented by error bars.

With the inevitability of coastal hazards which will arise due to sea level rise, this research evaluates the coastal management initiatives in Nigeria based on a suite of coastal sustainability indices. The appraisal system, which reflects the relationship between ICZM and sustainable development, allows for a review of management success over time, and it was able to identify areas that are in need of corrective measures. This is the first assessment of coastal management initiatives for the purpose of coastal sustainability in Nigeria. The appraisal system is applicable to Nigeria, and could serve as a foundation to developing a more geographically related appraisal system, which could be incorporated into an ICZM plan for Nigeria. Operating the appraisal system represents a learning experience for those involved in its

implementation, as Nigerian coastal managers will be able to develop new skills, which will enhance their professional roles.

8.4   Recommendations

With predictions of accelerated rise in sea levels in this century with the associated consequences highlighted in this research, recommendations are proposed with the view to more sustainable actions to ensure the coastal population can adapt to changing and rising sea levels. The recommendations are as follows:

- A major limiting factor in this study is the lack of coastal data. Advances in coastal data and information, which benefits scientific knowledge, should be made available through research. With the value of coastal data, which include forecasting, implementation of maritime and other coastal activities, etc. there should be adequate funding for this type of research. Data needed for sea level rise analysis include historical analysis of shoreline evolution, wave data for the whole coast, shoreface cross-section data, topographic data, high accuracy elevation dataset for detailed inundation assessment, and other sets of data that will be valuable in determining the vulnerability of the coast.

- High accuracy topographic and elevation datasets are necessary for sea level rise assessments to ensure accurate assessment. Lidar datasets - a cost-effective data collection over broad coastal areas - are the best for elevation information, as this provides highly detailed, accurate data over extensive areas, which is useful for sea level rise analysis and other applications. With Lidar data, sea level rise effects for scenarios less than 1 metre can be simulated.

- For a more detailed vulnerability analysis, elevation uncertainty information should be applied to give a range of values for an inundation zone for a given sea level rise scenario. Measuring the uncertainties for sea level rise assessment

293

is a challenging task, as many sea level rise studies have not reported vulnerability for a given scenario by a range of values based on the uncertainties of the dataset used. Therefore, experts need the capabilities of producing detailed reports with ranges to depict uncertainties. This will allow the users to understand values reported for zones inundated especially with data of low accuracy.

- Data management and archiving should be embraced. This will encourage the ease of coastal information dissemination for researchers and coastal stakeholders. Important issues in data management include data control, integrity of the dataset, and a clear methodology for data update, documentation and metadata among others. Methods for data collection and derivations of coastal information are to be well documented, as this will allow users to be able to take advantage of and appreciate the work done.

- ICZM would be a useful improvement in Nigeria to coordinate and integrate all the coastal initiatives, measures, policies, and institutions into a single unit to achieve a targeted goal – coastal sustainability.

- A coastal sustainability assessment such as carried out in this research should be adopted in Nigeria for Coastal Partnerships or government organisations involved in coastal management. To satisfy the geographical requirement of sustainability, Nigeria should develop a standardised appraisal system to identify the constructs of sustainability.

8.5 Further Research

This study has identified some lines of research that will add more to the knowledge of coastal vulnerability to sea level rise and sustaining the coast. These are as follows:

- Further research should estimate erosion in the Mud coast. There has not been any research to estimate erosion on the coast except for one or two sites within the coast. The result for these sites were published in 1988 and since then there has not been any other work to validate this or compare it with the present situation.

- Further research should be conducted into applying a different methodology/model from the Bruun model. This might involve the incorporation of different models such as the historical trend extrapolation, the sediment budget, the coastal vulnerability index and even probabilistic frameworks rather than deterministic models.

- A major dataset that serves one of the parameters for the Bruun model is the significant wave height obtained from a wave record. New studies should focus on minimising the errors associated with the collection of these types of data to prove the reliability of the predictions that will be made as well as limit the uncertainties associated. Other data that was found important in this study is the width of the profile shoreface. Uncertainties relating to its measurement need to be minimised.

- There are a number of possible responses to sea level rise and inundation is one (Leatherman, 2001; FitzGerald *et al.*, 2008). A research that focuses on recognising the complex nature of coastal change in Nigeria preceding a sea level rise assessment will be valuable as regards the effect of sea level rise on coastlines. This is because with the same sea level rise scenario, a coastal stretch might not experience the same impact as another.

- New studies on assessing the effect of inundation in a sea level rise assessment should be based on high resolution and high accuracy lidar elevation data for

detailed assessment. Lidar data have the capability to make precise measurements even in areas with small slopes (Gesch *et al.* 2009).

- Further studies either for shoreline retreat assessment or inundation analysis should report the extent of its uncertainties through mapping and statistical summaries. With regards inundation analysis, it will be valuable if the vertical accuracy, which is a measure of uncertainty, is clearly stated and highlighted in the vulnerability maps and statistical summaries. This uncertainty in the input elevation data can be incorporated into the development of sea level rise assessment maps (Gesch et al 2009). By doing this, the overall vertical error will be accounted for through vulnerability maps that will indicate areas of uncertainty. An example of this was carried out in section 7.2.2.1.

- A valuable research will be to estimate loss of ecosystem due to sea level rise and to express the loss in monetary value. An ecosystem approach coupled with GIS will be useful in conducting this type of research. In addition to this, research that focuses on impact of sea level rise on the coast with certain measure or levels of coastal protection or the comparison between a protected coast and a coast that is not protected will be vital.

- Lastly, concerning ensuring sustainability of the coast in the light of rising sea levels, research can focus on developing an ICZM framework for Nigeria. This will involve the development of a sustainability appraisal system, which is geographic specific. This type of research could look at the various coastal management policies in Nigeria; identify the policies that are in operation and the ones that are not operating well. This will require the evaluation of their significance to ensuring a sustainable coast. The research could also propose policies that will be relevant for ICZM in Nigeria.

REFERENCES

Abbott, V., Popoola, O. and Glegg, G. 2011. Policy with Sparse Data. *Marine Policy (Submitted for publication).*

Akinboade, L. 2011. Lagos flood, most devastating - National Emergency Management Agency. *Vanguard* *http://www.vanguardngr.com/2011/07/lagos-flood-most-devastating-%E2%80%93-nema/*.

Akoni, O., Usman, e. and Olowopejo, M. 2011. Lagos flood kills 25. *Vanguard, http://www.vanguardngr.com/2011/07/lagos-flood-kills-25/*.

AllAfrica, 2011. Lagos Government to kick-off new housing scheme, 23 May, 2011. http://allafrica.com/stories/201105241570.html

Almada-Villela, P., 2011: Coastal Data Access. A talk given at the Marine coastal Policy Forum, University of Plymouth. June 22-24.

Anderson, K. E., Cahoon, D., Gill, S. K., Gutierrez, B. T., Thieler, E. R., Titus, J. G. and Williams, J. S. 2009. Executive Summary. *Coastal Sensitivity to Sea- Level Rise: A Focus on the Mid-Atlantic Region.* Washington D.C., USA.

Andrade, F. and Ferreira M.A. 2006. A simple method of measuring Beach Profiles. *Journal of Coastal Research*. (22): 995–999.

Andrews, K.S., Dacunha, N.M.C., and Hogben, N. (1983). 'Wave Climatic Synthesis', NMI Report No. R149, London.

Anthoff, D., Nicholls, R. J., Tol RSJ., and Vafeidis, A. 2006. Global and regional exposure to large rises in sea-level: A Sensitivity Analysis. Working paper 96. Tyndall Centre for Climate Change Research. Available: http://www.tyndall.ac.uk/sites/default/files/wp96_0.pdf

Arnstein, S. R. 1969. A Ladder of Citizen Participation. *JAIP,* 35 (4)**,** 216-224.

ASPRS Lidar Committee, 2004. Vertical Accuracy Reporting for Lidar Data *ASPRS Guidelines*. Ed. Flood, M.

http://www.asprs.org/a/society/committees/lidar/Downloads/Vertical_Accuracy_Reporting_for_Lidar_Data.pdf

Awosika LF, Folorunsho R, Dublin-Green CO and Imevbore VO 2000. Review of the coastal erosion at Awoye and Molume areas of Ondo State. Chevron Nigeria Ltd.

