VULNERABILITY OF THE NIGERIAN COAST AND COMMUNITIES TO CLIMATE CHANGE INDUCED COASTAL EROSION

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ABSTRACT

Improving coastal resilience to climate change hazards requires understanding past shoreline changes. As the coastal population grows, evaluation and monitoring of shoreline changes are essential for planning and development. Population growth increases exposure to sea level rise and coastal hazards. Nigeria, where the study is situated, is among the top fifteen countries in the world for coastal population exposure to sea level rise. This study provided a novel lens in establishing a link between social factors and the intensifying coastal erosion along the Akwa Ibom State study coast. The mixed-method approach used in the study to assess the vulnerability of the Nigerian coast and communities to climate change-induced coastal erosion proved to be essential in gathering a wide range of data (physical, socio-economic, participatory GIS maps and social learning) that contributed to a more robust and holistic assessment of coastal erosion, which is a complex issue due to the interplay between the human and natural environments. Remotely sensed data was used to examine the susceptibility and coastal evolution of Akwa Ibom State over 36 years (1984 -2020). Longer-term (1984-2020) and short-term (2015-2020) shoreline change analyses were used to understand coastal erosion and accretion. From 1984-2020, the total average linear regression rate (LRR) was -2.7±0.18m/yr and from 2015-2020, it was -3.94 ±1.28m/yr, demonstrating an erosional trend along the study coast. Although the rate of erosion varies along the study coast, the linear regression rates (LRR) results show a predominant trend of erosion in both the short and longer term. According to the 2022 Intergovernmental Panel on Climate Change report, loss of land, loss of assets, community disruption and livelihood, loss of environmental resources, ecosystem, loss of life, or adverse health impact are all potential risks along the African coast due to climate change – this study shows that these risks are already occurring today. To quantify the anticipated future coastal erosion risk by 2040 along the study coast, the findings in this study show an overall average LRR of -2.73± 0.99 m/yr which anticipates that coastal erosion will still be prevalent along the coast by 2040. And, given the current global climate change situation, should be expected to be much higher than the current forecasting.

This study re-conceptualised the European Environmental Agency Driver-Pressure-State-Impact-Response (DPSIR) model to show Hazard-Driver-Pressure-State-Impact-Response-Observation causal linkages to coastal erosion hazards. The results showed how human activities and environmental interactions have evolved through time, causing coastal erosion. Removal of vegetation cover/backstop for residential and agricultural purposes, indicate that human activities significantly contribute to the study area's susceptibility, rapid shoreline changes, and vulnerability to coastal erosion, in addition to oceanic and climate change drivers such as sea level rise and storminess. Risk perception of coastal erosion in the study area was analysed using the rhizoanalytic method proposed by Deleueze. The method demonstrates how connections and movements can be related and how data can be used to show multiplicity, mark and unmark ideas, rupture pre-conceptions and make new connections.

This study shows that coastal erosion awareness is insufficient to build a long-term management plan and sustain coastal resilience. The Hino's conceptual model which provides in-depth understanding on planned retreat was used to illustrate migratory and planned retreat for the study coast where relocation has already occurred due to coastal erosion. The result fell within the Self-Reliance quadrant, indicating that people left the risk zone without government backing or retreat plans. Other coastal residents who have not relocated fell within the Hunkered Down quadrant, showing that they are willing to stay in the risk zone and cope with the threat unless the government/environmental agencies relocate them. This study shows that coastal resilience requires adaptive capacity and government support. However, multilevel governance has inhibited government-community dialogue and involvement, increasing coastal erosion vulnerability. The coastal vulnerability index to coastal erosion was calculated using the Analytical Hierarchy Process weightings. It revealed that 67.55% of the study coast falls within the high-very high vulnerability class while 32.45% is within the very low-low vulnerability class. This study developed and combined a risk perception index to coastal erosion (RPIerosion) and participatory GIS (PGIS) mapping into a novel coastal vulnerability index called the integrated coastal erosion vulnerability index (ICEVI). The case study evaluation in Akata, showed an improvement in the overall vulnerability assessment to reflect the real-world scenario, which was consistent with field data.

This study demonstrated not only the presence and challenges of coastal erosion in the research area but also the relevance of involvement between the local stakeholders, government and environmental agencies. Thus, showing the potential for the perspectives of the inhabitants of these regions to inform the understanding of the resilience capacity of the people impacted, and importantly to inform future co-design and/or selection of effective adaptation methods, to better support coastal climate change resilience in these communities. Overall, the study provides a useful contribution to coastal erosion vulnerability assessments in data-scarce regions more broadly, where the mixed-methods approach used here can be applied elsewhere.

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ACKNOWLEDGEMENTS

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My sincere gratitude goes to the Nigerian Government for the TETFund sponsorship and the Akwa Ibom State University, which offered me the opportunity to undertake this PhD degree. I would also like to thank the mobility scholarship, Sir Alwyn Williams, SAGES and GES fundings which enabled me to undertake my field work in Nigeria, The University of Glasgow extension funding, the financial assistance from Dr Brian Barrett to enable me to acquire some data/information needed for this study and Prof. Larissa Naylor for the python retreat sponsorship. A massive thanks to the European Space Agency project funding for the high-resolution data I acquired for this project.

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And to myself: for not giving up. Like I will always say:

"Veni, Vidi, Vici! I came, I saw, I conquered!"… Julius Caesar 47 BC

DEDICATION

This work is dedicated to God. For without Him, I am nothing and can do nothing. "And He said unto me, My grace is sufficient for thee: for my strength is made perfect in weakness…2 Corinthians 12:9a"

AUTHORS DECLARATION

I declare that this thesis is my own work, unless otherwise cited or recognised. This thesis has not been submitted for any degree at the University of Glasgow or any other Institution. Unless otherwise noted, the views, ideas and opinions stated here are mine.

Uduak Essien Affiah

2022

LIST OF ACRONYMS

ArcGIS	ARC/INFO Geographic Information System
ASLR	Accelerated Sea Level Rise
AWEI	Automatic Water Extraction Index
CVI	Coastal Vulnerability Index
DEM	Digital Elevation Model
DOS	Dark Object Subtraction
FCC	False Colour Combination
DSAS	Digital Shoreline Analysis System
ESRI	Environmental Systems Research Institute
EPR	End Point Rate
GIS	Geographic Information System
GPS	Geographical positioning system
HTA	Historical Trend Analysis
HWL	High-Water Line
IBR	Improved Band Ratio
ICEVI	Integrated Coastal Erosion Vulnerability Index
IHS	Intensity, Hue and Saturation
LGA	Local Government Area
LRR	Linear Regression Rate
MHW	Mean High Water
MNDWI	Modified Normalized Difference Water Index
MR	Managed Retreat
NDVI	Normalised Difference Vegetation Index
NDWI	Normalized Difference Water Index
NSM	Net Shoreline Movement
RGB	Red, Green and Blue

SCE	Shoreline Change Envelop
SRTM	Shuttle Radar Topography Mission
TOA	Top of the Atmosphere
PGIS	Participatory GIS
RS	Remote Sensing
UGSS	United States Geological Survey
WLR	Weighted Linear Regression
WRI	Water Ratio Index

Chapter 1: Background Information

Chapter one presents background information on coastal erosion, its causes, impacts and effects globally. It also introduces coastal erosion evidence from Nigeria, identifies research gaps in this field and presents the aims and objectives of this research.

Chapter 1

1.1 Introduction

The coast can be simply described as an interface between the land and ocean (Goncalves et al. 2015) or an interface where the land is influenced by the sea and vice versa (Yin-can 2017). Coastal environments are intensively used for industry, human habitation, nature conservation and recreation (Brown et al. 2017), and are often where global climate change impacts are most acutely felt (Addo 2013; Naylor et al. 2017). These natural environments experience many physical processes such as sea level rise (SLR), flooding, erosion, storm surges, land subsidence and erosion/sedimentation acting upon them (Neumann et al. 2015; Ekong 2017). These physical processes influence the shaping and reshaping of naturally dynamic coastal landscapes (Ginesu et al. 2016), whose forms are as a result of the prevailing coastal processes over long (centuries-millennial) timescales (Kaliraj et al. 2017). With 40% of the world's population (approximately 2.4 billion people) living within 100km of the coast (United-Nations 2017), the exposure of people globally to these coastal risks are expected to rise with the increased human migration to coastal areas that is predicted in the future (Neumann et al. 2015). It is estimated that by 2050, human population will be over 9 billion people implying that there will also be an increase in people living within 100km of the coast (United-Nations 2017). Based on this prediction, climate change related risks to coastal areas are also predicted to increase over this same time period and beyond (Oppenheimer et al. 2019). For example, the Intergovernmental Panel on Climate Change (IPCC) 2019 reports under the RCP 8.5 scenario[1] (representative concentration pathway) projection, that SLR is predicted to be approx. 15 mm yr^{-1} by 2100 (Oppenheimer et al. 2019).

The United-Nations (2017) showed that 10% of the world's population (about 750 million people) live in the low-elevation coastal zone (LECZ) which are coastal areas less than 10m above sea level. Barbier (2015) also described the LECZ of developing nations as the most vulnerable to sea-level rise, coastal erosion and other coastal hazards. The study showed that there is a steady rise in those living in the LECZ with 704 million people in 2010 and a

[1] RCP 8.5 refers to the concentration of carbon that provides global warming at an average of 8.5 watts per square meter across the earth (Oppenheimer et al. 2019)

projected increase to 1.06 billion people by 2100. Based on this latest World Bank's total population (World-Bank 2021), it implies that 3.14 billion (40% of 7.84 billion total world population) live within 100km of the coast and 28% of that population (about 879 million) living in the LECZ are at risk of coastal hazards. With a growing population in these areas comes an increased vulnerability to coastal hazards. Coastal hazards are the negative impacts of natural coastal processes such as storms and sea level rise, as well as anthropogenic activities such as land use changes and coastal infrastructure construction (Esteves 2018), which could cause changes in the sediment dynamics of the coastal zone, resulting in erosion or accretion. Natural causes include short-term events (like storm surges, wave action, tides, wind) (Prasetya 2006) and long-term events (such as sea-level rise, tectonic activities, glaciation) (Prasetya 2006; Esteves 2018). Flooding and SLR risks have been widely researched and climate change adaptation pathways typically focus on society adapting to SLR (Haasnoot et al. 2020), whilst much less research has focussed on coastal erosion risks. Coastal erosion is a natural process where coastal landforms change shape, size and position as sediments are deposited or lost, meaning that the coast is either advancing or retreating (Esteves 2018). Retreating coasts where there are large populations make a natural process – coastal erosion – into a hazard where the risk is excerbated by both anthropogenic activities and climate change. Past research has revealed that the anthropogenic causes of coastal erosion (i.e human activities such as agricultural activities, construction, coastal structures, etc) have received less attention but should be of serious concern (e.g Nicholls et al. (2010); Jonah et al. (2016); and Phong et al. (2017)).

Moreover, human activities have severely impacted on and/or pose serious environmental challenges in coastal regions, making it pertinent not only to address the physical or environmental factors but also human factors too (Rangel-Buitrago et al. 2018). Coastal areas are increasingly being used for e.g. tourism, agriculture, lumber, harbours and housing, leading to substantial engineering and impairment of natural coastal processes (Dias et al. 2013). The combined effect of an increasing population at risk and the anticipated impacts of climate change on coastal processes, will exacerbate the impacts of coastal hazards on social-ecological systems, defined as a system where a combination of both the social and ecological system controls its resource flow (Redman et al. 2004).

1.2 Climate change

The IPCC (2014) defines climate change as a variation in the state of climate that can be recognised by deviations in its properties for a longer period. The United Nations Framework Convention on Climate Change (UNFCCC) defines it as the change in climate that can be directly or indirectly attributed to human activities, as opposed to the natural climate variability observed over the same time periods (UNFCCC 2007). The greenhouse effect also triggers a steady rise in the earth's average temperature, thereby increasing global warming (WMO 2018) and is adequately enhanced by human activities, aerosols, land use changes, solar variabilities and volcanic activities (IPCC 2013). The atmospheric concentrations of aerosols and greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have increased significantly over the last 200 years (IPCC 2013). According to Micallef et al. (2018), it is quite normal to have slow changes in climatic features, but the increase of industrialisation and technological developments have increased the greenhouse effects, altering such natural patterns. This disruption is indisputable as the warming of the climate system has been noticed since the 1950s, and many of the observed changes reported are remarkable (UNFCCC 2007; IPCC 2013; WMO 2017; IPCC 2019).

The IPCC report by Oppenheimer et al. (2019) provides evidence that the average temperature of the world's oceans has been rising at a rate of 0.11 °C per decade since the 1970s. Another IPCC report by Wong et al. (2014) shows that the projected average global mean SLR (GMSLR) in the 21st century which was based on a high emission scenario (0.74 m by 2100), exceeds the previously observed rate for the period 1971–2010 (2.0 mm yr^{-1}). With this increasing rise, low-lying coastal regions, the landforms, ecosystems and communities they support, will be strongly affected (Enríquez et al. 2017). For instance, Wdowinski et al. (2016) discussed the effects of SLR in low-lying coastal communities due to their vulnerability of being exposed to high-tides and storm surges. According to Torresan et al (2012), report that the exposure of people and assets to coastal risks is growing quickly around the world and is projected to do so for the foreseeable future. The combined effects of human development pressures, natural coastal dynamics, and climate change risks create serious coastal hazards that threaten coastal community resilience (Bonetti et al. 2018) as well as a threat to coastal communities' natural resource base/livelihood (UNDP 2012). Owing to such impacts, Phong et al. (2017) proposed that combined human and physical environment studies be conducted to better understand the causes and impacts of coastal erosion. In their study, they discovered that while factors such as climate change and SLR are commonly cited as major causes of coastal erosion, human activities such as poor aquaculture pond construction, mangrove deforestation, construction and repairs of dykes are also significant contributors to coastal erosion. According to Esteves (2018), the degree of threat varies along different coasts and depends on the time scale of analysis. As a result, factors such as lack of understanding of natural processes and cycles have resulted in human disruption of these processes, thus, increasing coastal erosion and the vulnerability of people living along the coast. Consequently, and globally, there is an urgent need for improved coastal mapping to detect physical change along the coastal communities (Pérez-Alberti et al. 2019).

1.3 Coastal Hazards in Africa

Africa has a low contribution to greenhouse emissions, yet is a hub to the largest impacts of climate change (IPCC 2022). Although physical exposure influences vulnerability (refer to section 2.1.3.2 for definition of concept) for both human and natural systems, a lack of adaptive capacity is a significant factor negatively affecting human vulnerability (Akegbejo-samsons (2013). The situation is exacerbated by low societal adaptive capacity, with one of the most pressing adaptation requirements in Africa being to make climate change information more reliable and accessible (Filho et al. 2019). Mensah (1997) observed that in West Africa, urban development, industries and commercial activities along the beaches have already led to an unprecedented exploitation of coastal resources such coastal sand, mangrove forests, estuaries, and seagrass beds, resulting in coastal erosion. According to Addo (2013), coastal erosion contributes not only to environmental but, also to social and economic problems, particularly where there is infrastructure and population competition for coastal land and assets that are located in coastal erosion risk zones. Nicholls et al. (2010) noted that the African coast is highly vulnerable to the impacts of SLR due to several reasons including; under-development, low land elevation, rapid population growth, and low adaptive capacity. Neumann et al. (2015) recently conducted a global, remote sensing-based assessment of the effects of SLR on future coastal populations, making predictions for 2030 and 2060 against the year 2000 baseline and discovered that eight African countries are among the top 25 countries with populations that are vulnerable to SLR and coastal hazards. The research also indicated that less developed countries in Africa will be more affected than the developed nations. Coastal zones in Egypt and Nigeria, for example, are among the top fifteen countries in the world in terms of population exposure to SLR. Based on these findings, coastal vulnerability assessments in these regions are critical. Despite Africa being the most vulnerable continent to climate change, there are relatively few vulnerability assessments conducted in African countries that focus on local priorities (Trisos et al. 2022).

Table 1.1 summarises studies of high exposure and vulnerability to climate extremes (Nicholls et al. (2007); exposure of developing countries to SLR and storm surges (Dasgupta et al. (2011), global coast, nation and cities at risk (Strauss et al. 2015) and future coastal population growth and exposure to sea-level rise and coastal flooding (Neumann et al. 2015).

Table 1.1: Top fifteen countries with the highest populations per country exposed.

Nicholls et al. (2007)	Dasgupta et al. (2011)	Strauss et al. (2015)	Neumann et al. (2015)
China	China	China	China
USA	Japan	India	India
India	Netherlands	Bangladesh	Bangladesh
Japan	India	Vietnam	Vietnam
Vietnam	Egypt	Indonesia	Indonesia
Netherlands	Indonesia	Japan	Japan
Bangladesh	Vietnam	USA	Egypt
Egypt	Myanmar	Philippines	USA
Thailand	Pakistan	Egypt	Thailand
Indonesia	Brazil	Brazil	Philippines
Brazil	Philippines	Thailand	Brazil
Myanmar	South Korea	Myanmar	Myanmar
Cote D'Ivoire	Thailand	Netherlands	Netherlands
Nigeria	Bangladesh	**Nigeria**	**Nigeria**
Ecuador	**Nigeria**	Malaysia	United Kingdom

According to Neumann et al. (2015), Nigeria was ranked 14th among the top 25 countries with the highest LECZ population in 2000. It revealed that approximately 7.4 million people live in the LECZ accounting for 5.7 % of the country's population that year and approximately 1.18%

of the global LECZ population. It was also predicted that by 2060, Nigeria would rank seventh with an estimated 19.8 million LECZ population in 2030 and 57.7 million LECZ population by 2060. This reveals a significant number of people currently at risk of being exposed to SLR and that this number is expected to grow exponentially in the future.

1.3.1 Coastal Erosion in Nigeria

Coastal erosion due to SLR is known to be a serious challenge in Nigeria (Uyigue et al. 2007; Adelola et al. 2017). The country's coast is currently undergoing significant physical changes as a result of recent tidal surges, accelerated SLR (ASLR), and human activities (Federal-Government-Nigeria 2010). These changes are expected to continue with the projected SLR of 0.5 - 1 m this century (Federal-Government-Nigeria 2010; Oppenheimer et al. 2019). Using the projected global eustatic SLR values by Brown et al. (2011) and IPCC (2013), Musa et al. (2016) predicted a relative SLR in the low-lying Niger delta of 0.14m and 0.96 m by 2030 and 2050 respectively. Musa (2018) then demonstrated, that the Niger Delta already has an SLR of 0.14m (7mm subsidence multiplied by a period of 17 years between 2013-2030) based on the relative SLR values. The impacts of these SLR changes are exacerbated by the Niger Delta's rapidly growing population (Oyegun et al. 2016) which put pressure on the environment. Such human pressures include rapid urban growth, recreational activities, industrial activities (Famuditi et al. 2014), particularly the oil production companies. These pressures, when combined with a lack of environmental regulations, create significant environmental problems, including coastal erosion (Famuditi et al. 2014). Despite the fact that SLR and human activities have been linked to the erosion and degradation of parts of the Nigerian coast, there is a lack of awareness and ability to manage these risks within Nigeria (Danladi et al. 2017) which could be managed through a holistic, integrated and participatory approach (Famuditi et al. 2014).

Famuditi et al. (2014) and Kimenyi et al. (2014) describe the benefits of the holistic approach, which is based on stakeholders' approach to environmental development in Nigeria's Niger Delta region. They emphasised that a participatory approach that includes the community as stakeholders is preferable to a non-inclusive approach for sustainability. It also discussed the benefits of involving stakeholders intensively from the onset of a project, as this will reduce, if not eliminate, the issue of lack of cooperation from community stakeholders who may presume that the problems identified by an analytical approach are not a pressing need for them. It also reiterated that the top-to-bottom approach has been shown to be incapable of dealing with the complexities involved in coastal problems, and it reveals that, while the benefits of a participatory approach have long been recognised, this is still lacking in many environmental studies.

1.3.2 Geographical Characteristics of the Nigerian Coast

Nigeria, located between latitudes 4°N and 14°N and between longitudes 3°E and 15°E is bordered in the north by the Republics of Niger and Chad, in the west by the Republic of Benin, in the south-east by the Republic of Cameroon and in the south by the Atlantic Ocean, where it has an extensive coast of approximately 853 km^2 (Diemuodeke et al. 2019). The Nigerian coast is of extremely high economic and social value, with activities there accounting for 90% of the country's foreign exchange earnings (Uwakonye et al. 2006; Olorunlana 2013). The World Bank indicates Nigeria's gross domestic product (GDP) by 2018 to have reached $397.27 billion (World-Bank 2019). Oil revenue contributes about $357.54 billion to the total GDP. Nigeria has an estimated population of 210 million people, making it the most densely populated country in Africa (World-bank 2019), with approximately 25% of the country's population located along the coast (Mmom et al. 2011) with a population density of 491 inhabitants per km^2 (Neumann et al. 2015). The presence of natural gas/petroleum resources has led to increasing oil industries in the country especially along the coastal region where these resources are found and in turn, has led to a rapid growth in population in these areas. There has been an average annual population growth increase of 2.6% between 1990 – 2017 in Nigeria as a whole (World-Bank 2017) and the growth is slightly higher in the coastal states, and an average of 2.94% between 1991 – 2006 ((NBS 2012) (see table 1.2).

The Niger Delta region has Africa's largest known oil reserves and is ranked 13th amongst all oil producing countries (Kuenzer et al. 2014). The area has many oil and gas companies operating in the region with over 500 oil wells located onshore (Musa et al. 2014). The region comprises of the Stand coast (129km), Niger Delta coast (450km) and part of the Transgressive Mud coast (75km). The Niger Delta in Nigeria is one of the most dynamic deltas in the world and is experiencing serious environmental changes due to the interaction of natural and human-induced processes operating upon it (Kuenzer et al. 2014; Obowu et al. 2014).

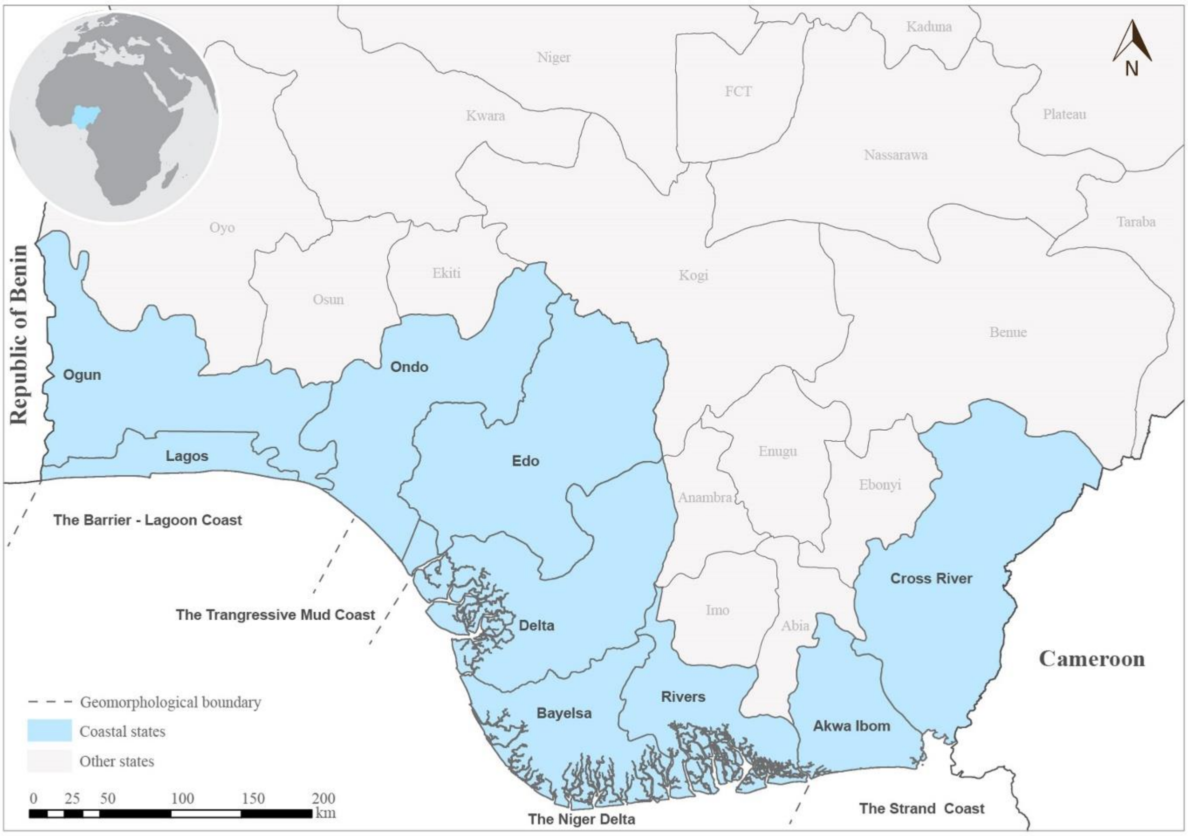


Figure 1.1: The Coastal Region of Nigeria - adapted from (GADM 2015)

The Nigerian coast is geomorphologically divided into four major physiographic zones (see figure 1.1): the Barrier-Lagoon coast, the Transgressive Mud or Mahin Mud coast, the Niger Delta, and the Strand Coast (Olorunlana 2013). The coastal region is characterised by low-lying topography, with most areas having an average height of no more than 3.5m (Mmom et al. 2011). The majority of the coast is prone to flooding (Fabiyi 2013) and erosion (Danladi et al. 2017). Aside from the low topography of the area that makes it vulnerable, Danladi et al. (2017) explained that high population density in the Nigerian coast, which is one of the country's most important economic and commercial locations, has contributed to the rapid rate of coastal erosion along the coast due to the development of infrastructure such as groynes, settlements, farmlands and recreational activity areas, all of which pose threats to the coast. Geologically, the Nigerian coastal areas are predominantly soft sedimentary materials (Alhassan et al. 2012) that are highly erodible. This makes the region’s coast geomorphologically dynamic, with erosion and accretion varying over space and time (Fabiyi et al. 2013). Adelola et al. (2017), for example, noted that coastal erosion caused by rising sea levels in Nigeria poses serious environmental issues, revealing that between 1984 – 2016, the shoreline change analysis for just the Rivers state coast showed that 70% of the coast was undergoing erosion while only 30% accreted. The fact that these areas are low lying may contribute to the high rate of erosion. Musa et al. (2014) noted that the average shoreline elevation in the Niger Delta is between 0-10m metres above sea level, making it prone to flooding and storm surges meaning that low-lying areas are seriously impacted by coastal erosion.

Table 1.2: Growth rate in the Niger Delta States calculated from population census data derived from National Bureau of Statistics (NBS 2012). In the nine states of the Delta region of Nigeria, there has been an average annual population growth rate of 2.94 % between 1991 and 2006.

<table>
<tr><th>States</th><th>Area (km^2)</th><th>Population 1991</th><th>Population 2006</th><th>Annual growth rate (%)</th></tr>
<tr><td>Akwa Ibom</td><td>6,900</td><td>2,409,613</td><td>3,902,051</td><td>4.13</td></tr>
<tr><td>Rivers</td><td>19,187</td><td rowspan="2">4,309,557</td><td>5,198,716</td><td rowspan="2">4.01</td></tr>
<tr><td>Bayelsa</td><td>9,059</td><td>1,704,515</td></tr>
<tr><td>Delta</td><td>17,108</td><td>2,590,491</td><td>4,112,445</td><td>3.92</td></tr>
<tr><td>Cross River</td><td>21,787</td><td>1,911,297</td><td>2,892,988</td><td>3.42</td></tr>
<tr><td>Abia</td><td>4,900</td><td>2,338,487</td><td>2,845,380</td><td>1.45</td></tr>
<tr><td>Imo</td><td>5,288</td><td>2,485,635</td><td>3,927,563</td><td>3.87</td></tr>
<tr><td>Edo</td><td>19,187</td><td>2,172,005</td><td>3,233,366</td><td>3.26</td></tr>
<tr><td>Ondo</td><td>15,820</td><td>3,785,338</td><td>3,460,877</td><td>-0.57</td></tr>
<tr><td></td><td></td><td colspan="2">Average annual growth rate</td><td>2.94</td></tr>
</table>

1.3.3 Geographical Characteristics of Akwa Ibom State

Akwa Ibom State has been selected as the study area for this research due to the author`s familiarity with the area and the fact that it has the highest annual population growth rate (4.13%) in Nigeria's Niger Delta region. This type of population increase in Akwa Ibom State, which has the third smallest land area (6,900 km^2), could pose serious environmental risks, particularly in coastal areas, where research on the vulnerability to the coast is still limited. According to Uyanga (1994), the population in the State in 1953 was 893,216, and by the 2006 population census, there had been a significant increase in the population. Figure 1.2 shows a projected population of Akwa Ibom State's coastal area based on the 2006 national census. Because there is no more recent population data, the 2006 data which was the last actual census data in the region was used.

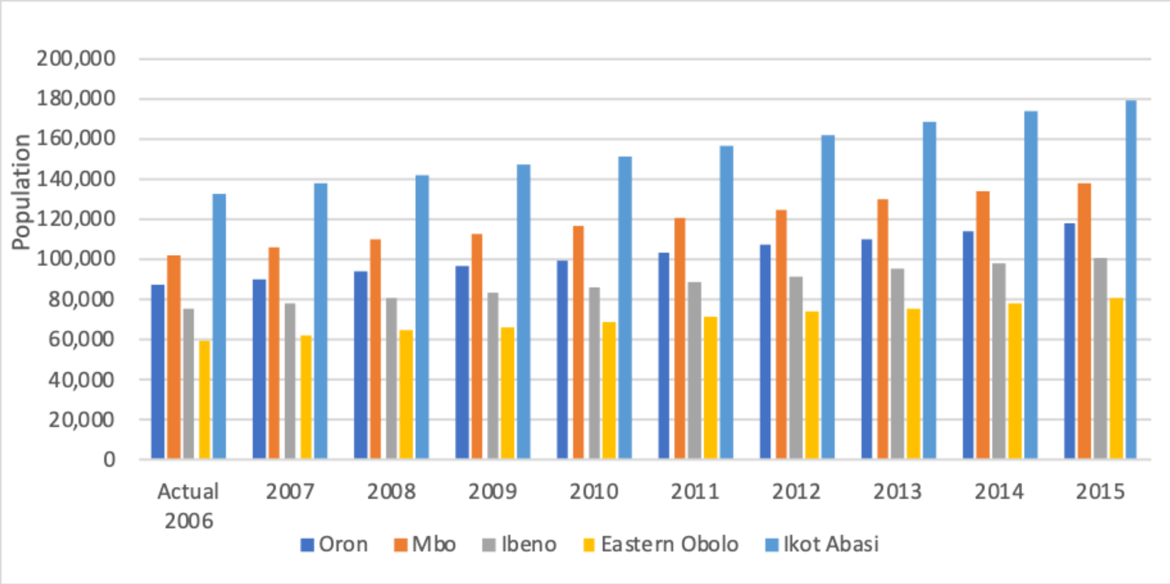


Figure 1.2: Population projections in the Akwa Ibom State coastal areas of Oron, Mbo, Ibeno, Eastern Obolo, and Ikot Abasi Local Government Areas which are part of the research study area (AKS-Government 2014).

With high population growth combined with natural and anthropogenic activities, coastal risks are likely to worsen (Oyegun et al. 2016). Murali et al. (2013) stated that there is an urgent need for improved coastal hazard/vulnerability assessments. However, according to Musa et al. (2016), data accessibility is one of the most crucial elements for the evaluation and modelling of physical and other phenomena connected to river and coastal systems, but it is severely limited.

1.3.3.1 Physical setting of Study Area

The Akwa Ibom state coast is located on the Strand coast. Akwa Ibom State (figure 1.1), in Nigeria's Southern region, lies between latitudes 4° 32′ N and 5° 33′ N and longitudes 7° 25′ E and 8° 25′ E. The Atlantic Ocean borders it on the South, Abia State on the North, Cross River State on the East, and Rivers State on the West. Akwa Ibom State has a shoreline spanning 129 km from Ikot Abasi in the west to Oron in the southeast and occupies an area of about 6,900 km^2 which includes the Qua Iboe River Basin, the western part of the lower Cross River Basin and the eastern part of the Imo River Basin (Inim et al. 2017). The study area falls within the tropical rain forest zone and is host to the nation’s oil palm belt and spans from the west of Cross River to the East border of the Niger Delta with three distinct vegetation zones: saline water swamp forest, freshwater swamp forest, and rain forest (AKICORP 2015). The ecosystem is extremely diversified, supporting a wide range of land and aquatic plants, as well as wildlife and human existence. The State has a tropical climate and two distinct seasons; the dry season which falls between November and March; and the wet season, which falls between April and October, with an average annual rainfall of about 4000mm (Inim et al. 2017) and average temperature of 23-31^{o}C.

Figure 1.3: Study Area – Coast of Akwa Ibom State, Southern Nigeria.

The study area is geologically underlain by late Cretaceous to Quaternary sediments (Edet et al. 2014) which include coastal plain sands, beach ridge complex, and alluvium. Edet (2017) notes that the alluvial sands are fine to very coarse grained, and light grey coloured floodplain mud and clays. According to OnlineNigeria (2003), deposits of recent alluvium and beach ridge sands exist along the coast and estuaries of the Imo and Qua lboe Rivers, as well as along the floodplains of creeks, with the majority of the state consisting of coastal plain sands that have weathered into lateritic strata with the geologic succession also gradually transitioning into thick sequences of clays, sands, and gravel. The study area (figure 1.3), comprises of a generally low-lying plain, and riverine areas showing no appreciably high relief that exceeds 175m above sea-level, apart for locations in the northern extreme corner of Obotme and Nkari and the north-eastern parts around ltu, Itam, Ibiono and Ini where the land is broken into a "valley and ridge" terrain (OnlineNigeria 2003; Beka et al. 2014). The study area has two geomorphic regions based on the topography which are the flat coastal plain regions, and the dissected regions (Ekpoh 1994). The physiography of the state can be divided into five based on the different landforms and terrain; beach ridge complex, alluvial plains, gently undulating sandy plains, sandstone hills and ridges with steep sided valleys (the dissected upland) and Obotme steep-sided and isolated hills with the mangrove swamps extensively developed in the coastal and estuarine areas and occupy the tidal mudflats laced with tidal channels, and the winding waterways (Ekpoh 1994; OnlineNigeria 2003). Ekpoh (1994) explained that the alluvial plains, the coastal stretch is made of well-developed mangrove swamps which occupies the tidal mudflats from Imo River estuary at Ikot Abasi local Government area (LGA) to the estuary of Cross River at Oron and is made up of numerous creeks, rivers, distributaries, meanders, and ox-bow lakes, and that the area comprises of dark to light grey carbonaceous mud and clay which are used for pottery making. It further describes the topography of the beach ridge to roll gently downward from the mangrove swamps to the shoreline with an average elevation between 30 – 50m above sea level and extends from the Guinea coast at Ikot Abasi to Oron LGA. Landwards, the gently undulating plains succeed the swampy and floodplain zone comprising of the younger plains of Benin formation. The dissected upland consists of gullies and ravines which are made up of laterites with gravels and ferruginous horizons while the Obotme hills are deeply weathered iron-stained sandstones and have terrains rising to 150m.

1.4 Problem Statement

The Akwa Ibom State coast has been identified as being highly vulnerable to hazards associated with coastal erosion, flooding, and SLR. The Akwa Ibom State Government presented the natural environmental issues in Akwa Ibom State as one of the most serious in Nigeria in a report of a community-based urban development project (World Bank assisted) in 2001, and described the prevailing beach erosion as "*relentless*"- AKS-Government (2001), pp 14. Despite such reports, it should be noted that most of the attention on environmental issues along the coast has been focused on coastal flooding, with less focus on coastal erosion. The few studies that exist either assessed the vulnerability of only some parts of Akwa Ibom to coastal erosion (Henry et al. 2013; Ekong 2017); conducted desktop analysis studies to qualitatively show possible changes in the coast (Adegoke et al. 2010; Udoh et al. 2014); or studied the general environmental degradation of the Niger Delta region with little or no reference to the scale and extent of coastal erosion in Akwa Ibom (Uyigue et al. 2007).

Similarly, none of the previous studies used an integrated approach involving physical parameters, participatory geographic information systems (PGIS) - a GIS (a computer-based tool for storing, mapping, and analysing geographically referenced data) that incorporates stakeholder viewpoints and local knowledge (Musungu et al. 2011) and social data from the coastal community, nor did they take into consideration the spatial variability to local landscape changes and geomorphic dynamics of the area. To the best of this researcher’s knowledge, there is currently no comprehensive understanding or detailed information on the rate of erosion and the areas severely impacted by it along the entire Akwa Ibom coast. The study area is a data-poor region, which contributes to the issue of a lack of vulnerability assessments for this area. This research aims to fill that gap by providing comprehensive documentation of the Akwa Ibom coast's vulnerability and susceptibility to coastal erosion. This information is required to develop adequate long-term risk and adaptation plans.

1.5 Aim

The aim of this research is to investigate and assess the vulnerability of the Akwa Ibom coast of Nigeria to the effects of coastal erosion on a scale that is useful for village planning and decision-making. Due to the spatial variability of coastal erosion, investigation at a village scale could help mitigate or reduce the vulnerability to coastal erosion in the area. The effects of coastal erosion vary along the coast, and an integrated approach combining physical vulnerability modelling, social vulnerability and risk perception through a community-based participatory approach is used to holistically address the coast's vulnerability to coastal erosion.

1.5.1 Objectives and Research Questions

The following objectives were addressed in this research with the associated research questions presented following these:

1. Identify the susceptibility of the Akwa Ibom State coast to coastal erosion using remote satellite image analysis and identify sections of the coast that are most susceptible to coastal erosion using shoreline change detection – (Chapter 3).

- *What is the trend of the shoreline change analysis in the study area?*
- *How rapid are the geomorphological changes in the study area?*
- *What is the temporal and spatial variations along the study area and which data resolutions are best suitable for the study area?*
- *Where are the most susceptible areas of the Akwa Ibom shoreline in the Niger Delta to the impacts of coastal erosion?*
- *What future coastal changes will likely occur, using historical rates of change in the area to assess the rate of change employing the Digital Shoreline Analysis System (DSAS) - Beta forecasting methodology which measures the rate of changes between shorelines?*

2. To assess spatial variability of the social-ecological drivers and impacts of coastal erosion along the Akwa Ibom state coast, and to examine the coping mechanism prevalent along the Akwa Ibom coastal areas to develop informed recommendations on possible adaptation strategies to enhance resilience to the effects of coastal erosion – (Chapter 4).

- *What is the local knowledge on coastal erosion?*
- *How has the prevalent social-ecological interactions along the coast changed over time and what is the impact on the vulnerability of the area to coastal erosion?*
- *How has the risk perception in the area influenced the emerging social-ecological patterns/processes in the area?*
- *What are the areas with greatest need and/or great capacity for adaptation and how does the coping mechanism currently used mitigate the impact of coastal erosion?*

3. To integrate the human (using a PGIS approach) and physical/environmental vulnerability assessments to assess the vulnerability of the Akwa Ibom coast to coastal

erosion using the widely used Coastal Vulnerability Index (CVI) model compared with a newly conceptualised Integrated Coastal Erosion Vulnerability Index (ICEVI) model and explore whether the use of social data can improve erosion vulnerability assessments in data poor countries – Chapter 5.

- *How vulnerable is the Akwa Ibom coast to coastal erosion?*
- *What is the benefit of participatory GIS (PGIS) in assessing coastal erosion?*
- *Does the integration of physical, socio-economic and social-risk perception characteristics contribute to an improved vulnerability assessment?*
- *What is the possibility of applying risk perception in a coastal vulnerability index assessment in an African context and to what extent will the combination of the community local knowledge on coastal hazards help in mitigating the effects of erosion?*

1.6 Thesis Structure

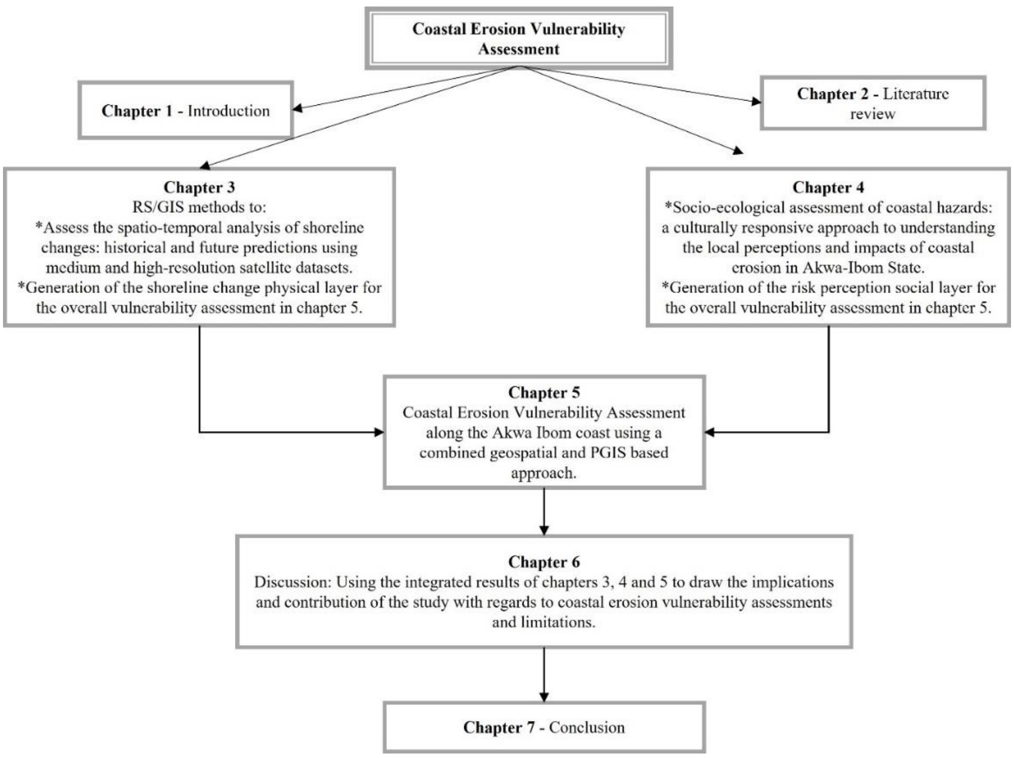


Figure 1.4: Flow chart of the thesis structure

The summary for the flow chart shown in figure 1.4 is discussed below:

Chapter 1 – Introduction

This chapter highlights some background information on coastal erosion, its causes, impacts and effects globally. It also introduces coastal erosion evidence from Nigeria, identifies research gaps in this field and presents the aim and objectives of this research.

Chapter 2 – Literature Review

This chapter extensively reviews past literature to provide and improve understanding of coastal erosion vulnerability assessments and identifies the gaps in knowledge in assessing the vulnerability of coastal regions to erosion globally and in Nigeria. It also discusses the socio-ecological factors affecting coastal erosion and its relevance in a more holistic approach to tackling environmental issues.

Chapter 3 – Spatio-Temporal Analysis of Shoreline Changes: Historical and Future Predictions Using Medium and High-Resolution Satellite Datasets.

This chapterfocuses on the spatio-temporal analysis of shoreline changes. It presents both the historical and future predictions of the Akwa Ibom coast using medium and high-resolution satellite datasets.

Chapter 4 – Socio-Ecological Assessment of Coastal Hazards: A Culturally Responsive Approach to Understanding the Local Perceptions and Impacts of Coastal Erosion in Akwa-Ibom State.

This chapter focuses on the data generation and analysis of social-ecological data using qualitative methods including questionnaires, interviews, and focus group responses to assess the local risk perception of coastal erosion, adaptive capacity, and threat/hazard mitigation. It analyses the complex relationship in a coupled socio-ecological system and community to individual level variations in perceived and physical vulnerability to coastal hazards.