Beatley, T., Brower, D. J. and Schwab, A. K. 2002. *An Introduction to Coastal Zone Management,* Washington, D.C, Island Press.

Beckley, B.D., Lemoine, F.G., Luthcke, S.B., Ray, R.D., Zelensky, N.P. 2007. A reassessment of global and regional mean sea level trends from TOPEX and Jason-1 altimetry based on revised reference frame and orbits. Geophysical Research Letters 34:L14608

Bell, S. and Morse, S. 2008. *Sustainability Indicators: Measuring the Immesurable?,* London, Earthscan.

Blenford, A. 2005. New Orleans: Nature's revenge? BBC News, http://news.bbc.co.uk/1/hi/world/americas/4201060.stm#.

BMT Fluid Mechanics 2010. Global Wave Statistics Online. http://www.globalwavestatisticsonline.com/index.html.

Bond, A. and Morrison-Saunders, A. Year. Transition Challenge for Sustainability Assessment. *In:* International Association for Impact Assessment, 2010 Geneva, Switzerland.

Bookman, C. A., T. J. Culliton and Warren, M. A. 1999. Trends in U.S. Coastal Regions, 1970-1998. Addendum to the Proceedings, Trends and Future Challenges for U.S. National Ocean and Coastal Policy. Silver Spring, U.S. Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA).

Bossel, H. 1999. Indicators for Sustainable Development: Theory, Method, Applications. A report to the Balaton Group. International Institute for Sustainable Development.

Brooks, N., Hall, J. and Nicholls, R. J. 2006. Sea-Level Rise: Coastal Impacts and Responses. Norwich, Berlin: WGBU.

Brown, E., Park, D., Philips, J., Rothery, D. and Wright, J. 1999. *Waves, Tides and Shallow-water Processes,* Walton Hall, Milton Keyness, England, Butterworth and Heinemann, in Association with The Open University, 2nd edition.

Bruun, P. 1962. Coastal erosion and the development of beach profiles. . *Journal of Waterways and Harbors Division* 88:**,** 117–130.

Bruun, P. 1988. The Bruun Rule of erosion by sea-level rise: a discussion of large-scale two- and three-dimensional usages. *Journal of Coastal Research,* 4**,** 627-648.

Bryn Mawr. 2011. *Schematic diagram of the Depth of Beach Profile Closure* [Online]. Pennsylvania. Available:

http://www.brynmawr.edu/geology/geomorph/Closure_depth.html [Accessed 15 September 2011].

Burke, L., Kura, Y., Kassem, K., Revenga, C., Spalding, M. and Mcallister, D. 2001. Pilot Analysis of Global Ecosystems: Coastal Ecosytems. Washington, DC: World Resources Institute.

Capra, F. 1996. *The Web of Life: A New Scientific Understanding of Living Systems* London, Anchor Books; 1 Anchor edition

CEDA (Centre for Environment and Development in Africa) 1997. Coastal Profile of Nigeria. *In:* Federal Environmental Protection Agency (ed.). Nigeria: Center for Environment and Development in Africa.

CIA (Central Intelligence Agency). 2011. *The World FactBook: Nigeria GDP* [Online]. Available: https://www.cia.gov/library/publications/the-world-factbook/fields/2003.html [Accessed 2011].

CIAT (International Centre for Tropical Agriculture) 2005. SRTM 90 m DEM data Version 2. http://gisweb.ciat.cgiar.org/sig/90 m_data_tropics.htm.

CIESIN and CIAT (The Center for International Earth Science Information Network and International Centre for Tropical Agriculture) 2005. Gridded Population of the World (GPW), Version 3. 2005 ed.: Socioeconomic Data and Applications Center (SEDAC), Columbia University, Palisades, NY, http://sedac.ciesin.columbia.edu/gpw/.

CIESIN and IFPRI (The Center for International Earth Science Information Network, International Food Policy Research Institute) 2005. Global Rural-Urban Mapping Project (GRUMP), Alpha Version. Socioeconomic Data and Applications Center (SEDAC), Columbia University, Palisades, NY, http://sedac.ciesin.columbia.edu/gpw/

Cicin-Sain, B. and Knecht, R. W. 1998. *Integrated Coastal and Ocean Management: Concepts and Practices.,* Washington, D.C, Island Press.

Ci: grasp (Climate Impacts: Global and Regional Adaptation Support Platform), 2010: Rural and Urban GDP at risk (India, 1 m SLR) http://cigrasp.pik-potsdam.de/maps/rural-and-urban-gdp-at-risk-india-1m-slr

Clark, J. R. 1998. Coastal Zone Management for the new century. *Ocean and Coastal Management,* 37**,** 191-216.

Clayton, A. and Radcliffe, N. 1996. *Sustainability: A systems Approach,* London, Earthscan.

CMEPSP 2009. *Report of the Commission on the Measurement of Economic Performance and Social Progress*, September 14 2009. http://www.stiglitz-sen-fitoussi.fr/en/index.htm

Connolly, N., O'Mahony, C., Buchanan, C., Kay, D., Buckley, S. and FEWTRELL, L. 2001. Assessment of Human Activity in the Coastal Zone. *Report on research project conducted by the Coastal Resources Centre, University College Cork and the Centre for Research into Environment and Health, University of Wales under the Maritime Ireland / Wales INTERREG II Programme, 2001.*

Convention on Biological Diversity. 1992. *Ecosystem Approach* [Online]. Available: http://www.cbd.int/ecosystem/ [Accessed 23 September 2011].

Cooper, J. A. G. and Pilkey, O. H. 2004. Sea-level rise and shoreline retreat: time to abandon the Bruun Rule. *Global and Planetary Change,* 43**,** 157-171.

Costanza, R., D'Arge, R., Groot, R. D., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P. and Belt, M. V. D. 1997. The value of the world's ecosystem services and natural capital. *Nature,* 387**,** 253 - 260.

Costanza, R., Andrade, F., Antunes, P., van den Belt, M., Boersma, D.,. Boesch, D. F., Catarino, F., Hanna, S., Limburg, K., Low, B., Molitor, M., Pereira, JG., Rayner, S., Santos, R., Wilson J. and Young, M. 1998. Principles for Sustainable Governance of the Oceans. *Science,* 281, 198 (1998).

Cowell, P. J., P.S. Roy and Jones, R. A. 1992. Shoreface translation model: computer simulation of coastal-sand-body response to sea level rise. *Mathematics and Computers in Simulation,* 33 (5-6)**,** 603-608.

Creswell, J. W. 2003. *Research Design; Qualitative, Quantitative and Mixed Method Approaches,* London, Sage.

Crooks, S. and Turner, R. K. 1999. Integrated coastal management: sustaining estuarine natural resources. *Advances in Ecological Research,* 29.

Crossett, K. M., Culliton, T. J., Wiley, P. C. and Goodspeed, T. R. 2004. Population Trends Along the Coastal United States: 1980 - 2008. *Coastal Trends Report Series.* National Oceanic and Atmospheric Administration.

Cummins, V., Mahony, C. J. and Connolly, N. 2005. Review of Integrated Coastal Zone Management and Principals of Best Practice. Cork, Ireland: Coastal and Marine Resources Centre, Environmental Research Institute, University College Cork.

Curtis, K.J. and Schneider, A. 2011. Understanding the demographic implications of climate change: estimates of localized population predictions under future scenarios of sea-level rise *Population & Environment* (33) 28-54

Dacunha, N.M.C., Hogben, N., and Andrews, K.S. 1984. 'Wave Climate Synthesis World-wide', Proceedings of International Symposium on Wave and Wind Climate World-wide, RINA London.

Dalal-Clayton, B. and Krikhaar, F. 2007. A New Sustainable Development Strategy: An opportunity Not To Be Missed. *The Netherlands Sustainable Development Strategy.*

Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D. and Yan, J. 2007. The Impact of Sea Level Rise on Developing Countries: A Comparative Analysis. *World Bank Policy Research Working Paper 4136.* Washington D.C.

Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D. and YAN, J. 2009. The impact of sea level rise on developing countries: a comparative analysis. *Climate Change,* 93**,** 379-388.

Dawe, N. K. and Ryan, K. L. 2003. The Faulty Three-Legged-Stool Model of Sustainable Development. *Conservation Biology,* 17 (5)**,** 1458-1460.

De Graaf, R. E. 2008. Reducing flood vulnerability of urban lowland areas. *11th International Conference on Urban Drainage.* Edinburgh, Scotland, UK.

Dean, R. G. and Dalrymple, R. A. 2002. *Coastal Processes with Engineering Applications,* New York, Cambridge University Press.

Dean, R. G. and E.M. Maurmeyer 1983. Models of beach profile response. *In:* Komar, P. D. (ed.) *CRC Handbook of Coastal Processes.* CRC Press, Boca Raton, FL, pp. 151-165.

DEFRA (Department for Environment, Food and Rural Affairs) 2005. Securing the Future: delivering UK sustainable development strategy. London.

DEFRA (Department for Environment, Food and Rural Affairs) 2010. Integrated Coastal Zone Management. Department for Environment, Food and Rural Affairs. http://www.defra.gov.uk/environment/marine/protect/iczm/.

DEFRA, (Department for Environment, Food and Rural Affairs) 2011: A description of the marine planning system for England. DEFRA, London.

Dennis, K. C., Niang-Diop, I. and R.J, N. 1995a. Sea-Level Rise and Senegal: Potential impacts and consequences. *Journal of Coastal Research,* Special Issue No 14**,** 243-261.

Dennis, K. C., Schnack, E. J., Mouzo, F. H. and Orona, C. R. 1995b. Sea-Level Rise and Argentina: Potential Impacts and Consequences. *Journal of Coastal Research,* Special Issue No 14**,** 205-223.

Denscombe, M. 2007. *The Good Research Guide: For small-scale social research projects,* New York, Open University Press.

Demirkesen, A.C., F. Evrendilek, S. Berberoglu, and S. Kilic, 2007. Coastal flood risk analysis using landsat-7 ETM+ imagery and SRTM DEM: A case study of Izmir, Turkey. *Environmental Monitoring and Assessment*, 131(1-3), 293-300.

Demirkesen, A.C., F. Evrendilek, and S. Berberoglu, 2008: Quantifying coastal inundation vulnerability of Turkey to sea-level rise. *Environmental Monitoring and Assessment*, 138(1-3), 101-106.

Earll, B. 2005. Putting sustainability into practice. *In:* Smith, H. D. and Potts, J. S. (eds.) *Managing Britain's Marine and Coastal Environment: Towards a Sustainable Future.* Oxford: Routeledge.

Easterby-Smith, M., Thorpe, R. and Lowe, A. 2002. *Management Research: An introduction,* London, Sage.

Encora 2009. The Coastal Zone. *Coastal Portal* [Online]. Available: http://www.coastalwiki.org/coastalwiki/The_Integrated_approach_to_Coastal_Zone_Management_(ICZM)#Evolution_of_Coastal_Zone_Management_practices [Accessed June 2011].

Ericson, J.P., C.J. Vorosmarty, S.L. Dingman, L.G. Ward, and M. Meybeck. 2006. Effective sea-level rise and deltas: causes of change and human dimension implications. *Global and Planetary Change*, 50(1-2), 63-82.

ESRI (Environmental Systems Research Institute) 2005-2008. Geoprocessing with ArcGIS Desktop: Getting Started with Geoprocessing. *ESRI Training Course.* http://training.esri.com/gateway/index.cfm.

ESRI (Environmental Systems Research Institute) 2009. ESRI Data, Country 92. *ArcGIS 9.3.1.* Redlands, USA.

European Commission 1999. Lessons from the European Commission's Demonstration Programme on Integrated Coastal Zone Management (ICZM). *In:* Office for Official Publications of The European Communities (ed.). Luxembourg: ec.europa.eu/environment/iczm/pdf/vol2.pdf.

European Commision. 2001. EU Focus on Coastal Zones: Turning the Tides for Europe's Coastal Zones. Environment Nuclear Safety and Civil Protection Luxembourg: EUR-OP.

European Commission 2002. Recommendation of the European Parliament and of the Council of 30 May 2002 Concerning the Implementation of Integrated Coastal Zone Management in Europe. *Official Journal of the European Communities,* 2002/413/EC.

FAO (Food and Agriculture Organisation) 2006. Integrated coastal management law: Establishing and strengthening national legal frameworks for integrated coastal management. *FAO Legislative Study 93.*

Federal Ministry of Environment 2005a. National Erosion and Flood Control Policy. Federal Ministry of Environment, Abuja, Nigeria. pp 41.

Federal Ministry of Environment 2005b. Technical Guidelines on Soil Erosion, Flood and Coastal Zone Management. Federal Ministry of Environment, Abuja, Nigeria. pp38.

Field, C. B., L. D. Mortsch, M. Brklacich, D. L. Forbes, P. Kovacs, J. A. Patz, S. W. Running, and M. J. Scott. 2007. North America. Pages 617-652 *in* M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, editors. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Firn Crichton Roberts Ltd and Graduate School of Environmental Studies University Of Strathclyde 2000. An assessment of the socio-economic costs and benefits of integrated coastal zone management. EU Demonstration Programme on Integrated Management in Coastal Zones 1997-1999 Luxembourg: ec.europa.eu/environment/iczm/pdf/socec_en.pdf.

Fitzgerald, D. M., M.S. Fenster, B.A. Argow and I.V. Buynevich 2008. Coastal impacts due to sea-level rise. *Annual Review of Earth and Planetary Sciences,* 36**,** 601-647.

Fletcher, S., Smith, H.D. 2007: Geography and Coastal Management. *Coastal Management*, 35: 419-427.

Fonteh, M., Esteves, L. S. and Gehrels, W. R. 2009. Mapping and valuation of ecosystems and economic activities along the coast of Cameroon: implications of future sea level rise. *Coastline Reports,* (13) 47-63.

Françoise Breton, Clive Gilbert, Xavier Marti and Working Group-Indicators and Data 2006. Report on the use of the ICZM indicators from the WG-ID: A contribution to the ICZM evaluation, Version 1. Barcelona: European Topic Centre Terrestrial Environment

http://ec.europa.eu/environment/iczm/pdf/report_wgid.pdf.

Frankfort-Nachmias, C. and Nachmias, D. 1996. *Research Methods in the Social Sciences,* London, Hodder Education.

French, G. T., Awosika, L. F. and Ibe, C. E. 1995. Sea-Level Rise in Nigeria: Potential Impacts and Consequences. *Journal of Coastal Research,* Special Issue No 14**,** 224-242.

Fuller, K. Year. Impact Assessment for sustainable development report: IAIA output report WS07. Conference of the International Association for Impact Assessment, 2002.

Gallagher, A. W. 2006. *Sustainability Systems Appraisal for Integrated Coastal Zone Management.* PhD, Nottingham Trent University and Southampton Solent University.

Gallagher, A. W. 2010. The coastal sustainability standard: A management systems approach to ICZM. *Ocean and Coastal Management,* 53 (2010)**,** 336-349.

Gallagher, A. W., Johnson, D., Glegg, G. and Trier, C. 2004. Constructs of Sustainability in Coastal Management. *Marine Policy,* 28 (2004)**,** 249-255.

Gaunt, C., Gudnadottir, E. and Waring, L. 2006. The Handy Guide to Planning. London: Urban Forum.

George, C. 2001. Sustainability appraisal for sustainable development: integrating everything from jobs to climate change. *Impact Assessment and Project Appraisal,* 19 (2)**,** 95-106.

Gertz, E. 2008. Fifteen years after the Great Flood of 1993, floodplain development is booming. *Grist, http://www.grist.org/article/gertz2*. (accessed 20 May 2011).