Chapter 5 – Coastal Erosion Vulnerability Assessment Along the Akwa Ibom Coast Using a combined Geospatial and PGIS based approach

This chapter critiques and identifies the optimum approach for combining human (using a PGIS approach) and physical/environmental vulnerability assessments to assess the vulnerability of the Akwa Ibom coast to coastal erosion. The widely used Coastal Vulnerability Models (CVI) was compared with a newly conceptualized ICEVI (Integrated coastal erosion vulnerability index) to assess the vulnerability and to explore whether the use of social data can improve erosion vulnerability assessments in data poor countries.

Chapter 6 – Discussion: Implications and Contribution of The Study to Coastal Erosion Vulnerability Assessments.

This chapter provides a comprehensive discussion and synthesis of the results from Chapters 3 – 5. A globally overlooked dimension of coastal hazard vulnerability assessments is incorporating local spatial knowledge. PGIS is used to create a PGIS layer and then incorporate the risk perception layer from the social data (Chapter 4) into the vulnerability assessment (Chapters 5) to give an integrated social and physical coastal erosion vulnerability assessment for the study area. This identifies areas of greatest risk, as well as adaptation strategies.

Chapter 7 – Conclusion

Provides a conclusion and recommendations drawing on the implications, limitations and contribution of the study with regards to coastal erosion vulnerability assessments.

Chapter 2: Literature Review

Chapter two reviews past literature to provide and improve understanding of coastal erosion vulnerability assessments and identifies the knowledge gaps in assessing vulnerability of coastal regions to erosion. It discusses the socio-ecological factors affecting coastal erosion and its relevance in a more holistic approach to tackling environmental issues.

Chapter 2

2.1 Introduction

With an increase in migration to coastal areas, there is a growing risk imposed by coastal hazards resulting from natural and anthropogenic processes (Mukhopadhyay et al. 2012). Carter et al. (1994) suggested that in studying coastal evolution, researchers must consider alternate ideas, even if they are uncommon since it comprises of analysing how and why the features and position of the shoreline have changed over time. Understanding how the physical, ecological and human components of the coast affect coastal vulnerability assessment and more broadly, coastal development and management, is crucially important. This chapter is organised into three sections; the first explores previous literature to provide an overview of coastal erosion vulnerability assessments. The second section focuses on socio-ecological aspects related to coastal erosion, and the third part discusses the use of Participatory Geographic Information Systems (PGIS) in vulnerability assessments. Finally, the conceptual framework used in this study is presented.

2.1.1 Coastal processes

Coastal processes continuously acting on the coast, according to Chaitanya et al. (2021), are responsible for shoreline changes mainly through the process of a) hydraulic action, where the breaking wave or moving water apply direct hydraulic effects or pressure by trapping water and air into the materials along the coast (the structure and lithology of the materials that are being impacted upon determines the effect and rate of breakdown. Coasts with unconsolidated materials will experience more rapid erosion rates than in hard rock coasts because it is the compressed air and water in the fractures of the rocks that reduce the shear strength of the rock, allowing a break down in the rock mass); b) abrasion, which is caused when suspended materials in the water continuously strike and erode the material of the coastal rocks; c) attrition which occurs as a result of loose particles constantly colliding with one another, eventually leading to a wearing and breaking down; and d) corrasion which is caused by the wearing and tearing of rock mass as a result of the abrasive action. Another important factor that causes the breakdown of coastal rock is the speed of the wind as it increases across the water's surface. These increases of wind form the small ripples which transform into waves that hit the coast (Hyndman et al. 2010). Aside from speed, the strength of the wave (Sanford et al. 2018), the fetches which is the distance the wave travels and the time it takes (Prahalad et al. 2015) are all influential factors in determining whether waves are destructive or constructive, leading to either coastal erosion or accretion. While wave properties are important, Trenhaile (2016) emphasises that geology (the rock structure and lithology) defines how susceptible or resistant a rock is to erosion when struck by waves. Most commonly, waves and geology are mostly taken into account, however, Masselink et al. (2020) explain how important the geomorphology of the coast is and reported that there is usually a variability in the vulnerability among different types of morphology in response to coastal erosion and flooding. Since coastal erosion is site-specific, Masselink et al. (2020), advise against generalising coastal response to climate change. This simply suggests that understanding how the various coastal landforms respond differently to change processes within a coastal system, is critical.

A coastal system, according to Wong et al. (2014), refers to both the natural (e.g beaches, sand dunes, estuaries barriers, salt marshes etc) and human systems (includes settlements, tourism, agriculture, culture etc) in the coastal zone near mean sea level. It is important to understand how the coast has changed through time. As such, studying and examining the coast as a system composed of various elements will provide a better understanding of the interactions that cause the system to change (Esteves 2018). For this study, changes that give rise to coastal erosion within the coastal system will be examined. Climate change induced sea-level rise influences the way waves and currents shape and reshape the shoreline over time. Shoreline changes could result in either a landward or seaward movement of the shoreline which indicates erosion and accretion, respectively (Chaitanya et al. 2021). The way the coast responds to the processes acting upon it varies and is influenced by a number of natural and anthropogenic factors. According to Gracia (2022), the coast is highly dynamic which enables rapid changes along the coast. The terms: shore and coast are commonly used distinctively by many scientists but have also been used by many to mean the same thing. Some studies refer to coast when discussing the subject on a global or regional scale and use shore when it is more local or referring to a precise location. For simplicity, this study will use the word interchangeably while referring to a transitional zone between the land and sea. The terms coastline and shoreline will be used interchangeably to mean the boundary or line between the water and the land.

Masselink et al. (2013) stated that coastal response to SLR is influenced by in-situ factors rather than a global change or regional change in sea-level and suggests that predictions of any coast to climate change should be based on a detailed dataset in the research location. They also contended that nothing is lost in a coastal system, meaning erosion causes accretion elsewhere. It is widely acknowledged that SLR and storminess are significant contributors to coastal erosion. Relative SLR (RSLR) provides a considerable risk for coastal areas (Nicholls et al. 2010). IPCC (2014) noted that due to SLR projected in the 21st century, the coast, particularly the low-lying areas will experience increased impacts of several hazards including coastal erosion. Globally, the combined effects from human development pressures, natural coastal dynamics and climate change threats produce serious coastal hazards affecting not only the resilience of coastal communities (Mentaschi et al. 2018), but also the landforms within the coastal system.

2.1.2 Coastal Landforms

The coastal processes give rise to a variety of coastal landforms, which can be erosional (where sediments are removed) or depositional (where sediments accumulate) in nature. Examples of erosional landforms formed by coastal processes are; headlands, formed by more resistant rock that erodes slowly; bays, formed by less resistant rock that erodes quickly; canyons formed by less resistant rock that erodes quickly; cliffs are the vertically steep sides of rocks formed by wave-induced erosion, and wave-cut platforms are the levelled areas formed when waves undercut a cliff. Depositional landforms include beaches, spits, tombolo, bar and salt marshes (refer to Earle (2019) for a more detailed description of the various landforms). According to Pollard et al. (2019), regardless of which of the processes occurs (erosional or deposition), the natural setting of the coast is being altered, making it vulnerable to coastal hazards.

2.1.3 Coastal Hazards

Hazard is defined as an event (the cause or source) with the potential to threaten/or cause harm and loss (Poljanšek et al. 2017), whereas risk is defined as the likely outcome of exposure to hazard in terms of occurrence and loss if it occurs (Smith 2004). Coastal hazards are influenced by the physical processes that expose a coastal area to land degradation while also increasing the risk of loss to lives and physical assets (Bhable et al. 2015). According to Bhable et al. (2015) there is a clear distinction between short-term and rapid onset coastal hazards (e.g. cyclone, hurricane, tsunami, flash flooding) that can last from minutes to several days and the long-term and slow-onset coastal hazards (e.g. land subsidence, SLR and coastal erosion) which develop over time. For this research the long-term and slow-onset hazard, coastal erosion will be studied. The term risk and hazards are sometimes used interchangeably; however, Scheer et al. (2014) stated that risk describes the potential for a specific hazard occurring and the consequences from it. Another distinction to make is between risk (see section 2.1.4 for definition) and vulnerability (see section 2.1.5 for definition). Wolf (2012) states that a researcher's field of study affects the various meanings and understanding.

Table 2.1: Table showing the definitions of the different concepts adopted in this research.

Hazards	Physical processes that not only expose a coastal area to land degradation but also increase risk of loss to lives and physical assets	Bhable et al. (2015)
Risk	A likelihood and consequence of losses that is as a result of hazard, exposure and vulnerability or that results from a combination of hazard and vulnerability	Wolf (2012)
Vulnerability	Is the degree to which a system is exposed and susceptible to coastal erosion or inundation	Benassai et al (2014)
	Simplifies vulnerability as the potential of society or an individual to be harmed.	Fuchs (2009)
Susceptibility Sensitivity	The degree to which a system undergoes changes caused by natural stresses	Anfuso et al. (2021)
Exposure	The elements at risk in an area in which hazard events may occur	Cardona et al. (2012).
Resilience	How much a system can be disrupted yet adapt and continue without changing function or structure	Kombiadou et al. (2019)

Table 2.1 summarises the definitions of the various terms used in this study. In the context of natural hazards, risk is defined as the probability and consequence as a result of hazard and vulnerability (Wolf 2012). According to Brooks (2003), the natural hazards and physical sciences place greater emphasis more on the concepts of risks and susceptibility while the social sciences place more emphasis on vulnerability, particularly in terms of people's ability to adapt with change.

2.1.3.1 Risk

Risk is the result of the interaction of hazard, exposure and vulnerability (Taubenbock et al. 2008; Wolf 2012; Poljanšek et al. 2017). Wong et al. (2014) agree with Wolf (2012) on the definition of risk, and further distinguished the drivers of hazards as natural or climate related. SLR, ocean surface temperature, winds, extreme events/storm surge, ocean acidity, emission of carbon dioxide, greenhouse gases, socioeconomic development, population growth, land use/land cover changes, and water demand are all examples of "external climatic drivers" (see figure 2.1) that contribute to coastal system change (IPCC 2014). For the purposes of this study, the definition of risk by Taubenbock et al. (2008) is used because it emphasises the multi-layered contribution of risk which is illustrated in figure 2.1. Figure 2.1 shows that risk is the outcome of a combination of hazard and vulnerability which are influenced by a number of other contributing factors.

According to Taubenbock et al. (2008), for an element at risk, the hazard threatening it could be either natural or anthropogenic, or a combination of both which is driven by either internal or external forces and the degree of effect is governed not only by the type, probability and severity of the hazard but also the elements of vulnerability which are in turn influenced by either exposure, resilience/coping or the sensitivity and susceptibility to the hazard present.

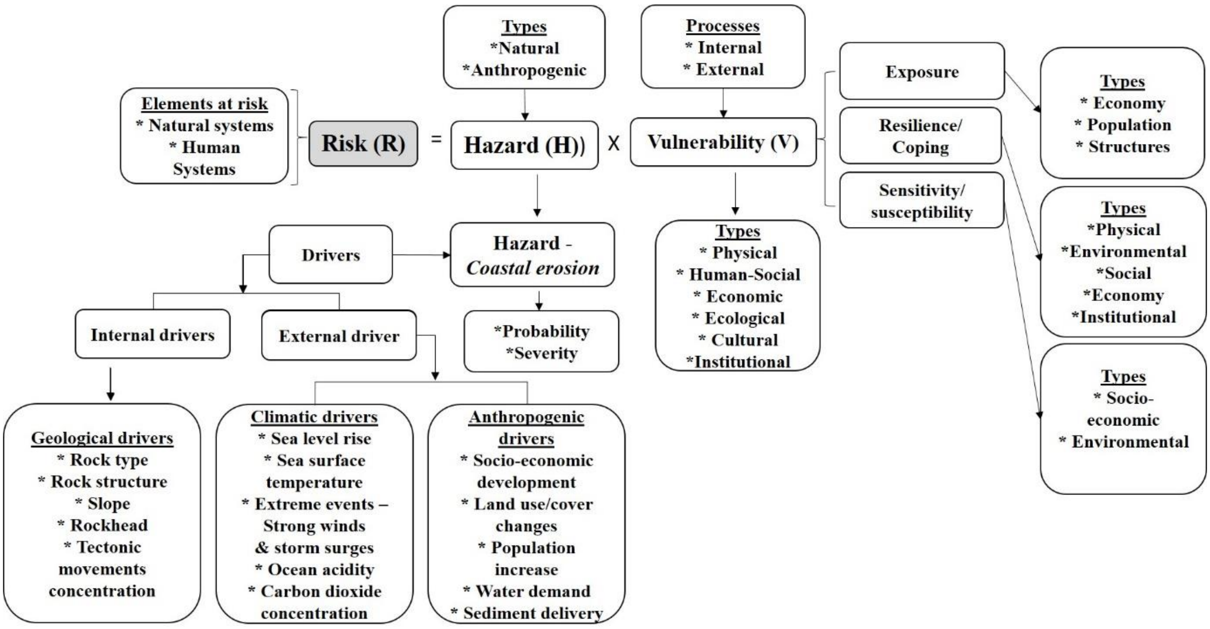


Figure 2.1: Illustration of risk concepts adapted from Taubenbock et al. (2008)

2.1.3.2 Vulnerability

According to Birkmann (2006) there has been no specific or global definition of vulnerability since the concept's evolution in the 1970s because there are several concepts of it with varying meanings depending on the disciplinary framework. For Brooks (2003), climate scientists use vulnerability to refer to the likelihood of climate-related occurrences, but social scientists evaluate vulnerability in terms of an individual's or community's ability to adapt with change in light of socioeconomic considerations. In the same context of the social sciences, Fuchs (2009) simplifies vulnerability as the potential of society or an individual to be harmed. According to Kundu et al. (2011), the ability to be harmed by hazards is crucial in a system's or an individual's vulnerability to a well-defined threat. Further, as highlighted by Fuchs (2009), the extent to which one is harmed serves as a proxy for their vulnerability. Vulnerability, then, is determined primarily by how exposed one is to the risk and is thus relatively invariant with respect to the magnitude of the hazard. Vulnerability, on the other hand, in Environmental Science, it is the degree to which a system or its parts are susceptible to damage from an environmental threat (Barnett et al. 2008).

The vulnerability components are multidimensional, which means that various factors influence the overall vulnerability (Fuchs 2009) and implies that understanding and combining these various factors is critical, as they have the potential to increase or decrease vulnerability. A person's or group's abilities determine their ability to anticipate, manage, resist, and recover from the effects of a natural hazard (Blaikie et al. 2004). Parry et al. (2007) has a similar definition by IPCC (2014) referring to vulnerability as the tendency of a system to be vulnerable to, and its incapacity to cope when exposed to impacts from climate change, together with the system's exposure, sensitivity, and adaptive capacity. The challenges that climate change poses to coastal communities have received a lot of attention (refer to (Klein et al. 1999; Mukhopadhyay et al. 2012; Giosan et al. 2014; Wong et al. 2014). Coastal erosion is a good example of such challenges and it is also the focus of this study, as such this study follows Benassai et al. (2014) which simplifies vulnerability as the susceptibility of a coastal area to be affected by inundation or erosion. While there may be some disagreement about the precise definition of vulnerability, there is a consensus that it refers to an individual's or group's susceptibility to harm. Definitions from a variety of fields are provided in Table 2.2 below. This study utilises the concept of coastal vulnerability by Benassai et al (2014) and Fuchs (2009), which is most applicable to the situation in Nigeria, because it allows for a more comprehensive and holistic evaluation of the vulnerability of the Akwa Ibom coast for both the physical and human factors.

Table 2.2: Examples of vulnerability definitions showing variability across disciplines

Definition	**Discipline**	**Reference**
Vulnerability is a potential of society or an individual to be harmed.	Social Sciences	Fuchs (2009)
Vulnerability refers to the extent to which systems or their components are susceptible to harm or damage as a result of an environmental hazard.	Environmental Sciences	Barnett et al. (2008)
Vulnerability is the effect of the ability of households to respond to risk which is dependent on underlying conditions.	Economics	Alwang et al. (2001)
Vulnerability refers to potential of physical, emotional and cognitive health at risk of being agitated, damaged or destroyed by dangerous influences or illness.	Medicine and Healthcare	Boldt (2019)
Vulnerability is the tendency to be seriously affected by hazard and dependent on various concepts which include sensitivity or susceptibility to injury and the lack of coping and adaptive capacity.	Disaster-Risk Management	IPCC (2014)
Vulnerability is ability of an individual or household to cope with shocks linked to basic necessities, food and nutrition access.	Food Security	Maxwell et al. (2000)
Vulnerability is the tendency to which a system is susceptible to and unable to cope when exposed to climate change impacts.	Climate Change	IPCC (2014), Parry et al. (2007)
Agricultural vulnerability to climate change is the ability of the farmers to adapt to the effects of exposure of crops to climate change and sensitivity of crops yields with such exposure.	Agricultural Science	(Fellmann 2012)

2.1.3.3 Exposure

The International Panel on Climate Change (2014) defines exposure as the presence of people, resources, and assets in a hazard-prone location. Exposure also refers to any elements at risk that are susceptible to probable loss if a hazard event occurs (Cardona et al. 2012) which includes not only the human population but the environment, property and agriculture that are threatened by hazards (Poljanšek et al. 2017). According to Nicholls et al (2002), exposure can be both direct and indirect. However, only a few studies have made a clear distinction when discussing exposure. Wong et al, (2014) noted that globally, research places much emphasis on the physical impacts of exposure to hazards. This research will intend to bridge that gap by assessing the physical and social exposure to the impacts of coastal erosion in subsequent chapters of this work.

2.2 Coastal Erosion

Coastal erosion occurs as a result of sediment loss from a coastal system or subsystem (Esteves 2018). With high confidence, the Intergovernmental Panel on Climate Change (IPCC) has expressed that increasing sea levels and other non-SLR-related drivers are causing increased coastal erosion in coastal zones, especially along low-lying coasts (Oppenheimer et al. 2019). Coastal erosion is influenced by a combination of several factors which include natural or anthropogenic, internal or external drivers (see figure 2.2).

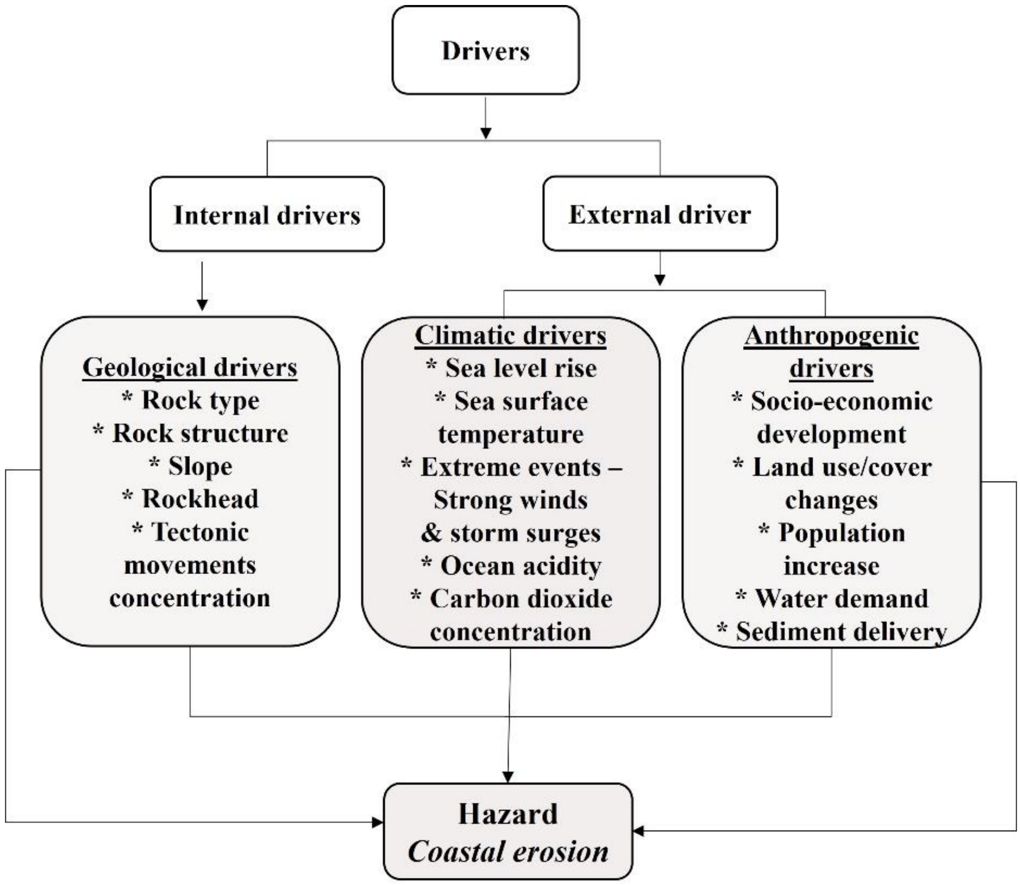


Figure 2.2: Drivers influencing coastal erosion adapted from Taubenbock et al. (2008)

2.2.1 External Driving Forces

In this study, the exogenous elements that influence erosion processes are broken down into two categories: climate-related and anthropogenic factors (human-caused).

2.2.1.1 Climate-Related Drivers

Coastal processes are influenced by climate variables such as SLR, which can either inundate or erode the coast, wind speed and direction, which creates waves that form sand dunes along the coast, wave height and frequency, storm intensity and frequency, which provides the current to disintegrate and transport soil particles along the coast. The most often discussed effects of climate change are the ensuing SLR and increased frequency of extreme weather events (storminess), which have exacerbated coastal erosion and floods. According to the IPCC (2014) climate change will exacerbate natural processes that affect the coast. The climate change intensity will result in increased coastal erosion rates (Nicholls et al. 2010; Cubasch et al. 2013; Westra et al. 2016) and would be devastating on low-lying barrier islands or oceanic atolls (Williams et al. 2018). Mentaschi et al. (2018) discovered that because of climate change, the global trend in coastal erosion could be exacerbated by SLR, higher intensities, and more frequent extreme events such as storms. According to Cazenave et al. (2010), the effect from SLR usually plays out through an inter-play with other natural factors or could be in combination with anthropogenic factors (figure 2.2).

2.2.1.2 Anthropogenic Drivers

Human activities and interference both directly and indirectly contribute to coastal erosion. According to Esteves (2018), human interference modifies the forcing conditions (the naturally occurring and dynamic agents present in coastal areas, such as wind and tidal waves) and, as a result, plays a critical and influential role in the changes in the coastal system, depending on the scale (time) of the study (see table 2.3). He reported that deforestation caused by human actions is a major contributor to coastal erosion because it exposes the soil, making it susceptible to erosion. Apart from deforestation, other anthropogenic activities like land reclamation, engineering works, seaports and jetty establishments, dredging, sand/gravel mining, and re-channelling of river channels (Prasetya 2006; Anthony et al. 2015; Esteves 2018) have exacerbated coastal erosion. Due to the current condition of climate change and SLR, Rangel-Buitrago et al. (2018) warned that coastal erosion may soon reach uncontrollable magnitudes as a result of rising urbanisation, which necessitates the removal or heavy exploitation of backshore vegetation for use as building materials and roofing sheets, leaving the coast vulnerable to weathering agents such as waves, strong winds, and SLR. They added that because the coast is one of the most urbanised and populous areas in the world, more substantial monitoring and management of coastal erosion is required. Poor coastal management practices, river diversion, water abstraction, construction works and sand mining (which increases the wave energy as a result of increased depth) could severely impact coastal erosion (Anthony et al. 2015). Given that coastal change is influenced by a combination of factors and that the knowledge of these interactions is hampered by a lack of data, He et al. (2019) suggest that it has become impractical to discern between natural and human-induced coastal erosion. However, in recent decades, the rate of human-induced physical changes along the coast has increased, as confirmed by Orme (2018). These human activities such as dam construction, irrigation systems, and structures alter the flux of sediments, or the clearance of coastal habitats like mangrove forests, were shown to be the primary cause of coastal change globally (Mentaschi et al. 2018).

Table 2.3: Time scales of coastal changes. Adapted from Stive et al. (2002), Masselink et al. (2003), Ferreira (2005), Esteves (2018).

Time Scale			**Change in Morphology**	**Natural factors**	**Human-induced factors**
Very long term	Geological time scale	Centuries to millennia.	The morphology changes are as a result of the mean trend in the forcing conditions	* Long term climate change * Geological structure *Sediment availability *Relative sea-level change	*Anthropogenic climate change
Long term	Engineering time scale	Decades to centuries.	The morphology changes result from many variations in the driving forces that span from years to centuries.	*Tidal inlets cycle *Regional climate variations *Sand waves migration *Extreme events *Relative sea level changes	*Soil stabilisation around inlets *Coastal engineering structures *Sediment retention by dams *Land reclamation *Sand/gravel mining *River rechannelling
Middle term	Event time scale	Years to decades.	The geomorphology changes range from a single event through to seasonal variation in the forcing condition.	*Waves, climatic variations *Surf zone cycles *Extreme events	*Land reclamation *Scarping of coastal dunes *Coastal land degradation *Vegetation removal along the coast
Short term	Instantaneous time scale	Hours to months.	The change in morphology could be during a single cycle of the forcing condition.	*Waves *Tides *Storm groups *Extreme storm events *Sediment fluxes	*Vegetation removal *Beach nourishment

2.2.2 Internal Driving Forces

Yin-can (2017) notes that internal geomorphic processes, such as local rock type, geological structure and tectonic movement, play crucial and incessant roles in coastal erosion. The shape of shorelines, local sediment sources, rate of change, and spatial and temporal variability are all controlled by the geology of the coastal environment (Esteves 2018). The interaction of tectonic, hydrological, and geological forces gives rise to the geomorphology of an area (landscape evolution), and it is crucial to comprehend the function of internal geomorphology (endogenetic processes) in this process.

While the landward migration of a coastal system is a natural reaction of a coastal system to rising sea levels, Masselink et al. (2020) stated that coastal erosion is also regulated by in-situ parameters (e.g. rock type, material) of the coast and their response to changing impacts. Cliff retreats on rocky coasts, for instance, are primarily determined by lithology and climate, as reported by Hurst et al. (2016) in their investigation of the factors that cause coastal change. As such, the rate of erosion will change according to the hardness or softness of the rock along the coast. It is therefore, expected that there will be a lower rate of erosion along hard rock when compared to the soft coast like a sedimentary environment. Even in the sedimentary environment, susceptibility to erosion to a large extent is dependent on the nature of the sediment. For instance, more consolidated rocks, will be more resistant than loosely or unconsolidated sediments. The resistance of the rock along the shore has a significant impact on how the coast is affected by erosion, both in terms of geographical and temporal variability and as such could vary along the coast. Coastal erosion is not only influenced by lithology, but also by other geologic elements (such as slope) and the shoreline itself is subject to change as a result of environmental conditions that cause changes in the coast over time (Masselink et al. 2003). It is worth noting here that the driving forces might not be limited to any certain time period, meaning that they could transcend different time scales (see table 2.3).

2.2.3 Coastal Erosion Assessments

Coastal erosion processes have been evaluated on a global, regional, and local scale using a wide range of methods. It could be determined by comparing dated historical maps, charts, aerial photographs, and widely used satellite imagery which Bird (2018), demonstrated that coastal changes could be identified. The changes are expressed as either advance of the shoreline or retreat of the shorelines from the land margin, representing accretion or erosion, respectively. Several approaches have been developed to assess coastal erosion as a result of rising coastal erosion rates and coastal vulnerability. A field measurement approach to estimate coastal erosion at the Sohr region of Oman was presented by Abushandi et al. (2020). From June 19th, 2016, through November 16th, 2016, researchers collected data from 19 shoreline locations generating two sets of field measurements. The results showed a considerable volumetric erosion with an average of -5.2m/year between the first measurements in June and those taken in November. Due to factors like cost implication, technical knowledge, and accessibility to the coast, field investigation may not always be possible. According to Naik et al. (2016), remote sensing and geographical information system (GIS) techniques have proven to be very useful in assessing shoreline changes particularly where field studies are not possible. They used the free, open-source Digital Shoreline Analysis System (DSAS) tool in ArcGIS to make an estimate of the changes to the shoreline in Karnataka, on India's western coast. There are different statistical analysis within DSAS that are commonly employed to make predictions about past and future shoreline changes (Oyedotun 2014; Himmelstoss et al. 2018; Terres de Lima et al. 2021) (see chapter 3.2.6 for more details on the DSAS approach). A regional-scale coastal erosion assessment of the entire Columbia coast was carried out by Stronkhorst et al. (2018) using the global coastal hazard wheel approach (CHW). The CHW categorises the coast for stakeholders' decision-making purposes based on the coastal location, the presence of hazards, defined management alternatives, and the exchange of coastal information. Here, Stronkhorst et al. (2018) classified the Columbia coast based on six biophysical parameters (geological layout, waves, sediment balance, tides, storms, and vegetation) derived from the global open access data. Although the results showed its usefulness for coastal planning in locating vulnerable areas to erosion, this method only looks at natural processes and ignores the effects of human constructions. It is most certain that the identification of hotspots of erosion is crucial, however, for more effective adaption and mitigation measures, understanding of not only the natural systems but the physical, socio-economic, environmental, and political vulnerabilities of coastal area to erosion, is necessary.

2.2.4 Coastal vulnerability assessments

Different approaches have been used in assessing coastal vulnerability to hazards. They include: index-based approaches, indicator-based approaches, Geographical Information System, GIS-based decision support systems, and methods based on dynamic computer models (Ramieri et al. 2011). While all these approaches can be used to assess coastal vulnerability, the data required for each approach differentiates them. The index-based approach is the most often employed method since it is simple to use and requires less data than other approaches (Koroglu et al. 2019). The most commonly used index-based approach is the coastal vulnerability index (CVI). The index-based approach ranks and assesses vulnerability using either a single metric or a set of metrics, as well as providing an overall overview of the hazard present and allows for comparison analysis. The disadvantage of this approach is that it is unable to accurately represent the complexity of the coast. The indicator-based approach is similar to the index-based approach but uses distinct, mostly local indicators to quantify risk in different locations. However, it does not support compared analysis of vulnerability across places because it uses localised indicators that may only be pertinent to the region of research. The GIS-based decision support tools are a collection of computer-based tools designed to assist in decision making (Wong-Parodi et al. 2020). According to Wong-Parodi et al. (2020), though it is useful for managing the human and environmental systems relationship in the coast and also promotes participation of stakeholders, it is data and time intensive, requiring user support and training to use. The dynamic computer models like the Dynamic Interactive Vulnerability Assessment model (DIVA) uses computer simulations to model and predict changes in coastal vulnerability over time. Despite being effective in analysing the dynamism of the coast, it is data dense, time consuming and requires expertise to understand and interpret (Hinkel 2005), exactly like the GIS-based DSS.

Coastal vulnerability assessments have been used to assess vulnerability to a variety of coastal hazards such as sea-level rise (Rocha et al. 2020), erosion (Jana et al. 2013), flooding, storm surge, and wave action (Pantusa et al. 2018). Vulnerability assessments are necessary because coastal vulnerability has the potential to destroy physical landforms as well as disrupt natural ecosystem relationships (Seenipandi et al. 2021). These assessments provide adequate understanding of the prevailing hazards and the interactions of the coastal system, and they are useful for management development (Mclaughlin et al. 2010). As earlier stated, the CVI is the most extensively used index-based technique (see Table 2.4) and it uses information on the physical, social and human factors along the coast at the regional and national levels to quantify the relative vulnerability of coast segments to the effect of SLR (Addo 2013; Musa et al. 2014). It ranks different parts of the coast numerically depending on how likely they are to change owing to different types of physical factors (Addo 2013). These changes as Sudha Rani et al

(2015) suggest, should not only identify and study vulnerabilities, but should also underpin appropriate adaptation and mitigation plans.

The original CVI, though widely used, is not without its limitations. The lack of incorporation of the demographic and economic data, as noted by Gornitz (1991), is the CVI's fundamental weakness. These factors are crucial for a more rigorous assessment of coastal vulnerability. Other limitations include the subjective nature of the user-defined weights that are applied to each parameter. Ramieri et al. (2011) addressed these limitations, by suggesting that the simplicity of the CVI may not accurately reflect the complexity of the coastal system; thus, it is necessary to combine indices that effectively model these complexities, such as taking into account the human contribution/exposure to erosion risk. Exposure variables are recognised as those predominantly exposed and vulnerable to the impact from a hazard or threat (Musa 2018). Interestingly, though exposure is important to determine risk, it is not always sufficient on its own (Cardona et al. 2012). With coastal vulnerability analysis, shorelines are often exposed to several variables. For example, it is important to understand shoreline exposure to the different factors considered when calculating the CVI. In simple terms, shoreline exposure measures the extent of which a particular portion of the shoreline is vulnerable which constitutes an important variable in assessing susceptibility (Suganya et al. 2015). Not only does a scientific understanding of the physical elements that contribute to coastal vulnerability remain crucial, so does the understanding of the social components in the assessment (Corell et al. 2014). As earlier stated, to address the limitations of the CVI, it is suggested that modification should be the approach to incorporate indices that will enable adequate understanding of the complex coastal vulnerability (Ramieri et al. 2011). Several updated versions of the CVI are shown in Table 2.4. For instance, to better assess vulnerability to SLR, the original CVI was amended (CVISLR) to include physical and human-influenced elements (such as sediment supply reduction, engineered structures, river flow regulation, coastal protection structures, and land use pattern) (Ozyurt et al. 2009). According to Ozyurt et al. (2009), the accuracy of vulnerability was found to be significantly influenced by taking into account local properties/variations and integrating human variables.

The original CVI assumes that all the parameters used have the same importance. However, some studies optimised the CVI by incorporating parameter weightings which assigns rankings based on the importance of the parameter in relation to coastal erosion, where the most important parameter is assigned the highest ranking value and the least important, the lowest ranking value (Kovaleva et al. 2022) - (refer to section 5.3.2 a more comprehensive discussion on weight parameters). The Analytical Hierarchical Process (AHP) have been successfully employed in assigning weights in a CVI (Cozannet et al. 2013; Murali et al. 2013; Bagdanaviciute et al. 2015) (see table 2.4). The AHP technique relies on the expert's knowledge, qualitative and quantitative data to make pairwise comparisons which are based on numerous criteria in defining and addressing the problem (Cozannet et al. 2013). The comparisons are then made using an absolute scale of the importance of one variable over another in relation to a specific property (Saaty 2008) (refer to chapter 5.2.2 for a more detailed description). Murali et al. (2013) examined the socioeconomic variable, which was not taken into account with the existing CVI weightings (calculated from the square root of the product of the ranking factors divided by the number of parameters examined) and found that it contributed to a better understanding of vulnerability. A similar result was obtained by Kunte et al (2014) that calculated the CVI for the state of Goa using seven physical and geologic risk indicators (historical shoreline change, rate of relative sea-level change, coastal regional elevation, coastal slope, mean tidal range, significant wave height, and geomorphology), plus two novel socioeconomic variables; population and tourist density data. The analyses were conducted with and without the social variables, and it was discovered that the vulnerability was dramatically reduced when the social variables were excluded from the analysis. This suggests that there is either a significant underestimation of vulnerability, implying that physical CVIs only estimate a limited range of vulnerabilities, or that the weightings used for the socioeconomic parameters are so high that they have a dominant influence on the index. Nevertheless, the CVI could be used as the primary guide for the assessment, however, it should be supplemented with other parameters such as social and economic parameters for a more comprehensive evaluation of coastal vulnerability while also incorporating community input to guarantee effective adaptive and mitigation actions. Several studies have emphasised the importance of including and engaging coastal communities and stakeholders (social inclusion) in vulnerability assessments, examples include: (Kundu et al. 2011; Horita et al. 2013; Islam et al. 2013; Gorokhovich et al. 2014; Labib et al. 2017; Bevacqua et al. 2018; Haworth 2018). Haklay et al. (2017), recognised that the participation of local stakeholders provides additional datasets that allow for a more comprehensive approach to vulnerability assessment.

A regional vulnerability assessment (RVA) is used to demonstrate the importance of regional scale social and physical data for assessing vulnerabilities at the local to regional, rather than global, scales (Torresan et al. 2012; Saxena et al. 2013). They discussed that this method requires various subsets of bio-geophysical (such as coastal geomorphology, topography, slope, etc) and socio-economic (vegetation cover, coastal defence, etc) data for its assessment. This method is similar to the AHP in that it uses expert opinion to establish the vulnerability factor classes and scores, as well as to aggregate environmental and socioeconomic indicators (Torresan et al. 2012). It did, however, show an improvement in analysis of hot spot zones for coastal disasters, which could be useful for minimising the vulnerability of current hot spot areas. The advantage of this assessment lies in its importance in decision making since the final vulnerability index ranging from very low, low, medium, high to very high vulnerability is a combined score of multiple contribution parameters. It considers the contributing elements, which area the susceptibility factors that determine the extent to which a receptor can be affected by the hazard, the pathway factors which refers to the physical characteristics of elements such as exposure and value factors that identifies receptors of value that needs to be preserved in the decision. The disadvantage, however, lies in the analysis of contributing elements that are relevant for prospective adaptation methods (Torresan et al. 2012). This means that the accuracy of the vulnerability is largely dependent on the accuracy with which the contributing components are calculated.

The composite vulnerability index is another vulnerability model that is used. According to Ghosh et al. (2017) and Salik et al. (2015) the composite vulnerability index approach provides an indicator-based estimation of coastal socioeconomic characteristics in connection to ecological and climatic factor, making it straightforward to represent vulnerability. Fitton et al. (2016) determined susceptibility of the Scottish coast to coastal erosion using the coastal erosion susceptibility which was calculated using the Underlying Physical Susceptibility Model (UPSM) and the Coastal Erosion Susceptibility Model (CESM). The UPSM model utilised the ground elevation, the distance from open coast, exposure to wave and the rock head elevation data in its analysis. The novelty of the study was the inclusion of the rock head elevation which had been previously excluded due to lack of data. Though two models used in Fitton et al. (2016) can be used individually, the result of the UPSM combined with the CESM model considers coastal defences and sediment accretion data to assess the physical susceptibility, providing an in-depth understanding of defences that are in place. This type of information influences a coast's overall susceptibility to coastal erosion. Despite its efficiency, it relies on data like the rockhead, defence and wave exposure that are not readily accessible, particularly in developing countries. Data availability limits the quality of coastal erosion assessment methods (Stronkhorst et al. 2018), unless the methods are modified to accommodate the limited data, which then raises confidence issues about the modification process and outcomes. As satellite data have become more widely and freely accessible, the use of satellite imaging techniques, remote sensing and geographical information systems (GIS) for the identification, mapping, and analysis of coastal changes has increased significantly (eg Mukhopadhyay et al. (2012), Adelola et al. (2017), Danladi et al. (2017), Ahmed et al. (2018), Apostolopoulos et al. (2021)), particularly in developing countries.

Table 2.4: Summary of Coastal Vulnerability Index (CVI) assessment variables and the modified Coastal Vulnerability Index (CVI) assessment types (updated and adapted from Abuodha and Woodroffe (2006)).