GESAMP 1996. The Contributions of Science to Integrated Coastal Management. *Reports and Studies, no 61.*

GESAMP (Group of Experts on the Scientific Aspects of Marine Environmental Protection) 2001. Protecting the Ocean from Land-Based Activities: Land-based sources and activities affecting the quality and uses of the marine, coastal and associated freshwater environment. UN, UNEP, FAO, UNESCO-IOC, WHO, WMO, IMO, IAEA.

Gesch, D.B., K.L. Verdin, and S.K. Greenlee, 1999. New land surface digital elevation model covers the earth. *EOS, Transactions of the American Geophysical Union*, 80(6), 69-70.

Gesch, D.B., 2009. Analysis of Lidar elevation data for improved identification and delineation of lands vulnerable to sea level rise. Journal of Coastal Research SI (53) 49-58.

Gesch, D. B., Gutierrez, B. T. and Gill, S. K. 2009. Coastal Elevations. *In:* Titus, J. G. (ed.) *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region* Washington DC: A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [J.G. Titus (coordinating lead

author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]. U.S. Environmental Protection Agency.

Gibson, R. B. 2001. Specification of sustainability-based environmental assessment decision criteria and implications for determining "significance" in environmental assessment. Available: http://static.twoday.net/NE1BOKU0607/files/Gibson_Sustainability-EA.pdf [Accessed 12 June, 2011].

Gilbert, C. and Pickaver , A. H. 2005. Measuring sustainable use of the coast. *In:* EARLL, B. (ed.) *Coastal Futures 2005: Review and Future Trends.* Ross-on-wye: Coastal Management for Sustainability.

Gill, S. K., Marcy, D. and Johnson, Z. 2009. Coastal Flooding, Floodplains, and Coastal Zone Management Issues. *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region.* Washington D.C: A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]. U.S. Environmental Protection Agency, pp. 123-138.

Gill, S.K., Wright, R., Kafalenos, R., Wright, K. 2009. Population, Land Use, and Infrastructure. *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region.* Washington D.C: A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]. U.S. Environmental Protection Agency, pp. 105-116.

Glavovic, B. C. 2006. Coastal Sustainability—An Elusive Pursuit?: Reflections on South Africa's Coastal Policy Experience. *Coastal Management,* 34**,** 111-132.

Glick, P., Clough, J. and Nunley, B. 2008. Sea-Level Rise and Coastal Habitats in the Chesapeake Bay Region. *National Wildlife Federation*, Washington D.C, 121 pp www.vcnva.org/anx/ass/library/23/sealevelrisereport.pdf.

Global Finance, 2011. Nigeria Country Report: GDP data and GDP forecasts; economic, financial and trade information; the best banks in Nigeria; country and population overview. http://www.gfmag.com/gdp-data-country-reports/207-nigeria-gdp-country-report.html#axzz1j3plvuGQ

Google Earth (2010): Google Earth Release Notes / Changelog History".

Gutierrez, B. T., S.J. Williams and Thieler, E. R. 2009a. Appendix 2: Basic approaches for shoreline change projections. *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region.* Washington DC: A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]. U.S. Environmental Protection Agency, pp. 239-242.

Hallermeier, R. J. 1981. A profile zonation for seasonal sand beaches from wave climate. *Coastal engineering,* 4**,** 253-277.

Hands, E. B. 1983. The Great Lakes as a test model for profile responses to sea level changes. *In:* Komar, P. D. (ed.) *Handbook of Coastal Processes and Erosion.* Boca Raton, FL: CRC Press, pp. 167-189.

Hanna, E., Huybrechts, P., Janssens, I., Cappelen, J., Steffen, K. and Stephens, A. 2005. Runoff and mass balance of the Greenland Ice Sheet: 1958-2003. *Journal of Geophysical Research,* 110.

Hannelore, M., Belpaeme, K., Lescrauwaet, A.-K. and Mees, J. 2006. Indicators as guides for Integrated Coastal Zone Management. [Accessed June 2011].

Hallegatte, S, 2011. SR17: The economic growth impact of sea level rise. *Migration and Global Environmental Change*. Sustainable Development Network, the World Bank.

http://www.bis.gov.uk/assets/bispartners/foresight/docs/migration/science-reviews/11-1136-sr17-economic-growth-impact-of-sea-level-rise

Hastings, D.A. and P.K. Dunbar, 1998. Development and assessment of the Global Land One-km Base Elevation digital elevation model (GLOBE). *International Archives of Photogrammetry and Remote Sensing*, 32(4), 218-221.

Hewawasam, I. 2002. Managing the Marine and Coastal Environment of Sub-Saharan Africa: Strategic Directions for Sustainable Development. *Directions in Development*. Washington, D.C.: The International Bank for Reconstruction and Development/The World Bank.

Hinrichsen, D. 1998. *Coastal Waters of the World: Trends, Threats, and Strategies,* Washington, DC, Island Press.

Hodgson, M. E. Jensen, J. R. Schmidt, L. Schill, B. 2003. Davis, *Remote Sensing of Environment* 84, 295

Hogben, N., Dacunha, N.M.C., and Andrews, K.S. 1983. 'Assessment of a New Global Capacity for Wave Climate Synthesis' Proceedings of OCEANS '83. San Francisco Publishers, IEEE, New York.

Hogben, N. and Dacunha, N.M.C, 1985. 'Wave Climate Synthesis: Some Recent Advances', Proceedings of the Offshore Technology Conference, Paper No. OTC 4938. OTC, Houston, May.

IAIA (International Association for Impact Assessment). 2002. Strategic environmental assessment performance criteria.

http://www.apho.org.uk/resource/item.aspx?RID=85481. [Accessed 10 June, 2011].

Ibe, C. E. 1988. *Coastline Erosion in Nigeria,* Ibadan, Nigeria, University Press, Ibadan.

ICF International 2007. The Potential Impacts of Global Sea Level Rise on Transportation Infrastructure: Phase 1 - Final Report: the District of Columbia, Maryland, North Carolina and Virginia. Available: www.bv.transports.gouv.qc.ca/mono/0965210.pdf [Accessed 30 June, 2011].

IlASA (International Institute for Applied Systems Analysis) 2007. GGI Downscaled Spatially Explicit Socio-Economic Scenario Data. Greenhouse Gas Initiative (GGI) Program of the International Institute for Applied Systems Analysis http://www.iiasa.ac.at/Research/GGI/DB/

Investopedia. 2011. *What is GDP and why is it so important?* [Online]. Available: http://www.investopedia.com/ask/answers/199.asp#axzz1ZvN034Qc [Accessed October 2011].

IOC (International Oceanographic Commission). 2006. A handbook for measuring the progress and outcomes of integrated coastal and ocean management. IOC Manuals and Guides, 46; ICAM Dossier, 2. Available: unesdoc.unesco.org/images/0014/001473/147313e.pdf

IPCC (Intergovernmental Panel on Climate Change), 2001: *Climate Change 2001: The Scientific Basis.* Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, UK, and New York, 881 pp.

IPCC (Intergovernmental Panel on Climate Change), 2007: *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth

Assessment Report of the Intergovernmental Panel on Climate Change In: Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, 996 pp.

Jenkins, B., Annandale, D. and Morrison-Saunders, A. 2003. The evolution of a sustainability assessment strategy for Western Australia. *Environmental and Planning Law Journal,* 20**,** 56-65.

Jevrejeva, S., Grinsted, A. Moore, J. C. Holgate S, (2006) *Journal of Geophysical Research* 11, C09012.

Jevrejeva, S., J.C. Moore, A. Grinsted and P.L. Woodworth 2008. Recent global sea level acceleration started over 200 years ago? *Geophysical Research Letters,* 35, L08715.

Kana, T. W., J. Michel, M.O. Hayes and J.R. Jensen 1984. The physical impact of sea level rise in the area of Charleston, South Carolina. *In:* Barth, M. C. and Titus, J. G. (eds.) *Greenhouse Effect and Sea-level Rise: A Challenge for this Generation.* Van Nostrand Reinhold, New York, pp. 105-150.

Kattenberg, A., Maskell, K. (Eds.), Climate Change 1995. The Science of Climate Change. Cambridge University Press, Cambridge, pp. 365–405.

Kay, R. and Alder, J. 2005. *Coastal Planning and Management,* New York, Francis and Taylor Publishing Group.

Kettle, (2010). Improving Reporting of Uncertainties in Sea Level Rise Assessments. *The Shifting Shorelines: Adapting to the future.* The Coastal Society's 22nd International Conference

Kitchin, R. and Tate, N. 2000. *Conducting Research into Human Geography: Theory, Methodology and Practice,* London, Prentice Hall.

Komar, P. D. 1998. *Beach Processes and Sedimentation,* Upper Saddle River, NJ, 2nd Edition, 544 pp, Prentice Hall.

Komar, P. D., W.G. Mcdougal, J.J. Marra and P. Ruggiero 1999. The rational analysis of setback distances: applications to the Oregon coast. *Shore and Beach,* 67(1)**,** 41-49.

Krabill, W., Hanna, E., Huybrechts, P., Abdalati, W., Cappelen, J., Csatho, B., Frederick, E., Manizade, S., Martin, C., Sonntag, J., Swift, R., Thomas, R. and Yunge, J. 2004. Greenland Ice Sheet: increased coastal thinning. *Geophysical Research Letters,* 31: L24402.

Kuruk, P. 2004. Customary Water Laws and Practices: Nigeria. Available: http://www.fao.org/legal/advserv/FAOIUCNcs/Nigeria.pdf. [Accessed 26 March, 2009].

Larson, M. and Wise, R. A. Year. Simple Models for Equilibrium Profiles Under Breaking and Non-Breaking Waves. *In:* Edge, B. L., ed. International Conference on Coastal Engineering, June 22-26, 1998 1998 Copenhagen, Denmark, . American Society of Civil Engineers, 2722-2735.

Le Roux, J. P. 2007. A simple method to determine breaker height and depth for different deepwater wave height/length ratios and sea floor slopes. *Coastal engineering,* 54**,** 271-277.

Le Roux, J. P. 2009. A function to determine wavelength from deep into shallow water based on the length of the cnoidal wave at breaking—Reply to discussion by T.S. Hedges. *Coastal engineering,* 56**,** 96-97.

Leatherman, S. P. 1984. Coastal geomorphic responses to sea level rise: Galveston Bay, Texas. *In:* Barth, M. C. and Titus, J. G. (eds.) *Greenhouse Effect and Sea-level Rise: A Challenge for This Generation* Van Nostrand Reinhold, New York, pp. 151-178.

Leatherman, S. P. 1990. Modeling shore response to sea-level rise on sedimentary coasts. *Progress in Physical Geography,* 14(4)**,** 447-464.

Leatherman, S. P. 2001. Social and economic costs of sea-level rise. *In:* DOUGLAS, B. C., Kearney, M.S., Leatherman, S.P. (ed.) *Sea-Level Rise, History and Consequences: International Geophysics Series.* New York: Academic Press.

Leatherman, S. P., Nicholls R.J and Dennis, K. C. 1995. Aerial Videotape-Assisted Vulnerability Analysis: A Cost-Effective Approach to Assess Sea-Level Rise Impacts. *Journal of Coastal Research,* 14**,** 15-25.

Leatherman, S. P., Zhang, K. and Douglas, B. C. 2000. Sea-level rise shown to drive coastal erosion. *EOS,* 81**,** 55-57.

Lehner, B. and Döll, P. 2004. Development and validation of a global database of lakes, reservoirs and wetlands. *Journal of Hydrology,* 296**,** 1-22.

Leuliette, E.W, Nerem, R.S, Mitchum, G.T. 2004. Calibration of TOPEX/Poseidon and Jason altimeterdata to construct a continuous record of mean sea level change. Marine Geodesy 27:79

Lowry, K., Olsen, S. and Tobey, J. 1999. *Coastal Planning and Management,* London, Routledge.

Masalu, D. C. P. 2008. Coastal data and information management for integrated coastal management: The role of IODE. *Marine Policy,* 32(2008).

Masselink, G. and Hughes, M. G. 2003. *Introduction to Coastal Processes and Geomorphology.* London, Hodder Education.

Mcgranahan, G., D. Balk and Anderson, B. 2007. The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment and Urbanization,* 19 (1)**,** 17-37.

Mcnamara, D.E., Murray, A.B. and Smith, M.D. 2011. Coastal sustainability depends on how economic and coastline responses to climate change affect each other. *Geophysical Research Letters,* 38 L07401.

Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver and Z.-C.Zhao 2007. Global climate projections. *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller]. Cambridge University Press, Cambrigde, UK and New York, 747-846

Mercer, J.H. 1978. West Antarctic ice sheet and CO2 greenhouse effect: A threat of disaster, Nature, 271, 321-325.

Morrison-Saunders 2011. Practical Guide to Sustainability Assessment *Impact Assessment and Responsible Development for Infrastructure, Business and Industry.* Puebla, Mexico: International Association of Impact Assessment

Moser, S. C. (2005) *Global Environmental Change* 14, 353.

Mwakumanya, A. M., Munyao, T. M. and Ucakuwun, E. K. 2009. Beach width analyses in beach erosion hazard assessment and management at Bamburi beach, Mombasa, Kenya. *Journal of Geography and Regional Planning,* Vol. 2(12)**,** 299-309.

NDBC (National Data Buoy Centre), 1995. National Oceanic and Atmospheric Administration Marine Environmental Buoy Data (F291) Wave Measurement Errors http://www.nodc.noaa.gov/BUOY/DOC/wavemeas.html

NDDC (Niger Delta Development Commisssion). 2005. Demography and Baseline studies - Rivers State. *Niger Delta Regional Development Master Plan.* Port Harcourt, Nigeria: Niger Delta Development Commission.

NDDC (Niger Delta Development Commisssion). 2006. Niger Delta Regional Development Master Plan - Popular version. *Niger Delta Regional Development Master Plan* Port Harcourt: Niger Delta Development Commission, http://www.nddc.gov.ng/?page=masterplan.

NDDC (Niger Delta Development Commisssion), 2007. *About NDDC: The Long Years of Neglect* [Online]. Available: http://www.nddc.gov.ng/?page=about [Accessed 30 April, 2009].

Nicholls R.J, Birkemeier, W. A. and Lee, G. 1998. Evaluation of depth of closure using data from Duck, NC, USA. *Marine Geology,* 148**,** 179-201.

Nicholls R.J, Dennis, K. C., Volonte, C. R. and Leatherman, S. P. 1993. Methods and problems in assessing the impacts of accelerated sea-level rise. *In:* BRAS, R. (ed.) *The World At-Risk: Natural Hazrds and Climate Change.* New York: AIP Conference Proceedings No 277, American Institute of Physics, pp 193-205.

Nicholls, R. J., Larson, M., Capobianco, M. and Birkemeier, W. A. Year. Depth of closure: Improving understanding and prediction. *In:* EDGE, B. L., ed. International Conference on Coastal Engineering,, June 22-26, 1998 1998 Copenhagen, Denmark. American Society of Civil Engineers, 2888-2901.

Nicholls, R. J. and Leatherman, S. P. 1995. Global sea-level rise. *In:* Strzepek and Smith, J. B. (eds.) *As climate changes: international impacts and implications.* Cambridge University Press

Nicholls, R. J., Leatherman, S. P., Dennis, K. C. and Volonte, C. R. 1995. Impacts of sea-level rise:Qualitative and Quantitative Assessments. *Journal of Coastal Research,* 14(4)**,** 627-648.

Nicholls RJ, Stive M.J.F (2004) Society and sea level rise requires modelling. *Science* E-letters 303:5665

Nicholls, R. J., P.P. Wong, V.R. Burkett, J.O. Codignotto, J.E. Hay, R.F. Mclean, S. Ragoonaden and Woodroffe., C. D. 2007. Coastal systems and low-lying areas. *In:* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. Van Der Linden and Hanson, C. E. (eds.). *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp 315-356.