Vulnerability Index	**Variables used**			**Location**	**Studies**
	Physical/Environmental parameters	Human-induced/Economic parameters	Equation		
Coastal Vulnerability Index (CVI)	Geomorphology, coastal slope, coastal regional elevation, SLR rate, shoreline erosion/accretion rates, tidal range and significant wave height.	Settlement/population variable, cultural heritage, roads, railways, landuse, conservation designation	$CVI = \sqrt{\frac{a*b*c*d*e*f*g}{n}}$ $CVIeco = \frac{a+b+c+d+e+f}{30} * 100$ For CVI, a, b, c, d, e, f, g are the different physical parameters used and n is the total number parameters used	Algeria	(Djouder et al. 2017)
	Dune height, barrier type, beach type, relative sea level change, shoreline erosion and accretion, tidal range, mean wave height	-	Adapts the original CVI to include more variables	Egypt	(Frihy 2017)
	Geomorphology, coastal slope, shoreline change rate, rate of sea level change, mean tide range, bathymetry and storm surge height.	-	Adapts the original CVI to include more variables	Bangladesh	(Islam et al. 2016)
	Physical and geologic risk variables: rate of relative sea level change, historical shoreline change, coastal slope, coastal regional elevation, mean tidal range, and significant wave height	Population.	Adapted from the original CVI to include socio-economic data	Karnataka Coast, India	(Jana et al. 2016)
	Topography (coastal slope), geology (coastal geomorphology), biota (fauna/flora of the coast)	Coastal land use.	Adapted from the original CVI to include socio-economic data	Saudi Arabian Red Sea coast	(Hereher, 2016)

	Shoreline erosion and accretion rates, geomorphology, regional slope, mean wave height, relief, tidal range and relative sea level change.	-	Follows the original CVI	Niger Delta, Nigeria	(Oyegun et al. 2016)
	The historical shoreline change rate, beach width and height, sediment properties, inclination of the underwater slope and appearance of sand bars, mean significant wave height.	-	Follows the original CVI + AHP weights	Lithuanian coast	(Bagdanaviciute et al. 2015)
	Historical shoreline change, rate of relative sea-level change, coastal regional elevation, coastal slope, mean tidal range, significant wave height, and geomorphology using conventional and remotely sensed data.	Population and tourist density data.	Adapted from the original CVI to include socio-economic data	Goa, India	(Kunte et al. 2014)
	Geomorphology, erosion/accretion rate, coastal slope	Participatory GIS	Adapts the original CVI and overlays with PGIS layers	Northwest Alaska, USA	(Gorokhovich et al. 2014)
	SLR, geomorphology, coastal slope, significant wave height, sediment budget, reduction of sediment supply, river flow regulation, engineered frontage, groundwater consumption, land use pattern, natural protection degradation, coastal protection structures, tidal range, proximity to coast, type of aquifer, hydraulic conductivity, depth to groundwater level above sea level, river discharge, and water depth at downstream location.	-	$CVSLRI = \frac{(CVEI \cdot CVSI)}{CVRI}$ CV_EI is the exposure parameter, CV_SI is the susceptibility parameter and CV_RI is the resilience parameter	Niger Delta, Nigeria	(Musa et al. 2014)

	Physical–geological parameters: slope, geomorphology, elevation, shoreline change, SLR, significant wave height and tidal range.	Population, land use/land cover, roads and location of tourist areas. Used analytical hierarchical process (AHP) to improve the CVI.	$PVI = W1X1 + W2X2 + W3X3 + W4X4 + W5X5 + W6X6 + W7X7 + \cdots \ldots WnXn$ $SVI = W1X1 + W2X2 + W3X3 + W4X4 + \cdots \ldots WnXn$ $CVI = \frac{PVI + SVI}{2}$ Where PVI is the physical parameters and SVI is the socio-economic parameters	Puducherry coast, India	(Murali et al. 2013)
	Shoreline change, bathymetry, means sea level, significant wave height, mean tidal range, regional elevation, geomorphology, storm surges.	-	Adapts the original CVI to include more variables	Chennai, India	(Kumar et al. 2012)
	Shoreline type, rivers, geology, drift geology, elevation, orientation, significant wave height, tidal wave, difference in modal and waves, frequency of storms	Settlement, cultural heritage, roads, railways, land use, conservation designation, population	Coastal vulnerability = (coastal characteristics sub-index + coastal forcing sub-index + socio-economic sub-index)/3	Northern Ireland	(Mclaughlin et al. 2010)
	Relief, rocky type, landform, shoreline displacement, vertical displacement, tidal range, and wave height	-	$CVI = \sqrt{\frac{a * b * c * d * e * f * g}{n}}$ where a, b, c, d, e, f, g are the different physical parameters used and n is the total number parameters used	USA	(Gornitz 1991)
Coastal Vulnerability Assessment (CVA)	Run-up distance (as a measurement of coastal inundation), beach retreat (as a measurement of potential erosion), and beach erosion rate (obtained through the shoreline positions in different periods).	-	$CVA = IRu + IR + ID + E + T$ where IRu is an index associated with wave run-up distance, IR is the short-term erosion index for the shoreline, ID is the backshore coastal protection structures stability index, E is the beach erosion rate, and T is the tidal range	Italy	(Paola et al. 2014)

Beach Vulnerability Index (BVI)	Topographic maps (1:550,000) and aerial photographs, long-shore sediment transport, cross-shore sediment transport, riverine sediment inputs, the effect of sea level change, erosion of associated coastal landforms, wave run up and aeolian transport.	-	$BVI = \frac{Ql + QC + LE + QA + WR + SLC + QR}{7}$ Where Q_l is the long-shore sediment transport, Q_C is the cross-sediment transport LE is the coastal landform erosion, Q_A is the aeolian transport, WR is the wave run-up, SLC is sea level change, Q_R is the riverine sediment influx and seven is the number of indicators involved.	Agia Anna beach, Greece	(Alexandrakis & Poulos, 2014)
Regional Vulnerability Assessment (RVA)	Coastal slope, geomorphology, elevation, vegetation cover, artificial protection, distance from coastline, dunes, sediment budgets, mouth typology.	Agricultural typology, wetland extension, urban typology and protection level.	Vulnerability index related to the receptor j and the impact k = weight of factor a* score related to the susceptibility factor a, the receptor j and the impact k + weight of factor b* score related to the pathway factor b, the receptor j and the impact k + weight of factor c*score related to the value factor c, the receptor j and the impact k	North Adriatic Sea, Italy	(Torresan et al. 2012)
Integrated Coastal Vulnerability Index (ICVI)	Physical Vulnerability Index (PVI): coastal slope, Coastal landforms/features, Shoreline change rate, Mean spring tidal range, and significant wave height.	Social Vulnerability Index (SVI): population density of adjacent coastal villages, land use/land cover, proximity to road network and settlement.	$PVI = W1X1 + W2X2 + W3X3 + W4X4 + W5X5$ $SVI = W1X1 + W2X2 + W3X3 + W4X4$ $ICVI = \frac{PVI + SVI}{2}$ Wn is the weight value of each variable and Xn is the vulnerability score of each variable.	India	(Mahapatra et al. 2015)
	Physical Parameters (PVI): Storm surge, Inundation extent, tidal range, rainfall, slope of continental shelf, topographic slope, rate of shoreline changes, coastal geomorphology, mean wave height, relative sea level change. .	Socio-economic (SVI) and environmental parameters (EVI): population density, vulnerable population, structural features, awareness system, transportation facilities, Land-Use Land-Cover (LU/LC), mining, and industrial units.	$ICVI = PVI + SVI + EVI$ Where PVI is the physical parameters, SVI is the socio-economic parameters and EVI is the environmental parameters	Odisha, India	(Sahoo et al. 2018)
Composite Vulnerability Index (CVI)	Exposure: sea surface temperature, precipitation, air temperature Sensitivity: Mangrove degradation, water and sanitation, freshwater flows, coast of climatic disasters,	Adaptive capacity: consumer pattern, income diversification, dependency ratio, education level, infrastructure, household asset holdings, family network, migration.	$CVI = 1/3\,(E + S + (1 - A)$ where E is exposure, S sensitivity capacity and A is adaptive capacity	Pakistan	(Salik et al. 2015)

	Relief, slope, depth, soil property, tidal range, tidal height	Habitat; socio-economic population, household, agricultural area Politico-administrative infrastructural aspects; infrastructure and amenities facilities	Composite vulnerability index (CVI) = hydrogeomorphic vulnerability + socio-economic vulnerability due to lack of infrastructure and amenities)/3	India	(Ghosh & Mukhopadhyay, 2017)
Coastal Vulnerability Index to SLR (CVI_{SLR})	Physical parameters: rate of SLR, geomorphology, coastal slope, hl/3, sediment budget, tidal range, proximity to coast, type of aquifer, hydraulic conductivity, depth to groundwater level, above sea water depth at downstream discharge. .	Human influence parameters: reduction of sediment supply, river flow regulation, engineered frontage, natural protection degradation, coastal protection structures, groundwater consumption and land use pattern.		Turkey	(Ozyurt et al. 2009)
MDim-CVI	Extreme sea level, shoreline evolution trend, distance from shoreline, coastal slope, elevation, geological coastal type, coastal protection structures	Population, GDP per capita, Land use patterns	$MDim - CVI = \frac{CF + ENV + SOC + ECO}{4}$ Where CF is the coastal forcing, ENV is environmental factor, SOC is the social factor and ECO is the Economic factor	Italy	(Furlan et al. 2021)

2.2.5 Remote Sensing Processes for Coastal Monitoring and Assessment

Remote sensing (RS) techniques are commonly used for shoreline detection, extraction and monitoring in developed nations (Gens 2010; Zhang et al. 2013; Xu 2018). This is because RS has a wider spatial coverage (Mishra et al. 2016; Russ et al. 2022), provides near real time data (Yu et al. 2018), and can be easily analysed and is cost-effective when compared to traditional ground survey methods (Elnabwy et al. 2020). Most coastal vulnerability assessments are data intensive and according to Musa et al. (2016), data availability is one of the most significant variables for coastal system assessment. This is the case in most African countries, including Nigeria, as data are either scarce or difficult to obtain/access in comparison to more developed countries. Due to the availability of free satellite imagery, remote sensing (RS) is utilised by the vast majority of data-deficient nations (Thomas et al. 2018). Adelola et al. (2017) emphasised that the examination of coastal change through remote sensing is particularly relevant for developing countries due to the lack of resources for local scale monitoring and low capacity to manage the risk associated with the coastal hazards. Despite the benefits of RS/GIS, it is not without its limitation. RS requires image processing (Toure et al. 2019) and this could introduce a variety of errors ranging from the pre-processing procedures, image classification, and the misinterpretation of images due to image resolution, image characteristics such as texture, colour, tone, etc during analysis. According to Elnabwy et al. (2020), data resolution influences the quality of mapping due to its dependence on accuracy and precision. Despite the significance of data resolution in coastal assessment, one may postulate that lack of data also influences the image resolution used in some analysis, particularly in developing countries with limited data. Also, the use of remote sensing approaches may not always be straightforward, requiring expert knowledge for intense data processing (Stahl et al. 2021). An example of such, is the smartline mapping approach by Sharples (2006) which has been successfully used to assess coastal vulnerability of Rio de Janeiro State, Brazil (Lins-de-Barros et al. 2013). This mapping method for identifying coastal areas was improved by Lins-de-Barros et al. (2013) by integrating socioeconomic variables such as population, urban density, monthly income, methods of water supply, and sewage disposal in the assessment to identify areas susceptible to coastal hazards and are expected to become even more vulnerable in the future. Though this approach was successful, it is not as straightforward as stated because it requires a substantial pre and post data manipulation to successfully use this method. Nonetheless, the broad applicability of RS across different disciplines and in tandem with other methodologies has contributed immensely to an advancement in research. Rangel-Buitrago et al. (2018) advised that, with the collaborative nature and widespread use of RS/GIS in recent times, the integration of spatial, temporal, environmental, physical, and social knowledge is essential in assessing coastal erosion processes which are necessary to prevent or mitigate economic and social losses.

2.3 Coastal Erosion and Social Learning

> *"The challenges posed at the land-sea interface by the impact of global environmental change and by intensive human use of coastal resources will require further cross-disciplinary collaboration and interdisciplinary consultation and study" Woodroffe (2002), p 2.*

Coastal environments are at risk of erosion, as such research into the interaction of social and natural systems is critical in the coastal erosion vulnerability, as several components of the linked socio-ecological systems (humans and the environment) influences it (Woodroffe 2002). As a result, a comprehensive approach to assessing environmental challenges must consider both the social and physical coastal systems. According to Walmsley et al. (1993), studying behavioural approaches will provide perspective into the how and why of human behaviour, as well as an understanding of how to characterise and interpret the meaning of attachment to place and landscape. The study indicated recent trends in combining scientific analysis of human behaviour spatially and attachment to place. The engagement of behavioural approach with other disciplines is further discussed by Argent (2017). Being open minded in social research and the opportunities they present, Strand et al. (2003), investigated the use of community-based research (CBR) participatory approach, which has since become a more prominent domain in modern research. The study highlighted the usefulness of this approach in data generation for research, since it is a collaborative effort between the researcher and members of the community (Strand et al. 2003). Evidence from previous studies (Gorokhovich et al. 2014; Haklay et al. 2017) suggests that a more inclusive approach is required to understand the relationship between the coupled human and environmental systems and how this affects coastal erosion.

2.3.1 Coupled Human-Environmental Systems

Corell et al. (2014) demonstrated that integrating research from natural and social sciences with research from other professions such as engineering, law, and business improves understanding of the coupled human-environment system. The study suggests that understanding how natural and social changes at varying spatial scales impact individuals and their surroundings is crucial as human activities contribute significantly to earth system processes. They indicated that while it is necessary to understand the fundamental scientific trends, variability and changes in the earth system suggests that research should not only include the physical, chemical, and biological components of the earth, but also the human components of the earth system as it will inform a more effective assessment of climate change impacts. For instance, it can provide information about environmental threats unique to their environment, and it can reduce community risk through the establishment of community-based disaster management mechanisms (Labib et al. 2017). However, having research models that result in tangible change can be difficult to create according to Kelly et al. (2013), because they require a holistic understanding of the system processes that is made up of different components, their complex relationships, and how they react to environmental shifts.

A participatory approach that includes stakeholders in the modelling process had been advocated in earlier years by Sandker et al. (2010), as a method to increase end-user approval and involvement in the outcome. The United States Global Change Research Program (USGCRP) recently discussed the benefits of integrating earth's natural and human components. According to USGCRP (2022)'s report, global change research has come a long way in the preceding three decades, expanding its scope to include ecosystems, human systems, and their interactions in response to environmental shifts. In Tri National de la Sangha, Sandker et al. (2010) used a participatory approach and a dynamic model to examine issues in environmental management (a conservation area in the Congo Basin that includes Cameroon, the Republic of Congo, and the Central African Republic). Stakeholders were involved in every step of this methodology, from fundamental data and information sharing to model structure creation and result interpretation. They looked into whether or not the participatory approach helped them better understand the landscape dynamics and potential treatments, and they discovered that it did, which means that this method is essential for addressing conservation and development concerns from a landscape viewpoint. The research also revealed that the method might be a helpful tool for stakeholders with the help of trained facilitators, as it leads to a deeper comprehension of landscape dynamics and more effective decision-making in environmental and natural resource management.

There are various environmental issues for which Parrott (2017) suggests might not have an obvious or simple solution. The researcher referred to them as "wicked problems" and highlighted that many ecological models failed due to the non-inclusive approaches used, implying that participatory ecological modelling can lead to effective environmental management and policies that solve the “wicked problems”. It also suggested that, in order to better understand an environmental system, the modeller should explore the social realm, becoming a facilitator and communicator. The study’s model provides a structure for involving stakeholders in both the model development and output, demonstrating that it can successfully create applied outcomes in management or policy. Furthermore, because stakeholders have a good understanding of the system to be modelled, the study recommended that a team of expert stakeholders engage with the modeller throughout the process to have a good understanding of the model and be participating partners as they can advise the modellers about a feasible model structure, given the available data. It also concludes that this is important because it allows knowledgeable stakeholders to share their insights about the system and help build sound management policies and assist stakeholders in identifying useful applications of the research results, rather than being merely passive recipients of the model's output. According to Vaughn et al. (2020), participatory approaches where stakeholders are included, bridges data gaps and offers shared responsibility for the research’s outcomes.

While there are certainly benefits to including stakeholders in the modelling process, it appears that this information is most useful as a supplement to existing models rather than a replacement for them. Parrott (2017) emphasised the fact that even though environmental modelling tends to focus on quantitative techniques, the qualitative ways incorporating the stakeholder participation during the modelling process are just as important as the quantitative methods. As such, Parrott (2017) comes to the conclusion that these methods should not be overlooked in a modelling endeavour, especially if the project's goal is to help with practical results. A good example of a sustainable approach and effective stakeholders participation is the shoreline management plans (SMPs) in England and Wales by the department for Environment, Food and Rural Affair, DEFRA (2006) which has since been replicated in other parts of the United Kingdom, for instance in Scotland (Hansom et al. 2010).

2.3.2 Participatory GIS

The usage of GIS, or Geographic Information Systems, is common to support decision-making. A GIS is a computer-based tool for storing, mapping, and analysing geographically referenced data.

Participatory GIS (PGIS) is a GIS that incorporates stakeholder viewpoints and local knowledge (Musungu et al. 2011). In the Kotzebue Sound region of Northwest Alaska, U.S.A., Gorokhovich et al. (2014) were the first to successfully integrate physical and social data from community-based participatory GIS mapping into a coastal vulnerability index. Additionally, Sy et al. (2016) demonstrated the value of using local knowledge to gather precise data that may be utilised to comprehend patterns of hazard and vulnerability. Although the paper's focus was on flood assessment, it made use of local expertise in Yeumbeul Nord (YN), one of Pikine's 16 municipal districts in Dakar, Senegal and generated quantitative household data through the participatory mapping that could be used to supplement traditional GIS and remote sensing data. They noted that the local representatives provided their expertise at three different levels of the dataset: the first was to confirm the accuracy of the preliminary land-use map created using remote sensing data, the second was to precisely map areas of water bodies, and the third was to conduct a thorough survey of key infrastructures like hospitals, schools, recreation areas, and public services in the region. In other words, the final land-use map of the study area created from remote sensing data was improved by including the local expertise of local teams and being confirmed by/with them. This demonstrates how the quality of the data produced by remote sensing can be greatly enhanced by local knowledge and how combining local knowledge with remote sensing could improve data, especially in cloudy areas. Notwithstanding the fact that their study focused on flood risk assessment, it revealed that the approach may be duplicated for risks in another context and their approach provides an alternative to using pricey high-resolution satellite images when financial resources are limited or when satellite images are not available in the study location.

Kienberger et al. (2005) developed a more comprehensive notion of vulnerability that spans from global to local social and ecological factors, and addresses the main objectives of PGIS, which allow the participation and representation of indigenous spatial knowledge and methodologies. Their assessment of flood and drought risks relied heavily on semi-structured interviews, transect walks, and community mapping, all of which are examples of participatory approaches. According to their findings, PGIS methods effectively incorporate indigenous people's knowledge and may be applied in a way that is understandable and flexible for easy adaptation for the less empowered people. They also showed that vulnerability assessment, GIS, and participative approaches all overlap (see figure 2.3), indicating that all spatial modelling should be explored.

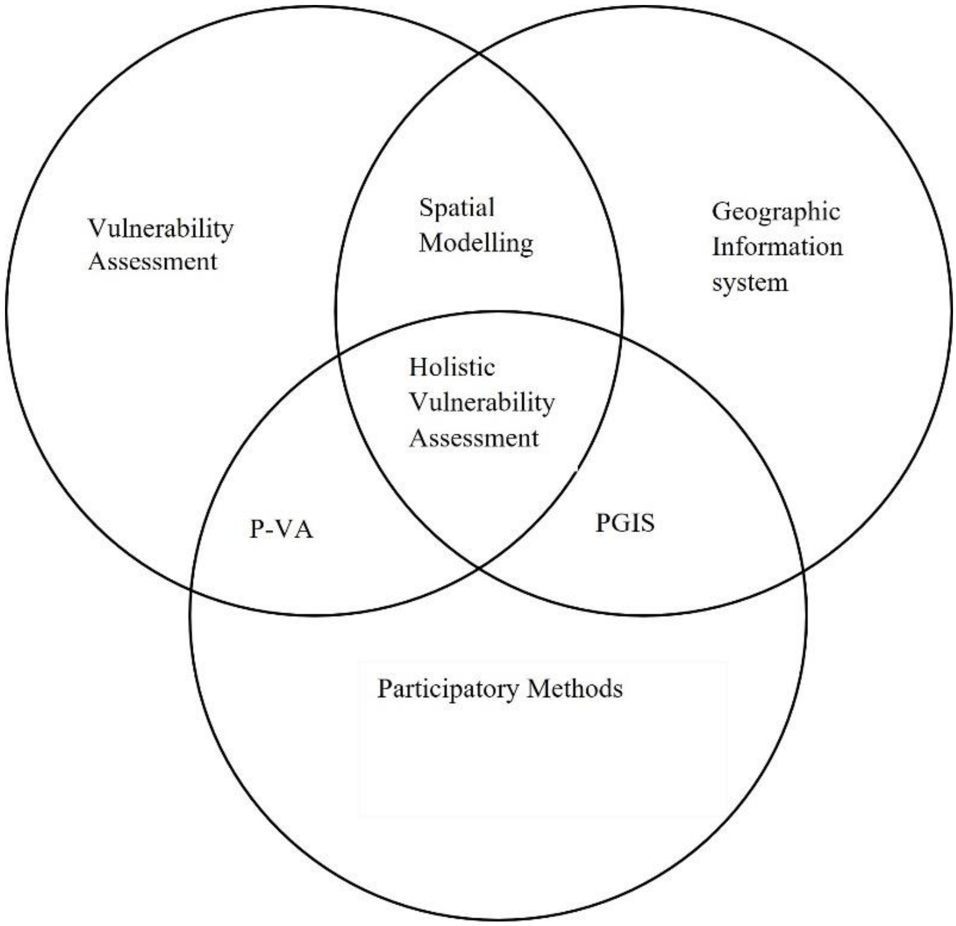


Figure 2.3: Overlaps between Vulnerability Assessment, GIS and participatory approaches adapted from Kienberger et al. (2005).

To aid in identifying potential implications of anthropogenic activities including climate change in coastal areas, Licuanan et al. (2014) presented a participatory vulnerability assessment approach, in which stakeholders discuss the coping and adaptation mechanism necessary to mitigate these impacts. As a result, the approach increases the number of stakeholders who participate in participatory planning and collective decision-making, which in turn improves the opportunities for learning. The ability to collect data and analyse them opens the door to greater discourse, more reliable data, and a more collaborative strategy. Labib et al. (2017) conducted research on the efficacy of public participatory GIS mapping in community-based disaster management, providing another example of PGIS mapping. Here, one Bangladeshi village in Dhaka's Ward-13 was successfully mapped using this technique to show how susceptible it is to earthquake damage. Indigenous knowledge can provide local information that regular GIS mapping cannot, which is why the study emphasised the benefits of employing indigenous knowledge and community-based mapping above traditional GIS mapping. Based on their findings, they propose that community resilience and management can be strengthened through the use of participatory geographic information system (GIS) mapping to identify risk. Although stakeholder participation is encouraged, Hasanzadeh (2021) highlights the risk of unintentional biases due to the inclusion of people from different backgrounds and socioeconomic status and how this would affect the outcome. While PGIS attempts to incorporate several viewpoints into decision-making, Radil et al. (2018) pointed out that there is little evidence to support the claim that increased public participation improves outcomes. Despite the shortcomings, most studies agree that incorporating local knowledge into coastal assessment, especially for poor nations with limited access to quality data, can help get a better understanding of coastal risks at the micro level (Stronkhorst et al. 2018).

2.3.3 PGIS and Local Knowledge in Coastal Erosion Assessment

PGIS has been used successfully in assessing coastal vulnerability. Musungu et al. (2011) demonstrated the use of PGIS to collect and integrate community-based information into a GIS that was used by the Cape Town City Council (CTCC) for flood risk assessment. The study reported how data gathered from communities may be used to highlight micro levels of vulnerability, drive risk management techniques, and thereby add to the corpus of Participatory GIS. The study concluded that solutions vary even within a settlement, highlighting that macro-level solutions implemented were ineffective. It reported that, despite the difficulties in this technique, PGIS is a crucial tool for enhancing data gathering for flood risk management in informal settlements. Another study by Gorokhovich et al. (2014) effectively linked coastal vulnerability with community-based resource mapping for subsistence in Northwest Alaska. According to McCall (2015), community and individual local spatial knowledge are critical for identifying disaster risk conditions and developing community-based management plans. It also emphasised the limitations, such as establishing relevant standards and metrics for credibility and dependability as well as understanding the scale and method for combining participatory data on the timing of common hazards with remote sensing data.

Recent studies recommend a more mix-method and interactive approach to monitoring coastal erosion processes to prevent or alleviate losses (Woodroffe 2002; Kienberger et al. 2005; Famuditi et al. 2014; Phong et al. 2017; Rangel-Buitrago et al. 2018). It is recommended that in addressing environmental issues for the rural and data-poor environment including the Niger Delta region in Nigeria, a participatory approach that includes them as stakeholders in a dialogue would be a better solution for prescribing solutions to environmental problems than a prescriptive and non-inclusive approach (Singh et al. 1995). According to Douglas et al. (2008), which used a participatory approach to assess flooding in the Makoko slum area of Nigeria's Barrier-Lagoon coast (Western Nigeria), the local residents were already observing physical changes that worsened their vulnerability to coastal hazards, leading to the adaption of a common approach to improving resilience which is erecting their houses on stilts. Also, along the study coast in Southern Nigeria, this method is also used together with sandbags to reinforcements around their homes to promote resilience along the coast (see figure 2.4).

Figure 2.4: Photo A shows stilts built in homes to relocate to the upper deck during flooding at Itak Edim Ekpe, Ibeno L.G.A. Photo B shows sandbags used as defence around houses at Mbo L.G.A. All photos were taken by the researcher in September-October 2018.

Although most studies applied PGIS in other environmental issues such as flooding and not in coastal erosion, the successful implementation of the approach makes it relevant to this current research. Given that there is a need and paradigm change to incorporate communities and stakeholders, especially those that are settled in these hazard prone locations, this often-disregarded aspect of coastal erosion risk assessment can help to comprehensively address these challenges. In addition, it will test a more nuanced approach to coastal vulnerability assessment by integrating scientific, demographic, and local knowledge and awareness, which, while being piloted on the coast of Nigeria, has the potential to be applied to a wide variety of global contexts and hazards/vulnerabilities. The conceptual framework of incorporating the social science data in a PGIS is discussed in chapters 4 and 5.

2.4 Coastal Erosion Assessment in Nigeria

A comprehensive search of current knowledge on coastal erosion vulnerability assessment in Nigeria using Scopus and the Web of Science databases was the primary source for this section's literature analysis. These two databases were initially used since they are huge interdisciplinary databases that provide information on a variety of journal articles and other scholarly publications (Chadegani et al. 2017). A systematic literature review was planned for this chapter to demonstrate rigour. However, because the literature on PGIS in the context of coastal erosion, which is a critical element of this thesis, is limited both globally and in the study area, this study had to rely on grey literature for information. For example, a search on Scopus was conducted using "coast* AND "erosion*" in the title, topic, keywords and abstract. The initial result obtained without any exclusion/inclusion parameter on Scopus was n= 13,364, when an inclusion parameter of "Nigeria" was included in the title, topic, keywords and abstract, n = 48 and "participatory geographic information system" was used in the title, topic, keywords and abstract, n=0. A variety of other keywords like "assessment" and "vulnerability" were used but the search return was very low. Other sources of information, such as Google scholar, grey literature sources, official reports, and material from government and non-governmental organisations, were used to avoid underrepresentation of previous publications relevant to this study. As a result, no systematic literature review was used.

This section examined recent assessments and developments in coastal erosion assessment from 2010 to the present in order to comprehend the country's current state of coastal hazard. The Nigerian coast is highly dynamic, with varying rates of erosion and accretion through space and time (Fabiyi et al. 2013) due to predominant presence of soft sedimentary materials along the coast that are extremely erodible (Alhassan et al. 2012) . The coast is already undergoing major morphological change due to sea surges and tidal waves as a result of accelerated SLR (ASLR), and further SLR are anticipated to reach between 0.5 and 1 m this century (Olorunlana 2013). This increase in sea level has contributed immensely to the rapid rate of coastal erosion (Musa et al. 2014). Given that SLR and heavy human activity have been connected to the erosion and deterioration of areas of the Nigerian coast, there is a lack of knowledge of this risk in Nigeria, as well as a lack of effort to control these hazards (Danladi et al. 2017). The evidence from the publications reviewed for this chapter shows that coastal flooding hazards and risks have received a lot more attention in Nigeria than coastal erosion. However, Uyigue (2009) suggests that the most serious environmental concern in the Niger Delta is coastal erosion, which explains how it has led to the destruction of coastal vegetation and the relocation of coastal communities. The coastal erosion assessments in Table 2.5 were undertaken in the various geomorphological zones of Nigeria and were chosen for their relevance to this study.

2.4.1 Coastal Erosion Along the Strand Coast

The Akwa Ibom Coast is also known as the Strand Coast. Geographic information systems have been widely used to determine the area's susceptibility to coastal hazards (Henry et al. 2013; Ituen et al. 2014; Udoh et al. 2014; Ekong 2017; Udo-Akuaibit 2017). Ituen et al (2014) used remote sensing and GIS to evaluate the shoreline change along Ibeno from 1986-2008; the findings showed erosion and accretion rates of -3.9m/yr and 2m/yr, respectively. These results are similar to those reported by Ekong (2017), which showed an average erosion rate of change of -3.9 m/yr and an average accretion of 2 m/yr between 1986 - 2008. They both reported that excessive rains exacerbated coastal erosion, washing away several tiny fishing ports in the area. Hence, erosion rates were therefore higher than accretion rates along this stretch of the Strand shoreline for the time period under consideration. Along another section of the strand cost, Henry et al. (2013) evaluated coastal erosion and accretion from 1990 to 2010 in Mbo Local Government Area (L.G.A) and their findings demonstrate that the coast is highly dynamic and sensitive to erosion and accretion, with parts changing from land loss to land gain or vice versa over the time period of assessment.

Udoh et al. (2014) used GIS to assess the vulnerability of Akwa Ibom State to climate change-based exposure, sensitivity and adaptive capacity. The findings which focused on the entire state and not only the coastal area, showed that the high class of vulnerability covers an area of 616 km^2 (9% of the state); the medium class of 4996 km^2 (73% of the state) and low class covering an area of 1232 km^2 (18% of the state). It also revealed that Akwa Ibom State's shoreline area is especially vulnerable to climate change-related hazards such as erosion, flooding, and SLR. It evaluated the locations based largely on socio-economic parameters and only one physical parameter which was proximity to the coast. At Itak Abasi, in the Ibeno Local Government Area of Akwa Ibom state, GIS was also used to analyse the coastline changes by Udo-Akuaibit (2017). The findings revealed that between 2002 and 2013, approximately 0.18km^2 of this village was lost to the Atlantic Ocean. During this assessment period, in 2011, a storm surge hit the Strand coast causing significant land loss and causing a fishing community (Itak Abasi) to be pushed 600m landwards from its 2002 position, leaving many homeless. Here, coastal erosion and floods were particularly bad along the updrift beach, while accretion occurred along the downdrift shoreline. As a result, Udo-Akuaibit

(2017) noted that erosion and storm occurrences had significantly altered the Strand coast in under a decade. Amangabara et al. (2021) performed a thirty-year shoreline change analysis, along a section of the Nigerian shoreline including the Eastern Obolo-Ibeno axis of the strand coast 1986-2016 using geospatial techniques. The result, which was estimated from the land use/landcover change analysis, suggests that major coastal accretion was observed in the Ibeno area between 2000-2016 while high levels of erosion were associated with the Eastern Obolo axis. This possibly indicates that an updrift accretion was taking place at Ibeno with sediments eroding from the Eastern Obolo axis. Despite the alternating cycles of erosion and accretion, evidence from past studies suggests that coastal erosion is a major issue along this coast. Abija et al. (2020) assessed the shoreline changes between 1991-2018 and discovered that the average erosion and accretion rates were-5.5m/yr and 2.8m/yr respectively, indicating a prominent trend of erosion along this coast. According to Oloyede et al. (2022), which calculated the coastal vulnerability index of the Nigerian coast using an aggregate of both physical and socio-economic vulnerability indexes combined with the AHP approach by Saaty (1987), discovered that a shoreline change analysis conducted on a national scale between 1986-2015, showed that pronounced erosion were observed along the strand coast. Their findings suggest that the strand coast was prone to coastal erosion because of the presence of high wave heights with increased wave energy, exacerbated by anthropogenic factors (such as mangrove exploitation and construction), increasing the vulnerability of the coast to coastal erosion.

2.4.2 Coastal Erosion Along the Niger Delta

A recent study was carried out by Abija et al. (2020) to assess shoreline changes along the Niger Delta region between 1991-2018 using GIS and remote sensing techniques. The findings showed coastal erosion rates along the Rivers and Bayelsa sections of the coast to be about -11.1m/yr and -7.2m/yr respectively while accretion rates were 5m/yr and 4.6m/yr respectively, suggesting a predominant trend of coastal erosion which has been exacerbated by human activities like dredging. The coastal erosion trend was also observed by Adegoke et al. (2010) which investigated changes in the Niger Delta shoreline over a 17-year period using GIS and remote sensing techniques (between 1986-2003). According to the statistics, there was a significant coastal erosion throughout a 46.535 km^2 stretch of the coast, with 27.65 km^2 eroding (59.43%) and 18.88 km^2 accreting (40.57%) respectively. These findings, when compared with an earlier work by Ibe in 1988, discovered that erosion was still dominant in the Brass area only, while the Escravos area and the Forcados river mouth of this coast were now predominantly accreting, differing from Ibe's results which had observed high erosion in these areas. As they imply, one possible explanation for the high accretion rates, could be attributed to the coastal protection works undertaken by the oil companies in the area (like the Shell Petroleum Development Company, SPDC). Several studies like that of Adegoke et al. (2010) have been carried out in the Niger Delta coastal system and have indicated that there is a high vulnerability to climate change impacts such as flooding, inundation and coastal erosion in the Niger Delta (Mmom et al. 2013; Musa et al. 2014; Adeyeri et al. 2017; Ojile et al. 2017). These studies demonstrate an appreciable pattern of erosion and accretion along this coast; however, it is not uniform across the entire coast. A good example is the case of the Rivers state, where a 32-year time series examination of shoreline evolution revealed alternating patterns of erosion and accretion. According to Adelola et al. (2017), the results showed that that section of the coast experienced accretion of about 1990.33m and erosion of about -403.48m between 1984-2000. However, between 1984 – 2016, the rate of accretion decreased to 706.18m while erosion was increased to -750.84m. It was determined that throughout a 32-year period, over 70% of the region underwent erosion and 30% underwent accretion. Although the study contends that rates of erosion have grown in the region between 1984 and 2016, it does not define or quantify the precise areas of the shoreline that are accumulating and eroding, giving the report the appearance of being overly ambitious in its assertions. In contrast, Oyegun et al. (2016) noted that between 1986 and 2010, mean volumetric shoreline erosion and accretion were recorded to be 3.39 km^3 and 0.13 km^3 in the Western Niger Delta, respectively, and 2.29 km^3 and 4.77 km^3 in the Eastern Niger Delta. According to these data, the western portion of the Niger Delta has experienced more erosion between 1986 and 2010 than the eastern portion. In contrast to Adelola et al. (2017), Oyegun et al. (2016) demonstrate the benefit of hazard assessment at a local scale as opposed to generalising it along the entire coast. That is not to discount regional, national or global studies because they offer an overview of the general trend.

Over the last few decades, GIS techniques have been employed in the Niger Delta to demonstrate dynamic patterns in accretion and erosion. The use of RS/GIS is the most common technique for analysing coastal erosion. From the findings of the studies conducted in Nigeria, some of the studies used this method to either visually interpret changes, calculate shoreline changes or incorporate a coastal model into the analysis. According to Henry et al. (2013), GIS and image processing tools are effective and useful for analysing coastal hazards. Adegoke et al. (2010) noted that despite the efficiency of utilising GIS, the biggest drawback was the spatial resolution of the satellite imagery that was readily available, noting that a better resolution would improve the accuracy of coastal change measurements.

2.4.3 Coastal Erosion Along the Transgressive Mahin Mud coast

The impacts of coastal erosion on the Transgressive Mud coast have been extensively discussed by Olorunlana (2013). The study observed that over the past three decades, there has been an increase in coastal erosion, seawater intrusion, and flooding caused by waves rather than currents. This has had an effect on the physical and the socioeconomic situation. According to the study, coastal erosion is happening at a pace of 35 metres per year and that the Awoye village has moved 3 kilometres inland from where it was originally. Olorunlana (2013) found that the area's rapid rate of erosion also coincides with the 1970s' crude oil and gas exploration. In the Aiyetoro region, between 1974 and 1999, the coast receded 570m. The study further points out that the locals in the Aiyetoro area claimed in a memo to the Nigerian National Petroleum Corporation (NNPC) in 1981 that seismic investigations carried out in the region by the company produced shock waves that significantly damaged the King's concrete palace and other buildings in the town; however, the Corporation refuted the claim. The study emphasised how anthropogenic activities, in addition to SLR, affected coastal erosion and accretion patterns in Nigeria, causing it to vary between different geomorphic coast types. Dada et al. (2019) examined the anthropogenic effect of land use/land cover (LU/LC) patterns between 1987-2017 along this coast. The evaluation was done through shoreline changes along this coast. The study, which employed multispectral Landsat TM/OLI 8 pictures in a GIS environment, found that the Mahin Mud coast was experiencing severe erosion, with a coastal retreat of roughly 58% (50.7 km). Furthermore, they noted that 10.64 km^2 of land has been lost to the Atlantic Ocean over the course of 30 years. These findings agree with Olorunlana (2013), that both marine variables such as wave storms and increased flooding owing to sea level rise, together with anthropogenic variables such as land use/ land cover changes that exposes and leaves the coast vulnerable, influence these rapid rates of erosion.

Oyedotun (2015) conducted a time series analysis to calculate change statistics along this muddy coast of Ondo between 1972 and 2014 to evaluate shoreline changes along the coast using the DSAS in the ArcGIS environment. He reported that the average net shoreline change was of -25m, implying that coastal erosion was predominant during the assessment period. More recently Komolafe et al. (2022), conducted an assessment of the Ilaje axis of the coast to estimate shoreline changes from 1986 to 2017 (31 years) and found that roughly 40 km of the total 80 km of the dynamic portion of the coast was accreting at a rate of + 1.08 m/yr while about 35.4 km of the shoreline was eroding at a rate of -1.40 m/yr. The evidence from these publications, indicate that substantial erosion was taking place along the transgressive coast.

2.4.4 Coastal Erosion Along the Lagoon – Barrier coast

A long term spatio-temporal analysis was conducted along the Lagos coast 1900-2016 by Nwilo et al. (2020), using maps for the years 1900, 1946 and 1964 and satellite imageries for the years 2001, 2012 and 2016 to assess the coastal erosion and accretion along this coast. The results showed varying rates along the coast; the highest rates of erosion and lowest rates of accretion observed along the western side were -15.91m/yr and 0.02m/yr respectively. On the eastern side the highest rate of erosion was -26.5m/yr which was observed at a section of the coast where the Apese community has since been lost to the Atlantic Ocean. They determined that, during the study period, coastal erosion was more prevalent along the eastern axis of the coast while accretion was more prevalent along the western axis. However, they also noted that erosion rates along the eastern axis have decreased in recent years due to the Eko Atlantic city coastal defence. Still along the eastern section of the coast, Ajide (2016) determined the rate of erosion and accretion in Etiosa, Victoria island. The study used GIS techniques with social research methods (structured interviews and questionnaires) to assess coastal changes. Although the focus of the study was on flooding, analysis of the Landsat images showed 31.4% rate of erosion between 1962 -1984 and interestingly, accretion of 81.89% between 1984-2000 and 62.11% between 2000-2011.

Danladi et al (2017), used remote sensing techniques with geological maps and digital elevation models to assess coastal erosion due to SLR in the Lekki area over a 43-year period (1973 - 2016). The rate of erosion was analysed before and after a breakwater structure was erected in 2013 to prevent coastal erosion, suggests that from 2010 – 2012, coastal erosion and accretion alternated; it observed that in 2011, erosion was predominant while 2012 there was more accretion than erosion. It further reports that, in 2013, a breakwater structure which was constructed to help prevent erosion, escalated the situation by interrupting this erosion-accretion pattern, escalating the rates of erosion as observed between 2013-2016. By 2016, a significant loss of about 10.9m of a section on the Goshen beach estate axis to the ocean was recorded. Apparently, that axis of the coast was initially measured to be about 77m of land lateral to the shoreline in 2013 but 2016 after the breakwater structure was erected, the area now measured 66.1m, an indication that 10.9m of land was eroded into the sea. This remarkable sediment loss raises concerns about the type and design of the structure. For instance, the findings by Darwish et al. (2016) along the Alexandria coast in Egypt showed that when engineering structures (seawall) were emplaced, there was a decrease from -1.90m/yr average erosion between 1984-2001 before the seawall to 1.49m/yr between 2001 – 2015 after the seawall was emplaced. The finding is the opposite for accretion with an increase of average accretion from 2.50 m/yr between 1984-2001 to 4.40m/yr between 2000-2015. This shows that either the engineering structure's design and structure were flawed, or it may not be the ideal management practise along the Goshen beach estate axis of the Lagoon – Barrier coast.

Table 2.5: Studies on Coastal Erosion in Nigeria.

Authors/year	**Summary of findings**				**Approach/parameters**				
		Trend	**Scale**	**Risk**	**RS/GIS**	**PGIS**	**Physical parameters**	**Social parameters**	**Fieldwork**
Oloyede et al. (2022)	This study used seven physical parameters which includes coastal slope, bathymetry, geomorphology, wave height, mean tidal range, shoreline change rate and relative sea-level rise and four socioeconomic parameters which includes population, cultural heritage, land use/land cover and road network to estimate the coastal vulnerability of the Nigerian coast. The study found that between 59% and 65% of Nigeria's coastline is at moderate to high risk from rising seas. In particular, as the SLR, the Barrier, Mud, Delta, and Strand coastlines will see increased flooding and erosion.	Erosion	Long term shoreline changes at a national scale		*		*	*	
Komolafe et al. (2022)	high accretion (> + 1 to + 2m) to high erosion (-1 to – 2m) reported in the Ilaje, Ondo State with 35.4km of the active coast experiencing significant erosion.	Accretion	Long term shoreline changes at a local scale		*				
Amangabara et al. (2021)	Significant coastal accretion was observed in Ibeno area between 1986-2016 while high levels of erosion were associated with the Eastern Obolo axis of the strand coast, Akwa Ibom state. Generally, accretion between 1986-2000 was 107.76m while between 2000-2016, it was 297.5m	Erosion	Long term shoreline changes at a regional scale	Loss of Land	*				

Nwilo et al. (2020)	Shorelines along the Lagos coast were assessed from 1900 – 2016. The results show that coastal erosion was predominant in eastern axis of the coast while accretion was prominent in the western axis of the coast. However, the rates of erosion along the eastern axis have in recent times reduced since the construction of the Eko Atlantic city coastal defence.	Erosion and Accretion	Long term shoreline changes	Loss of Land, eroded village	*				
Abija et al. (2020)	The study assessed shoreline changes along the Niger delta region of Nigeria (Bayelsa, Rivers and Akwa Ibom State) between 1991-2018. Average coastal erosion rates -9.5m/yr were observed along the entire Nigerian coast, -11.1m/yr along the Bayelsa section, -7.7m/yr along the Rivers State coast and -5.5m/yr along the Akwa Ibom State coast. The rates of accretion were lower with an average of 4.3m/yr for the entire Nigerian coast, 5m/yr in Bayelsa, 4.6m/yr in Rivers state and 2.8m/yr along the Akwa Ibom coast. Study suggests that ground subsidence as a result of hydrocarbon extraction has immensely contributed to the observed changes along the coast.	Erosion	Long term shoreline changes at a national scale		*				
Dada et al. (2019)	The shoreline changes along the Transgressive Mahin mud section from 1987 – 2017 showed that coastal erosion is the dominant process along the coast, revealing that about 58% of the coast was retreating and that there has been a land loss of about 10.64km^2 to the Atlantic Ocean.	Erosion	Long term shoreline changes at a local scale	Loss of Land	*				
Akinluyi et al (2018)	The changes in the Lagos section of the Lagoon-Barrier coast revealed mean end point rate, EPR and net shoreline movement, NSM of -0.57m/year and -18.1m/period respectively from 1984-2016 revealing that 77.9% of the transects used experienced accretion.	Reduced rates of erosion	Long-term shoreline changes at a local scale	Loss of land	*				
Danladi et al (2017)	The Lekki area in Nigeria has shown the prevalence of sediment loss as a result of SLR and human activities. There has been a progressive coastal erosion along the	Increasing rates of erosion		Loss of land	*				

	Goshen beach estate phase since 2013 after the construction of the breakwater structure. As of 2016, 66.1m of land had been lost to the sea.			Loss of property and infrastructure					
Adebola et al (2017)	There is a progressive increase in the rate of coastal erosion along the coast. 70% of the Rivers state coast in the Niger Delta was experiencing erosion and 30% accretion over the 32-year period between 1984 -2000 accretion was 1990.33m and erosion -403.48m while 1984 – 2016 accretion was 706.18m and erosion was -750.84m.	Increasing rate of coastal erosion	Long-term shoreline changes at a local scale	Loss of land	*				
Oyegun et al (2016)	From 1986 – 2010, the entire coast had a volumetric accretion of 103.2km^3 and erosion of 67.72 km^3. However, spatial variations of erosion were observed. The volumetric mean shoreline erosion and accretion for the Western Niger Delta were 3.39 km^3 and 0.13 km3, respectively, whilst it was 2.29 km^3 and 4.77 km^3, respectively, in the Eastern Niger Delta.	Reduced rate erosion in the Eastern Niger Delta	Long-term shoreline changes at a regional scale	Little or no risk	*				
Ajide (2016)	Showed that between 1962-1984, the Etiosa area of the Lagoon-Barrier coast had a 31.4% of erosion. Then between 1984 – 2000 had an accretion rate of 81.89% which dropped to 62.11% between 2000-2011.	Increased rate of erosion	Long-term shoreline changes at a local scale	Loss of land	*			*	
Oyedotun (2015)	Studies revealed the prevalence of coastal erosion. showing that between 1972 and 2014 had an average net shoreline of -25m loss was estimated.	Increased rate of erosion	Long-term shoreline changes at a local scale	Loss of land	*				
Ituen et al (2014)	Between 1986 to 2008, the Ibeno axis of the Akwa Ibom coast had an average erosion rate of change for the area was −3.9 m/yr while the average accretion was 2 m/yr.	Increased rate of erosion	Long-term shoreline changes at a local scale	Loss of land	*				

Udoh et al. (2014)	Vulnerability assessment of the entire state Akwa Ibom state showed that the most vulnerable locations are within the coastal areas because of the very high exposure to SLR. The High class of vulnerability covers an area of 616 km2 (9%); the medium class of 4996 km2 (73%) and Low class covering an area of 1232 km2 (18%).	High erosion rates					*	*	
Olorunlana (2013)	The present rate of coastal erosion in Ondo State which is located in Transgressive Mud coast is estimated to be 35m per year.	Steady erosion rate		Loss of land The Awoye settlement is now 3km inland of its original location					
Adegoke et al (2010)	Between 1986-2003, erosion was higher than that of accretion. It observed that $46.535km^2$ of the coast $27.65km^2$ was eroding (59.43%) whilst $18.88km^2$ accreting (40.57%).	Increased erosion rate		Loss of land	*				

Overall, it is observed that for the studies (see table 2.5), the most used approach to assess coastal erosion was the shoreline change analysis and for studies that incorporate a vulnerability model, only the CVI vulnerability assessment techniques were used in assessing vulnerability in the coast. Other methods used were the focus group discussion, interviews, questionnaires and a descriptive/desktop analysis. It should be emphasised that the field observations and PGIS, which are highly important tools, were not used in any of the coastal assessments along the Nigerian coast. These approaches could provide researchers with unique and useful information on specific locations as a more complete set of information concerning the locality can be obtained using PGIS. According to Famuditi et al. (2014), addressing ecological and socioeconomic impacts in the Niger Delta necessitates a holistic, integrated, and participatory approach. Multiple coastal hazards, as well as physical and social data factors, should be examined to provide a thorough overview of the physical risks, social hazards, and hence the vulnerability of coastal populations.

2.4.5 Coastal Erosion Risk Assessments in Nigeria

Flooding, coastal erosion/accretion, coastal salinity, biodiversity loss, and agriculture and aquaculture health effects are all risks associated with SLR in the area. Most studies focused on the risk associated with coastal flooding owing to SLR, with few addressing coastal erosion risk. Coastal erosion risk reported in Nigeria includes loss of land (erosion), oil well loss, and loss of livelihood. The main risk posed by coastal erosion is land loss. According to Danladi et al. (2017), elevation of the Nigeria coast and human activities put the regions at risk to hazards arising from SLR. The study, which evaluated the risk of coastal erosion using digital elevation data and geology maps, found that erosion predominates along the coast in Lekki Phase I of the barrier-lagoon coast, along Goshen Beach Estate, Lagos State. According to the study, a 0–2 m SLR will have a significant impact on communities in Lagos and the Niger Delta, where coastal lands in Forcades (Warri), coastal communities in Okposo, Kwa Ibo, and James Town in Akwa Ibom State, as well as other coastal villages, will be lost. Similar analyses of the Niger Delta were conducted by Musa et al. (2016), which showed that similar assessments concerning the Niger Delta, demonstrating that the region might lose up to 1119.3 km^2 by 2030 with a relative sea level increase of 0.14 m and up to 1175.9 km^2 by 2050 with a rise of 0.29m.

The Nigerian coast is under threat from rising sea levels. By incorporating seventeen physical, social, and human factors into a coastal assessment, Musa et al. (2014) used the Coastal

Vulnerability Index to assess the vulnerability of the Niger Delta to SLR. The results found that based on the CVSLRI ranking, 42.2% of the coast was classified as very low to low vulnerability; 22.2% as moderate vulnerability while 42.6% was ranked as high to very high vulnerability to impacts of SLR such as flooding, erosion, and saltwater intrusion into underground aquifers. Rather than assume uniform values for all the coastal regions in the Niger Delta, the study's segmentation took into account local differences. According to Olorunlana (2013), it has been observed that one coastal settlement, Awoye settlement in Ondo State (transgressive mud coast) is now 3km inland of its original location. Apart from the well-known loss of land, incidences of oil well loss have also been observed in Nigeria. According to Etuonovbe (2006) the risk of coastal erosion in the Forcados South Point area is best seen in comparison to Shell Petroleum Development Company (Nigeria)'s efforts to protect their oil and gas wells and flow stations around the coast from the risk of erosion, having lost eight of its wells that were abandoned in 1983.

Another study that addressed the disappearance of oil wells, was that of Uyigue (2009)'s. Uyigue (2009) reported that in some locations along the Niger Delta, like at Forcados, some oil wells have been lost to the ocean owing to coastal erosion. The study also claims that the Niger Delta could lose around 15,000 km^2 of land to SLR by the year 2100. As a result of SLR, an estimated 180000m^2 along the coast of Itak Abasi village in Ibeno Local Government Area of Akwa Ibom State, Nigeria, has been submerged in the Atlantic Ocean (Udo-Akuaibit 2017). The study emphasised that the updrift shoreline is severely impacted by coastal erosion and flooding, which resulted in the submergence of a large portion of Itak Abasi Village in 2011, displacing many indigenous people, whereas the downdrift shoreline accumulated (accreted) the sediments eroded from the updrift. Indigenes were forced to relocate because of the loss of their houses, schools, and overall surroundings. This had not only affected them physically, but also the emotional health of others who lived in the area. Other recognised risks are the loss of livelihood (source of income) and risk of displacement. Coastal erosion threatens people's livelihoods along the coast, which range from farming to fishing and marine businesses, coastal tourism, and agro-industries (Kemper 2017). Loss of business infrastructure, houses and destruction of plantain plantation situated along the coast have been identified in this current research's study area, which in some cases has led to displacement of the indigenes affected, thus creating resettlement challenges when accessibility to available facilities are limited. According to Barua et al. (2020), unplanned and uncoordinated resettlement could lead to variety of political, socio-economic and cultural issues. For instance, if encroachment into inland communities is not well managed, it could pose the risk of a communal war breaking out between the further inland communities and the displaced community.

In general, this section solely evaluated coastal erosion in Nigeria, omitting other sea-level rise implications which falls outside the scope of the study. However, it should be emphasised that most of the previous studies in this region are primarily focused on floods and subsidence or wave/storm surge, lending importance to the current study to assess coastal erosion along the Akwa Ibom coast of Nigeria.

2.6 Summary of Chapter

The literature review for coastal erosion vulnerability assessments in Nigeria revealed that the impact of coastal erosion is prominent along the Nigerian coast. According to the findings, Nigeria currently lacks a comprehensive vulnerability assessment tool. Furthermore, there is no consistent methodology for estimating the vulnerability of the entire nation's shoreline to coastal erosion, which makes assessing the accuracy of findings along the entire coast difficult. Given the high rates of erosion seen in the findings, there is an urgent need to assess coastal communities' resilience to coastal erosion and the related risks, hence improving decision-making that promotes proactive adaptation (Brown et al. 2017). Chike (2017) advocated boosting the awareness and knowledge about climate change and its related hazards, as well as successfully disseminating and publicising early warnings from agencies such as NIMET (Nigeria's meteorological agency) to enable vulnerable populations to be prepared and mitigate the effects. As a response, it is necessary to establish a local emergency response system that relays information such as warnings from the national to the state to the municipal level. The results indicate that many studies that quantified coastal erosion in Nigeria, concentrated only on shoreline changes, leaving out other additional susceptibility/vulnerability indicators which could well inform the assessment. It is probable that a lack of available data, according to (Musa et al. 2016) have hindered the ability to apply other approaches such as the CVI or modified versions of it. Furthermore, it is noted that only a small number of studies used high resolution photos; most of them made use of the readily available and free Landsat imagery, which has a spatial resolution of 30m. The use of higher resolution imagery would increase the accuracy of measurements of physical changes along the coast, however these data are not always readily available due to their high cost. Hence the over-reliance on openly accessible and free satellite images. There appears to be a clear need to establish funding sources for high-resolution data gathering in order to employ high-resolution images to improve coastal erosion assessments.

There is, therefore, an immediate requirement in Nigeria to conduct a high-quality vulnerability assessment of coastal erosion which will consider these factors both at a local and national scale. Unfortunately, this could be hindered due to data availability. When data is lacking in an area, a participatory geographic information system (PGIS) can be used to gain insight into local-scale variations in erosion risks and resilience. PGIS could be integrated with the physical and social data, giving a better understanding on how vulnerable communities are to erosion which could be useful for coastal managers and a well-informed management policy.

Chapter 3: Spatio-temporal analysis of historical shoreline changes and future predictions using medium and high-resolution satellite datasets.

Chapter three focuses on the spatio-temporal analysis of shoreline changes along the Akwa Ibom coast. It presents the historical shoreline change dynamics and future predictions of the Akwa Ibom coast using medium and high-resolution satellite datasets.

Chapter 3

3.1 Introduction

The coast constantly undergoes changes that may accelerate under extreme events (NIMET 2013; Oyedotun 2014; Moussaid et al. 2015; Xie et al. 2016; Gracia et al. 2018; Nigerian-Navy 2020) and understanding these changes is an important element of effective coastal management because of the societal and economic risks posed by coastal erosion and flood hazards (Ahmed et al. 2018). Several techniques could be used to derive information on shoreline changes. These include ground-based topographic and GPS measurements which are the most reliable way to collect accurate information on the shoreline position. However, they can be costly and time-consuming and difficult to obtain, especially in developing countries (Sunder et al. 2017). Globally, several advances have been made in shoreline extraction and change assessment using remote sensing and geospatial approaches which can be more convenient, less time-consuming and have wider spatial coverage than ground-based methods (Nandi et al. 2018; Salauddin et al. 2018). The use of RS and GIS data for shoreline detection, delineation, extraction and monitoring are also commonly used in developed nations (Gens 2010; Zhang et al. 2013; Xu 2018) and are widely transferable (Gens 2010; Temiz et al. 2016).

The delineation of the shorelines could be done manually or through automated/semi-automated processes (Sunder et al. 2017). The most commonly used technique for manual shoreline extraction is through visual interpretation (Gens 2010), which is considered more accurate than other techniques but also more labour-intensive (Nandi et al. 2018). Gens (2010) explained that due to the dynamic nature of the shoreline boundary, the use of shoreline indicators has been widely accepted as a proxy in coastal studies. These indicators, however, may not be consistent in their use across different types of coasts. Toure et al. (2019) states that since the coast profile varies with different coasts, there are no definite indicators that can be used for the entire coast; rather, they are chosen based on the coast profile and the aim of assessment or monitoring. The indicators include those limited to water levels, such as the high water level (HWL) (Pajak et al. 2002; Liu et al. 2004), vegetation edge (Nandi et al. 2018), morphological reference lines (dune crest and toe, cliff or bluff crest and toe) (Young et al. 2013; Toure et al. 2019), tidal level and storm lines beach contours (Toure et al. 2019). Oyedotun (2014) has illustrated the use of shoreline geometry and position as indicators to assess the changes in coastal regions.

3.1.1 Objectives and questions

The research objectives and research questions for this chapter are:

- Identify the susceptibility of the Akwa Ibom shoreline to coastal erosion using remote satellite image analysis and identify sections of the coast that are most susceptible to coastal erosion using shoreline change detection.
  - *What is the trend of the shoreline change analysis in the study area?*
  - *How rapid are the geomorphological changes in the study area?*
  - *What are the temporal and spatial variations along the study area and which data resolutions are best suitable for the study area?*
  - *How susceptible is the Akwa Ibom Shoreline in the Niger Delta to the impacts of coastal erosion and where are the most susceptible areas of the coast?*
- Model future shoreline changes using historical data
  - *What future coastal changes will likely occur, using historical rates of change in the area applying the DSAS-Beta forecasting methodology?*

To address these research objectives and questions, medium (30 m Landsat) and high (0.5 m Pleiades and 1.5 m SPOT) spatial resolution remote sensing datasets are used to measure the shoreline changes along the Akwa Ibom State coast. Though Landsat images are very useful for regional studies as they give wide coverage of the area of interest, they are less useful for a more local scale investigation (Mullick et al. 2020), hence, the need for higher spatial resolution data for local scale data analysis. A combination of manual and semi-automated methods was explored to quantify shoreline changes over 36 years (1984 - 2020) using Landsat datasets and a 5-year period (2015-2020) using SPOT images. The Pleiades data (2015) served as reference data for the accuracy assessment of the extracted shorelines using both the manual and semi-automated methods because of its high resolution. The latter analysis will concentrate on coastal change 'hot spots' – areas identified as being the most susceptible to erosion or depositional change from the evaluation of coastal dynamics over the 1984 - 2020 period. Finally, the future shoreline changes to 2030 and 2040 will be modelled based on the historical data analysis.

3.2 Methods

This study uses ArcGIS 10.6.1 to process and extract the shorelines for the historical shoreline change analysis (see Figure 3.1) and for future changes up to 2040. Though the Landsat level 1 datasets were already ortho-rectified and in the WGS84/UTM 32N projection when downloaded, they had to be radiometrically corrected and this was done using the QGIS 3.4 software which allows for a time effective automatic correction process.

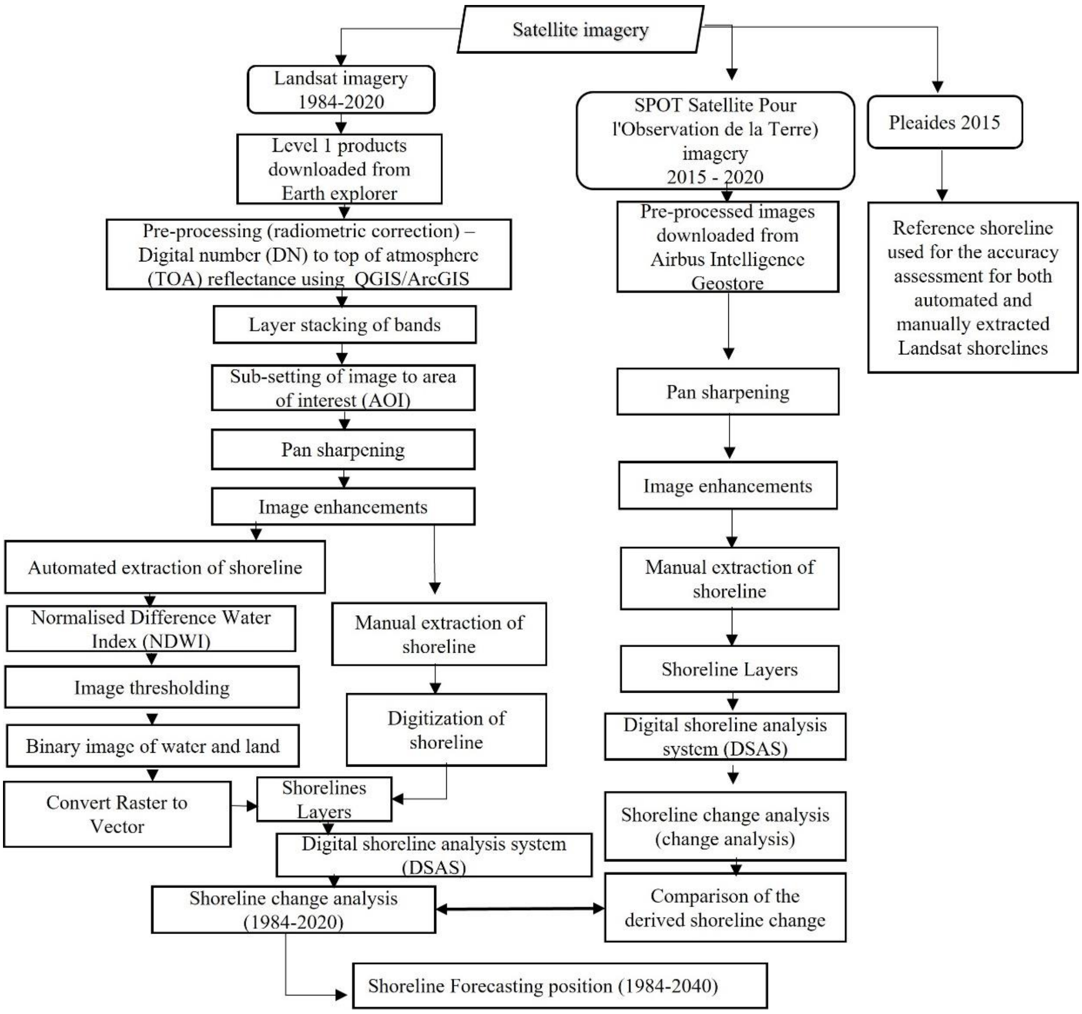


Figure 3.1: Data Processing workflow

The analytical approach used in this chapter is as follows: (1) satellite image acquisition and image processing within ArcGIS 10.6.1 (2) shoreline extraction using both manual and semi-automated processes to detect and extract the shoreline from satellite images. Shorelines extracted from high-resolution imagery were used as an independent accuracy assessment for both the manually extracted and the semi-automatically extracted shorelines from the Landsat imagery for 2015, and (3) Historical Trend Analysis (HTA) and future trend prediction using DSAS v5.0 (Digital Shoreline Analysis System).

3.2.1 Datasets

The data used in this study included imagery from Landsat 5 multispectral scanner (MSS) and Landsat 8 Operational Land Imager (OLI), shuttle radar topography mission (SRTM) digital elevation model (DEM) and high-resolution Pleiades and SPOT imagery were used (See appendix 3.1 for a summary of the data used and analysis carried out for each objective).

3.2.1.1 Landsat and SRTM datasets

The Landsat and SRTM (30m) 2014 datasets were downloaded as level 1 and 2 pre-processed products in GeoTIFF format from the United States Geological Survey (USGS) earth explorer website (https://earthexplorer.usgs.gov/) (see table 3.1). All available cloud-free Landsat Level 1 images (Table 3.1) were downloaded from the same path (188) and row (57) and ortho-rectified in the WGS84/UTM 32N projection. The downloaded images were clipped to a digitised polygon representing the study area (AOI) using ArcMap. The atmospheric corrections for the Landsat level-1 products were carried out using the semi-automated classification plugin (SCP) within QGIS 3.4 software. This plugin allows different pre/post-processing of satellite data. The dark object subtraction – DOS (Chavez 1988), was selected as the method for atmospheric correction because it is commonly used and is noted to be the simplest technique for atmospheric correction and does not require in situ observations (Zhang et al. 2010). The DOS works on the assumption that dark objects reflect no light; hence, if there is any reflectance value greater than zero, then it must be the effect of atmospheric scattering.

Table 3.1: Landsat dataset characteristics

Date	Sensor	Resolution (meters)	Product Level	Wavelengths (micrometers)
13th December 1984	Landsat 5 MSS	60m	Level 1	Band 1 – 0.5-0.6 Band 2 –0.6-0.7 Band 3 –0.7-0.8 Band 4 – 0.8-1.1
17th January 2015 27th December 2018 13th January 2020	Landsat 8	Band 1 – 30m Band 2 – 30m Band 3 – 30m Band 4 – 30m Band 5 – 30m Band 6 – 30m Band 7 – 30m Band 8 – 15m Band 9 – 30m Band 10 – 100m Band 11 – 100m	Level 1	Band 1 – 0.43-0.45 Band 2 – 0.45-0.51 Band 3 – 0.53-0.59 Band 4 – 0.64-0.67 Band 5 – 0.85-0.88 Band 6 – 1.57-1.65 Band 7 – 2.11-2.29 Band 8 – 0.50-0.68 Band 9 – 1.36-1.38 Band 10 – 10.6-11.19 Band 11 – 11.50-12.51

To correct this in the entire scene, the DOS technique removes the scattering by subtracting this value from every pixel in the band (Chavez 1988). The Landsat images were converted to the top of atmosphere, TOA reflectance using equation 3.1 and the data needed for the calculation were available in the product metadata.

$$P\lambda^{1} = M\rho \; x \; Qcal + A\rho \qquad (3.1)$$

where $P\lambda^1$: TOA planetary reflectance, without correction for solar angle

$M\rho$: Band-specific multiplicative rescaling factor from the metadata (reflectance_mult_band_x, where x is the band number).

$A\rho$: Band-specific additive rescaling factor from the metadata (reflectance_add_band_x, where x is the band number)

$Qcal$: Quantized and calibrated standard product pixel values (DN)

And the resulting reflectance is corrected with the sun angle using equation 3.2

$$P\lambda = \frac{P\lambda^1}{\cos(\theta SZA)} = \frac{P\lambda^1}{sin\theta SE} \qquad (3.2)$$

where $P\lambda$: TOA reflectance

θSE is the low sun elevation angle. The scene center sun elevation angle in degrees is provided in the metadata (sun_elevation).

θ_{SZA}: local solar zenith angle

$\theta_{SZA} = 90^o$- sinθSE

3.2.1.2 Pleiades and SPOT datasets

The Pleiades and SPOT datasets (table 3.2 were ordered from the Airbus Intelligence Geostore through an ESA Category-1 proposal (ID 49813). However, due to the limited availability of cloud-free images, the entire coast could not be covered, and the research only used available cloud-free SPOT and Pleiades data (see table 3.3). The image datasets were ortho-rectified (WGS84/UTM 32N), atmospherically corrected and delivered in a public format for describing a geographical data, DIMAP (digital image map)-regular jpeg 2000 format. The shoreline extracted from the high-resolution data serve as reference shorelines for an accuracy assessment of the shoreline extraction processes for the Landsat data since the digitising error associated with it is much lower than the Landsat images.

Table 3.2: Pleiades and SPOT data characteristics

Year	Date	Sensor	Resolution	Wavelengths (micrometers, μm)
2015	7th January	Spot 6/7	Panchromatic band: 1.5m Multi-spectral (4 bands): 6m:	Panchromatic band- 0.455–0.745 Blue - 0.455–0.525 Green- 0.530–0.590 Red - 0.625–0.695 Near-infrared - 0.760–0.890
	14th January			
	2nd December			
2019	2nd January			
	9th January			
2020	28th April			
	17th May			
2012	26th April	Pleiades	Panchromatic band: 0.5m Multi-spectral (4 bands): 2m	Panchromatic band- 0.480–0.830 Blue - 0.480–0.550 Green- 0.490–0.610 Red - 0.600–0.720 Near-infrared - 0.750–0.950
	24th April			
	25th December			
2013	20th December			
2015	13th January			
	3rd February			
	13th March			
	25th December			
2019	2nd January			
	9th January			
	21st January			
	23rd February			
	15th April			
	26th December			
2020	1st January			
	13th January			
	26 January			

3.2.2 Image processing

To allow for improved visual interpretation of the satellite imagery, false colour composites were generated, and pan-sharpening (process is in section 3.2.2.1) was performed. Natural **c**olour composites refer to the display of an image using the visible red, green and blue (RGB) wavelengths while a false colour composite, FCC uses a combination of any other wavelengths (see table 3.3).

Table 3.3: Summary of the bands used for the false colour composite

Images	**False colour composite bands (FCC)**	**Spectral characteristics**
Landsat 8	5,4,3	bands 5 (NIR-near infrared band), 4 (red band) and 3(green band)
Landsat 5 MSS	4,3,2	bands 4 (NIR), 3(NIR) and 2 (red band)
SPOT 6/7	4,3,2	bands 4 (NIR), 3 (red), 2 (green)
Pleaides	3-2-1	bands 3 (NIR), 2(red), 1(green)

As seen in figure 3.2, FCC can give prominence to features such as shoreline edges, vegetation, water bodies and residential/industrial areas.

Figure 3.2A-B**:** A) Natural colour composite and B) false colour composite of parts of the Ibeno section of the Akwa Ibom coast (28th April 2020 SPOT Image data).

3.2.2.1 Pan sharpening

The images were pan-sharpened to enhance the spatial resolution of the multispectral bands. This is a process that uses a single panchromatic band of a higher spatial resolution to increase the spatial resolution of the multispectral bands. For example, the spectral bands of Landsat 8 have a resolution of 30m while the panchromatic band is 15m.

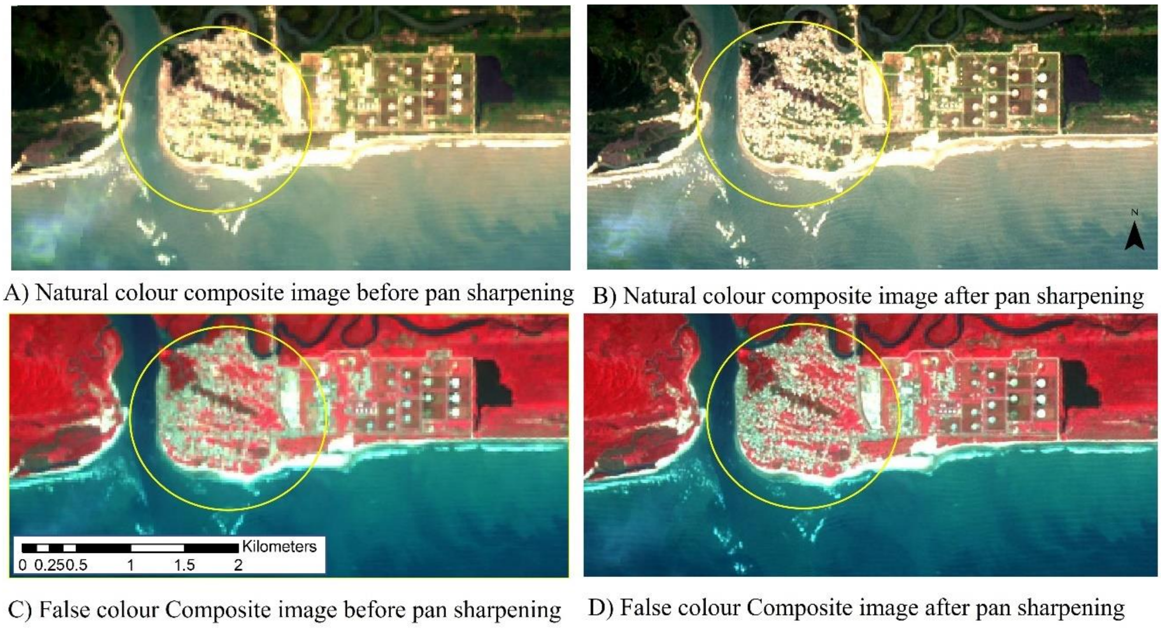


Figure 3.3: Landsat 8 image before (A &C) and after pan sharpening (B &D). The circled features showing residential areas allow visualisation of the enhanced detail in the image pre/post-pan sharpening.

For Landsat datasets, the pan sharpening process generated a single dataset with a resolution of 15m that contains both high spectral and spatial resolution thus allowing the image to be sharper and features enhanced (figure 3.3). For Landsat 5 MSS with a resolution of 60m, the image was resampled to 30m. Various pan sharpening algorithms can be used to fuse the panchromatic and multispectral bands to enhance the resolution of an image. They include the Brovey Transformation, Esri, Gram-Schmidt, IHS (intensity, hue and saturation) and the simple mean that averages values between the red, green, and blue values and the panchromatic pixel value. Ose et al. (2016) note that the Brovey transformation is the most used pan sharpening algorithm because it gives a better contrast between features and consequently it was used in this study.

The pan-sharpening process was also carried out on both SPOT and Pleiades datasets. The SPOT multi-spectral data which contains 4 bands (blue, green, red, and infra-red bands) with a resolution of 6m was pan-sharpened using the panchromatic band which has a resolution of

1.5m. The Pleiades multispectral bands (2m) were pan-sharpened with the panchromatic band (0.5m) to produce multispectral bands with the higher 0.5m resolution.

3.2.3 Shoreline extraction

Different methods were used to extract the shoreline in order to determine which provided a better representation of the shorelines due to the coarseness of the Landsat dataset. These consist of both the automated and manual shoreline extraction. For the manual extraction of the shoreline, a false colour composite was created from the pan-sharpened images which enhanced the distinction between the land and water features.

Table 3.4: Shoreline indicators used by previous studies

Shoreline Indicators	Description	References
Mean high water (MHW)	The shoreline is derived from the elevation or tidal datum.	(Hapke et al. 2011)
High water line (HWL)	The highest and visually identifiable run-up of the last high tide.	(Pajak et al. 2002; Liu et al. 2004; Toure et al. 2019)
Vegetation edge	The vegetation edge that forms along the coast is used as a proxy for shoreline.	(Nandi et al. 2018)
Morphological reference	Uses coastal features such as dune toe or crest, toe or berm of the beach, cliff base or top as a proxy for land/water boundary.	(Young et al. 2013; Toure et al. 2019)
Geographical positioning system (GPS)	Uses differential GPS mounted on a vehicle, driven along the clearly visibly line representing the shoreline.	(Babu et al. 2015)

Table 3.4 shows some of the widely used shoreline indicators and the most commonly used indicator as being the high water line, HWL (Babu et al. 2015). Pajak et al. (2002) advised that the usage of these indicators must be practical and consistent along the shoreline. For example, Del Río et al. (2012) noted that sometimes HWL could be the only obtainable indicator, especially on well-developed coasts with embankments and sea walls. For this research, the high-water line (HWL) is used as a proxy for the shorelines because there are no dunes or constant features along the coast; as such it was the only constant proxy obtainable.

Optical remote sensing has played an important role in water studies (Xie et al. 2016). Xie et al. (2016) highlighted that the detection of shorelines and demarcation of land and water can be characterised into four types using spectral reflectance for semi-automated extraction: 1) hard classification, where the water bodies can be detected and extracted with high precision. Here, it is possible to use either supervised or unsupervised image classification methods to successfully extract water bodies and distinguish between image features. However, Du et al. (2014) noted that the clear demarcation of features is highly dependent on the training samples used which heavily relies on human expertise. Another downside of this method is that it is time-consuming and not straightforward and not easy to reproduce; 2) spectral water indexes - involves the use of two spectral bands to extract the shorelines and is indicated as the most widely used method for water extraction due to the simplicity, high precision and cost-effectiveness (Jiang et al. 2014). The indices approach allows for the combination of different image bands to enhance water and land features, making it easy to distinguish between the water and land pixels; 3) single band thresholding - the simplest and also an effective method. It uses just a single band in the infrared for shoreline extraction and it is based on the reflectivity difference of the water body and other features; and 4) spectral unmixing - involves subpixel mapping to extract water bodies and is mostly used when applications are in urban areas with different classes of features to map. According to Jiang et al. (2014), the presence of several features to classify, can easily lead to a misclassification of features.

Some studies agree with Xie et al. (2016) on the effective use of spectral indexes to extract the shoreline. Nandi et al. (2018) and Salauddin et al. (2018) highlighted that the spectral indices method is the most effective approach for water extraction because of its cost-effectiveness and better performance when compared to the automated approaches in the identification of water bodies. Following the studies by Nandi et al. (2018) and Salauddin et al. (2018), the use of spectral indices was adopted for use by this study. They used the Normalised Difference Water Index (NDWI) by McFeeters (1996) and Modified NDWI (MNDWI) by Xu (2006) in their study. Other spectral indices are known as the automated water extraction index (AWEI), water ratio index (WRI), and normalised difference vegetation index (NDVI) were also used by Nandi et al. (2018) in their study to delineate the water bodies from multispectral Landsat images and compare the performance of different spectral indices. Feyisa et al. (2014) explained that the limitation in using NDWI and MNDWI lies with the fact that there is no proper thresholding for the separation of water and land, especially in inland water areas and proposed a new automated method known as the automated water extraction index (AWEI) which uses five bands ranging from the visible to the short-wavelength infrared (see equation 3.3 & 3.4) to give a better optimal output by extracting surface water from dark surfaces and shadows that are easily excluded in other methods. The AWEI is given by Feyisa et al. (2014) as;

$$AWEInsh = 4x(\rho band2 - \rho band5) - (0.25x\rho band4 + 2.75x\rho band7) \quad (3.3)$$

$$AWEIsh = \rho band1 + 2.5x\rho band2 - 1.5x(\rho band4 + \rho band5) - 0.25x\rho band7 \quad (3.4)$$

Where *nsh* represents images with no show pixels, *sh* represents images with show pixels, ρ is the reflectance value of spectral bands of Landsat 5 TM: band 1(blue), band 2, band 4 (near infrared -NIR), band 5 (short wave infrared - SWIR) and band 7 (SWIR). Equation 3.3 is used to adequately suppress non-water pixels, including dark built surfaces in areas with an urban background while equation 3.4 improves the accuracy of equation 3.3 by eliminating any remaining shadow pixels. Sunder et al. (2017) carried out a comparison of four widely used spectral indices along different stretches of India; the results showed that Improved band ratio (IBR) generated good results along lee turbid waters, NDWI performed better even in turbid coastal waters but overestimated the water pixels especially dense built-up areas along the coast, MNDWI estimated the precise position of the coast in most of the study locations and was not influenced by the density of built-up areas or water turbidity and the AWEI gave the best optimum output as consistency in the overall accuracy (OA) of over 80% irrespective of landcover type. Overall, they noted that AWEI and MNDWI performed better along the different stretches of the Indian coast than NDWI and IBR methods. This limitation in the AWEI was also discussed by Feyisa et al. (2014) and Toure et al. (2019) noted that the choice of indicator used depends largely on the nature of the investigation.

Table 3.5: Spectral reflectance commonly used water indices for shoreline delineation

Water indices	Formula	No. of bands	Reference
Normalized Difference Water Index (NDWI)	NDWI = (GREEN - NIR)/ (GREEN + NIR)	2	McFeeters (1996)
	NDWI = (NIR-SWIR) / (NIR+SWIR)	2	Gao (1996)
Modified Normalized Difference Water Index (MNDWI)	MNDWI = (Green - MIR) / (Green + MIR)	2	Xu (2006)
	MNDWI = (Green - SWIR) / (Green + SWIR)	2	
Automatic Water Extraction Index (AWEI)	AWEInsh= 4x(ρband2 (green) − ρband5 (SWIR)) − (0.25xρband4 (NIR) + 2.75xρband7 (SWIR))	4	Feyisa et al. (2014)
	AWEIsh= ρband1 (blue) + 2.5xρband2 (green) − 1.5x(ρband4 (NIR) + ρband5 (SWIR)) − 0.25xρband	5	
Water Ratio Index (WRI)	(Green + Red)/(NIR + SWIR1)	4	Acharya et al. (2017)

Table 3.5 shows some commonly used water indices for shoreline classification and extraction. Though previous studies have indicated the advantage of having a more prominent distinction of features using the MNDWI over the NDWI (figure 3-6), it will not be used for this study because the Landsat 5 MSS image used as part of this study does not have the short-wavelength infrared band (band 6) needed for the MNDWI index calculation. Therefore, for consistency of approach, the NDWI which requires only the green band and near infrared band is used in the study. The resultant image from the NDWI index will be classified into water and land to extract the water/land boundary line which will serve as a proxy for the shoreline. Also, the semi-automatically extracted shorelines will be compared with the manually digitized shorelines as a form of accuracy assessment.

3.2.4 Manual digitization of shorelines

The manual extraction of the shoreline was carried out using ArcGIS on a Wacom digitising tablet at a scale of 1:25000. This scale enabled appropriate zooming into the edges to assess a clear change of pixel colour/tone which was used as a proxy to delineate the HWL. The scale was also kept constant throughout the entire digitising process of the satellite images for the years; 1984, 2015, 2018 and 2020. The resultant shorelines appeared step-like and did not have a realistic orientation. To give the shorelines a smoother and more realistic look, the smooth line parameter in ArcGIS was applied to the manually extracted shorelines.

Smoothing is a spatial analysis tool that is used to improve the jagged or step-like pattern of the shoreline to give it a more realistic result (Giannini et al. 2015). Within the Arc Toolbox of ArcGIS, various smoothing tolerance thresholds such as 50m and 100m were used but after several iterations with lower values, conspicuous step-like lines were still apparent. Hence, the 150m tolerance value used by this study gave a better and smoother outline, which was adopted for this study. The two types of smoothing techniques were explored: the Polynomial Approximation with Exponential Kernel (PAEK) and the Bezier-interpolation. PAEK uses a parametric continuous averaging technique which means the newly produced line is derived from weighted averages and approximation with polynomials to the second degree of all the points along a specified source line defined by the user while Bezier-interpolation does not use any tolerance; rather, it simply fits a Bezier curve through every line segment along the input line (Saeedrashed 2014; Giannini et al. 2015). Figure 3.4 shows the shoreline smoothing by different smoothing techniques. The smoothing of the shoreline for this research was done using the PAEK algorithm (see figure 3.4) as it gave the best optimal visual results. The results from Bezier-interpolation (figure 3.4b) produced a new shoreline with overestimated line vertices and visually did not align with the manually digitized shorelines and as such were not used in this study.

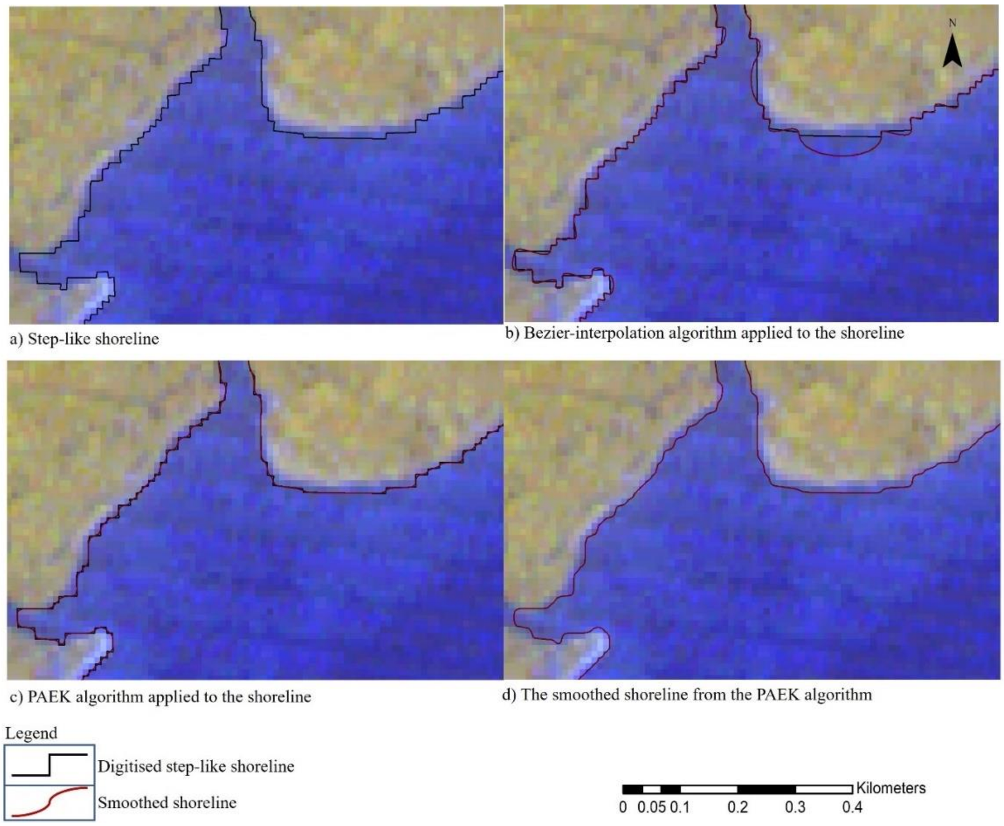


Figure 3.4: Different smoothing algorithms applied to the shoreline (Background: Landsat 2015)

3.2.5 Automated shoreline delineation

The water index approach was used to extract the land and water information from the satellite images. The Normalized Difference Water Index (NDWI) by McFeeters (1996) was used in this study. The NDWI (see figure 3.5) extracts the water features by using the reflected near-infrared (NIR) radiation and visible green light bands and is calculated as (see equation 3.5).

$$NDWI = \frac{GREEN - NIR}{(GREEN + NIR)} \quad (3.5)$$

Where the resultant range of NDWI is from -1 to +1 with positive values representing water and negative values representing non-water. The NIR is the reflectance in the near infrared band (0.85-0.88μm OLI and 0.76-0.90μm for Landsat TM – Thematic Mapper/Landsat Enhanced Thematic Mapper plus - ETM+) and Green is the reflectance in the visible green channel (0.53-0.60μm Landsat OLI - Operational Land Imager and 0.52-0.60μm TM/ETM). Another NDWI is proposed by Gao (1996) but this is mostly used for agricultural purposes where the water moisture in the leaves is used to assess plant health. The NDWI by Gao is represented by equation 3.6:

$$NDWI = \frac{(NIR - SWIR)}{(NIR + SWIR)} \quad (3.6)$$

Following equation 3.6; NDWI was calculated for Landsat (5 MSS) using equation 3.7.

$$NDWI = \frac{(band\ 2 - band\ 4)}{(band\ 2 + band\ 4)} \quad (3.7)$$

While for Landsat 8 (OLI), it is calculated using equation 3.8;

$$NDWI = \frac{(band\ 3 - band5)}{(band3 + band\ 5)} \quad (3.8)$$

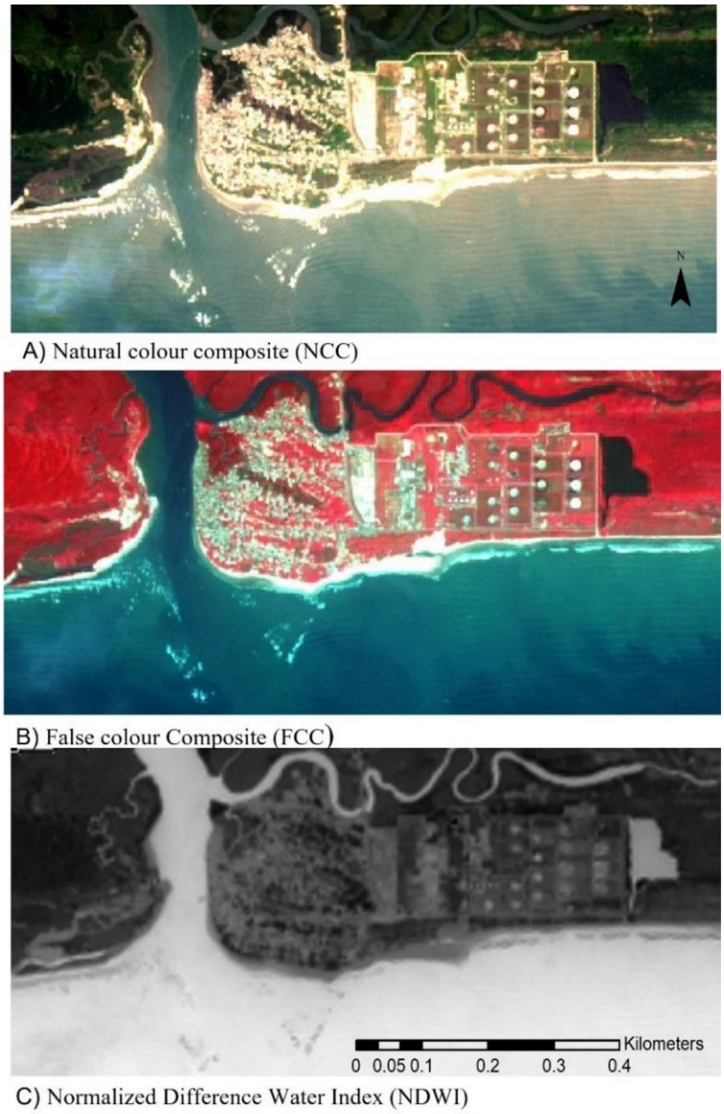


Figure 3.5: Picture A shows the natural colour composite Landsat 8 Image, picture B shows the False colour composite of the image while picture C shows the NDWI of a section of Ibeno Local Government Area along the Akwa Ibom coast on Landsat 8, 2020 image.

The images in figure 3.5 were reclassified using natural breaks (Jenks) into a raster image containing two classes representing land and water classes (figure 3.6). The boundary on the reclassified maps was visually compared to the original NDWI and the composite image to check if the boundaries aligned.

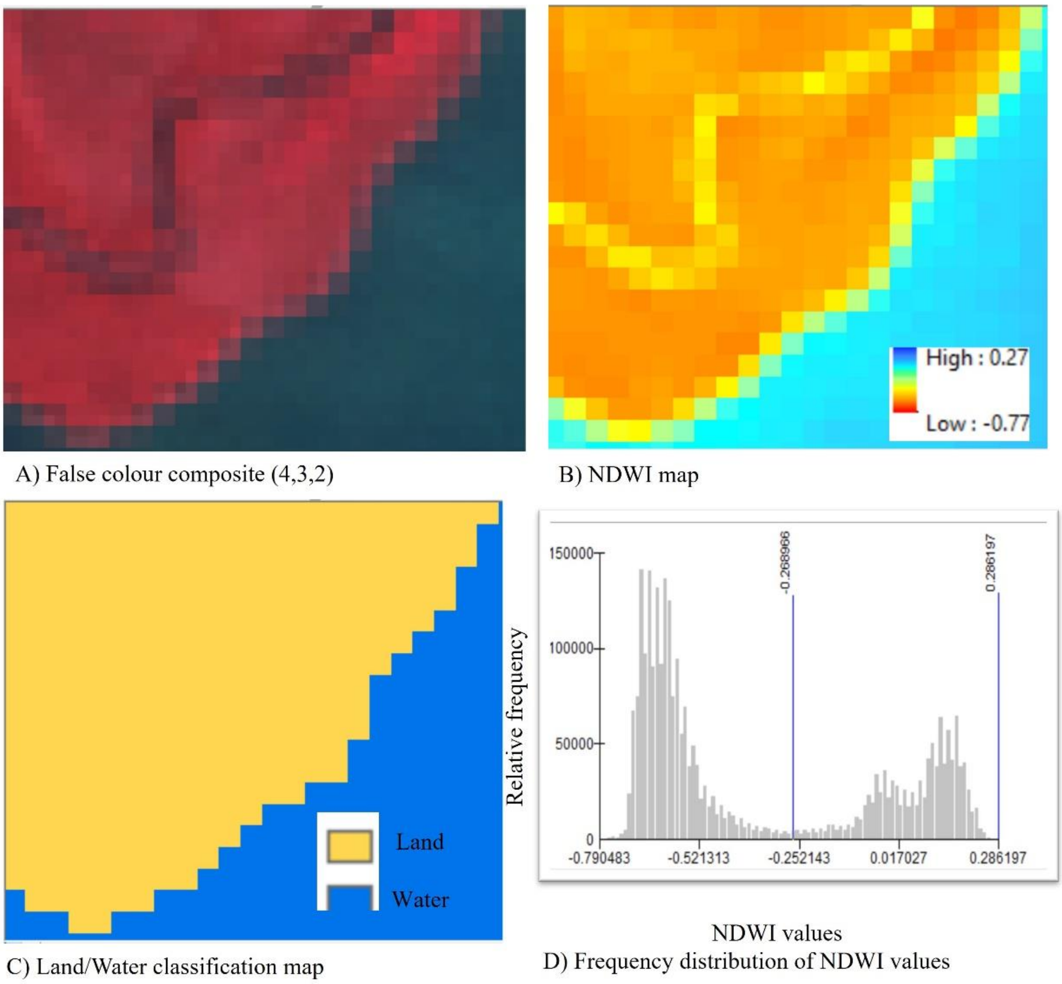


Figure 3.6: Land/water classification on a Landsat Image (31st January 2020) showing part of the study area (a) False colour composite of the area (b) NDWI (c) land/water classification of the area (d) frequency distribution of the NDWI.