Nigerian Navy 2008. Tide Tables containing tidal predictions for Nigerian Ports and River Channels for the year 2008. *In: Hydrographic Office Nigerian Navy Tides Table,* Lagos.

NIOMR (Nigerian Institute of Oceanography and Marine Research). 2006. Nigeria. *ODINAFRICA III: First Review Meeting* [Online]. Available: http://www.nodc-nigeria.org/report_apr_06.htm [Accessed 24 June 2011].

NPC (National Population Commission). 2011. National and State Population and Housing Tables: 2006 Census Priority Tables Abuja.

Nzeshi, O. 2011. Lagos Floods - House Asks President to Sign Climate Change Bill. *This Day, http://allafrica.com/stories/201107140001.html*.

O'riordan, T. (ed.) 2000. *Environmental Science for Environmental Management,* 2nd edition, Harlow: Pearson, Prentice Hall

O'Riordan, T. 2003. connecting people to nature: Johannesburg and beyond. *Ecos,* 24**,** 5-9.

OECD (Organisation for Economic Co-operation and Development). 2003. Environmental Indicators: Development, Measurement and Use. Available: www.oecd.org/dataoecd/7/47/24993546.pdf [Accessed 13 June, 2011].

Ogba, C. O. and Utang, P. B. Year. Geospatial Evaluation of Niger Delta Coastal Susceptibility to Climate Change. *In:* FIG Congress 2010: Facing the Challenges - Building the Capacity, 2010 Sydney, Australia.

Okude, A. S. and Ademiluyi, I. A. 2006. Coastal Erosion Phenomenon in Nigeria: Causes, Control and Implications. *International Digital Organization for Scientific Information,* 1(1)**,** 44-51.

Olsen, S. B. 2003. Frameworks and indicators for assessing Progress in integrated coastal management initiatives. *Coastal Management* 46 (2003)**,** 347-361.

Olson, S. B. 2002. Assessing progress toward the goals of coastal management. *Coastal Management,* 30**,** 325-345.

Open University. 2011. *Systems thinking and practice* [Online]. Available: http://openlearn.open.ac.uk/mod/oucontent/view.php?id=399236andsection=3.4 [Accessed 14 September 2011].

Overpeck, Jonathan. T. and Weiss, Jeremy, L. 2009. Projections of future sea level becoming more dire Proceedings of the National Academy of Sciences of the United States of America

Personal Communication. 2008a. Niger Delta Wetland Centre, Port-Harcourt

Personal Communication, A. 2008b. *RE: Sustainability assessment interview.* Pro-Natura Intenational, Nigeria

Personal Communication, F. 2008c. *RE: Sustainability Assessment Interview,* Flood Erosion and Coastal Zone Management, Rivers State.

Pezzoli, K. 1997. Sustainable Development: A Transdisciplinary Overview of the Literature. *Journal of Environmental Planning and Management,* 40 (5)**,** 549-574.

Pfeffer, W.T., Harper, J.T., and O'Neel, S. 2008. Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise. Science 5 September 2008: Vol. 321 no. 5894 pp. 1340-1343 DOI: 10.1126/science.1159099

Pickaver, A. 2008. Implementation of ICZM in Europe: Results of the EU Progress Indicator. *EU-COMET 2 Coastal management education and training.* Leiden, Tempus Joint European Project.

Pickaver , A. H., Gilbert, C. and Breton, F. 2004. An indicator set to measure the progress in the implementation of integrated coastal zone management in Europe. *Ocean and Coastal Management,* 47 (2004)**,** 449-462.

Pilkey, O. H., Young, R. S., Riggs, S. R., Smith, A. W. S., Wu, H. and Pilkey, W. D. 1993. The concept of shoreface profile of equilibrium: a critical review. *Journal of Coastal Research,* 9(1)**,** 255– 278.

Pilkey, O. H., W. J. Neal, S. R. Riggs, C. A. Webb, D. M. Bush, D. F. Pilkey, J. Bullock and Cowan., B. A. 1998. *The North Carolina shore and its barrier islands.,* Durham, Duke University Press.

Pilkey, O.H, Cooper, J.A.G. 2004. Society and sea level rise. *Science* 303:1781-1782

Pinter, L., Hardi, P. and Bartelmus, P. 2005. Sustainable Development Indicators: Proposals for a Way Forward. Available: www.iisd.org/pdf/2005/measure_indicators_sd_way_forward.pdf

PNI. (Pro-Natura International). 2009. Innovation Towards Sustainable Development. *25 Years of real innovation for the development of the global south: Combining poverty reduction, biodiversity conservation and climate change mitigation* [Online]. Available: neofit.webfactional.com/pronatura/archives/Newsletter_25years.pdf [Accessed 21 July, 2011].

PNIN (Pro-Natura International Nigeria) 2005. The Akassa Development Foundation. *The Akassa Community Development Foundation.* Port Harcourt: Pro-Natura International, Nigeria.

PNIN (Pro-Natura International Nigeria). 2011a. *About PNI Nigeria: Our Vision and Mission* [Online]. Port Harcourt, Nigeria. Available: http://www.pronatura-nigeria.org/splash/?page_id=6 [Accessed 21 July 2011].

PNIN (Pro-Natura International Nigeria). 2011b. The Institute for Sustainable Development. *Institute for Sustainable Development, Brochure* [Online]. Available: http://www.pronatura-nigeria.org/splash/?cat=6 [Accessed July, 2011].

Pope, J., Annandale, D. and Morrison-Saunders, A. 2004. Conceptualising sustainability assessment. *Environmental Impact Assessment Review,* 24 (2004) 595-616.

Popoola, O.O., Abbott, V.J., and Glegg, G, 2011: Impact of Sea Level Rise: Barrier Coast, Nigeria. Impact Assessment and Responsible Development *for Infrastructure, Business and Industry* Proceedings, 31st Annual Meeting of the International Association for Impact Assessment Puebla, Mexico.

Post, J. C. and Lundin, C. G. 1996. Guidelines for Integrated Coastal Zone Management. Washington, D.C: The World Bank.

Post Note, 2010. Sea Level rise Number 263. House of Parliament Parliamentary Office of Science & Technology

Postel, S. 1997. *Last oasis: Facing water scarcity,* New York, Norton.

Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea-level rise. *Science,* 315(5810)**,** 368-370.

Rahmstorf, S., A. Cazenave, J.A. Church, J.E. Hansen, R.F. Keeling, D.E. Parker and Somerville, R. C. J. 2007. Recent climate observations compared to projections. *Science,* 316(5825), 709.

Rahmstorf, S. 2010. A new view on sea level rise, *Nature Reports, Climate Change.* Vol 4. http://www.nature.com/climate/2010/1004/pdf/climate.2010.29.pdf

Ramsar. 2011. *Key Message 8: "Wetlands and Urbanization"* [Online]. Available: http://www.ramsar.org/cda/en/ramsar-home/main/ramsar/1_4000_0__ [Accessed 14 September 2011].

Ranasinghe R., Watson, P, Lord D, Hanslow, D, Cowell. P. 2007. Sea level rise, coastal recession and the Bruun rule. In: *Proceedings coasts and ports' 07.* Coastal and Ocean Engineering Conference, Australia

Ranasinghe, R, Stive, M.J.F. 2009. Rising seas and retreating coastlines. Climate Change 97: 465-468

Ranasinghe, R, Callaghan, D, Stive, M.J.F. 2011. Estimating coastal recession due to sea level rise: beyond the Bruun rule. Climate Change 1-14

Resio, D. T., BRATOS, S. M. and Thompson, E. F. 2003. Meteorology and Wave Climate, Chapter II-2, Coastal Engineering Manual. *US Army Corps of Engineers,.* Washington D.C, 72pp.

Rignot, E. and Kanagaratnam, P. 2006. Changes in the velocity structure of the Greenland Ice Sheet. *Science,* 311**,** 986-990.

Rivera-Arriaga, E. 2005. Assessing foreign aid efforts for coastal management in Latin America and the Caribbean regions. *Ocean and Coastal Management,* 48**,** 693-720.