Thereafter, the reclassified map was converted to a polyline where the boundary between the land and water was extracted to represent the shoreline of the corresponding year of acquisition (see figure 3.7).

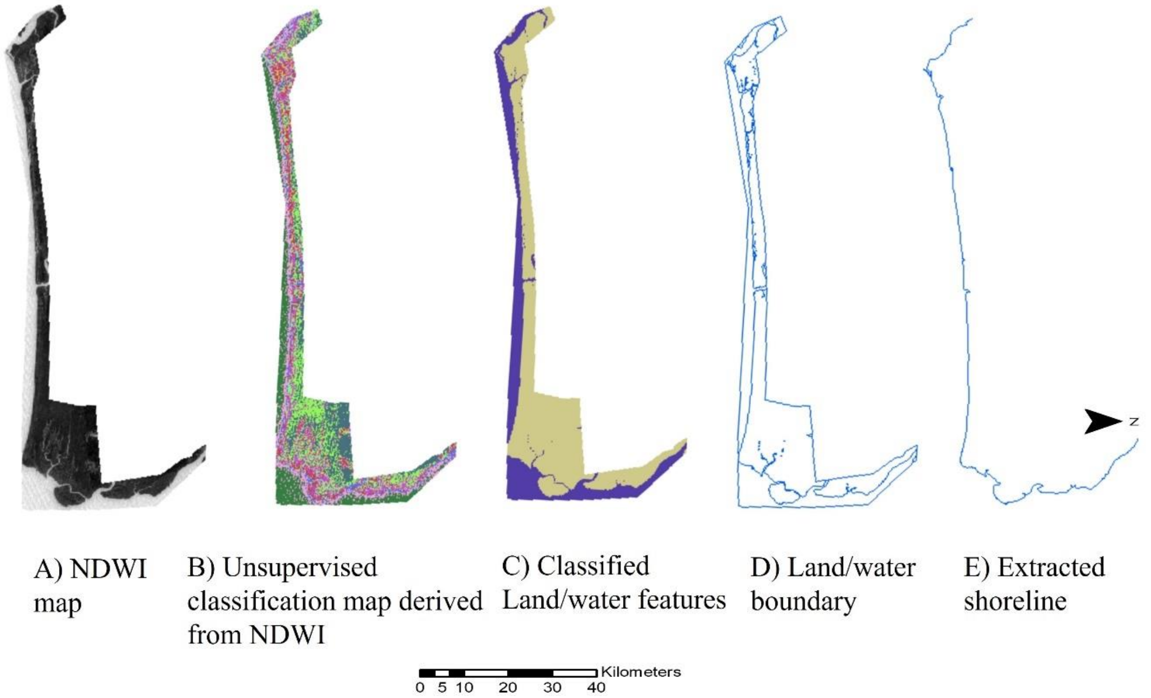


Figure 3.7: Shoreline data mining process using an NDWI approach.

Figure 3.7 shows the resulting shoreline extraction for a section along the Ibeno axis of the studied coast to highlight the differences in positioning using both the manual and semi-automated processes. The shorelines were extracted from Landsat images of 1984 – 2020. Figure 3.8 shows positional differences in the four shorelines used for this study. For instance, the black arrow in figure 3.8, shows the difference in the position of the 2015 shoreline (light green colour). The position of the 2015 shoreline derived manually when overlain with the Landsat image that was used for extraction, reveals the best fit when compared to that semi-automatically derived. This agrees with Nandi et al. (2018) that though manual digitizing is time-consuming, it gives a better representation of the shoreline position which is evident in the derived shorelines in figure 3.8.

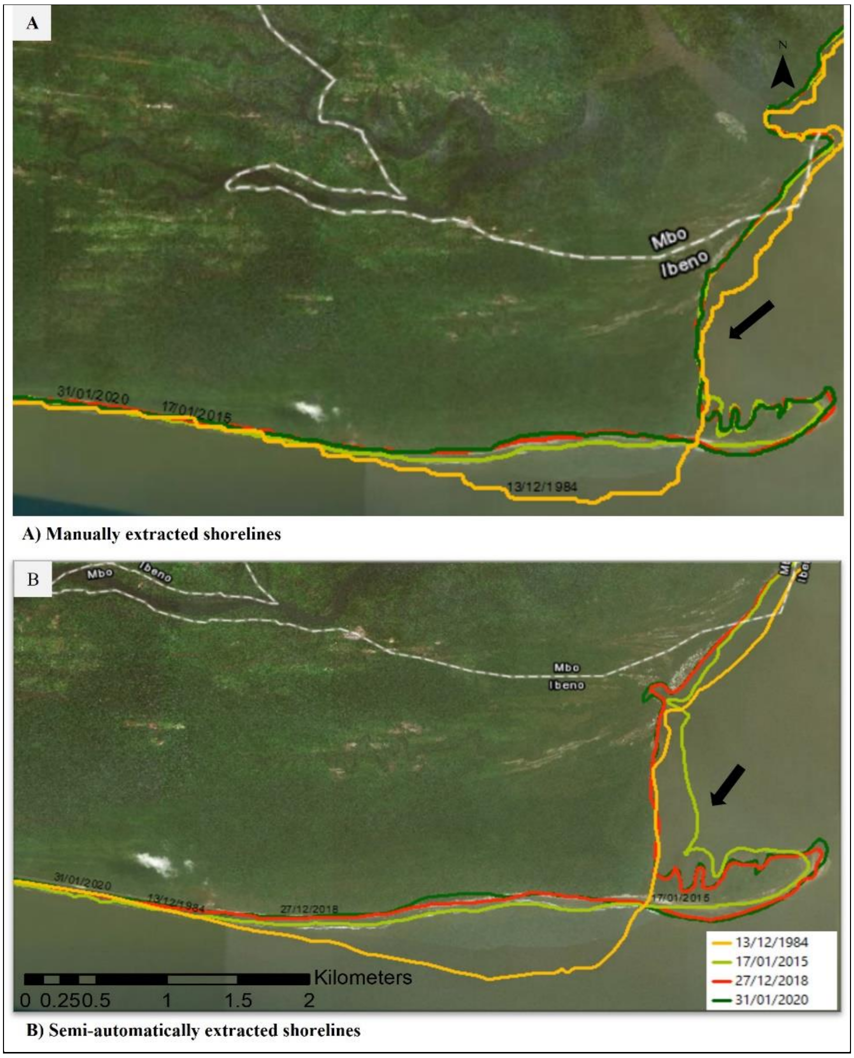


Figure 3.8: A) Manually extracted shorelines of a section of the studied coast (Ibeno axis) overlain on an ArcGIS base map (Landsat 2015) of the area alongside B) Semi-automatically extracted shorelines of thesame section of the studied coast overlain by the Landsat 2015 map of the area.

3.2.6 Historical trend analysis/shoreline forecasting

A workflow for the shoreline extraction, historic trend analysis and shoreline forecasting is presented in figure 3.9. The Historic Trend Analysis (HTA) analyses the changing position of shorelines through time. Babu et al. (2015) discussed the importance of analysing a shoreline using a temporal range since, in nature the water/land boundary is dynamic and not static. They further discuss the importance of the changing shoreline information for coastal management and engineering. To quantify the changes along the shoreline, the Digital Shoreline Analysis System (DSAS) has been commonly used by many studies (Oyedotun 2014; Elbagory et al. 2019). DSAS is an open-source software that is used within ArcGIS software. It uses shorelines that have been delineated and extracted from aerial photographs, satellite images or ground surveys to quantify the rate of change. DSAS is a widely recognised and used method for historical trend analysis in analysing the rate of coastal change (Mishra et al. 2020; Terres de Lima et al. 2021) and was used in this study for HTA.

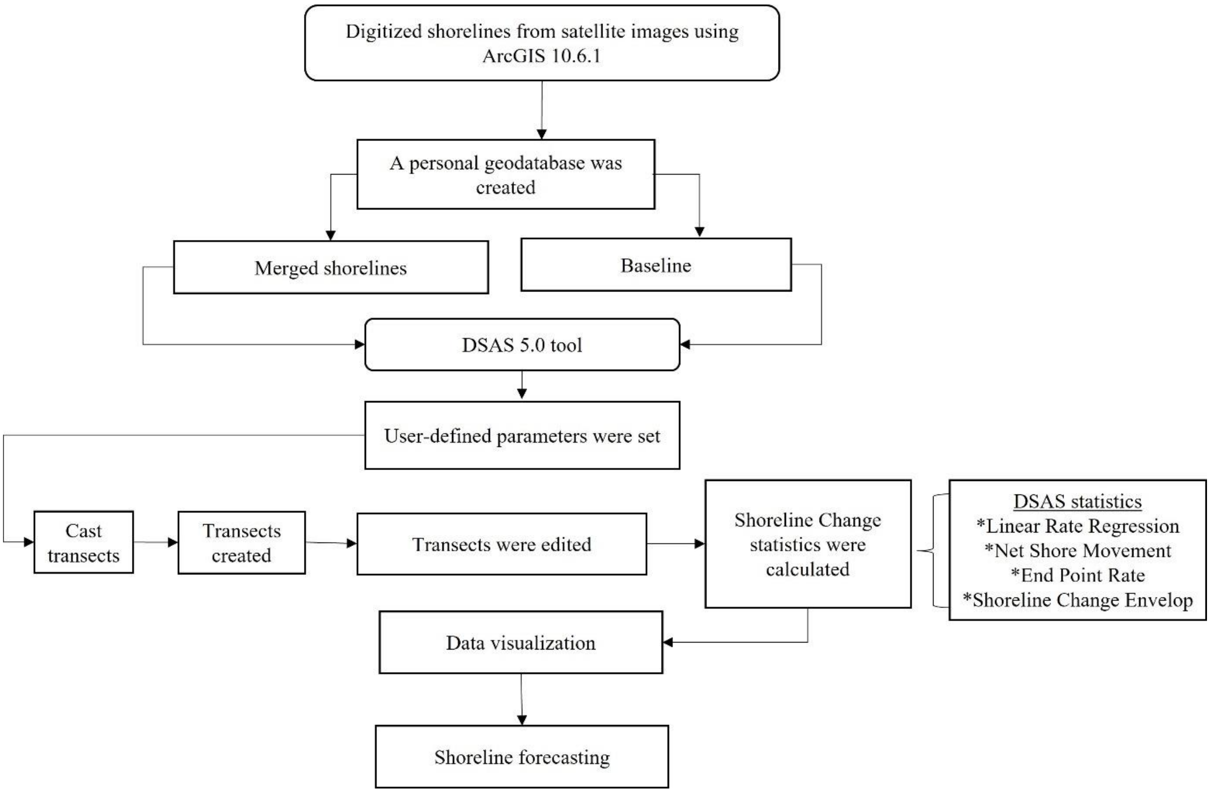


Figure 3.9: DSAS tool flow chart used in computing shoreline change statistics.

DSAS has various statistical approaches to calculate and represent shoreline changes. The most commonly used approaches include:

1) Net shoreline movement (NSM)

The NSM is the distance between the oldest and youngest shorelines and indicates how much the shoreline has changed. This shoreline change is calculated using equation 3.9;

$$NSM = d1 - d2 \tag{3.9}$$

Where d_1 and d_2 represent the distance between the oldest and youngest shorelines. It is usually represented in meters (m) (Oyedotun 2014; Himmelstoss et al. 2018).

2) End point rate (EPR)

The EPR enables the quantification of erosion and accretion per year. It uses only the two shoreline positions: the oldest and youngest shorelines and is usually represented as meters/year (m/yr) and calculated using equations 3.10 and 3.11.

$$EPR = \frac{NSM}{time\ elapsed\ between\ oldest\ and\ youngest\ shoreline} \quad (3.10)$$

$$EPR = \frac{(d1-d2)}{(t1-t2)} \quad (3.11)$$

where t_1 and t_2 represent the time elapsed between the oldest and youngest shoreline. The EPR does not assume a linear rate of change between the two shorelines; rather it is an indication of the net change between them (Hapke et al. 2011).

3) Weighted Linear Regression (WLR) method

This uses all the shorelines involved to calculate the rate of change by fitting a least-square regression to all the shorelines at a specific transect and incorporating the uncertainty identified by the study. This method gives the most reliable shoreline data greater weight in determining the line of best fit (Himmelstoss et al. 2018). The uncertainty field of the shoreline data is incorporated into this calculation using equation 3.12.

$$W = \frac{1}{e2} \quad (3.12)$$

Where *W* is the weight and *e* is the shoreline uncertainty value

4) Shoreline change envelop (SCE)

The SCE measures the total change in shoreline movement with reference to all the shorelines used in the computation and is it usually represented in meters. It is only concerned with the distance between the shorelines without any reference to the individual dates of the images.(Oyedotun 2014; Himmelstoss et al. 2018).

5) Linear regression rate (LRR)

The LRR uses all the shorelines involved to calculate the rate of change by fitting a least-square regression to all the shorelines at a specific transect used for computation (Himmelstoss et al. 2018). LRR is calculated (Hashmi et al. 2018) using equation 3.13;

$$Y = Mx + B \quad (3.13)$$

where *Y* denotes the shoreline position, *M* is the rate of shoreline movement, *X* is the date, and *B* is the intercept. Hashmi et al. (2018) highlighted the advantage of the LRR method when compared to other DSAS statistical methods (EPR, NSM and SCE) and indicated that the results derived were better. For example, though the EPR is simple and uses just two shorelines to analyze change, the drawback lies in the fact that if one shore has errors then the entire result will be inaccurate (Ekong 2017). The LRR minimizes this error by involving more than two shorelines (Hashmi et al. 2018) and Mullick et al. (2020) noted that positional uncertainty was reduced with the LRR method when compared to other techniques. However, Himmelstoss et al. (2018) noted that the drawback of this method is the tendency to underestimate the rate of change when compared to other methods because it minimizes the sum of the squared residuals. According to Mullick et al. (2020), the LRR method is a more suitable change assessment tool on an alluvial coast due to the highly dynamic nature of these coastal landforms where changes can occur rapidly. This is because LRR takes into account more than two shorelines which could span different temporal scales, making it easy to assess the rate of change overtime, as well as dynamism of the change pattern. They further explain that the LRR is most suitable in a tide-controlled coast because it can account for the variability in the dynamics in nature and rapid changes regularly due to tidal currents and storm surges acting upon the coast. The LRR method assumes there is a linear change along the coast between the years under investigation. The LRR is used for this study because previous studies have shown that it is the most robust DSAS method which uses multiple time periods (Natesan et al. 2015), and, as Mullick et al. (2020) have demonstrated, it is very well suited to the alluvial coasts in the study area.

6) Shoreline Forecasting

To predict future shoreline trends, the DSAS v5.0 which uses the beta forecasting tool to predict the future shoreline trend, as presented by Himmelstoss et al. (2018), was used in this study. Himmelstoss et al. (2018) highlights that the beta forecasting tool uses the Kalman filter method for forecasting shoreline evolution by Long et al. (2012) to combine both observed and model-derived positions to predict a reliable future trend and its uncertainty. This process uses four or more shorelines for prediction and generates either a 10 or 20-year forecast from the run date. The Kalman filter output behaves like that of the linear regression model but is extrapolated into the future. It is important to note that this method may not be suitable for all types of shorelines, such as the extremely curvy coast which make it have difficult to cast transects that do not overlap, introducing errors in the results; data type (most suitable for long term data), patterns and locations (does not work well in locations where there is a constant coastal change) and therefore, must be used with caution since it does not quantify the rate of change but only indicates potential change locations (Himmelstoss et al. 2018). However, this method is adopted to indicate areas of potential hot spots which can lead to more informed coastal management decisions. Esmail et al. (2019) note that though shoreline prediction is usually not straightforward, it is useful in giving a pictorial sense of where the future shoreline position will be and is dependent on the historical rates of erosion and accretion. In other words, the prediction is only as good as the accuracy of the historical data. This means that the entire process of data analysis, statistical methods and error reduction techniques are critical in the accuracy of the predicted results. Due to the resolution of the Landsat images and inadequate data such as tidal range and wave attenuation, this study initially set out to only use the prediction to indicate the future position of shoreline for management purposes and not necessarily quantifying it. However, since this DSAS v5.0 software allows predictions for the next 10 and 20 years using four measured shorelines; this study will attempt to use both the predicted shorelines and measured shorelines to quantify the future shoreline change.

3.2.6.1 Digital shoreline analysis system (DSAS) statistics parameters

DSAS v5.0 uses two data inputs to calculate the rate of change statistics. These are the shoreline data and the baseline data. For the shoreline data, DSAS measures the change rates between the shorelines used for the analysis. The required attribute fields are object identifier, shape, shape length, shoreline dates and shoreline positional uncertainty attached to the shoreline data stored in an accepted DSAS format (refer to https://pubs.er.usgs.gov/publication/ofr20181179 for the description of shoreline attribute fields). The extracted shoreline positions are merged into a single feature class and should contain a positional uncertainty associated with each shoreline and stored in a personal geodatabase. For the baseline data, the necessary attribute features which include object identifier, shape, shape length, baseline ID, group and search distance needed for DSAS statistics were created (see appendix 3.2 for the description of baseline attribute fields). The baseline was created from a 600m buffer that was made around the shorelines. The baseline for this research had a seaward orientation. That means the baseline was digitised from the buffer line that was closest to the sea (offshore) (e.g., see Figure 3.10).

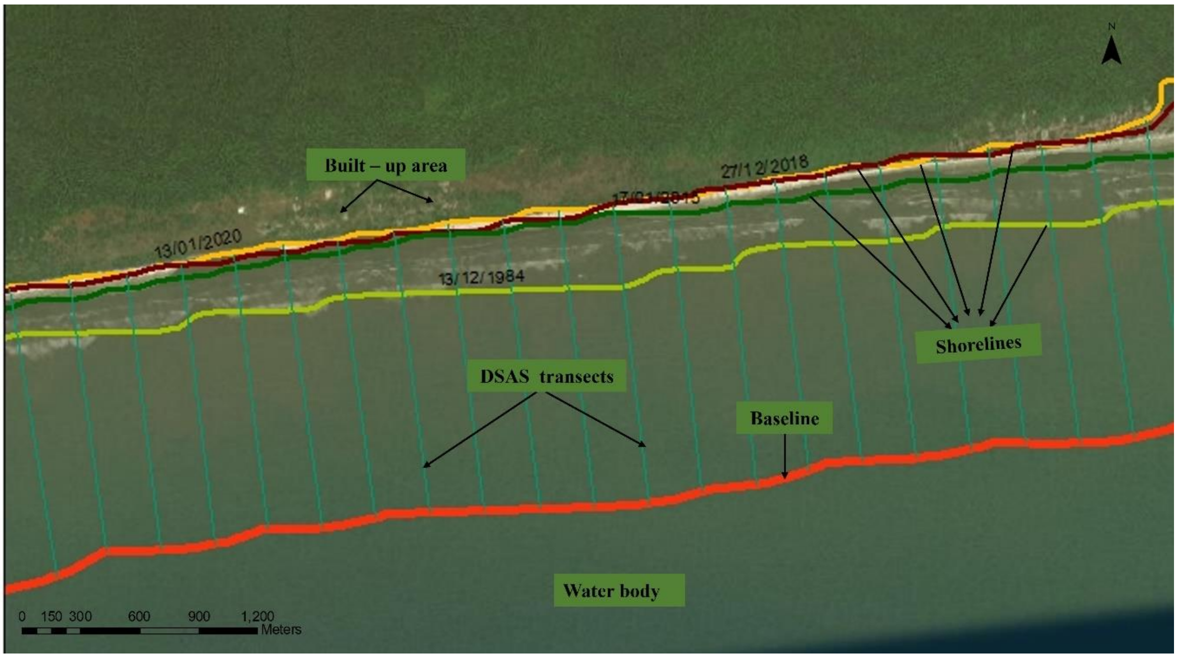


Figure 3.10: Baseline placement and transects used in the shoreline change analysis for the Landsat datasets.

The transects are cast perpendicular to the baseline and user-defined parameters are shown in Figure 3.10 at a spacing of 50m intersects along the shorelines and are used to establish the measurements. Table 3.6 summarizes the user-defined parameters for this chapter.

Table 3.6: Shows a summary of the parameters used for the calculation of the change analysis from Landsat datasets

Shoreline dates	**13/12/1984, 17/01/2015, 27/12/2018, 31/01/2020**
Transect spacing	50m
Transects Smoothing distance	2000m
Maximum search distance from the baseline	2000m
Transects intersection threshold	4 for long-term changes 3 for short-term changes
Baseline placement	offshore
Uncertainty	Used the information from the uncertainty column of the shoreline attribute table in ArcGIS
Confidence interval	90%
Change statistics computed	Linear regression rates, End point rate

The smoothing distance was gradually increased from no smoothing to 2000m to select the most optimal smoothing distance to avoid intersections of the transect lines in the curved sections of the coast. Although, increasing the smoothing distance produces uniform transects, excessively increasing the distance will in turn increase the reference maximum search, thereby incorporating undesirable data that is irrelevant to the investigation at hand and overestimate the rate of change along that transect. Figure 3.11 shows the smoothing distance applied along a section of the Akwa Ibom shoreline. The 2000m smoothing distance was adopted for this study because it eliminated the overlapping transect lines that could introduce errors in the calculations.

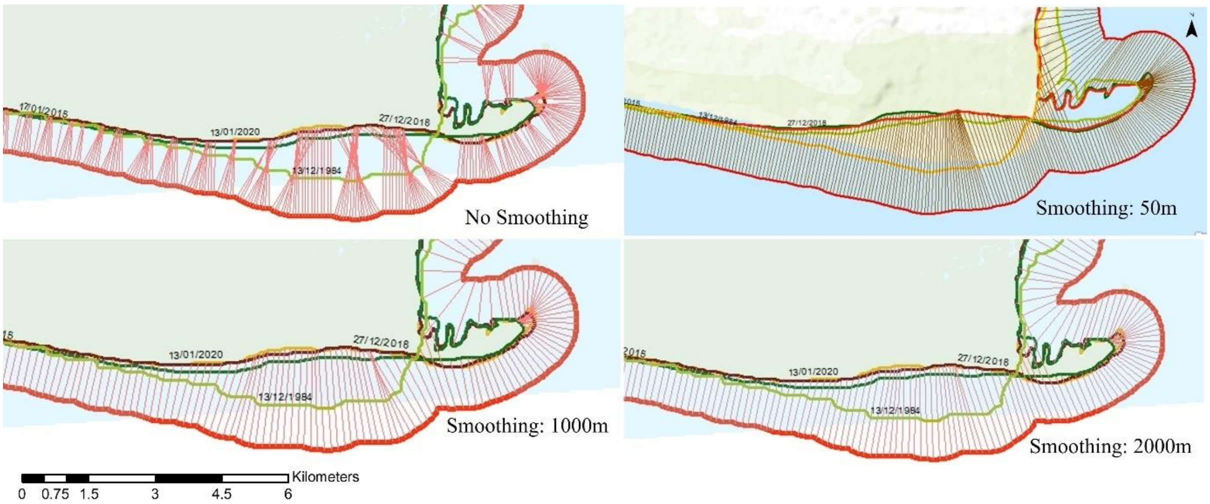


Figure 3.11: Transect Smoothing distance applied in the DSAS statistics

The Akwa Ibom State shoreline was divided into three zones enable a proper comparative study and a more local assessment of the coastal area. The study area is divided into three zones: zone A (comprises of Oron and Mbo Local Government Areas) which is about 48km, zone B (Ibeno Local Government Area) which is about 58km and zone C (Eastern-Obolo and Ikot Abasi Local Government Areas which is about 44km long. The study coast is predominantly alluvial consist of several estuaries. The estuary inlets along the coast all showed extreme and significant erosion and accretion but were excluded from this analysis because they produced significant outliers in thousands of meters which resulted from the stretch of the estuary that allowed and accommodated the search distance of 2000m. Figures 3.12 shows some of the estuary outlets that were cut off along the coast. Due to the cut-off inlets, the baseline used for calculating the shoreline change was divided into 15 sections which excluded the estuaries.

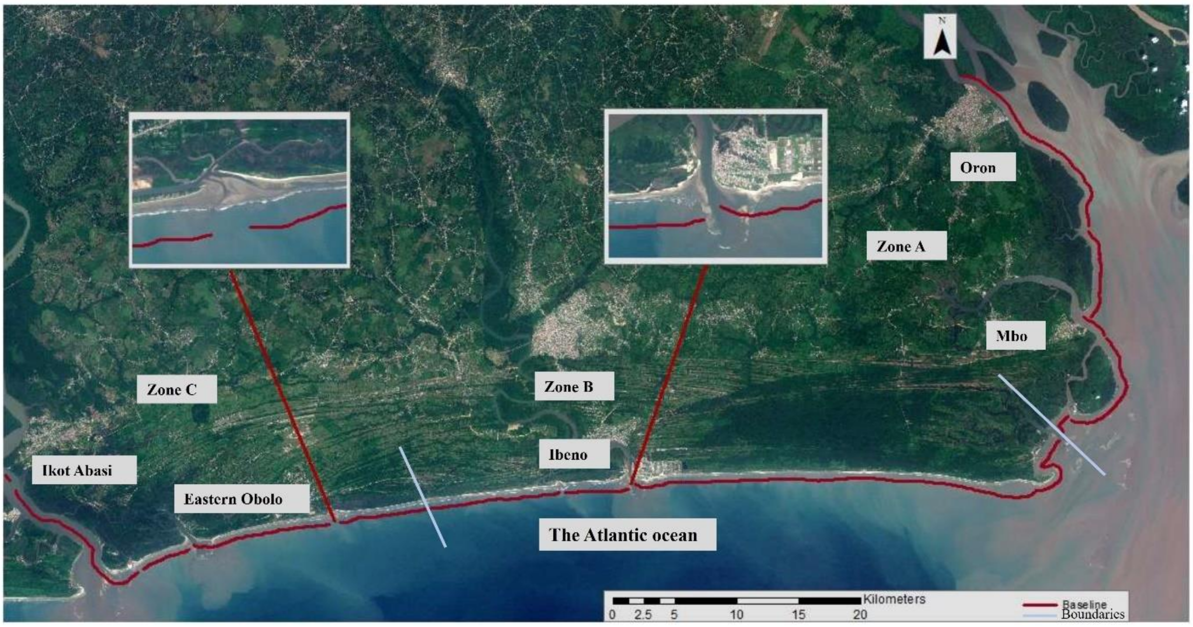


Figure 3.12: Shows the cut-off estuary outlets in the study location excluded from coastal change analysis overlain on a Sentinel 2A image (26th December 2019) of the study area

3.2.6.2 Mapping uncertainties and errors

To improve the accuracy of the statistical results of the computed rate, the uncertainties for each shoreline position should be accounted for. There are potential errors that can be introduced during shoreline mapping. Discussion on potential sources of errors which include the positional uncertainty and measurement errors can be found in Gibbs et al. (2017) and Anders et al. (1991). They explain that the accuracy error is a positional error that describes how the map position of the shoreline truly represents the ground shoreline while the precision error relates to the measurement techniques used for the mapping. The error quantification is essential in the shoreline change analysis since the accuracy of the results is dependent on the data used in the analysis and the source of measurement of the data (Moore 2000). Shoreline position errors or related uncertainties have been widely applied in previous shoreline change analysis studies (Anders et al. 1991; Crowell et al. 1991; Moore 2000; Dar et al. 2009; Ruggiero et al. 2013). The overall error should account for both different positional (like seasonal error, tidal range) and measurement errors such as digitizing error, rectification error and pixel error (Kankaraa et al. 2015). For this research, the identified HWL shoreline position uncertainties based on Ruggiero et al. (2013) are that of tidal range (U_{pd}) and that of the instrument of measure - pixel size (U_i) which will greatly influence the digitization of the shoreline. The tidal range in the Ibeno section of the coast is between 2-5m (Udo-Akuaibit 2017). For this study, the average tidal range derived from the Nigerian Navy report (Nigerian-Navy 2020) is considered for the calculation of uncertainty. Some studies have shown that for the Landsat image with a pixel size of 30m, it may not be considered because it is negligible when compared to the spatial resolution of the Landsat image (Gens 2010; Addo et al. 2011). However, for uniformity throughout the Landsat images used in this analysis, this study considered it for the Landsat images but not for the SPOT and Pleiades data since the tidal range is larger than its pixel size of 1.5m and 0.5cm respectively. As such, for this research, the total shoreline position uncertainty (U_p) is calculated as the square root of the sum of the uncertainty of the instrument (pixel error), the uncertainty of the high waterline at the time of the survey, and the digitizing error (see equation 3.14).

$$U_p = \sqrt{U_i^2} + U_{pd}^2 + U_d^2 \quad (3.14)$$

where

U_i is the uncertainty associated with the pixel size

U_{pd} is the uncertainty of the high waterline which is influenced by the tidal range in the area.

U_d is the digitizing error

The uncertainty associated with the dataset used for this study is summarised in table 3.7

Table 3.7: Uncertainty parameters used in this study

Uncertainty (u)	**Uncertainty value used**	
Uncertainty of instrument (pixel error), U_i	Landsat 8	15
	Landsat 5 MSS	30
	Pleiades	0.5
	SPOT	1.5
Uncertainty of the high waterline, U_{pd}	2.4	
Digitizing error, U_d	3	

These shoreline uncertainties (table 3.7) were incorporated as an attribute to the shoreline polyline table. The calculated overall uncertainty for the linear regression rates (LRR) averages are presented in Table 3.8

Table 3.8: Shoreline uncertainty values

Akwa Ibom Shorelines	Calculated uncertainty with statistical analysis (LRR) using Landsat-derived shorelines							
	Long-term (1984-2020) shoreline changes (m)				Short-term (2015-2020) shoreline changes (m)			
	Entire coast	Zone A	Zone B	Zone C	Entire coast	Zone A	Zone B	Zone C
Manually digitized shorelines	+/-0.18	+/-0.13	+/-0.34	+/-0.99	+/-1.28	+/-0.75	+/-3	+/-6.69
Semi-automatically extracted shorelines	+/-0.47	+/-2.64	+/-0.25	+/-0.9	+/-3.91	+/-14.73	+/-3.8	+/-10.98

The results of the uncertainty values in Table 3.8 show that for the long-term shoreline analysis, the uncertainty associated with the overall average LRR rate derived from the manually digitized shorelines is ±0.18m while that of the semi-automated shorelines is ±0.47m. This simply means that for every LRR average obtained, the true value is or lies between + or – the uncertainty values. For the short-term changes, the uncertainty value is ±1.28m for the manually extracted shorelines and ±3.91m for the semi-automated shorelines. The table also shows the uncertainty values for the different sections (zones) of the coast (refer to figure 3.12 for the spatial locations of the different zones). The results here also show that the uncertainty values of LRR averages derived from the manually extracted shorelines are much lower than that of the semi-automated shorelines.

3.2.6.3 Accuracy assessment for shoreline extraction

Previous studies have used different methods to assess the accuracy of the extracted shorelines. They include, though not limited to, shoreline change envelop (SCE) (Apostolopoulos et al. 2020), and mean net shoreline movement (Liu et al. 2017). The accuracy method by Apostolopoulos et al. (2020) compared and overlayed two shorelines from different image data resolutions and compared them with a reference shoreline from a high resolution image to assess the degree to which they overlapped, as well as the standard deviation between the results. In the mean net shoreline movement approach, the reference (most accurate shoreline) is merged separately with the shorelines from different image data resolutions and the NSM is calculated to determine which pair of shorelines with the reference shoreline had a low NSM rate. This means that a lower value NSM suggests a close fit between the extracted and reference shorelines. Both strategies are dependable and effective. However, due to the advantages of the SCE being simple and less time consuming, this study follows the SCE approach by Apostolopoulos et al. (2020), to average SCE between both the manual and semi-automated shorelines with the reference shore is used to determine the most accurate shoreline to use in this study.

As previously stated in section 3.2.3, two methods of shoreline extraction were undertaken due to the coarseness of the Landsat images. DSAS is used to calculate the difference in movement between the extracted measured shorelines and compare them with a reference shoreline. The reference shoreline used is a high-resolution image from the Pleiades satellite image derived from a section of the coast. The reference shoreline which is considered more accurate due to its resolution (0.5m) was used to carry out the accuracy assessment for the Landsat data derived for the same area. The closer the mean of the difference (SCE) to zero, the more accurate the method is to extract the shoreline (Abualhin et al. 2009). To assess the accuracy of the extracted shorelines, the extracted Landsat shorelines of the same year with the reference data were used. The manually and semi-automatically delineated shorelines of 2015 were merged separately with the extracted shoreline from the Pleaides data of 2015. For the accuracy assessment, the following parameters were used (see table 3.9).

The parameters used for this assessment were a baseline of 150m created from the merged shorelines and this, together with the merged shorelines, served as input parameters in the DSAS v5.0 used to calculate the SCE between the two shorelines. In the DSAS interface, a 50m transect spacing, a search distance of 1000 m and a smoothing distance of 1000 m were user specified for calculation. The search and smoothing distances of 1000m were selected because the accuracy assessment was only carried out on a considerably straighter, non-curvy axis of the coast and did not necessitate greater search and smoothing distance values.

Table 3.9: Parameters used for the accuracy assessment

Shoreline dates	Landsat 2015, Pleiades 2015
Transect spacing	50m
Transects Smoothing distance	1000m
Maximum search distance from the baseline	1000m
Transects intersection threshold	shorelines
Baseline placement	offshore
Uncertainty	Used the information from the uncertainty attribute of the shoreline table
Confidence interval	90%
Change statistics computed	SCE (shoreline change envelop)

This was done to determine which shorelines (manually or semi-automated shorelines from Landsat) are considered the accurate shorelines to use in this study when compared with the reference shoreline which is of a much higher resolution (Pleiades). With the individual user-defined parameters set, the SCE statistics were calculated to estimate the average difference between the shorelines extracted using both the manual and semi-automatic method and the reference shoreline (figure 3.13).

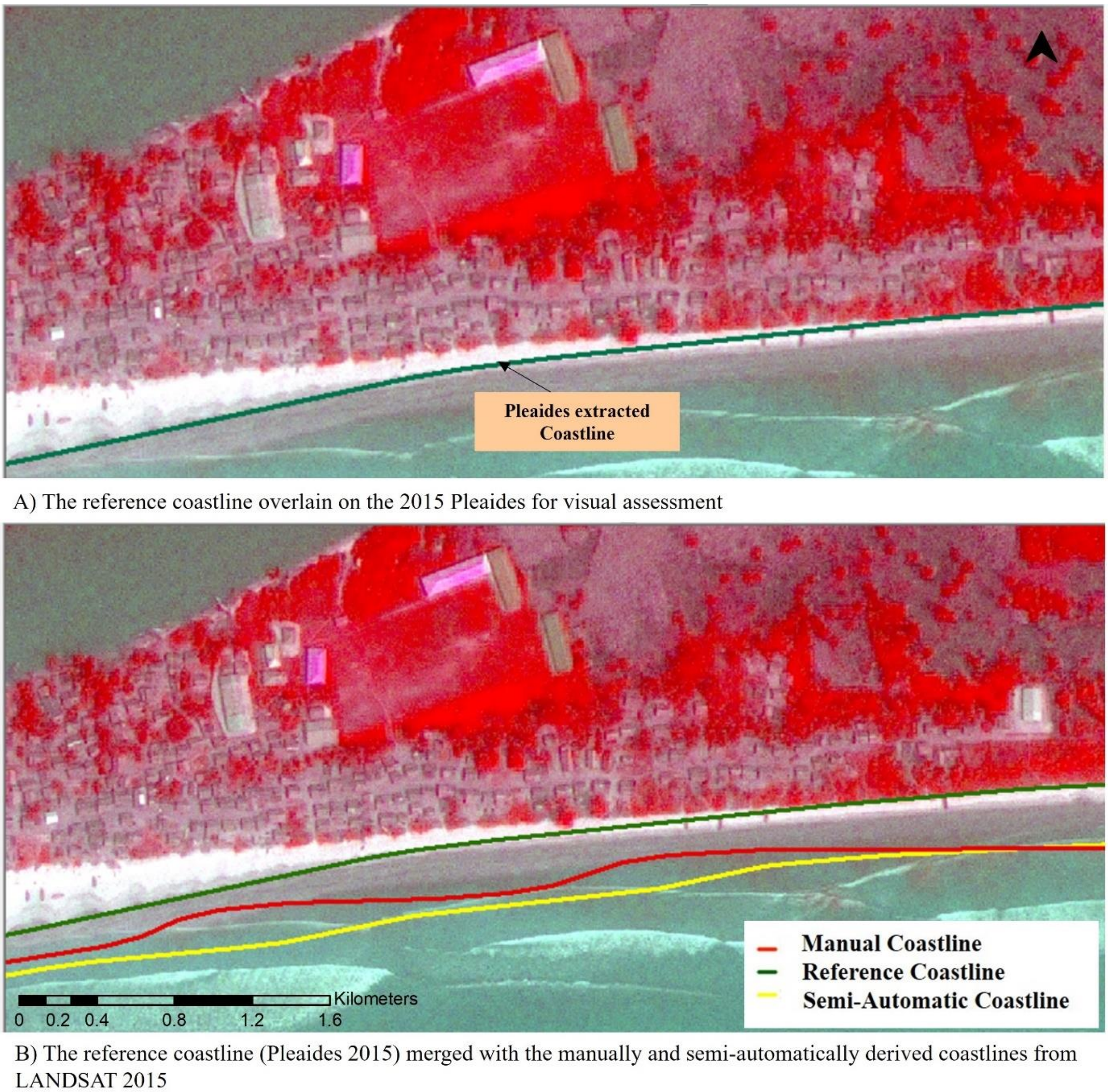


Figure 3.13: A) shows reference shoreline (extracted from Pleiades image) for 2015 overlain a 2015 Pleiades image for visual assessment and B) all the shorelines (2015) used in the SCE analysis.

The results of 445 transects for that section of the coast used for this analysis show that the average SCE between the manually extracted shoreline and reference shoreline is 34.22m while the average SCE between the semi-automated shoreline and the reference shoreline is 39.47m. The results here reveal that the manually extracted shoreline shows a much shorter distance to the reference shoreline than the semi-automated shorelines; though the margin seems close, there is a difference of 5.25m between the individual results.

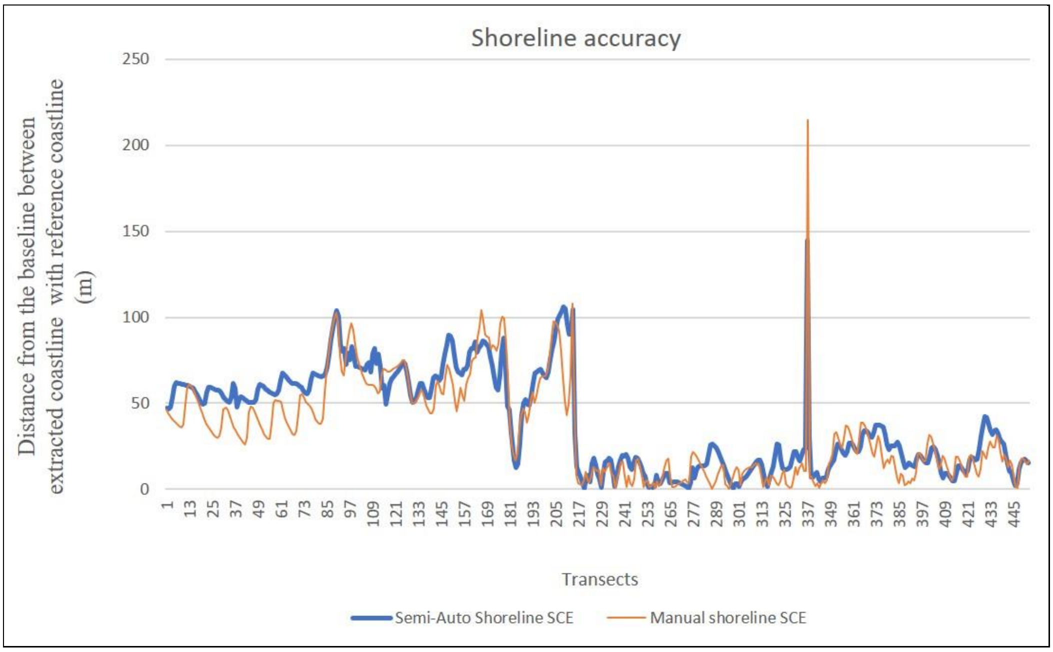


Figure 3.14: Average distance moved between the extracted shorelines and the reference shoreline

Figure 3.14 shows a combination of the SCE values of the two different shoreline approaches to enable the proper visualisation and comparison of the minimum difference between the extracted shorelines and the reference shoreline. The spike around transects 337 corresponds to an inlet tributary, hence the high figure of SCE results both on the manually digitized shoreline and on the semi-automated shoreline. Based on these average SCE results and improved accuracy, the manually digitized shorelines will be considered the more accurate shorelines, and discussion on shoreline change in this study will be based on that (see appendix 3.3). This pilot data analysis shows that the manual process is better, and based on this result, this study used manually extracted shorelines for shoreline change analysis.

3.3 Results

3.3.1 Rate of change along the Akwa Ibom State axis of the Strand Coast from 1984 - 2020

An overall historical trend assessment along the entire coast is performed, as well as a change assessment in the different zones delineated for this study.

3.3.2 Long-term coastal change (1984-2020)

The results derived using both the manual and semi-automated derived shorelines show noticeable and significant changes in the movement of the shoreline (figure 3.15).

Figure 3.15: Long-term (1984-2020) coastal change analysis (LRR) along the studied coast overlain on a Sentinel 2A image (26th December 2019) of the study area.

The similarities and differences in erosion trends between the three different zones are studied here. The Linear regression rates (LRR) enable the quantification of erosion and accretion per year from 1984 to 2020 and results for the overall LRR calculation can also be seen in figure 3.17. The results obtained in this section demonstrate the variability of coastal erosion and accretion in the different zones over 36 years assessed over a four-step time interval of 1984, 2015, 2018 and 2020 (see figure 3.17). The total number of transects used for the entire coast is 2591, with erosion accounting for 76.15 % (1973 transects) and accretion accounting for 23.85 % (table 3.10). The overall average LRR of -2.7$\pm$0.18m/yr derived from the result, indicates that the area is predominantly eroding.

3.3.2.1 Comparative analysis of the long-term shoreline changes along the different zones in the study area

Using the LRR results derived from the manually derived shoreline, a comparative analysis of long-term shoreline changes between three zones of the study area was completed. This enabled an assessment of the spatial variation in patterns and rates of change between zones, as well as an assessment of the trend analysis relationship. Table 3.10 summarises the results of the comparative analysis.

Table 3.10: Summary of the LLR results across the study area

Section of zone	Maximum Erosion (m/yr)	Maximum Accretion (m/yr)	Average LRR (m/yr)	Uncertainty of average rate (m/yr)
Entire shoreline	-24.8	38.82	-2.7	±0. I8
Zone A	-24.8	3.09	-0.54	±0.13
Zone B	-24.7	38.82	-4.46	±0.34
Zone C	-14.86	14.85	-2.44	±0.99

For zone A, a total of 788 transects were used to analyse shoreline changes, with 51.52% (406 transects) showing erosion and 48.48% (382 transects) showing accretion. Only 33.12% of the erosional transects showed significant erosion, while 14.97% showed significant accretion. In the DSAS, significant erosion or accretion refers to all transects with a magnitude greater than the uncertainty (plus/minus the confidence interval value). From 1984 to 2020, the maximum landward movement (erosion) observed in the zone was -24.8m/yr with an average of -1.91±0.13m/yr, while the maximum seaward movement (accretion) was 3.09m/yr with an average of 0.91±0.13m/yr. The overall average LRR of -0.54±0.13m/yr indicates that the area is eroding, albeit at a low rate. For zone B, a total of 1079 transects were employed to analyse shoreline changes, with 91.1% (983 transects) showing erosion and 8.9% (96 transects) showing accretion. 77.02% of the erosional transects exhibited significant erosion, while 4.91% exhibited significant accretion. From 1984 to 2020, the maximum landward movement (erosion) measured in the zone was -24.7m/yr with an average of -5.23±0.34m/yr, whereas the maximum seaward movement (accretion) was 38.82m/yr with an average of 3.44±0.34m/yr. The total average LRR of -4.46±0.34m/yr indicates that the land is eroding. For zone C, a total of 724 transects were cast from the offshore to the land at an interval of 50m. According to the findings, 80.66% (584 transects) of the transect area is erosional, and 61.45% of the erosional transects had significant erosion. The maximum erosion rate in this zone is -14.86m/yr, while the average erosion rate is -3.82±0.99m/yr, which implies that the shoreline is moving landward at a rate of at least 3m/yr. The maximum accretion rate in the area is 14.85m/yr, with only 140 transects (19.34%) demonstrating rates of accretion, while the average rate of accretion is 3.28±0.99m/yr. The overall average LRR is -2.44±0.99m/yr, which indicates that the land is predominantly erosional (table 3.12).

Overall, the average erosion and accretion rates computed from the extracted shorelines of the entire coast (table 3.11) from 1984-2020, as well as the bar plots in figure 3.16, reveal that zone B has the highest average erosion and accretion rates, whereas zone A has the lowest erosion and accretion rates.

Table 3.11: Results showing long-term changes (1984-2020) along the Akwa Ibom state coast

Strand Coast of Akwa Ibom State	**LONG-TERM CHANGES (1984-2020)**												
	Linear regression rate (LRR) Results												
	Total no. of Transects	**Max. Erosion rate (m/yr)**	**Average erosion (m/yr)**	**No. of erosional transects**	**% Of erosional transects**	**% Of statistically significant erosion**	**Max. Accretion rate (m/yr)**	**Average Accretion (m/yr)**	**No. of accretional transects**	**% Of accretional transects**	**% Of statistically significant accretion**	**Overall average LRR (m/yr)**	**Uncertainty of average rate (m/yr)**
Entire coast	2591	-24.8	-4.13	1973	76.15	59.32	38.82	1.84	618	23.85	8.49	-2.7	+/- 0.18
Zone A	788	-24.8	-1.91	406	51.52	33.12	3.09	0.91	382	48.48	14.97	-0.54	`+/- 0.13
Zone B	1079 (789-1867)	-24.7	-5.23	983	91.1	77.02	38.82	3.44	96	8.9	4.91	-4.46	+/- 0.34
Zone C	724 (1868-2591)	-14.86	-3.82	584	80.66	61.45	14.85	3.28	140	19.34	6.77	-2.44	+/- 0.99

Zone B also has the highest average rate (LRR) erosion in the area, at -4.46+0.0.34m/yr, whereas zone A has the lowest, at -0.54+0.13m/yr. The findings indicate that the predominant trend of shoreline change is erosional. The data also suggest that all zones in the study region have an erosional trend. The positive values represent sediment accretion or deposition along such transects, whereas the negative values show erosion in the research area.

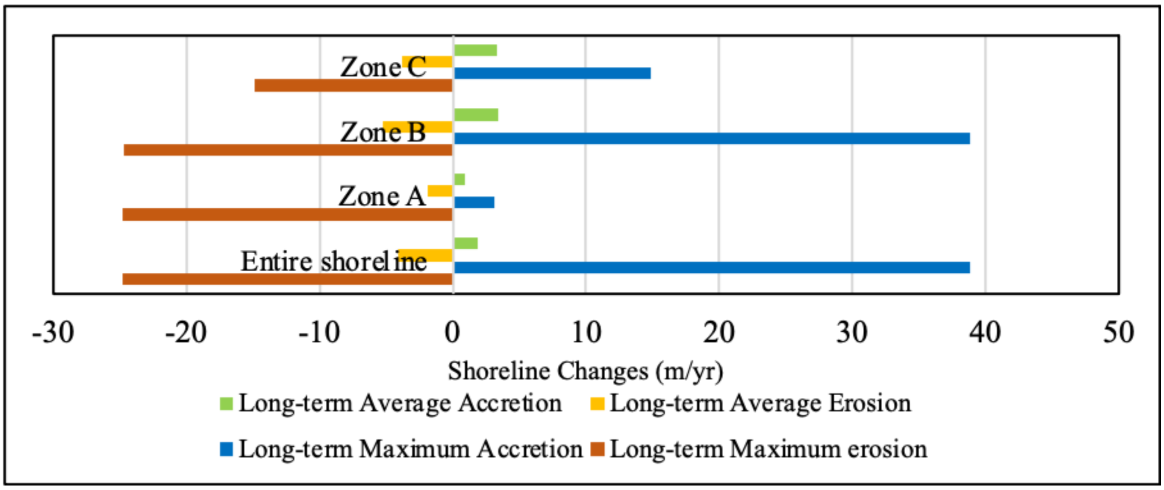


Figure 3.16: Bar chart showing the summary of the Long -term Erosion and Accretion (1986-2020) results across the entire Coast

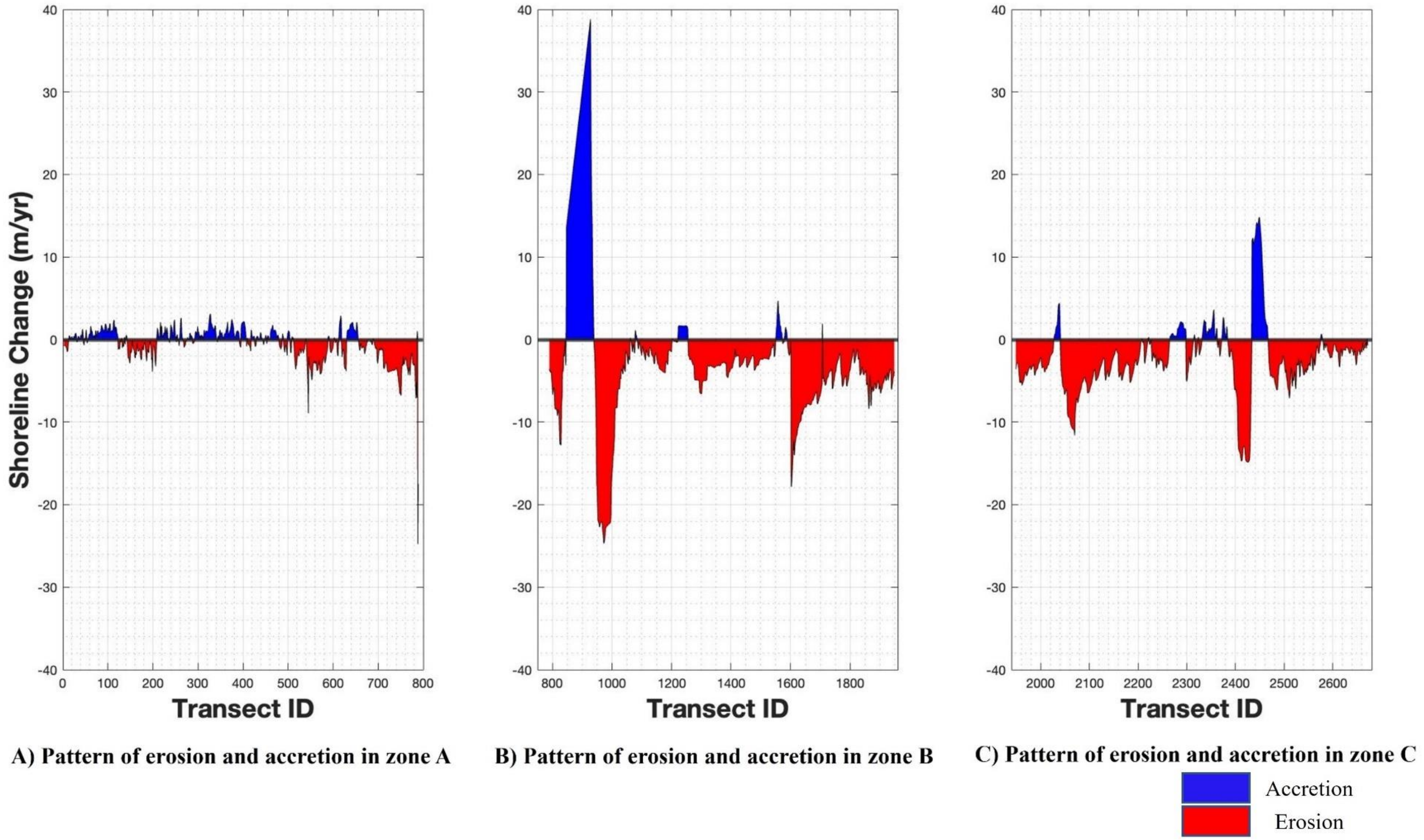


Figure 3.17: Graphs (A-C) showing spatial variability of erosion and accretion along the different zones in Akwa- Ibom shoreline between 1984-2020.

3.3.3 Short-term coastal change (2015 – 2020)

A five-year coastal trend behaviour of the study shoreline was assessed using the Linear Regression Rate (LRR). This was done to analyse the most recent geomorphological changes along the Akwa Ibom coast, as well as to determine how quickly these changes are occurring, which could be valuable in informing coastal management plans in the area. The short-term changes were calculated between 2015 and 2020. The rate of change was calculated using shorelines from three different years (2015, 2018, and 2020) by using a least-squares regression to all of the shorelines along a given transect (Himmelstoss et al. 2018).

Table 3.12: Short-term (2015-2020) change results derived from the manually digitised shorelines along the Akwa Ibom state coast

Strand Coast of Akwa Ibom State	SHORT-TERM CHANGES (2015-2020) Linear regression rate (LRR) Results												
	Total no. of Transects	Max. Erosion rate (m/yr)	Average erosion (m/yr)	No. of erosional transects	% of erosional transects	% of statistically significant erosion	Max. Accretion rate (m/yr)	Average Accretion (m/yr)	No. of accretional transects	% of accretional transects	% of statistically significant accretion	Overall average LRR (m/yr)	Uncertainty of average rate (m/yr)
Entire coast	2656	-55.81	-7.03	2178	82	20.82	46.07	10.13	478	18	3.01	-3.94	±1.28
Zone A	781 (1-781)	-41.41	-3.95	593	75.93	15.75	13.37	2.68	188	24.07	5.25	-2.35	±0.75
Zone B	1158 (782-1939)	-55.81	-8.74	1007	86.96	22.63	44.24	13.16	151	13.04	2.85	-5.89	±3
Zone C	717 (1940-2656)	-48.68	-7.22	578	80.61	23.43	46.07	16.93	139	19.39	0.84	-2.54	±6.69

An overview of the short-term shoreline dynamics and geographic distribution of erosion and accretion in the research region is shown in Figures 3.18 and 3.19. Figure 3.19 presents a visual comparison of short-term changes in the various zones along the study coast using shorelines obtained from both the manual and semi-automatic methods while Figure 3.18 shows the spatial distribution of shoreline changes along the entire coast.

The overall results of the DSAS calculation (table 3.12) show that 82% (2178 transects) of the total transects of 2656 are erosional, with only 20.82% having significant erosion (with at least erosion of 2m/yr), while 18% (478 transects) are accretional, with only 3.01% having significant accretion (with at least erosion of 2m/yr) along the coast. The maximum erosion in the entire coastal area is -55.81m/yr, with a five-year average erosional rate of -7.03±1.28m/yr, whereas the maximum accretion is 46.07m/yr, with a five-year average accretion of 10.13±1.28m/yr. As seen by the overall average LRR of -3.94 ±1.28m/yr, there is an erosional trend across the entire study coast. The graphs in figure 3.22 a-c provide a summary of the shoreline's behavioural trend from 2015 to 2020 along the three zones examined in this study. The results were determined by LRR statistics carried out on digitised shorelines from Landsat 2015, 2018, and 2020 imagery.

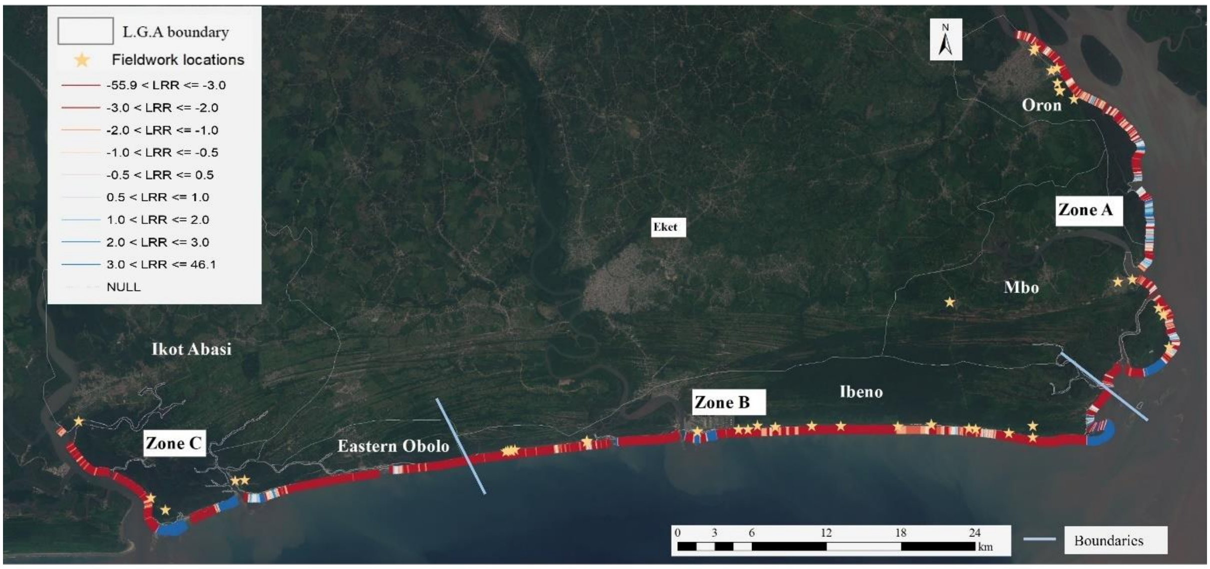


Figure 3.18: Spatial distribution of the short-term Linear regression results (2015-2020) for the entire study giving a synopsis of the trend of change along the coast overlain on a Sentinel 2A image (26th December 2019) of the study area.

3.3.3.1 Comparative analysis of the Short-term shoreline changes along the study area

The variability of the short-term shoreline changes along the study coast can be seen in figure 3.20. The results of the DSAS computation using the manually generated shorelines for zone A show that 75.93% (781 transects) of the total transects are erosional, with only 15.75% having significant erosion, and 24.07% (478 transects) having significant accretion. The maximum erosion rate in the area is -41.41m/yr, with a five-year average erosion rate of -3.95±0.75m/yr, whereas the maximum accretion rate is 13.37m/yr and an average accretion rate of 2.68±0.75m/yr. The general average LRR is -2.35 ±0.75m/yr, indicating an erosional trend in zone A. For zone B, the DSAS result generated indicates that the study area is erosional with an average LRR of -5.89±3.0m/yr. The results show that 86.96% (1007 transects) of the entire 1158 transects used are erosional while only 22.63 % have significant erosion. The maximum erosion in the area is -55.81m/yr and the average rate of erosion per year is -8.74 ±3.0m/yr. And it also showed that 13.04% of the transects are of accretion, meaning that only 151 transects showed accretion and from these, only 2.85% are significant. The maximum rate of accretion in the study area is 44.24 m/yr and the average rate of accretion is 13.16±3.0m/yr. For zone C, the shoreline change is carried out using the LRR for both shorelines manually digitized and semi-automatically extracted. For the manual shorelines, a total of 717 transects were cast from the offshore to the landward at an interval of 50m. The results show that 80.61% (578 transects) of the transects area are erosional and 23.43% of the erosional transects show significant erosion. For zone C, the maximum erosion is -48.68m/yr while the average erosion in the area is -7.22±6.69m/yr which implies that the shoreline is experiencing a landward movement at a rate of not less than 7m/yr. With only 139 transects (19.39%) showing rates of accretion, the maximum accretion rate in the area is 46.07m/yr and the average rate of accretion is 16.93±6.69m/yr. The overall average LRR is -2.54±6.69m/yr and it shows that the area is predominately erosional.

In general, the results demonstrate that zone B shows the strongest erosional trend among the three zones with an average rate of erosion at -8.74 ±3.0m/yr throughout the five years studied. This zone consequently experienced an average yearly landward movement of more than 8m/yr, which implies that the shoreline was eroding by 8 m/year on average between 2015 and 2020.

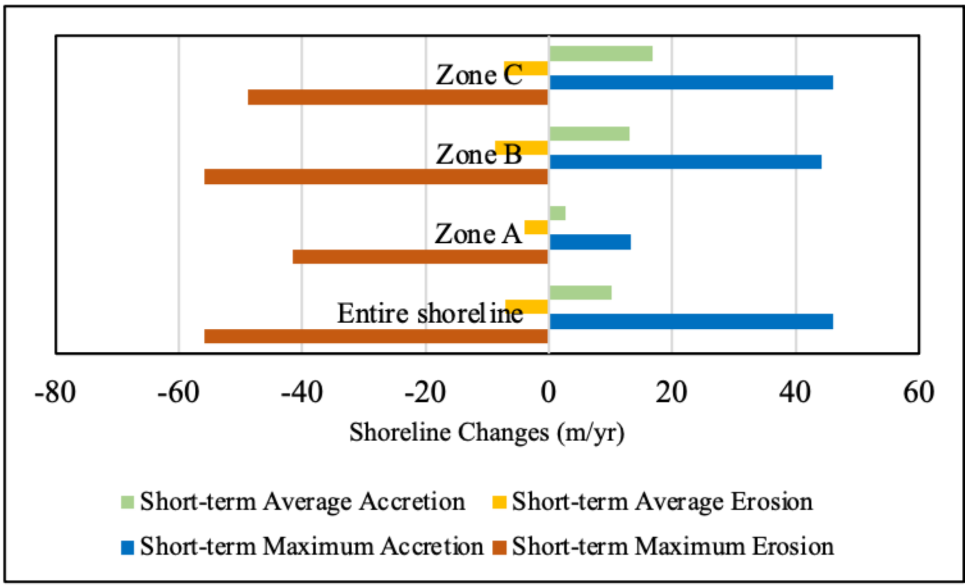


Figure 3.19: Bar chart showing the summary of the short-term (2015-2020) Erosion and Accretion results across the entire Coast.

Based on the linear regression rates, the results demonstrate the dynamism and variability of the coast through the amount of land lost and gained in the different zones of the study area over 5 years. The positive values in the result represent the land gained which means that sediment accretion is taking place along such transects. Figure 3.19 indicates the extent of coastal land erosion and accretion in the research area.

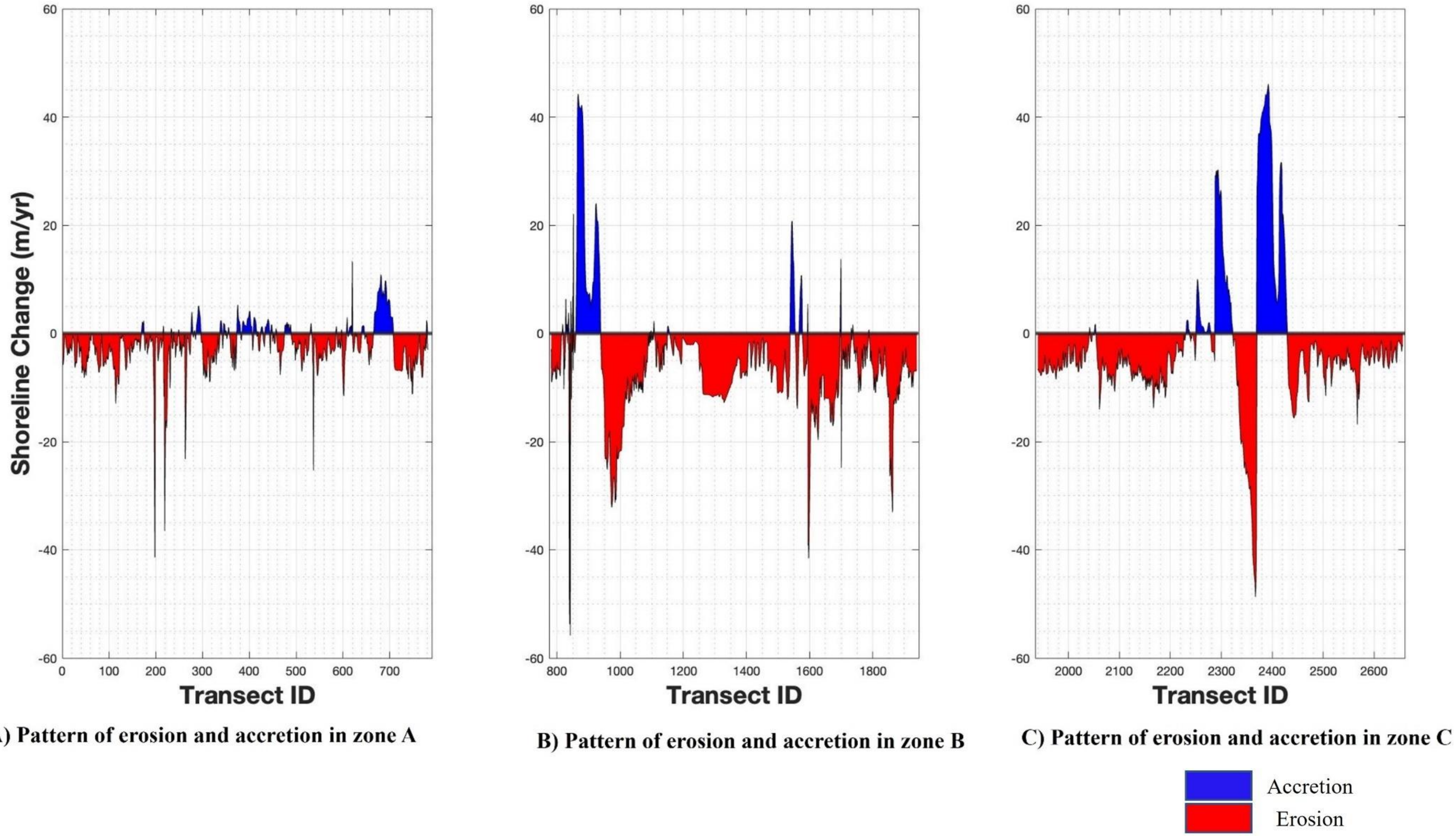


Figure 3.20: A-C shows Graphs of the spatial variability of the short-term rates of erosion and accretion along the different zones in Akwa- Ibom shoreline between 2015-2020.

3.3.4 Comparative analysis of the long-term and short-term results

To analyse the temporal and spatial differences along the study area, a comparative analysis was performed between long-term and short-term coastal changes. Table 3.13 summarises the results of the LRR statistical calculation used to analyse the historical shoreline changes.

Table 3.13: Summary of the Shoreline change rate using LRR in the different study zones calculated from Landsat data.

No	Change parameters	Zone A		Zone B		Zone C	
		Long-term LRR results	**Short-term LRR results**	**Long-term LRR results**	**Short-term LRR results**	**Long-term LRR results**	**Short-term LRR results**
1	Shoreline length in km	38		55		37	
2	Total no. of transects	788	781	1079	1158	724	717
3	Total erosional transects	406	593	983	1007	584	578
4	Total accretional transects	382	188	96	151	140	139
5	Average erosion rate (m/yr)	-1.91	-3.95	-5.23	-8.74	-3.82	-7.22
6	Average accretion rate (m/yr)	0.91	2.68	3.44	13.16	3.28	16.93
7	Maximum erosion (m/yr)	-24.8	-41.41	-24.7	-55.81	-14.86	-48.68
8	Maximum accretion (m/yr)	3.09	13.37	38.82	44.24	14.85	46.07
9	Overall average LRR (m/yr)	-0.54 ± 0.13	-2.23 ± 0.75	-4.46 ± 0.34	-5.89 ± 3	-2.44 ± 0.99	-2.54 ± 6.69
10	**Overall trend**	**Erosion**	**Erosion**	**Erosion**	**Erosion**	**Erosion**	**Erosion**

According to the results presented in table 3.13 and figure 3.21, the short-term overall average LRR along all three sections of the shoreline indicates an erosional trend which is similar to the erosional trend observed with results for the long-term analysis. Although, the results show a similarity between the trends in the two results, the average rate of erosion from the short-term analysis for zone A is -3.95 m/yr which is about two times higher than that of the long-term analysis which was -1.91 m/yr while the average accretion rate of 2.68m/yr is about three times higher than the long-term which was 0.91 m/yr. For zone B, the results were similar to that of zone A, with an average rate of erosion from the short-term analysis being -8.74 m/yr which was higher than that of the long-term analysis which was -5.23 m/yr while the average accretion rate of 13.16 m/yr was much higher than the long-term results which showed an average accretion rate of 3.44 m/yr. Likewise the case of zone C, the results showed similarity to that of zone A and B with an average rate of erosion from the short-term analysis being -7.22 m/yr which was much higher when compared to that of the long-term analysis which was -3.82 m/yr and the average accretion rate of 16.93 m/yr was much higher than the long-term results which showed an average accretion rate of 3.28 m/yr.

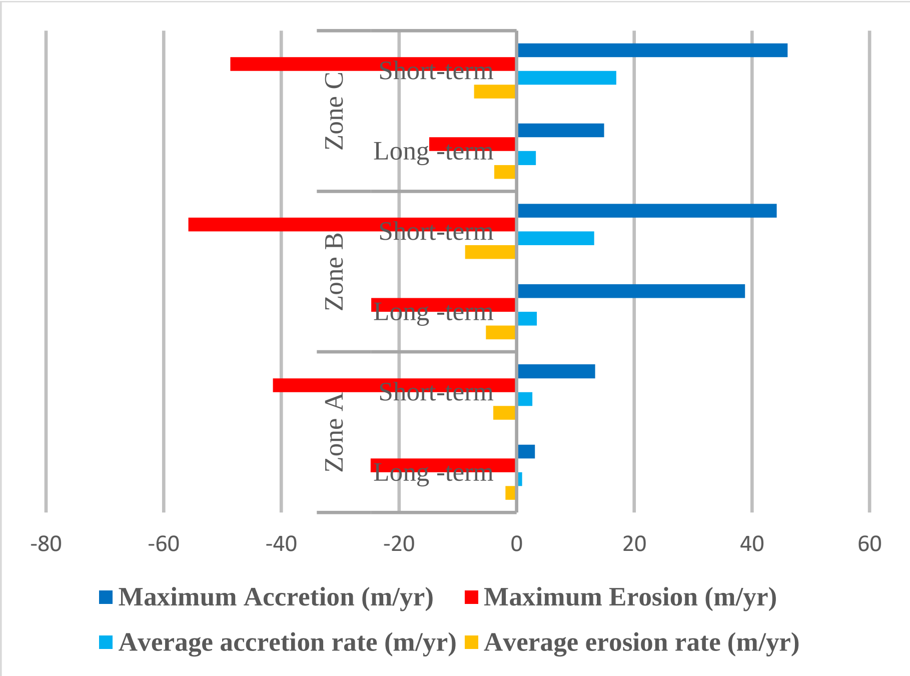


Figure 3.21: Bar chart showing the summary of both short-term (2015-2020) and long-term (1984-2020) Erosion and Accretion results across the entire Coast

3.3.5 Short-term change analysis using a higher resolution image, SPOT (2015-2020)

Firstly, this analysis was performed to assess which data resolution is best suitable for the study area. This study compared using high-resolution data like SPOT, which may not be widely accessible due to the high acquisition cost and limited spatial/temporal coverage, with using information from free and freely available 30m Landsat data, especially in a data-scarce location like the study area. Secondly, to assess and extract information on coastal erosion 'hot spots' using the Landsat images (medium resolution). It allows for the assessment of coastal changes that are not easily explained using low-medium resolution images (see section 3.3.5) and will enable an in-depth understanding of how rapidly the shoreline is changing and socio-ecological implication for such rapid changes (see chapter 6 for the more details).

3.3.5.1 Short-term changes using high-resolution data (SPOT) (2015-2020)

The short-term analysis for 5-year shoreline change was carried out using SPOT image data from 2015-2020 (figure 3.22). Due to non-availability of data for the year 2018 for the entire shoreline, the shorelines from 2015 and 2020 were selected for this analysis. The EPR approach was chosen because it only needs two shorelines and is the most appropriate method to employ based on the shorelines that are currently available from the 2015 and 2020 SPOT imageries. Unlike the LRR approach, used to analyse the multi-temporal Landsat images, the EPR (refer to 3.2.6 for description) does not assume a linear rate of change between the two shorelines involved, rather, it is an indication of the net change between the shorelines. The EPR results showing erosion and accretion rates are seen in tables 3.14 and 3.15.

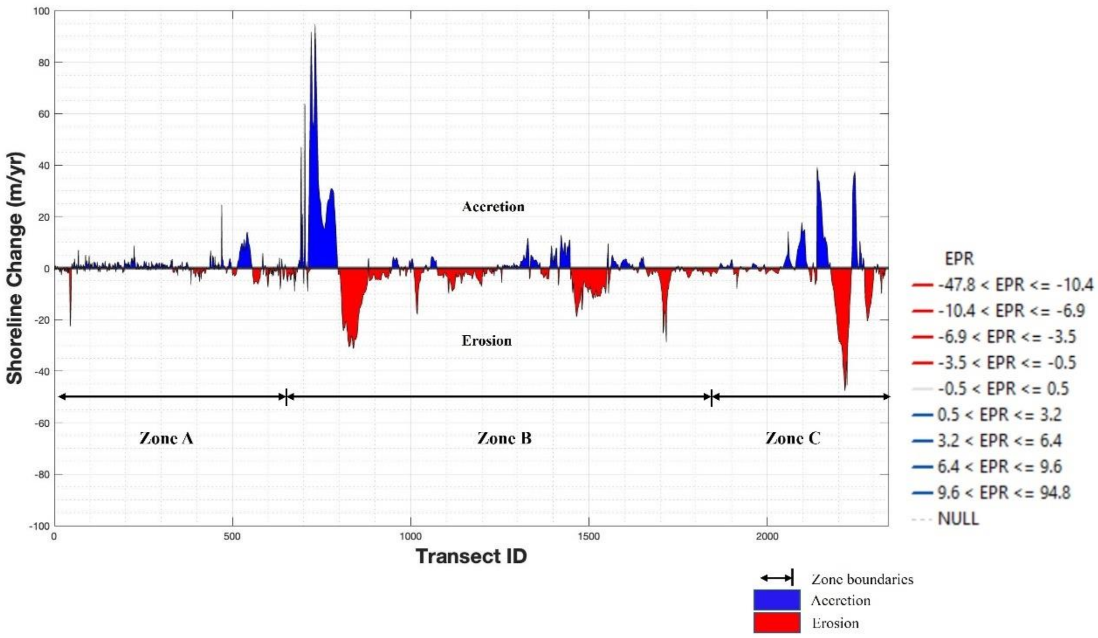


Figure 3.22: EPR erosion/accretion pattern generated from manually digitized shorelines of high-resolution data (SPOT Image) for 2015-2020

Table 3.14: Summary of the short-term Erosion and Accretion results across the entire Coast derived from the EPR method applied on the 2015 and 2020 shorelines from SPOT imagery**.**

Section of zone	Maximum erosion (m/yr)	Maximum Accretion (m/yr)	Average Erosion (m/yr)	Average Accretion (m/yr)	Overall Average EPR (m/yr)
Entire shoreline	-47.73	94.8	-5.36	5.66	-0.54 ±-0.23
Zone A	-22.67	24.55	-1.79	2.2	0.5 ±-0.4
Zone B	-31.37	94.8	-5.65	7.25	-0.91 ± -0.4
Zone C	-47.73	39.24	-8.49	8.47	-1± -0.4

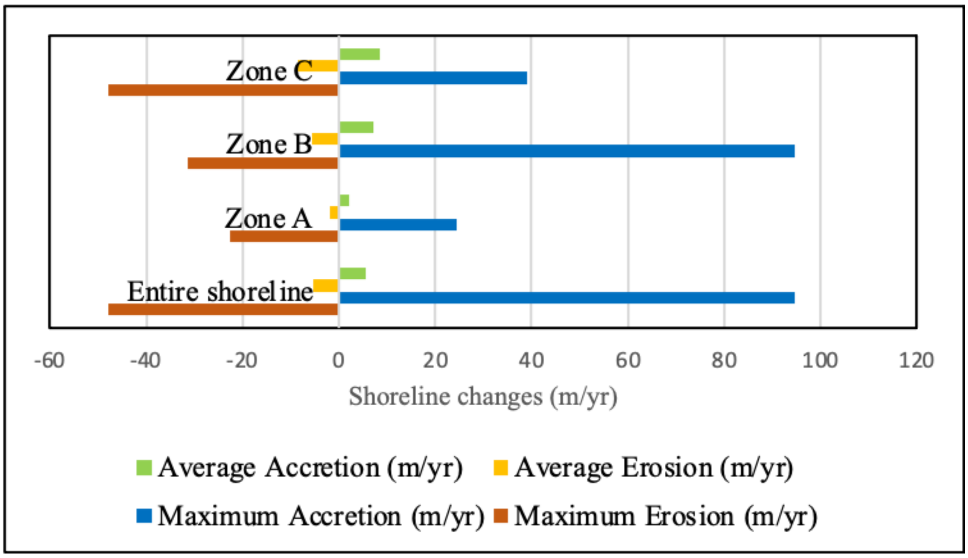


Figure 3.23: Bar chart showing the summary of the short-term (2015-2020) Erosion and Accretion results derived for the SPOT image across the Coast

The findings (table 3.14) indicate that accretion is the major trend in zone A, with the overall average rate of change in that zone being 0.5 $\pm$ 0.4 m/yr, unlike the results seen in zone B and C where the overall average rates of change were -0.91 $\pm$ -0.4 m/yr and -1$\pm$ -0.4 m/yr which indicates that erosion was predominant in these zones. The EPR results show that between 2015 and 2020, there was an erosional trend in the entire study coast with an overall average rate of -0.54$\pm$0.23 m/yr with the highest rate of erosion occurring in zone C at the rate of -47.73 m/y. It is important to note that the entire zone C, the Ikot Abasi axis, was not captured in this analysis (see figure 3.22) due to the limited spatial coverage of the SPOT data to cover the entire coastal region. The maximum rates of erosion for zone A and B are -22.67 m/y and -31.37 m/yr respectively (see figure 2.23). The findings also demonstrate that zone B has the highest accretion rate of 94.8 m/yr whereas zones A and C, have rates of 24.55 m/yr and 39.24 m/yr respectively.

Table 3.15: Shoreline change rate derived from the EPR method (2015-2020)

	SHORT-TERM CHANGES (2015-2020) End Point Rate EPR Results from SPOT satellite images												
	Total no. of Transects	**Max. Erosion rate (m/yr)**	**Average erosion (m/yr)**	**No. of erosional transects**	**% Of erosional transects**	**% Of statistically significant erosion**	**Max. Accretion rate (m/yr)**	**Average Accretion (m/yr)**	**No. of accretional transects**	**% Of accretional transects**	**% Of statistically significant**	**Overall average EPR (m/yr)**	**Uncertainty of average rate (m/yr)**
Entire coast	2317	-47.73	-5.36	1304	56.28	51.01	94.8	5.66	1013	43.72	38.45	-0.54	±0.23
Zone A	1-633	-22.67	-1.79	270	42.65	33.18	24.55	2.2	363	57.35	48.03	0.5	±0.4
Zone B	1265-1898	-31.37	-5.65	800	63.24	60.63	94.8	7.25	465	36.76	33.2	-0.91	±0.4
Zone C	1899-2317	-47.73	-8.49	234	55.85	48.93	39.24	8.47	185	44.15	39.86	-1	±0.4

3.3.5.2 Comparison Of The Data Resolution Used For The Short-Term Change Analysis

This research was privileged to have access to high-resolution SPOT data for this work. However, given the financial costs and the scope of the data, this could not always be easily accessible to researchers. In the light of this, it is excellent to employ freely available and accessible data, like Landsat, especially in emerging and data-scarce regions. To assess the suitability of information derived from the Landsat data for the study area, the short-term EPR rates derived from the SPOT imageries (2015-2020) were compared to the short-term LRR rates derived from Landsat imageries (2015-2020) (figure 3.26). This was done to determine how best the results derived from a medium-resolution image explained the coastal dynamics when compared to results derived from high-resolution images such as the SPOT data, which will promote the use of freely accessible data like LANDSAT in data scarce regions like the study area. Despite the limitation of the EPR approach, which invovles only two shorelines, and cannot assess change dynamics over time, Nassar et al. (2018) were able to establish significant affinity between the results EPR, LRR and LMS (least median of squares) result. Based on the findings by Nassar et al. (2018), this study compares the short term analysis of two alternative statistical approaches.

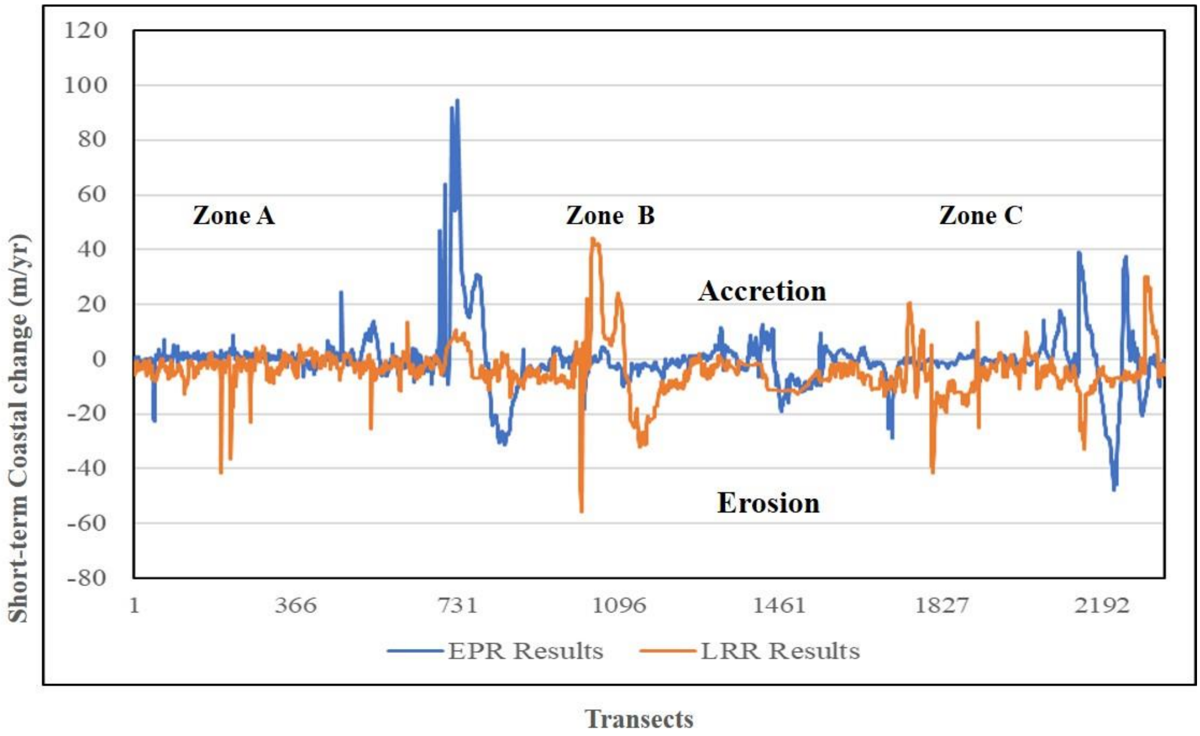


Figure 3.24: Coastal Change rates for the Akwa Ibom coast obtained from End-point rates (SPOT- high-resolution data) and Linear regression rates (Landsat-medium resolution data) for 2015-2020

Figure 3.24 of the data demonstrates similarity in the pattern of change processes (either erosion or accretion), particularly in zone A and parts of zone B, with the exception of areas of high accretion rates around transects 730 and 2192 for the EPR results and transects 1096 and 1827 for the LRR results. A summary of the Landsat (LRR) AND Spot (EPR) results for coastal change rates between 2015-2020 can be seen in table 3.16.

Table 3.16: Summary of the Landsat (LRR) and Spot (EPR) results for coastal change rates between 2015-2020

Variables	Entire shoreline	Zone A	Zone B	Zone C
EPR Maximum Erosion (m/yr)	-47.73	-22.67	-31.37	-47.73
LRR Maximum Erosion (m/yr)	-55.81	-41.41	-55.81	-48.68
EPR Maximum Accretion (m/yr)	94.8	24.55	94.8	39.24
LRR Maximum Accretion (m/yr)	46.07	13.37	44.24	46.07
EPR Average Erosion (m/yr)	-5.36	-1.79	-5.65	-8.49
LRR Average Erosion (m/yr)	-7.03	-3.95	-8.74	-7.22
EPR Average Accretion (m/yr)	5.66	2.2	7.25	8.47
LRR Average Accretion (m/yr)	10.13	2.68	13.16	16.93

Figure 3.25 illustrates a positive correlation between the results derived from the EPR and LRR for 2015-2020 in the three zones along the coast (A, B & C). The R-square (coefficient of determination) for the linear regression model was utilised to demonstrate a linear relationship between the EPR and LRR variables. The percentage or proportion of the overall variance between the obtained LRR rates and the EPR is displayed in figure 3.25. The results reveal a positive correlation between the Landsat (LRR) and Spot (EPR) rates obtained for this section. For zone A, r^2 is 0.88 while the r^2 for zone B is 0.98 and for zone C, the r^2 is 0.86.