Rollason, V., Patterson, D., and Huxley, C. 2010. Assessing Shoreline Response to Sea Level Rise: An Alternative to the Bruun Rule Department of Environment Climate Change and Water DECCW. Draft Guidelines for preparing Coastal Zone Management Plans, NSW Department of Environment, Climate Change and Water, August 2010.

Rowley, R. J., Kostelnick, J. C., Brateen, D., Li, X. and Meisel, J. 2007. Risk of Rising Sea Level to Population and Land Area. *EOS, Transactions, American Geophysical Union,* 88 (9)**,** 105-107.

Royal Town Planning Institute. 2001. A New Vision for Planning: Delivering Sustainable Communities, Settlements and Places, 'Mediating Space - Creating Place' The need for action. Available: www.rtpi.org.uk/download/245/RTPI-New-Vision-for-Planning.pdf [Accessed 11 April 2009].

Sadler, B. 1999. A framework for environmental sustainability assessment and assurance *In:* Petts, J. (ed.) *Handbook of environmental impact assessment.* Oxford: Blackwell.

SECRU. 2001. Indicators to Monitor the Progress of Integrated Coastal zone Management: a Review of Worldwide Practice. Available: www.scotland.gov.uk/Resource/Doc/1057/0030528.pdf.

Sheate W, Dagg S, Richardson J, Aschemann R, Palerm J and U, S. 2003. Main Report European Commission: Contract No. B4-3040/99/136634/MAR/B4 Imperial College Consultants ICON.

Sheate, W. R., Dagg, S., Richardson, J., Aschemann, R., Palerm, J. and STEEN, U. 2003. Integrating the Environment into Strategic Decision-Making: Conceptualizing Policy Sea. *European Environment,* 13**,** 1-18.

Slott, J. M., Murray, A. B., Ashton, A. D. and Crowley, T. J. 2006. Coastline responses to changing storm patterns. *Geophysical Research Letters,* 33: L18404.

Slott, J. M., Smith, M. D. and Murray, A. B. 2008. Synergies between Adjacent Beach-Nourishing Communities in a Morpho-Economic Coupled Coastline Model. *Coastal Management,* 36:**,** 374-391.

Slott, J. M. Murray, A. B. Ashton, A. D. Crowley, T. J. (2006) *Geophysical Research Letters* 33, L18404.

Small, C. and R.J. Nicholls, 2003. A global analysis of human settlement in coastal zones. *Journal of Coastal Research*, 19(3), 584-599.

Small, C., and Cohen, J. 2004. Continental physiography, climate, and the global distribution of human population. Current Anthropology, 45, 269–277.

Smith, H.D., Maes, Frank., Stojanovic, T.A., Ballinger, R.C. (2011). The Integration of land and marine spatial planning. *Coast Conservation*, 15: 291-303.

Solow, R. 1956. A contribution to the theory of economic growth. Quarterly Journal of Economics 70: 65–94.

Sorenson, J. 1997. National and international efforts at integrated coastal management: Definitions, achievements, and lessons. *Coastal Management,* 25**,** 3-41.

Sorenson, J. Year. Baseline 2000. Background paper for Coastal Zone Canada 2000. *In:* Coastal Stewardship—Lessons learned and the paths ahead, September 17–22 2000 New Brunswick, Canada.

Sorenson, J. 2002. The Status of Integrated Coastal Management as an International Practice. *Baseline 2000 Background Report. Second Iteration.*

Souto, R. D., Polette, M. and Kampel, M. 2009. Evaluation of Sustainability Indicators for the Coastal Zone of Rio de Janeiro, Brazil. *Journal of Coastal Research (Proceedings of the 10th International Coastal Symposium),* SI 56**,** 1311-1315.

Stive, M. J. F., Devriend, H. J., Nicholls R.J and Capobianco, M. Year. Shore nourishment and the ActiveZone: A time Scale Dependent View. *In:* Proceedings 23rd Coastal Engineering Conference, 1992 New York. American Society of Civil Engineers, 2464-2473.

Stolper, D., J.H. List and E.R. Thieler 2005. Simulating the evolution of coastal morphology and stratigraphy with a new morphological-behavior model (GEOMBEST). *Marine Geology,* 218(1-4)**,** 17-36.

Surfline/Wavetrak, Inc (2011)

http://www.buoyweather.com/wxnav6.jsp?region=nigeria&program=Maps

Surf- forecast (2011) http://www.surf-forecast.com/weather_maps/Nigeria

Sutherland, M. Year. Sea-Level Rise and Coastal Zone Management. *In:* FIG Working Week, 2004, 2004 Athens, Greece.

Takeda, I. and Sunamura, T. 1982. Formation and height of berms. *Transactions, Japanese Geormorphological Union,* 3**,** 145-157.

The Guardian, 2011. Lagos Approves more low cost housing schemes. Written by Oropo, KT, on 17 October, 2011. http://propertygateplc.com/News/lagos-approves-more-low-cost-housing-schemes.html

Thieler, E. R., Pilkey, O. H., Young, R. S., Bush, D. M. and CHAI, F. 2000. The use of the mathematical models to predict beach behavior for U.S. coastal engineering: a critical review. *Coastal Research,* 16(1)**,** 48-70.

Thom, B. G. 1983. Transgressive and regressive stratigraphies of coastal sand barriers in southeast Australia. *Marine Geology,* 56**,** 137–158.

Tilman, W. M. K., Leclerc, J. P. and Jakobsen, P. R. 1989. Coastal Erosion in the bight of Benin: National and Regional aspects. *Report of EEC/EDF Project No 6607.43.94.155.*

Titus J.G and Narayanan V.K (1995) The probability of sea level rise. A report to the United States Environmental Protection Agency (EPA), Office of Policy, Planning, and Evaluation EPA 230-R-95-008.

http://www.epa.gov/climatechange/effects/downloads/probability.pdf

Titus, J. G., M. Craghan, S.K. Gill and Williams, S. J. 2009. Shore protection and retreat. *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region.* Washington DC: A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research.J.G. Titus (coordinating lead

author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]. U.S. Environmental Protection Agency.

Titus, J.G. 2009. *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region.* Washington DC: A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]U.S. Environmental Protection Agency.

Tobey, J. and Volk, R. 2002. Learning Frontiers in the practice of Integrated Coastal Management. *Coastal Management,* 30**,** 285-298.

Tol, R. S. J., Bohn, M., Downing, T. E., Guillerminet, M.-L., Hiznyik, E., Kasperson, R., Lonsdale, K., Mays, C., Nicholls, R. J., Olsthoorn, A. A., Pfeifle, G., Poumadere, M., Toth, F. L., Vafeidis, N., VAN DER Werff, P. E. and Yetkiner, I. H. 2005. Adaptation to Five Meters Sea Level Rise. *Journal of Risk Research,* 9:5**,** 457-482.

UNCED (United Nations Conference on Environment and Development) 1992. *Earth Summit: Agenda 21*.

UNEP (United Nations Environment Programme). 1981. *Abidjan Covention* [Online]. Available: http://www.unep.org/AbidjanConvention/index.asp [Accessed 25 May 2011].

UNEP (United Nations Environmental Protection). 2002. The Status of the Nigerian Coastal Zones. Available: http://www.unep.org/AbidjanConvention/docs/THE%20STATUS%20OF%20THE%20NIGERIAN%20COASTAL%20ZONES%20version%202.pdf [Accessed 23 June 2010].

United Nations 2002. UN Atlas of the Oceans. http://www.oceansatlas.org/.

United Nations, Department of Economic and Social Affairs, Population Division (2011): World Population Prospects: The 2010 Revision. New York

USAID (United States Agency for International Development). 2001. Towards a water secure future: USAID's obligations in water resources management for FY 2000. Report prepared by the USAID Water Team. United States Agency for International Development. Washington, D.C.

US Today (2005) World: Some industrialised nations to lose population by 2050. http://www.usatoday.com/news/world/2004-08-17-world-population_x.htm

Van Der Weide, J. 1993. A systems View of Integrated Coastal Management. *Ocean and Coastal Management,* 21**,** 129-148.