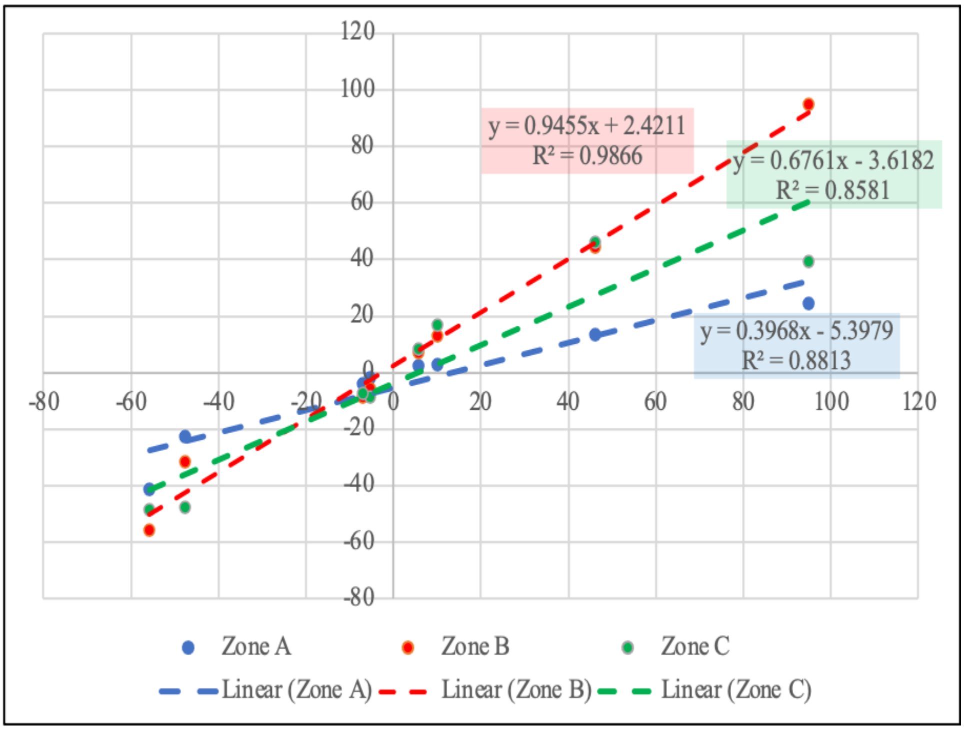


Figure 3.25: The R-square (coefficient of determination) for the linear regression model used to establish a linear relationship between the EPR and LRR variables in the short-term prediction (2015-2020**).**

3.3.6 Shoreline change susceptibility ranking/hot spot analysis of the Akwa Ibom Coast

The susceptibility ranking of the coast to shoreline change and 'hot spot' analysis was carried out using the long-term data (1984-2020) shoreline change rates calculated using DSAS-Linear regression rate method. The results identified areas that are potentially susceptible to coastal erosion.

3.3.6.1 Shoreline Change Susceptibility ranking

The shoreline change result from the linear regression rate (1984-2020), was classified into four susceptibility classes, with 4 being the most susceptible class to shoreline changes and 1 being the least susceptible. The rank classification (see table 3.17) was done based on Murali et al. (2013), where accretion > 2m is classified as very low susceptibility; accretion < 2m as low susceptibility; < 2m erosion as high susceptibility; > 2m erosion as very high susceptibility. The spatial distribution based on the susceptibility of the studycoast to shoreline changes can be seen in figure 3.26.

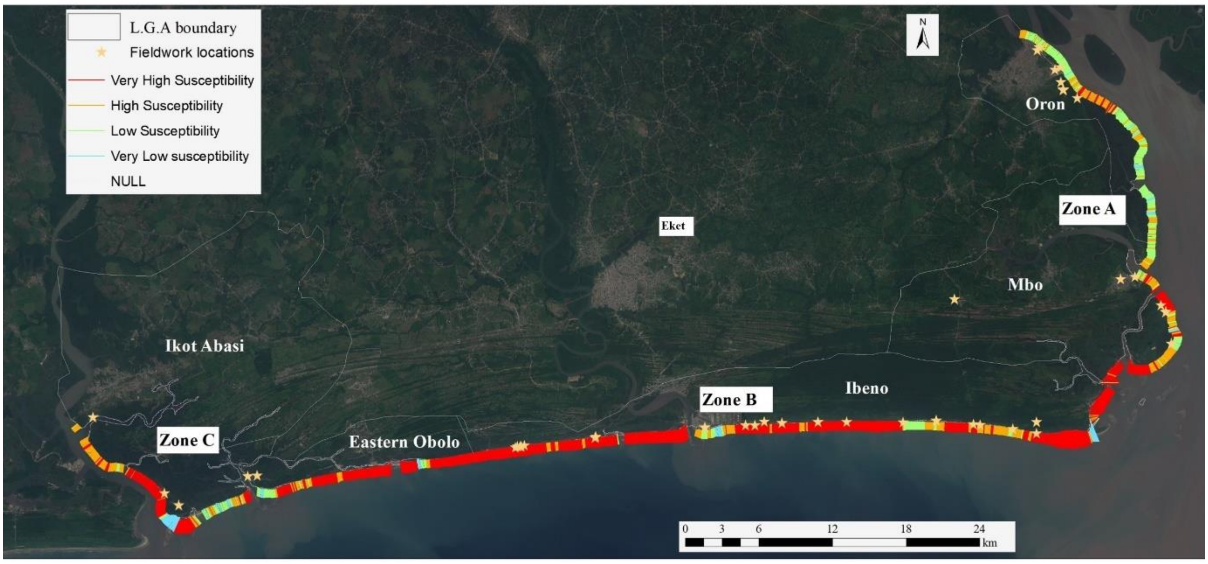


Figure 3.26: Map shows the spatial distribution of the susceptibility of the Akwa Ibom coast to coastal erosion overlain on a Sentinel 2A image (26th December 2019) of the study area.

Table 3.17: Shoreline change susceptibility ranking

Parameter	**Shoreline change Susceptibility ranking**			
	Very low (1)	**Low (2)**	**High (3)**	**Very High (4)**
Shoreline change (m/yr)	Accretion >2	Accretion < 2	Erosion < 2	Erosion > 2
% coverage	4.01	19.81	22.73	53.45
Total	23.82%		76.18%	

Table 3.17 shows that 76.18% of the coast is susceptible to erosion while 23.82% is susceptible to accretion. It suggests that coastal erosion is the most prominent process along the coast between 1984-2020. While erosion is predominant, accretion is also recorded in 23.82% of the coast indicating the land gained in the area for 36years.

3.3.6.2 Erosion and Accretion 'Hot Spot' Assessment

Both hotspots for erosion and accretion were determined using the findings from the LRR statistics in the long-term change (1984-2020) results. Figure 3.27 shows a thirty-six-year coastal change of erosion and accretion that has taken place along the Akwa Ibom coast. It highlights areas of hot spot erosion with 53.45% of the coast having erosion rates $\geq$ 2 m/yr and hot spot of accretion with rates $\geq$ 2 m/yr along 23.82% of the studied coast.

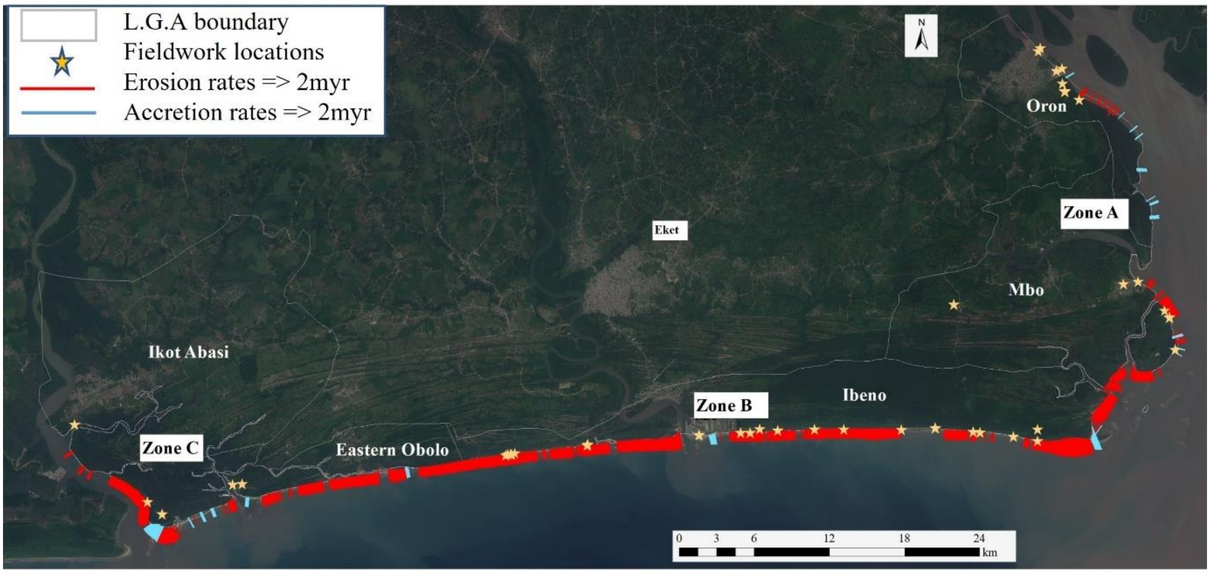


Figure 3.27: Erosion and Accretion map generated from the extracted shorelines (1984-2020) overlain on a Sentinel 2A image (26th December 2019) of the study area.

In this study, the changes along the coast were evaluated using both fieldwork and desktop analysis. A preliminary desktop GIS analysis was conducted to determine the zones with the highest human densities prior to the fieldwork, and four locations were selected that served as a guide for the research area's ground truthing. Since this study follows an interdisciplinary mixed-approach and is concerned with the vulnerability of the people in the study area, the final hot spots chosen to assess vulnerability at a much local scale are locations with the largest human settlements along the coast, significant erosion and locations where adequate social data through participatory GIS (PGIS), focus group discussions (FGD) and interviews were generated. These locations were then utilised as field study locations to generate data using local knowledge and direct field observations (Chapter 4). Chapter 4 is not just an extension of the research but serves as an integral part of this research which encompasses the way/process the research was carried out and is vital to validating the DSAS results analysed in this chapter.

Also, the rate of changes (erosion and accretion) derived in this chapter will serve as input parameters in the vulnerability assessment chapter (chapter 5).

3.3.7 The Akwa Ibom State shoreline prediction

Figure 3.28 shows the future position of the shoreline together with the surrounding polygon which indicates the uncertainty of the forecast shoreline. Additionally, it considers the magnitude of discrepancy between the model and the data for each historical shoreline position as well as measurement noise, process noise, and measurement error (Himmelstoss et al. 2018). Using the beta shoreline forecasting tool in DSAS, it was possible to project future long-term coastal change along the Akwa Ibom coast up until 2040 using the 1984, 2015, 2018, and 2020 shorelines determined in this chapter (see section 3.3.2) using the LRR approach to estimate the long-term coastal change. Furthermore, the LRR approach was most appropriate for this investigation because a shoreline forecast using the DSAS requires three or more shorelines.

Figure 3.28: The final shoreline positions used in the LRR method to predict future long-term coastal change along the Akwa Ibom coast (1984-2040) overlain on a Sentinel 2A image (26th December 2019) of the study area.

The shorelines of 1984 and 2020 were further combined with the projected shorelines for 2030 and 2040, and the rate of future change was then calculated using the LRR (see figure 3.29), EPR, NSM, and SCE procedures in DSAS.

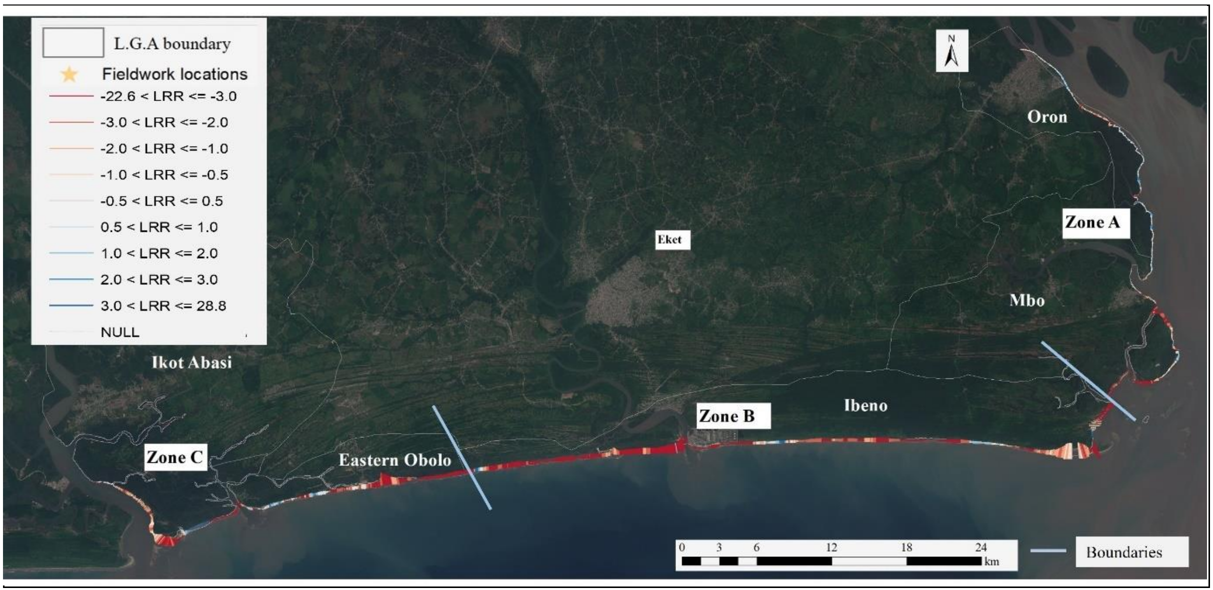


Figure 3.29: Linear regression results for the entire study giving a synopsis of the predicted trend of change along the coast (1984-2040) overlain on a Sentinel 2A image.

A synopsis of the predicted results is seen in figure 3.29 and table 3.18. The results derived from the predicted shorelines are seen in table 3.18. It predicts an average shoreline change movement of 202.62m. The average net shore movement of -153.15m by the year 2040 indicates the average projected distance of land lost during the 56-year duration. The percentage of negative transects which is 75.84% shows that coastal erosion will remain the dominant trend by 2040 with an average erosion of -233.8m.

Table 3.18: Results showing shoreline change envelop (SCE) and Net shore movement (NSM) between 1984 - 2040

Total No. of transects	**Average SCE distance (m)**	**Average NSM distance(m)**	**% Of transects with negative distance (%)**	**Maximum negative distance**	**Average of negative distances**	**% Of transects with positive distance (%)**	**Maximum positive Distance**	**Average of positive distances (m)**
2657	202.62	-153.15	75.84	-1266.58	-233.8	24.16	1613.83	100

Table 3.19 and Figure 3.30 show the expected linear regression rates, which support NSM's forecasts that coastal erosion will continue to be the major trend by 2040 with an overall LRR of -2.73 ± 0.99 m/yr.

Table 3.19: Predicted Shoreline change rates derived from the LRR method (1984-2040)

	PREDICTED SHORELINE CHANGES (1984-2040)												
	LINEAR REGRESSION RATES (LRR)												
	Measured shorelines (1984 &2020) and beta predicted shorelines (2030&2040) from Landsat satellite images												
	Total no. of Transects	Max. Erosion rate (m/yr.)	Average erosion	No. of erosional transects	% of erosional transects	% of statistically significant erosion	Max. Accretion rate (m/yr.)	Average Accretion	No. of accretional	% of accretional transects	% of statistically significant accretion	Overall average LRR	Uncertainty of average rate
LRR results	2657	-22.58	-4.17	2016	75.88	69.63	28.77	1.79	641	24.12	16	-2.73	± 0.99

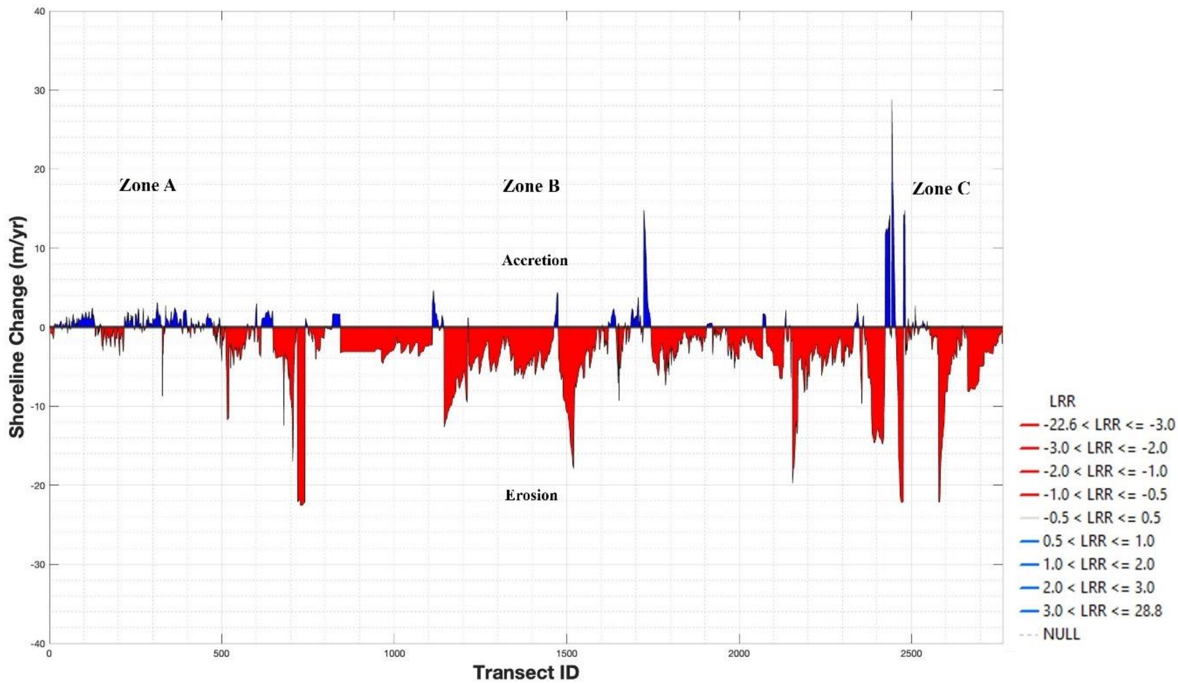


Figure 3.30: LRR erosion/accretion rates generated for predicted coastal change from 1984-2040.

According to the LRR data in Table 3.19, by the year 2040, the coast will experience an average accretion and erosion rates of 1.79 m/yr and - 4.17m/yr respectively. The maximum accretion of 28.77 m/yr and erosion of -22.58 m/yr are also predicted along the coast by the year 2040. Although this study used the LRR method to quantify the future rates of shoreline changes, a prediction using the EPR method which only requires two shorelines (1984 and 2040) was also carried out to assess any possible correlation between the methods and the potential of using either. Even though it was not required for this analysis, the results derived from the EPR method showed that the average erosion rate is - 4.35m/yr; average accretion of 1.78 m/yr; the maximum erosion rate of -28.01 m/yr and maximum accretion of 28.78 m/yr. Both methods revealed similar results except where the maximum erosion for the EPR a higher value had when compared to the LRR (see appendix 3.3 for the EPR results).

3.4 Discussion

3.4.1 What is the trend of the shoreline change analysis in the study area?

A comprehensive evaluation of the coastal changes from 1984 -2020 was carried out along the Akwa Ibom State coast. The shoreline change map for this study is based on results from the DSAS-LRR change statistical approach which was used to evaluate erosional and accretional rates along the Akwa Ibom State coast for thirty-six years from 1984 - 2020.

3.4.1.1 Long-term historical trend analysis along the Akwa Ibom Coast (1984-2020)

The long-term shoreline changes results show locations that are susceptible to both erosion and accretion. This study used DSAS calculations to evaluate erosional and accretional trends across three zones in the study area. The findings are corroborated with field survey observations/information generated in chapter 4 (see chapter 4 for a comprehensive field work analysis and discussion). The division of the study coast into three zones (A, B & C) allows for a more localised interpretation of both accretion and erosion rates, as well as understanding the spatial diversity of shoreline dynamics. These findings reveal that erosion and accretion vary throughout different portions of the shoreline over the course of 36 years.

Zone A: The results demonstrate that while erosion is the dominating trend in zone A, there is a low overall average values with LRR of -0.54$\pm$0.13 m/yr, an average erosion rate of -1.91 m/yr and an average accretion of 0.91 m/yr which could be attributable to a variety of factors that are discussed further on. However, despite the low overall average LRR values, erosion and accretion rates vary by location, with some areas experiencing greater erosion and accretion than others. These variances and low rates could be attributed to the fact that two of the three locations in this zone (Oron L.G.A. and Mbo L.G.A.) have portions of their sections of the coast embanked to decrease the impact of erosion while leaving other areas of the coast exposed and susceptible.These hard-erosion control measures (embankment) are located at Esuk Oro, which is home to the oldest wood carving in Africa as well as other ancestral sculptures (masquerades) and a historical museum that was created in 1958. Other locations include the jetty at the Maritime Academy in Oron, as well as Ibaka in Mbo L.GA. where the sea port is located (see figure 3.31).

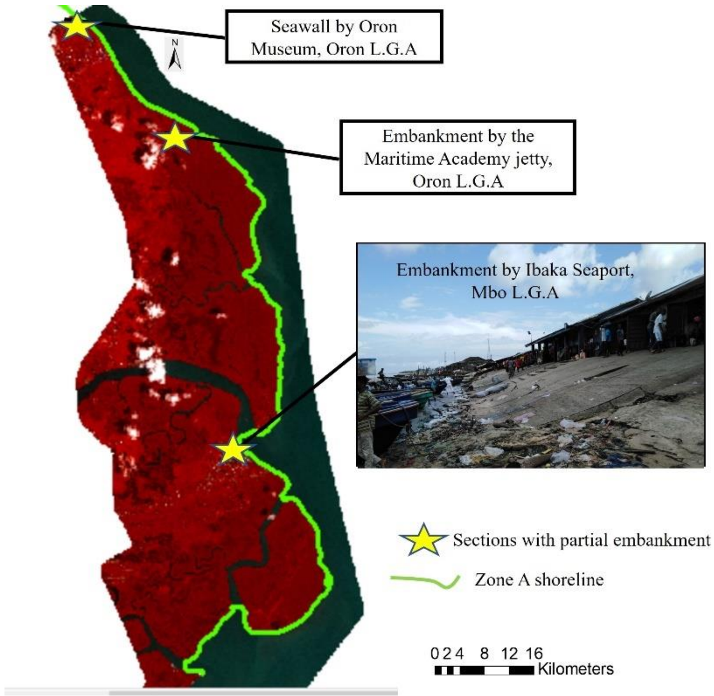


Figure 3.31: Shows sections of zone A at both Oron and Mbo L.G. A with partial embankment (overlain on a SPOT 2020 image) (inserted picture by author)

The area's low susceptibility to erosion and reduced rates of erosion in this zone are probably explained by the embankment of some areas with substantial human activity. According to Rangel-Buitrago et al. (2018), adopting hard erosion controls has garnered substantial attention as one of the best techniques for reducing coastal erosion, but it is not without drawbacks. Pranzini et al. (2015) described one such limitation in the Baltic coast in Russia that was built in the 1800s, where the hard buildings proved problematic many years later and had to be replaced by alternative soft erosion measures that are more effective for coastal protection. Only about 15–20% of zone A is protected by the embankment, leaving other locations along the coast susceptible to flanking or downdrift erosion. In this zone, downdrift erosion has affected several locations, including numerous fish terminals/villages like the Brama community, which is located immediately after the Ibaka community and where the sea port with embankment is situated (see figure 3.31). The impacts of the embankment on coastal erosion in zone A are similar to the findings by Frihy et al. (2013) which demonstrates how different regions of Egypt's Mediterranean coast were affected by coastal erosion. The study's findings revealed that beach erosion has a significant impact on the Nile delta because approximately 60% of its coast is made up of dunes, as opposed to other areas of the coast that are not erosion-controlled because the North-western coast, the Alexandria coast zone is protected with approximately 67% consolidated carbonate ridge and 20% by engineered structures which is similar with the Sinai coast that is protected except for the low-lying regions. A similar study in Eygpt by Darwish et al. (2016) which assessed a morphological 70-year change in the coast between 1945-2015, showed that the Damietta and Rosetta section of the coast are undergoing serious erosion but that the engineered structure along the Alexandria coast has kept the area stable, which is not the case for Damietta, which explains the rapid rate of erosion there. Their data showed a steadily increasing trend in erosion in the region before the sea wall was built, demonstrating that the management structure put in place had slowed erosion and, as a result, the region is now experiencing more accretion.

The same could not be stated for a similar breakwater structure erected in the Lekki district of Nigeria's Barrier Lagoon. In a study by Danladi et al. (2017), sediment loss over 43 years owing to SLR in the Lekki area of the Barrier-Lagoon coast is investigated using remote sensing technologies. The investigation was conducted before and after the construction of a breakwater structure to prevent coastal erosion. This research also looked at the differences in erosional patterns before and after the construction of a breakwater structure. Its findings revealed that between 2010 and 2012, there was an interchanging trend between coastal erosion and accretion, with more erosion taking place in 2011 while in 2012 there was more accretion in the area than erosion. However, in 2013, a breakwater construction was built to prevent erosion, but according to the report, it exacerbated the situation by interrupting the erosion-accretion pattern and producing a progressive erosion pattern. So, between 2013 and 2016, a steady erosion pattern was detected in the area, and by 2016, a section on the Goshen beach estate axis had experienced a significant loss of approximately 66.1m to the ocean. In 2013, this location was measured to have about 77m of land lateral to the shoreline. However, after the breakwater construction was built, roughly 6.1 m was lost to the sea. This buttresses the point by Rangel-Buitrago et al. (2018) that, while hard-coastal defences appear to keep the shoreline static, they are not without limitations, and lean toward the suggestion that countries using hard defence strategies replace them with soft strategies such as ecosystem-based coastal erosion management, which is not only economical but also viable. Despite the benefits of implementing the ecosystem-based erosion management (measures such as restoration of the coast’s natural wetland), Rangel-Buitrago et al. (2018) and Gracia et al. (2018) note that the success of this method is dependent on the availability of sufficient land between the settlement and the shoreline. Successful applications of soft erosion measures such as the ecosystem-based management programme have been extensively discussed by Gracia et al. (2018). Secondly, geology and geomorphology play an integral role in the rates of shoreline changes there. Boateng (2012) emphasised that geology has an effect on the resistance of rocks to erosion, with soft rocks being less resistant than harder rocks. The study noted that this was the case of Keta in Ghana, where the softer geology of the rocks is one of the factors regulating erosion elements, similar to this current research's study coast. The fieldwork undertaken in this study revealed that the locations with relatively high topography in the region had underlain substantial layers of weathered laterites that are exposed at the base (figure 3.32).

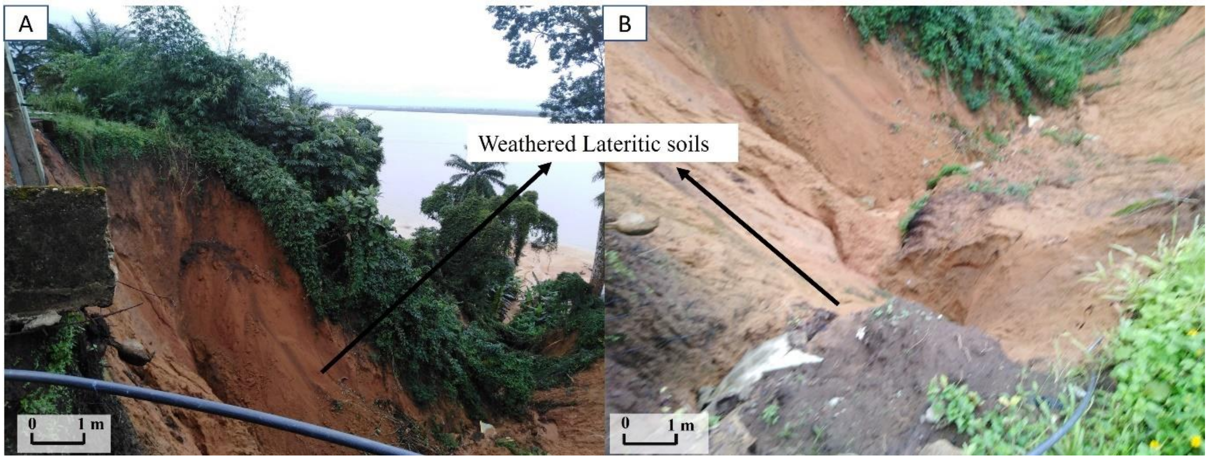


Figure 3.32: Pictures A & B shows the weathered lateritic soil and high topography of Oron L.G.A in Zone A

Compared to the other zones along the study coast, which are low-lying and composed of easily eroded loose coastal plain sands, these weathered laterites, which contain clay, are harder and more erosion-resistant. The erodibility factor was evaluated in the field using the texture feel analysis of soil's stickiness and cohesiveness to understand the resistance of the soil to deformation (FAO 2006). In addition to its geology, the zone has a relatively high topography along with the majority of its shoreline and also the highest topography when compared to the rest of the other zones in the study area.

Zone B: According to the long-term results, zone B is the most dynamic section of the study coast, with an average erosion rate of -5.23 m/yr and average accretion of 3.44 m/yr. This makes coastal erosion the dominant trend in the zone. This erosional trend was also observed during the study's fieldwork. Additionally, the findings are comparable to and agree with those obtained by Ituen et al. (2014) who examined shoreline change in zone B from 1986-2008 and measured erosion and accretion rates of -3.9m/yr and 2m/yr, respectively. The high rates of erosion in this zone derived from DSAS results are most likely due to its proximity to the community and openness to the Atlantic Ocean, which makes the zone highly susceptible to SLR (see figure 3.33). According to Williams et al. (2017), the proximity of the community to the coast is an important factor in the susceptibility to coastal erosion. Williams et al. (2017) highlights some examples of coastal management setbacks regulatory measures present along with several types of coastal area globally and mandate that buildings be at a minimum set distance from the Mean High-Water Mark. They pointed out that there is no fixed minimum distance for coastal areas, but, a variety of distances along different coasts which is dependent on not just the regulatory body overseeing coastal planning in the area but also on the different types of coasts. Williams et al. (2017) illustrated a typical example of having different setbacks along different types of beaches along the same coast. They showed that there was a 30m minimum setback along the Barbados sandy beach but 10 m along the cliff edge. Although this form of management has been implemented by many countries globally, it is not without its limitation. There have been complaints about homes continuing to be flooded in severe weather, which raises the question of the ideal minimum distance to use (Williams et al. 2017). In the study coast for this present study, implementation of developmental setbacks is certainly an issue as there are no minimum setbacks on the distance to the mean high-water mark, which was one of the recommendations made by Ekong (2017) to reduce impacts of coastal erosion.

Figure 3.33: Pictures A & B shows the proximity of the community to the Atlantic Ocean in Ibeno L.G.A (zone B) and the relatively flat topography in that section of the coast.

The community's proximity to the coast and openness to the sea are not the only variables affecting coastal erosion. Fourie et al. (2015) discussed how wave action, the geology and load on the substratum play a significant role in the rate of coastal erosion. Geomorphologically, Zone B is a sandy beach made up of loose sediments which is similar to Monwabisi, Northern shoreline of False Bay, Cape Town, South Africa, which is mostly sandy and easily erodible due to wave action (Fourie et al. 2015) and is characterized by several estuaries making it susceptible to erosion. The DSAS results show that the long-term overall average LRR for zone B is -4.46±0.34 m/yr, indicating that erosion is the predominant trend along this zone. This demonstrates how susceptible the area is to coastal erosion. The overall average LRR result also reveal that this zone is the most susceptible to coastal erosion when compared to other zones along the coast. During the ground truthing exercise, it was observed that this barrier island (zone B) is also the flattest region among the three zones. It is classified as a low elevation coastal zone (LECZ), with elevations of 10m and less, and as such is greatly influenced by the tides, waves, and currents of the sea. Geologically, the study area is underlain by the late Cretaceous to Quaternary sediments (Edet et al. 2014) which is part of the coastal plain sands, beach ridge complex and alluvium. Edet (2017) showed that the alluvial sands are fine to very coarse-grained and light grey coloured floodplain mud and clays.

In **Zone C**, a similar erosional trend, as observed in other zones of the coast, can be seen here with an overall average LRR -2.44±0.99m/yr. The results indicate that erosion is the predominant process in the study area. The results indicate that this zone is the second most dynamic area of the study coast, with an average erosion rate of -3.82 m/yr and average accretion of 3.28 m/yr. Even though there is a significant amount of erosion taking place here, the impact of erosion from direct observation in the field is currently not as high as that of zone B because of the prominent vegetation backstop (see figure 3.34a-d) along a reasonable section of the coast. Additionally, the inherent engineering properties of the mangroves are essential for protecting the coast from erosion (Gracia et al. 2018; Brunier et al. 2019). Brunier et al. (2019) conducted a 38-year-old (1976-2014) study on the shoreline changes in the Guianas coast of South America and concluded that the coast was experiencing higher rates of erosion of up to -200m/yr in rice polders that were previously mangrove. However, the erosion rates were less than -100m/yr before the conversion of these mangrove and backstop marshes to rice polders. Another good example is provided by Winterwerp et al. (2020) of how the presence of mangroves promoted accretion in the Suriname part of the Guyana coast while the ongoing erosion in some locations along the coast has been linked to the deforestation of mangroves. Although the community in this zone C has been relocated behind the vegetation backstop, there are still sections along that coast with settlements directly open to sea (see figure 3.34e-f), making those areas more susceptible to erosion than the areas along rivers channels. This is understandable given that Gracia et al. (2018) highlighted that more constricted channels could reduce the speed of wind and waves passing through it, as well as its impact on the coast. In addition, the vegetation backstop acts as a buffer against wave action and winds. The migration of settlement behind the vegetation backstop in this zone, also contributed to lesser impacts from coastal erosion.

Overall, the results also showed that the rate of erosion is higher in areas exposed to the Atlantic Ocean. It is probably since these areas are subject to constant ocean waves, tidal currents and winds, tsunamis, and SLR, all of which will be exacerbated by climate change. Aside from climate change impacting erosion rates, an important anthropogenic activity observed during the field work that could explain and contribute to the erosion in these areas, are the frequencies and intensities of strong boat waves (a wave pattern created by moving boats/vessels) in the area. Herbert et al. (2018) demonstrated how high-energy boat waves could lead to the loss of shoreline plants like salt marshes and ultimately, erosion. Because the main economic activities in the area include fishing, and commercial and leisure vessels, there is a high volume of waterway transportation and boat wakes along the Akwa Ibom coastal area and is a probable contributor to the erosion along the study coast. According to Bilkovic et al. (2017), there is a link between turbidity, shoreline erosion and boat wakes which was demonstrated in their study along the Chesapeake Bay.

Figure 3.34: A-C shows the vegetative backstop in some areas in zone C while D-F shows settlements directly open to the sea within the same Zone

Given the complexity of the factors that contribute to coastal erosion, an assessment, especially in low-coastal and data-poor environments, requires a more flexible approach that allows for a combination of physical and social knowledge to understand the situation and provide useful management advice. This approach should be encouraged. This proposal supports the IPCC's call for flexibility in coastal erosion mitigation strategies (Oppenheimer et al. 2019).

3.4.2 How rapid are the geomorphological changes along the coast?

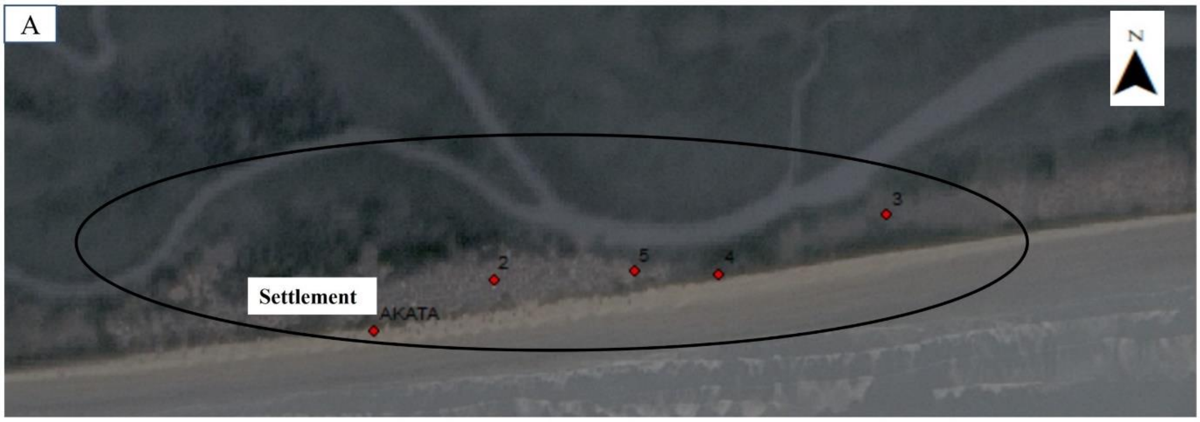
The rapid geomorphological changes along the coast were evaluated using the results derived from the short-term coastal change assessment using Landsat medium-resolution data (2015-2020). The erosional trend revealed from the long-term analysis along the entire coast in section 3.4.1.1, makes it essential to compare and assess how rapid the changes in the coast are taking place. This evaluation will enable a deeper understanding of the shoreline changes which could inform management practices in the area. To examine these rapid changes, a short-term (2015-2020) historical trend analysis was carried out. The average LRR result for the short-term analysis was -3.94±1.28m/yr, which demonstrates that erosion is prevalent along the coast. The magnitude of changes observed within 2015-2020 results suggests high dynamism along the coast within the short-term period of 5-years. The short-term overall average LRR along all three sections of the shoreline showed an erosional trend (refer to table 3.12) along the study coast which also is like the erosional trend observed with results for the long-term analysis. From the overall average LRR, it is revealed that Zone B was the most dynamic segment of the coast with an overall average LRR of -5.89±3 m/yr while zone A was the least dynamic with an overall average LRR of -2.23± 0.75 m/yr which are also consistent with the findings derived from the long-term analysis. The possible reasons for this erosional trend observed from the results have been discussed in section 3.4.1.1. Despite that, this study observed that the recent and rapid shoreline erosion could be attributed to a combination of natural and anthropogenic factors. There were evidence in the field on the impact of the recent and rapid erosional rates exacerbated by anthropogenic activities through the destruction of properties, farmlands and reports of loss of lives by the locals in different sections of the coast. Due to the growing recognition of the importance of indigenous knowledge to scientific research; a good example of integrating both knowledge can be seen in Haikou village in China by Wang et al. (2019) where the study successfully integrated scientific knowledge and indigenous knowledge in community-based research. This study also draws on local knowledge to acquire a better understanding of how rapid the rate of coastal erosion in the area has been (refer to section 2.3.1.1).

3.4.3 What are the temporal and spatial variations along the study area and which data resolutions are best suitable for the study area?

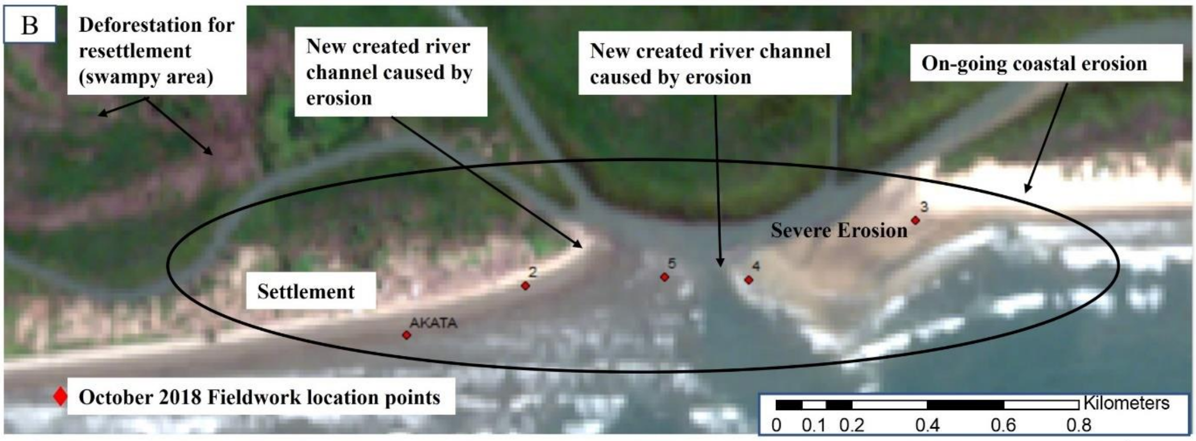
This section examines the temporal impact of shoreline changes and compares long- and short-term coastline changes. Alongside this, the effects of spatial resolution on the results of shoreline changes are analysed using both Landsat (30m) and SPOT (1.5m) data images to highlight the applicability of using free and readily available images such as Landsat despite its medium resolution for coastal monitoring and management purposes in the study coast.

3.4.3.1 Comparative analysis of both the long-term and short-term coastal change

In the study of the coast, both long-term and short-term change analyses were conducted; the long-term shows a more comprehensive overview of the pattern of changes in the area, while the short-term explains any variations of events that have occurred (refer to table 3.13 for a summary of results).The LRR results for the short-term changes derived show higher values of shoreline changes when compared to the long-term changes for all three zones. The average LRR for the short-term (5-year) analysis which was -3.94±1.28m/yr is higher than the average overall LRR of the long-term (36years) result which was -2.7±0.18m/yr. This suggests that the magnitude of changes within 2015-2020 was higher than that of the longer-term indicating high dynamism along the coast within the short-term period of 5-years. It also shows more recent and rapid coastal changes in the short-term results from 2015-2020 (5 years) when compared with the long-term results from 1984-2020 (36 years). These recent rapid changes were confirmed during the fieldwork and post-fieldwork survey (see Figure 3.35). Figure 3.36 shows the Akata-Ibeno section of zone B which is heavily impacted by erosion, flooding and big waves. Pictures a-d for figure 3.36 were taken during the field work on the 5th of October 2018. On the 28th of September 2018, a pre-field reconnaissance mapping was conducted at the Akata community, and the highlighted region in figure 3.36 was a land with settlements on it, gradually eroding as a result of little developing channels linking the river behind the community and the ocean running through it (see figure 3.36b). These rapid rates of erosion can be confirmed in the SPOT satellite images downloaded for the years 2015 and 2020 (before and after the 2018 shows severe coastal erosion in some sections of zone B) (see figure 3.35). The SPOT imageries in figure 3.35 clearly illustrate how rapid coastal erosion is occurring in the location and this confirms findings by Udo-Akuaibit (2017) about the state of erosion in the area and also the global assessments by IPPC on the impacts of climate change in coastal zones, particularly on low coastal elevation zone.



A) Shows the Akata Section of Ibeno L.G.A. (zone B) taken on the 2nd February, 2015 (SPOT image)



B) Shows the Akata Section (same location as picture A) of Ibeno L.G.A. (zone B) taken on the 17th may, 2020 (SPOT image)

Figure 3.35: Pictures A & B compares SPOT image of the Akata area of the Ibeno section (Zone B) of the coast taken in 2015 with a more recent image of 2020

These rapid and adverse impacts of erosion in the Akwa Ibom coastal area could be attributed to the recent climate change status (Williams et al. 2018; IPCC 2019) and the increased presence of anthropogenic activities along the coast such as mangrove/vegetation removal and land exploitation for settlements/tourism (Rangel-Buitrago et al. 2018) which was observed during field work. It can be observed in figure 3.35b that the community is already undertaking the removal of vegetation (deforestation) right behind the river channel to accommodate housing needs.

Unfortunately, if no intervention in the anthropogenic activities along the coast is implemented and based on the erosion rates derived from the short-term analysis and under the present climate change condition together with increasing human activities, it will only be a matter of years that the ocean will merge with the river and catch up with the settlements. A similar situation is reported of the Sohar region in Oman by Abushandi et al. (2020) that carried out a five-month shoreline erosion assessment from 19th June - 16th November. The results revealed severe erosion rates of -5.2m/yr in some areas within that short time frame. Although long-term erosion assessments give detailed information about the geomorphic history of the coast, the short-term analysis should be essential and considered to understand the present situation of the coastal dynamics which will be very useful for coastal management/policies.