Vaughan, D. and Spouge, J. 2002. Risk Estimation of Collapse of the West Antarctic Ice Sheet *Climatic Change,* 52**,** 65-91.

Velicogna, I. and Wahr, J. 2006. Measurements of time-variable gravity show mass loss in Antarctica. *Science,* 311**,** 1754-1756.

Vermeer, M. Rahmstorf, S. 2009. Global sea level linked to global temperature. Proceeding National Academy of Sciences, USA 106:21527–21532. http://www.pnas.org/content/106/51/21527.full

Verheem, R. and Draaijers, G. 2006. Experiences on Sustainability Assessment in the Netherlands. *International Association of Impact Assessment 06* [Online]. Available: docs1.eia.nl/os/bibliotheek/integratedassessmentnl0601.pdf [Accessed 12 June, 2011].

Vincent, C. L., Demirbilek, Z. and Weggel, J. 2002. Estimation of Nearshore Waves. *Coastal Engineering Manual (EM 1110–2-1100) Part 2, Chapter 3.* Washington, D.C, pp 42: US Army Corps of Engineers.

Volonte, C. R. and Arismendi, J. 1995. Sea-level rise and Venezuela: potential impacts and consequences. *Journal of Coastal Research,* Special Isuue No 14**,** 285–302.

Volonte, C. R. and Nicholls, R. J. 1995. Uruguay and Sea-Level Rise: Potential Impacts and Response. *Journal of Coastal Research,* Special Issue No 14**,** 262-284.

Warrick, R.A., Le Provost, C., Meier, M.F., Oerlemans, J., Woodworth, P.L., 1996. Changes in sea level. In: Houghton, J.T., Meira Filho, L.G., Callander, B.A., Harris, N.,

Walton, T. L., JR, and Dean, R. G. 2007. Temporal and Spatial Change in Equilibrium Beach Profiles from the Florida Panhandle *Journal of Waterway, Port, Coastal, and Ocean Engineering,* 133, **,** 364-376.

Watson, R. T., Zinyowera, M. C., Moss, R. H. and Dokken, D. J. (1997) *Summary for Policy Makers - The Regional Impacts of Climate Change: An Assessment of Vulnerability.* A special report of Intergovernmental Panel on Climate Change (IPCC).

Watson, R. T., Mccarthy, J. J. and Canziani, O. F. 2001. Preface; in Climate Change 2001: Impacts, Adaptation and Vulnerability. *In:* J.J. Mccarthy, O. F. Canziani., N.A. Leary, D.J. Dokken and K.S. White (ed.) *contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press.

WCED (World Commission on Environmnet and Development). 1987. *Our Common Future* Oxford and New York, Oxford University Press.

Westcott, G. 2004. The theory and practice of coastal area planning: Linking strategic planning to local communities. . *Coastal Management,* 32**,** 95-100.

Williams, C. and Millington, A. C. 2004. The diverse and contested meanings of sustainable development. *The Geographical Journal,* 170 (2)**,** 99-104.

Williams, S. J., Gutierrez, B. T., Titus, J. G., Gill, S. K., Cahoon, D. R., Thieler, E. R. and Anderson, K. E. 2009a. Sea-Level Rise and Its Effects on the Coast. *In:* TITUS, J. G. (ed.) *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region.* Washington DC: A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]U.S. Environmental Protection Agency.

Woodworth, P. L (2006): Some Important Issues to do with long-term sea level change. Philosophical. In Sea level Science, *Transactions of the Royal Society A* (364), 787-803.

http://rsta.royalsocietypublishing.org/content/364/1841/787.full.pdf+html

Wolf. 2009. Coastal Flooding – Impacts of coupled wave-surge-tide models. Available: nora.nerc.ac.uk/8087/1/Coastal_Flooding_paper_final.pdf [Accessed 27 June, 2011].

Wolf, J. 2008. Coupled wave and surge modeling and implications for coastal flooding. *Advances in Geosciences,* 17**,** 1-4.

WRI and IFPRI (World Resources Institute and The International Food Policy Research Institute) 2005. Pilot Analysis of Global Ecosystems (PAGE): Agroecosystems,. Washington, DC: http://www.ifpri.org/dataset/pilot-analysis-global-ecosystems-page.

Zhang, K., Douglas, B. C. and Leatherman, S. P. 2004. Global Warming and Coastal Erosion. *Climatic Change,* 64**,** 41-58.

APPENDIX

Interview Questions to experts and stakeholders on sustainability of coastal management initiatives in Nigeria.

A   Coastal Management

1   Can you explain what you consider to be coastal management?
2   Are there coastal management initiatives in Nigeria?
3   Can you explain how coastal management works in Nigeria?
4   Who is responsible for the various tasks in coastal management?
5   What laws/policies are in place to ensure a more sustainable management of the coast?
6   How sufficient are these laws and how effectively are they been adhered to?

B   Coastal Sustainability Standard

7   *What "planning" activities are employed in coastal management?*
    a   map for the management area showing explicit references to natural processes
    b   map for the management area showing explicit references to cultural aspects
    c   management structure showing responsibilities of individuals and organizations
    d   goals and objectives
    e   objectives systematically identified in relation to their significance
    f   operational procedures and methodology to meet objectives
    g   plan design (long term and short term objectives)
    h   monitoring, coordination and evaluation of performance of each objective
    i   plan review/feedback
    j   appropriate reference to appropriate baselines for management decisions
    k   management process adaptive in the light of changing events or poor performance
    l   commitment to continually improve performance
    m   audit of management system

8   *How "involved" is the community and interest groups in the process of decision making in coastal management process in Nigeria*
    a   stakeholders/interest groups participation
    b   the extent to which stakeholders understand their role and responsibility within the management process
    c   Do stakeholders fully understand the planning and the decision-making process?
    c   working relationship between the statutory empowered regulators and interest group
    d   participatory process of conflict resolution
    e   active system of stakeholder review and feedback
    f   Accountability for actions by decision-makers

9 ***In what ways is coastal information and education "communicated" over to interest groups and the community?***
  a easy access to relevant coastal information
  b do stakeholders understand the information being passed to them?
  c full awareness by the general public and stakeholders of the management system and its relevance
  d use of sustainability indicators in passing information both to the stakeholders and the community
  e formal outreach system of coastal sustainability education
  f two way communication

10 ***In what ways are various issues relating to coastal management "integrated"?***
  a interactive and problem solving techniques in analysing coastal sustainability issues [focus groups, workshops, visualization and mind mapping/brain storming events]
  b impact of decision making and policies on the areas outside the management system
  c consistent accord between vertical policies
  d consistent accord between horizontal policies
  e equality in disciplines and management units
  f role of science in achieving coastal sustainability
  g resources focused on facilitating greater integration
  h evidence of continuing improvements in integration

11 ***What are your "responsibilities" in ensuring a sustainable coastal management system?***
  a legal basis
  b information/evidence on effective regulation of the coastal environment
  c promote the efficient of use of natural resources in carrying out its actions [best practice, code of conduct, developing of monitoring, indicators etc.
  d evidence of operating the best practicable means
  e 'precautionary principle' in the absence of sufficient information
  f adoption of the 'polluter pay principle'
  g evidence of risk assessment
  h consideration to the life cycle and impact of coastal activities
  i good budget
  j is there an attempt to adopt the ecosystem approach to management?

12 ***Is there some sort of "balance" between the coastal management system in Nigeria and other issues?***
  a conservation, protection and restoration of the health and integrity of coastal biodiversity
  b in the management system is there social fairness consideration in environmental and economic decision making?
  c protection and enhancement of optimum environmental quality with regards to its impact on employment, income and wealth generation
  d any commitment to maintain cultural heritage?
  e any commitment to maintain and improve intra and intergenerational equity?
  f attempt to improve quality of life

g   are temporal variations in the coastal system effectively managed?

h   does coastal management considers the costs and benefits for environmental quality, social welfare and economic growth?

i   do stakeholders perceive and understand the trade-offs made with regard environment quality, social welfare and economic growth.