Pictures A-D are pictures of the most recent eroded section in Akata, Ibeno in Zone B taken the 5th of October, 2018 by the researcher during field work

Pictures E-H are pictures of the same eroded section of Akata, Ibeno in Zone B taken via Drone on the 27th May, 2019 by the research fieldwork assistant

☆ Shows the same section on the coast on all pictures

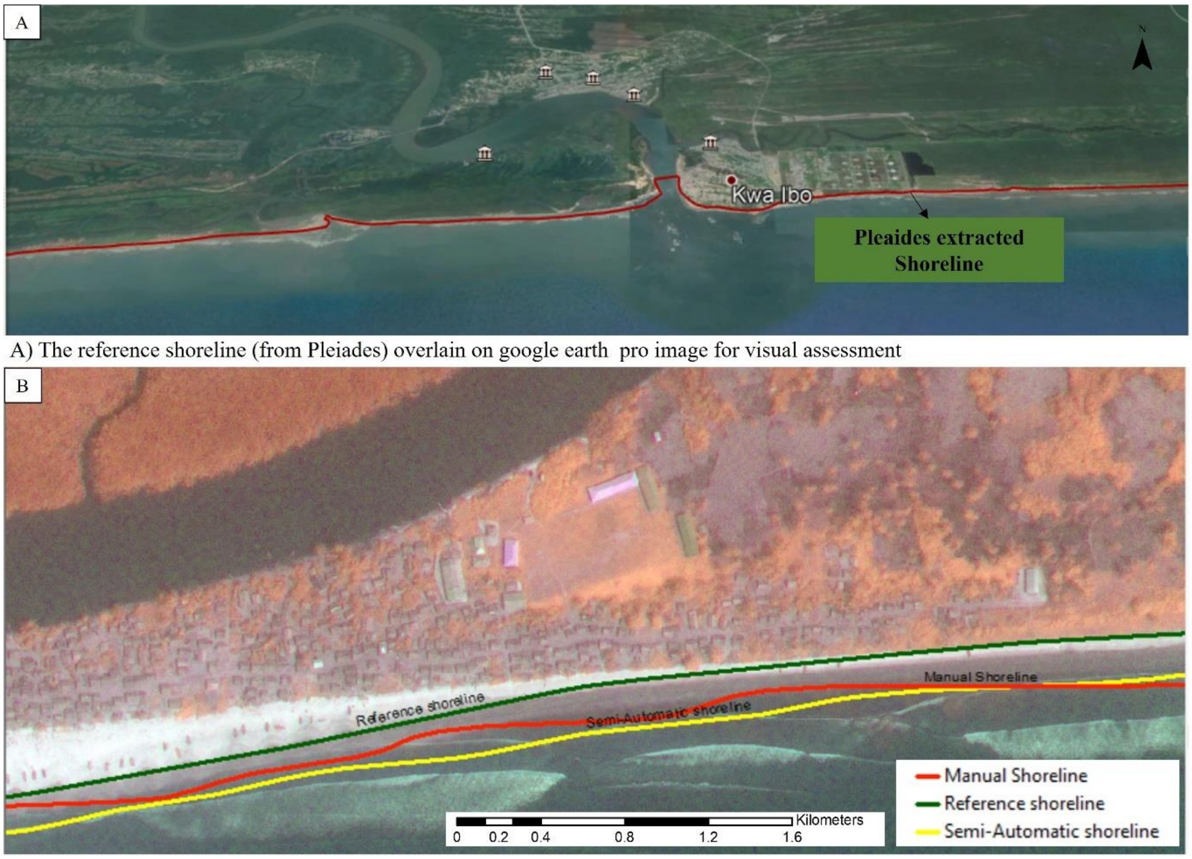
Figure 3.36: A-D Shows the eroded section Akata section of zone B and E-H shows how rapidly the section has been further eroded and widened within eight months.

3.4.3.2 Comparing Short-term coastal change assessment using Landsat medium-resolution data and short-term coastal change assessment using SPOT high-resolution data

When high-resolution data is available, it is advantageous to use it for coastal evaluation because it can extract features that are difficult to see in medium- to coarse-resolution data with greater precision (Ozturk et al. 2015; Nandi et al. 2016). However, the fact that they are expensive and limited in both temporal and spatial coverage, makes medium-resolution data a widely considered choice, particularly in developing countries such as Nigeria.

For the study area, SPOT image data was used to assess the short-term coastal change which will enable a broader understanding of the study area at a resolution higher than that of the Landsat imagery. A summary of the results is presented in figure 3.22. Due to the lack of availability of images for the entire coast, the research considered only two shorelines representing 2015 and 2020. Even though the SPOT data did not cover the entire study coast (excluded part of zone C), it proved to be a very useful resource for the hot-spot analysis which will provide a more detailed assessment of the shoreline changes at a more local scale. Due to the fact that only two shorelines were available, the DSAS- end point rate (EPR) method that utilises only 2 shorelines in calculating change rates was used. The EPR results confirms that between 2015 and 2020, there has been an erosional trend in the area with an overall average rate of -0.54±0.23 m/yr which was much lower than the results derived from the short-term analysis using Landsat data (-3.94±1.28m/yr). The results further reveal that the highest average rate of erosion (-8.49 m/yr) and accretion rate (8.47 m/yr) occurred in zone C, contrary to the findings from the short-term analysis using Landsat data, which identified zone B as the most dynamic zone along the coast. However, there was a similarity in both results derived for zone A. Both methods revealed that zone A was the least dynamic zone. The short-term results from the SPOT data also showed an average erosion rate of -1.79 m/yr while accretion was 2.2 m/yr.

The difference in results could be attributed to the different image resolutions and spatial extent of the data used for the analysis. Ozturk et al. (2015) noted that one of the problems relating to the use of Landsat data for assessment, is that of mixed pixels which results from the medium resolution of the image. The higher resolution images enable a more accurate distinction of pixels contributing to an overall accuracy of the shoreline delineation and extraction. This is demonstrated in the accuracy assessment done for this study where the reference shoreline digitised from a Pleiades image with 0.5m resolution showed a perfect fit on the google earth shoreline (see figure 3.37)



A) The reference shoreline (from Pleiades) overlain on google earth pro image for visual assessment

B) The reference shoreline merged with the shorelines derived from both manually and semi-automatically from Landsat 2015 overlain on a Pleiades 2015 image

Figure 3.37: Accuracy of shoreline delineation using a higher resolution image (Pleiades 2015)

Also, different DSAS statistical methods were applied here (EPR and LRR) due to available shoreline parameters. For the Landsat, an LRR was calculated using three shorelines which was not the case for the SPOT data where an EPR was calculated using only two available shorelines. The advantages and disadvantages of using these approaches are detailed in Hashmi et al. (2018). Lastly, a different number of shorelines and transects were used for both approaches. The fact that the SPOT data shorelines did not cover the entire extent of the shoreline in Zone C like the short-term results derived from the Landsat shorelines, will account for the variances in the shoreline change patterns. However, when the r-square (coefficient of determination) for the linear regression (see figure 3.25) was applied to the intersecting/corresponding sections of the coast on both results, the r^2 revealed a positive correlation between the two rates obtained. For zone A, r^2 is 0.88 while the r^2 for zone B is 0.98 and for zone C, the r^2 is 0.86 which suggests that the results derived from the Landsat data, provided adequate shoreline positional accuracy for assessing the coastal changes along the Akwa Ibom coast.

3.4.4 Where are the most susceptible areas of the Akwa Ibom shoreline in the Niger Delta to the impacts of coastal erosion?

The results from section 3.3.6.1 show that the study area is highly susceptible to shoreline changes along the entire coast. Although there is an erosional trend along all zones of the study coast, the LRR results show that zone B is the most susceptible section of the coast to coastal erosion with an overall average LRR of -4.46±0.34 m/yr and -5.89 ±3 m/yr recorded for both the long-term and short-term results respectively. The results also show that zone A is the least susceptible to coastal erosion (refer to table 3.13). Apart from high rates of accretion around the ExxonMobil terminal due to sand filling and engineering structures in place, the gravity of coastal erosion in other sections of zone B has been described by Ituen et al. (2014) as disturbing and requiring crucial attention. Aside the high rates of erosion recorded in zone B, the Eastern Obolo L.G.A section of zone C also shows high rates of coastal erosion. These high rates of coastal erosion in zone B and C can be attributed to the fact that Ibeno L.G.A in zone B and Eastern Obolo L.G.A section of zone C which show high rates of erosion >2m/yr are directly open to the Atlantic Ocean (figures 3.36 and 3.34 respectively). Additionally, the lower elevations in these zones contribute to the increased coastal erosion (Udoudo et al. 2018) and also the impacts. The severity of the impacts, however, lies in the management factors in place, if any, like in the successful case of Norfolk Virginia adaptation and mitigation programme. Although Norfolk Virginia is a low-lying coastal city with serious coastal hazards due to rising local sea levels, the impacts from these hazards have been mitigated by the implementation of natural and nature-based coastal defences such as restoration of the coastal habitats like that wetlands, coral and oyster reefs (Fleming et al. 2018). The severity of coastal erosion in zones B and C are discussed in sections 3.4.1.1 and 3.4.2.1. Due to the fact that the highest susceptibility to coastal erosion is found in Zone B, a case study from a location in this zone will be examined and discussed in chapter 5.

3.4.5 What future coastal changes will likely occur, using historical rates of change in the area applying the DSAS-Beta forecasting methodology?

It is, however, important to understand that the temporal scale in coastal erosion assessment is an essential factor when forecasting/future prediction is the aim of that investigation. As earlier described in 3.2.6, forecasting is best done with long-term data because short-term fluctuations are based on several sources which could be noise from recent activity. The long-term LRR was used to attempt to calculate the position of the future shorelines for 10 years and 20 years based on historical shoreline positions for 1984, 2015, 2018 and 2020. Future shorelines change quantification was done using the LRR method where the predicted shoreline positions for the years 2030 and 2040 were incorporated with historical/measured shoreline positions of the years 1984 and 2020, with 1984 being the oldest and 2040 the recent shorelines used in this study (see figure 3.29).

The future shoreline changes results predict an average erosion rate for the LRR of -4.17 m/yr, a relatively low average rate accretion of 1.79 m/yr, maximum erosion of -22.58 m/yr and maximum accretion of 28.77 m/yr in the study area by 2040. The results for the 56-year long-term prediction (1984-2040) were similar to that of the long-term prediction for 1984-2020. The anticipated shoreline changes from 1984-2040 have an overall average LRR of -2.73± 0.99 m/yr which is similar to the overall average LRR results derived from 1984-2020 (-2.7±0.18m/yr). This suggests that the predicted shoreline rates model a similar pattern like actual shorelines used for the prediction. It is important to note here that other erosion contributing factors (e.g human activities, sea-level rise, geology, wave height) were not considered in this forecast analysis. This means that the future change rates are simply based on the historical measured rates, and therefore, incorporates the same uncertainties as the historic shorelines and does not account for any other factors that may influence future positions (Himmelstoss et al. 2018). The limitation in using this method is that it simply models the future shoreline position using the historical shorelines, meaning that if the initial LRR results showed accretion as the dominant trend, the future trend will most likely be accretion too. Himmelstoss et al. (2018) highlighted these uncertainties and Oyedotun (2014) noted that the accuracy of the results is contingent on the accuracy of the input data meaning that the uncertainty attached to the input data affects the results of the coastal change analysis and should be adequately accounted for.

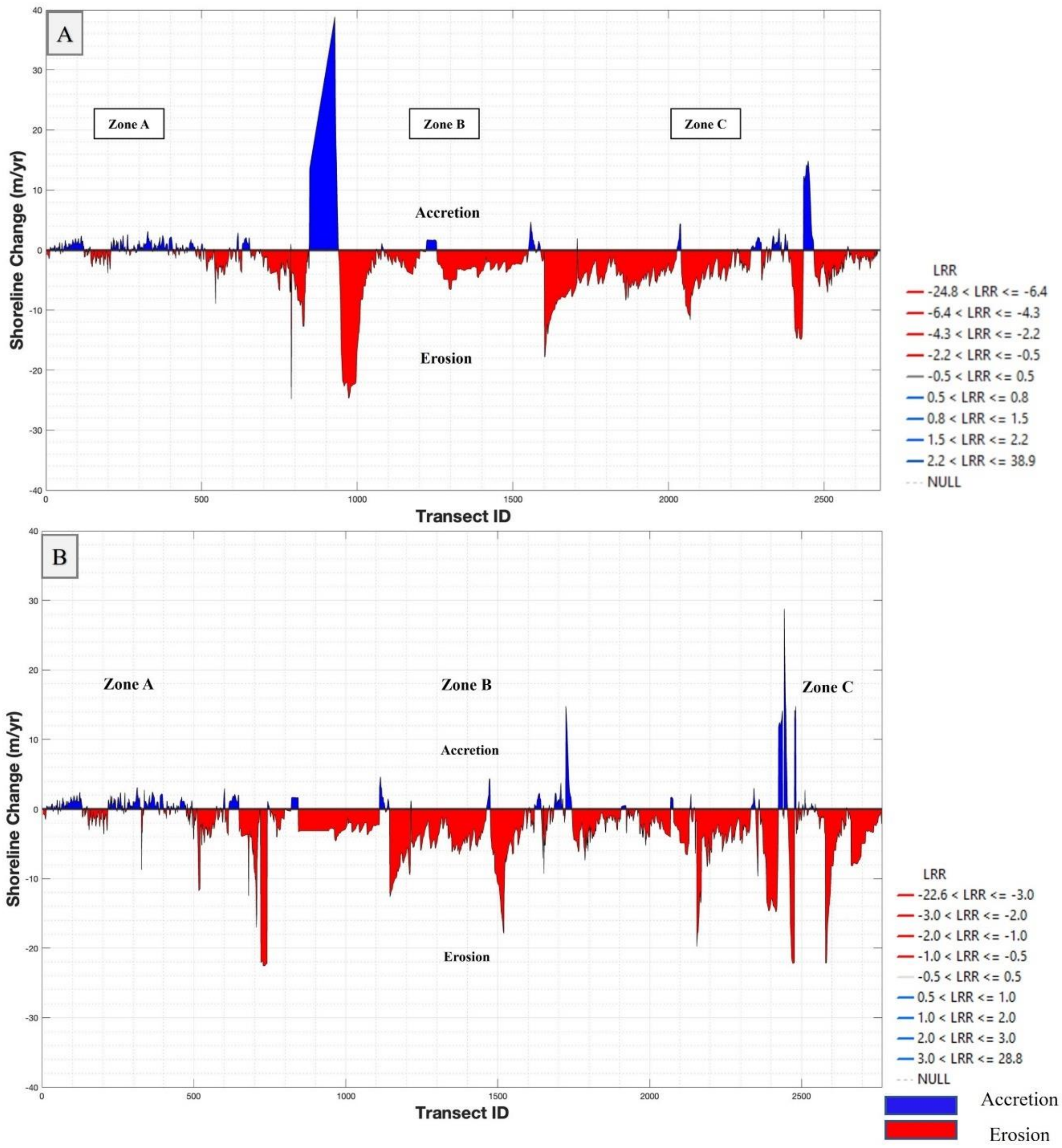


Figure 3.38A-B: Comparison of the long-term shoreline changes (1984-2020) (figure A) using measured shorelines with long-term predicted changes (1984-2040) (figure B)

Despite these limitations, a future erosional trend is predicted along the Akwa Ibom coast by 2040. Although the results provide future trend which gives a picture of what is expected in the future and could be very useful for policy makers by informing management practices, it should be used with caution. These uncertainties explain why many coastal erosion studies exclude future erosion rates and locations from their assessment. Climate prediction centres like National Oceanic and Atmospheric Administration, NOAA, have explained why predictions for hazards such as a hurricane that are contingent on climatic conditions are not made; because such hazards are largely influenced by climatic conditions with probabilistic future predictions (NOAA 2021) and human interference (Fitton et al. 2016) occurring at the time of the hazard. Since these factors are unpredictable, it is challenging to predict the hazard rates or time of occurrence.

An attempt to quantify future erosion rates is seen in a study by Abushandi et al. (2020) along the Sohar region of the Oman coast. Here, they used shoreline erosion rates derived from field measurements coupled with Multiple Linear Regressions Models (MLR) for 5 months to predict future changes for the next 30 months. Although they were able to show future rates of erosion up to an average of -5.2 m/yr in some locations, it is important to note that other shoreline change forcing factors were not also included and can give a misrepresentation of the exact rates of erosion in the future. The future rates of shoreline change predicted by this current study likewise show this shortcoming. Nonetheless, the observations made from future rates calculated using the beta forecasting tool, while not practical in predicting future erosion rates due to its exclusion of other factors that contribute to shoreline changes, are useful for indicating anticipated shoreline change locations and can be useful to policymakers for management purposes in identifying areas susceptible to shoreline changes.

3.5 Summary

In summary, this chapter attempted to answer the research questions in table 3.1. The study coast has an erosional trend along the three zones investigated. The results obtained for the long-term (1984-2020) and short-term (2015-2020) shoreline change analysis show that coastal erosion is predominant in the study area and a major issue in the research area. The average LRR for the long-term (36years) derived was -2.7±0.18m/yr while that of the short-term (5 years) was -3.94±1.28 m/yr which demonstrated the predominance of erosion in the study coast. The erosional trend was observed and confirmed during the study's field work (September-October 2018). The long-term and short-term findings demonstrated that zone B is the most dynamic and susceptible zone to erosion along the coast with the highest average rate of erosion and accretion values of -5.23 m/yr and 3.44 m/yr respectively for the long-term assessment and average erosion of -8.74 m/yr and accretion of 16.93 m/yr for the short-term assessment. The high rates of erosion in zone B indicates how highly susceptible the area is to coastal erosion and with such rates, this study recommends urgent attention and management along zone B. The other sections of the coast, Zones A and C also exhibit erosional trends which also reveal a high susceptibility to coastal erosion also requiring attention. Despite the rapid geomorphological changes along the Akwa Ibom State shoreline and its relative impacts such as coastal erosion, there are still limited studies about coastal erosion in the area. This makes this study very essential to understanding the shoreline changes in the entire coast and the susceptibility of the coast to erosion.

Historic shorelines change analysis is necessary for any future shoreline prediction. Although future shoreline prediction seems difficult (Nandi et al. 2016) and most especially due to the non-availability of data, the method used in this study indicates the future trend of shoreline changes that could be useful for coastal management. The future predicted shoreline findings of an overall average LRR of -2.73± 0.99 m/yr, shows that coastal erosion is expected to be the pre-dominant trend along the coast by 2040. These future results are associated with uncertainties derived from the input data shorelines and exclusion of other erosion forcing parameters. As such, the future prediction results should be used or considered with caution. However, the information derived here is critical and could be incorporated into decision-making/mitigation parameters, especially with the influx of human population to the coastal areas, coupled with increased climate change impacts. According to the global climate change report of 2020 by the World Meteorological Organization (WMO 2021), there is a continuous acceleration in the major climate change indicators with an increase in major greenhouse gases (CO_2, CH_4 and N_2O) with averaged mole fractions of carbon dioxide (CO_2) already exceeding 410 parts per million (ppm). It further explains that if the CO_2 concentration continues to follow this trend, it may not only reach but exceed 414 ppm in 2021, causing accelerating sea-level rise and a rise in temperature, with the year 2020 being recorded as one of the third warmest years to date, with a global mean temperature of 1.2 ± 0.1 °C above the 1850–1900 baseline (WMO 2021). It furthermore noted that the year 2020 saw a major climatic disruption that was made worse by human-caused climate change, which has had a serious impact, especially in impoverished countries (WMO 2021). Based on these continued accelerations in recent reports, it can be certain that the shoreline changes rates and the current impacts in the Akwa Ibom coast should be expected to be more severe with an increased vulnerability in the future than the present because the study area is a low elevation coastal zone (LECZ) and also in a developing nation with limited management and mitigation measures.

Overall, this chapter has demonstrated the dynamism and susceptibility of the study coast to shoreline changes and the result demonstrates that coastal erosion is the dominant trend along the coast. Having established the presence of coastal erosion along the study coast, the next chapter (chapter 4) will consider the underlying social drivers and impacts of the observed shoreline changes from a social standpoint.

Chapter 4: Socio-ecological assessment of coastal hazards: a culturally responsive approach to understanding the local perceptions and impacts of coastal erosion in Akwa-Ibom State.

Chapter four focuses on the data generation and analysis of socio-ecological data using qualitative methods including questionnaires, interviews, and focus groups to assess the local risk perception of coastal erosion, adaptive capacity, and threat/hazard mitigation. It analyses the complex relationship in a socio-ecological system/community with individual-level variations in perceived and physical vulnerability to coastal hazards.

Chapter 4

4.1 Introduction

As discussed in chapter one, there are many factors, including physical, social, ecological and economic factors that, influence coastal dynamics and societal risks associated with coastal erosion hazards. Coastal erosion hazard is a major global environmental and ecological problem (Petrakis et al. 2014). Over the years, this problem has intensified due to the high migration of populations to coastal zones (Ginesu et al. 2016), and due to the high diversity of economic and recreational resources that attract human migration to these areas. The interaction of social and natural systems plays an important role in the vulnerability of the coastal zone. Understanding how this relationship contributes to the vulnerability of the coast is essential for the sustainability of the environment (Berkes et al. 2003). Hence, there is a crucial need to apply holistic approaches to assessing this complex relationship in a coupled socio-ecological system. The coupled socio-ecological system simply refers to the connection between human activities and the environment in which they live and explains how anthropogenic (human) activities have influenced, shaped and re-shaped the landscape or form of the environment. Kelly et al. (2013) expressed that designing research models that lead to real change can be challenging because they need to be informed by a holistic understanding of the coupled socio-geomorphological system processes comprising of different components, their complex relationship and how they respond to environmental changes.

Coastal erosion vulnerability and adaptation options are the subjects of extensive study globally, where there are notable geographic and social vulnerability information gaps (i.e. data-scarce regions; see chapter 2.3 for a comprehensive review). This chapter focuses on how stakeholders' participation and local knowledge in coastal erosion can underpin a combined physical and social vulnerability assessment. This chapter involves local knowledge to inform the development of a PGIS process in which the local communities actively participate in the gathering, processing, and interpretation of spatial data and a layer of data applied to the overall coastal erosion assessment.

4.2 Aim

This section of the research aims to produce a comprehensive assessment of coastal erosion from the perspective of the communities in Akwa Ibom State and using local knowledge

(PGIS). Qualitative methods are used to gather and analyse local knowledge to develop community-based coastal analysis. Results from this assessment are subsequently used in chapter 6 to provide a social (PGIS) data layer in the physical vulnerability model. This combined approach allows more locally suited and nuanced awareness-raising and adaptation strategies to improve community resilience to coastal erosion hazards. Furthermore, the globally overlooked dimension in coastal erosion vulnerability assessments – social knowledge and understanding of coastal erosion risks – will improve understanding of local and indigenous knowledge and perception on the erosion situation in the coast and their vulnerability, which could be incorporated in decision making and mitigation measures.

4.2.1 Objectives

- To assess the spatial variability of the socio-ecological drivers and impacts of coastal erosion along the Akwa Ibom State coast.

- To examine the coping mechanisms prevalent along the Akwa Ibom State coastal areas to develop informed recommendations on possible adaptation strategies to enhance community resilience to coastal erosion impacts.

- To collate the key findings from this analysis to inform the development of a PGIS layer in Chapter 6 (The perception analysis will provide data input to the combined physical and social coastal vulnerability index analysis of the hotspots in chapter 6).

4.2.2 Research questions

Successfully addressing each of these objectives will help answer the following research questions:

- What is the local knowledge on coastal erosion?
- How have the prevalent socio-ecological interactions along the coast changed over time and what is the impact on the vulnerability of the area to coastal erosion?
- How has the risk perception in the area influenced the emerging socioecological patterns/processes in the area?
- How well do the coping mechanisms currently used for adaptation affect the impact of coastal erosion?

4.3 Data and Methods

An overview of the workflow for this chapter is presented in figure 4.1 and outlines the different components of practice undertaken to assess indigenous knowledge, local perception, and adaptive capacity to coastal erosion.

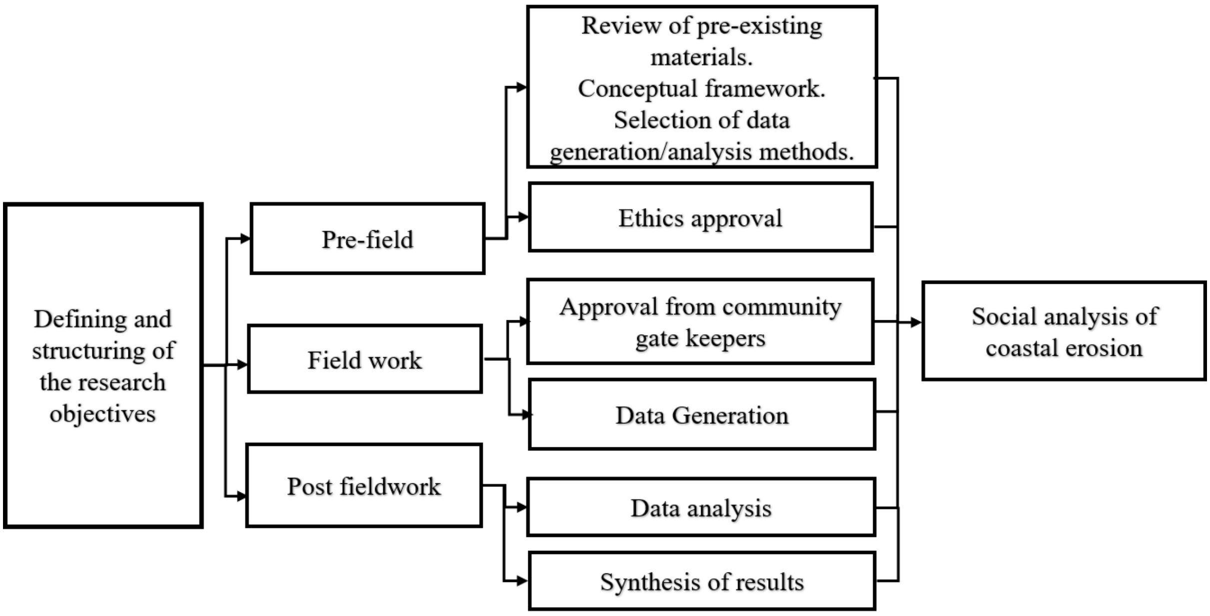


Figure 4.1: Workflow implemented for this research

4.3.1 Conceptual Framework

Before embarking on the fieldwork, I researched into several theoretical frameworks used in coupled human-environment research contexts that would guide the data collection and analytical process. Unsurprisingly, I had aligned with the deductive, positivist ideology of objectivity (Johnson et al. 2004). These ideologies at the time seemed ideal because of the promise of objective results that could be generalised to represent a large population. However, an interpretive philosophy hinges on the subjectivism of the real world which has ultimately led me to a deeper understanding of the subject of discussion (Gicheru 2013).

As I progressed with my literature review, exploring social research, I recognised how human migration to the coast has tremendously impacted the natural processes and increased the vulnerability of the coastal areas to coastal hazards. This knowledge motivated the research into understanding local perceptions along the coastal region towards coastal erosion. I needed an approach that would allow me to have an in-depth understanding of the social world which is limited if using only quantitative methods for assessment. Villares et al. (2006) discuss how traditional management methods based on physical approaches and engineered structures are limited in properly assessing and creating sustainable management of an area and should integrate other factors that play a role in coastal erosion like social and cultural factors in the overall process.

This marked the beginning of my journey into a mixed-method approach. These approaches best provide an understanding of an investigation without quantifying and are most useful when a complex system is under investigation and participants' perception is needed to give a better perspective on the phenomenon (Tavallaei et al. 2010). Amaratunga et al. (2002) noted that the information derived from this approach gives an expression of reality. The expression of reality is derived from the fact that it uses intensive procedures to collect the data, analysing it from individual data to emergent themes (Creswell 2014) which gives more understanding of a complex reality (Queirós et al. 2017).

A holistic approach to assessing environmental issues should involve the key players in the environment because their responsive action is a result of their relationship with the environment. Ittelson (1978) noted that people are an essential part of the environment and should be treated as an integral unit when studying it. My understanding here is that, if studying and incorporating behavioural approaches is neglected, the research will lose a valuable data resource that can give insights into the 'how' and 'why' of human behaviour which would give an appreciable understanding of how to interpret and assign meaning on attachment to place and landscape (Walmsley et al. 1993). This has a strong connection with the African philosophy of Ubuntu which suggests that knowledge is a product of the environment, relationships and experiences of one's reality (Maluleka 2019). Exploring how these relationships shape a person's or community's view on a matter is essential to understanding the community's ability to have a common objective and work collectively in mitigating the impacts of environmental hazards.

Studies suggest that recent trends in this approach have combined scientific analysis of human behaviour across various locations and attachment to place (Walmsley et al. 1993). This trend is frowned upon by humanists who are critical of scientific methods which aim at the quantification of variables and as such, overlook important issues concerned with values and beliefs which Queirós et al. (2017) describe as experiences that cannot be easily quantified; whereas positivism advocates a combined process and argues that using scientific approaches in assessing human behaviour provides connections between the physical form and behavioural process. This made me challenge myself to critically assess which processes would give me the passage into understanding the perceptions that govern the relationships in the socio-environmental system.

Participatory research (PR) incorporates local knowledge where the people studied are active participants in the whole process. It bridges the gap between the researcher and the participants by equal involvement in the research project with prominence on sharing the discoveries with both the participants and the public (Vaughn et al. 2020). A typical example of this research is participatory action research. Neuman (2014) explains that participatory action research (PAR) allows participants to work together with the researcher from the point of design to conducting the research. This process leaves the participants more informed of the situation under investigation and empowered in the solution process.

The PR paradigm is perfectly suited for this study since the participation of the stakeholders in the coastal area is a key element to this work. If sustainability must be attained, Turner et al. (2016) emphasises that a new paradigm that combines responsiveness to social needs and social-environmental systems (SE), also known as socio-ecological systems (SES), is necessary. Lewison et al. (2016) reveal a useful framework to understand the interaction between the societal and the environmental systems, the Driver-Pressure-State-Impact-Response (DPSIR). This framework organises data generated according to the various overlapping components of the model which I explore further.

The DPSIR model gives an immediate synopsis of the indicators that can be used for an environmental assessment, especially on a short-term basis. For instance, it begins with identifying the *driving forces* (the causal agents) and then shows a connection representing how these driving forces put *pressure* on the environment which is responsible for the current *state* of environmental change which causes negative *impacts*, and finally how these impacts have been managed, known as the *responses*. This kind of chain process supports my understanding that the state of the environment is not only dependent on the natural or the physical processes at work but that it is a collective and as such, the different components should be investigated together. However, it does not necessarily capture the connections of the indicators under each component which could be the underlying issue needed for a paradigm change in understanding relationships between humans and their physical environments. In addition, how well can one understand the social system when studied objectively? That is why the participatory action approach sits well for the scope of this research.

Due to the complexity of human-environmental systems, I use four disciplinary lenses to provide the theoretical framework for my research. The context in which this research is situated, are among the following: the participatory research; culturally responsive methodologies; socio-ecological systems; and the DPSIR. Since this research spans multiple fields with various definitions, the terms socio-geomorphological systems, social-ecological systems, socio-environmental systems and socio-ecological systems are terms used to refer to the human-environmental/natural systems, and these will be used interchangeably in this work. This is because there is no stated differentiation for this research and because their definitions are founded on interactions between humans and nature.

4.3.1.1 Participatory Research (PR)

The participatory research perspective encourages the participation of the community members and stakeholders in the research process to co-create relevant knowledge. In other words, PR takes place together with the people as opposed to *on* the people which non-participatory models can often do. In this research paradigm, the participants' feelings and opinions on the research phenomenon are uncovered without any form of intended manipulation and influence from the researcher (MacDonald 2012). Fundamentally, participatory research encourages partnership between the researcher and the stakeholders (Jagosh et al. 2012). The purpose of PR is democratic and is primarily directed towards social change, empowerment and sustainability (Jagosh et al. 2012; Smajgl et al. 2015; Vaughn et al. 2020). This research approach stands out from other forms of research largely due to the ownership it provides the research participants who seek to improve their circumstances and effect social change with the results and outcomes (Amaya et al. 2014).

PR has a noted presence in environmental science as available literature indicates that resident participation increases the chances of identifying environmental risks and addressing them. As Calheiros et al. (2000) demonstrate, the incorporation of local knowledge to a scientific inquiry should be encouraged as it gives in-depth understanding of the environment, management and conservation practices. Such importance, has led researchers working with the residents in environmental hazards zone through PR to seek local knowledge to understanding the problem, finding a solution and preventing similar challenges in the future. Environmental education, at its core, seeks to develop general ecological and environmental knowledge enough to facilitate the utilization of sustainable actions (Bywater 2014); and as earlier stated, a primary goal of PR is to encourage understanding which will lead to action and potentially, social change – this includes the adoption of sustainable practices. Adoption of this research paradigm has far-reaching benefits; for instance, new knowledge and action plans help address the increased vulnerability residents incur as a result of insufficient access to environmentally conscious services and inadequate infrastructure (Meyer et al. 2018). Due to the active encouragement of participation, participatory research aligns with the interpretivism research philosophy which encourages subjective interpretation of data, in opposition to positivism which encourages objectivism and non-interference (Gicheru 2013).

4.3.1.2 Socio-Ecological systems (SES)

The interrelation of humans and the natural environment can be described in terms of socio-ecological systems. According to Refulio-Coronado et al. (2021), SES offers an interdisciplinary perspective in understanding complex environmental problems like the coastal environment. This is not without its challenges. Berkes et al. (2003) discussed the challenges in understanding this system through disciplinary approaches due to the complexity of the natural environment and social systems even when considered as individual units. Hence, the emergence of the socio-ecological system theory which incorporates these complexities in its model. Social-ecological systems, as described by Redman et al. (2004), are a system where a combination of the social and ecological system controls its resource flow. Importantly, Redman et al. (2004) noted that epistemologically, the SES address and gives tools for the organisation of findings and acquired knowledge, and are well suited for comparative analysis. Not only that, but they also noted that linkages in the framework show interactions between a wide range of social-ecological components including land use, landcover changes, land surface changes and biodiversity.

This framework is different from others that integrate the social and environmental systems like the integrated assessment of ecosystem services (IAES) (Müller et al. 2020), and the Human ecosystem framework (HEF) (Machlis et al. 1997) whose emphasis is on policies and decision-makers. Machlis et al. (1997) suggested that the social system mainly regulates the flow and use of resources. Hence, changes in that system will also affect the social ecosystem. As indicated by Lopez et al. (2019), the way risk is perceived plays an essential role in how the social system interacts with the environment through its use and management which, in turn, impacts the level/degree of hazards prevalent in the area (e.g. see figure 4.2).

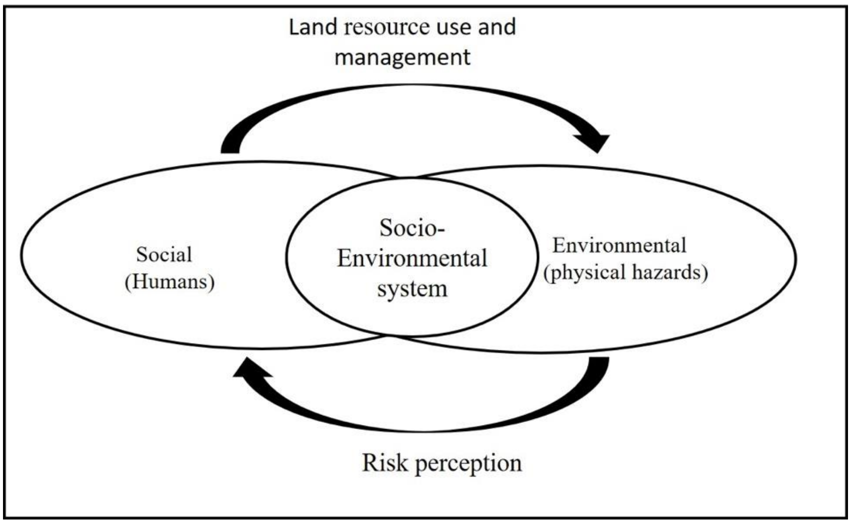


Figure 4.2: Example of a Socio-environmental system relationship. Source: (Lopez et al. 2019).

4.3.1.3 Culturally Responsive Methodologies

Culture refers to the way of life of a group of people. It encompasses a wide spectrum of ideologies that shape the way of life from values, beliefs, common practices, communication, knowledge, perceptions, gestures, behaviour, to expectations, social habits, food and language (Cole 2020). Basically, culture is everything about a place and the people, and one would be right to say the culture is the society. Therefore, being culturally sensitive in research is essential to any community-based research, especially in a cross-cultural study (Pelzang et al. 2018).

Culturally Responsive Methodologies, which is positioned within the critical and Kauapa theoretical framework, can simply be understood as an alternative research framework developed to question the current traditional research methodologies which do not respect, value or even humanise their participants. Instead, culturally responsive methodologies seek to develop and build relationships with the participants in a respectful manner, allowing the participants to maintain their dignity during the research (Berryman et al. 2013). At the moment, traditional research methodologies cannot be considered as inclusive or culturally diverse, as such, the research procedures are not reflective of the diverse ways in which people interact with their worlds and their realities (Biermann 2011; Berryman et al. 2013).

To successfully adopt culturally responsive methodologies, researchers and participants are expected to allow their identities, culture and belief systems to influence the way the research is viewed and implemented to collectively create authentic new knowledge representative of all involved in the research (Bhabha, 1994; Soja 1996). Without this consideration, researchers are likely to interpret their data from their cultural perspective and belief systems without taking into account the source of the knowledge; these limitations typically come from a place of unbridled privilege and unchecked authority of early researchers who perceive their worldviews as the universal truth (Pirsig 1991). For this reason, the need to decolonise research methodologies has never been more necessary. By design, culturally responsive methodologies intend to dismantle the existing cultural practices in favour of a fairer, more inclusive, and equal society (Kincheloe et al. 2001).

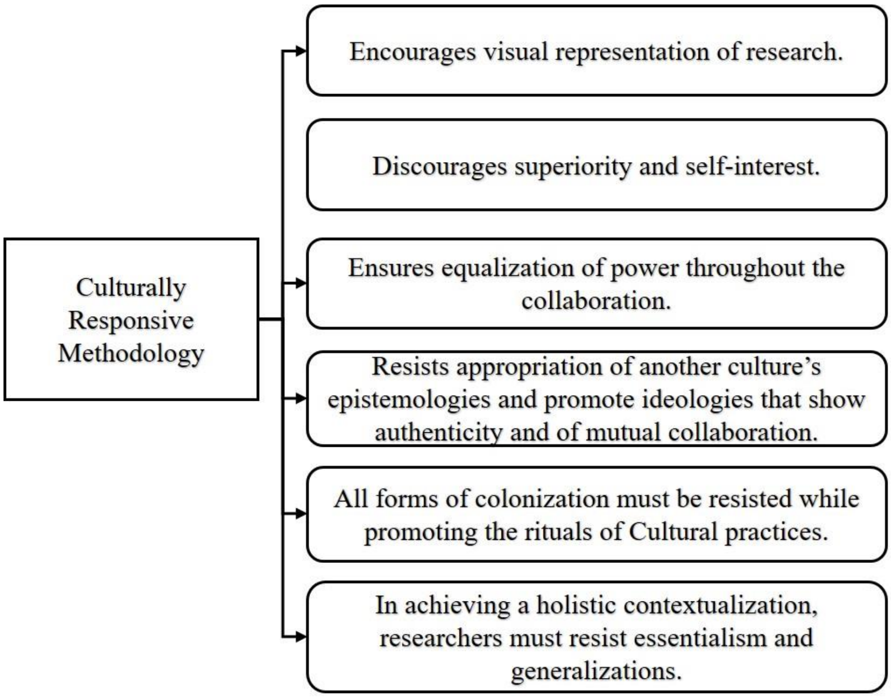


Figure 4.3: Overview of the Culturally Responsive Methodologies Framework. Source: (Berryman et al. 2013).

While culturally responsive methodologies is still an emerging field in traditional Western academic research, it has the potential to become one of the most inclusive forms of research methods as it gives the participants a voice in the research outcomes. Figure 4.3 provides a summary of this methodology which encourages a break-away from traditional research methods and the development of new and inclusive ways of thinking through research methods. This inclusiveness and responsiveness make the culturally responsive methodology relevant for this study.

The researcher's role in the project evolves from 'expert' to 'learner', as they seek to learn about the participants and their world which allows the participants to adopt leadership roles and more agency as well (Freire 1998). However, it is important to note that in this emerging field of research practice, it is not only the culture of the researched or participants that takes centre stage but that of the researcher as well. As a result, both parties can unite their cultures and experiences *"to construct a process of relevant and significant meaning-making"* (Berryman et al. (2013) p. 5).

My perception about the whole process as a researcher is that a subset of temporal culture in place could also be helpful in one's research. It is not just about bringing both cultures to the table but creating a fusion of cultures for the purpose of an activity that results from a mutual agreement for the duration and context of the research. A "*pop-up*" cultural concession which is usually not the norm could be allowed because it does not have the potential to harm either the researcher or the participant, and as such, preserves both cultures; meaning that the concessions form a '*temporary culture'* borne out of permission rather than compromise for the duration of the activity and both parties can return to their norm again. But if the researcher happens to go back to such communities again, it is pertinent that the researcher respects the expectations and conventions of that culture. I will call this perspective a *'Cultural-holding concept'* because it is on a temporary basis. This can only happen if there is a mutual agreement and is ethically bound. Below is an example of how the cultural-holding concept worked in practice:

There was a location that frowned on wearing trousers when meeting with the Elders and considered it to be inappropriate. Interestingly, it is not a spoken cultural taboo and as such, was not related to me. But on getting there via boat, the community stakeholders realising that the researcher was an African and from their state, believed that as an 'African' lady, I should have known that ladies should be properly adorned with the traditional attires especially in rural areas. They said, had I been a foreigner, they would have excused it. That means they were willing to put a stay on their culture if it was a foreigner. That was culturally a shock to me because I have not really encountered such silent ideologies before when back at home in Nigeria. Rather, notices such as 'Ladies with trousers not allowed', 'ladies without hair cover not allowed' are examples of such ideologies known to me. However, for the duration of the stay, I was granted full access to successfully carry out my research there. And that is where my concept of cultural-holding' is embedded.

The concept of *'cultural-holding'* is different from the cultural fusion theory (Croucher et al. 2017) in which the newcomers and the host fuse some aspect of each other's culture to create a fused intercultural identity. The newcomer takes up the dominant culture while keeping some aspects of their own culture.

It is important to remember that a culturally responsive methodology is an in-depth undertaking that expects the researcher to question all they have already learned regarding a research methodology and in turn, develop new, sensitive and enlightened options instead; for example, researchers are encouraged to question existing research paradigms like Positivism and support multi-logicality instead (Berryman et al. 2013). Multi-logicality holds the belief that different numerous truths can subsist concurrently and successfully without endangering one another (Deleuze et al. 1987). Positivism is not the only research paradigm to be called into question, but researchers are encouraged to recognise the cultural limitations of different existing research paradigms and should build new concepts which take into account the wider lens of contextualisation required to view and understand the ideas and phenomena being researched.

4.3.1.4 Driver-Pressure-State-Impact-Response (DPSIR)

The DPSIR is a structured model that has been adopted by the European Environmental Agency (EEA) in understanding coastal social-ecological systems (Kristensen 2004). My understanding here is that the word 'structure' does not represent a way of doing things (like a pre-defined methodology) but simply an abridged version of the indicators giving meaningful insights on the knowledge acquired concerning an area/object of interest. The model shows a chain of causal linkage from how the driving force (e.g., human activities) puts pressure on the state of the environment which has impacts on the system and finally to any responses in terms of management or policy towards the identified hazards/risk which will in turn feed back to the driver (see figure 4.4).

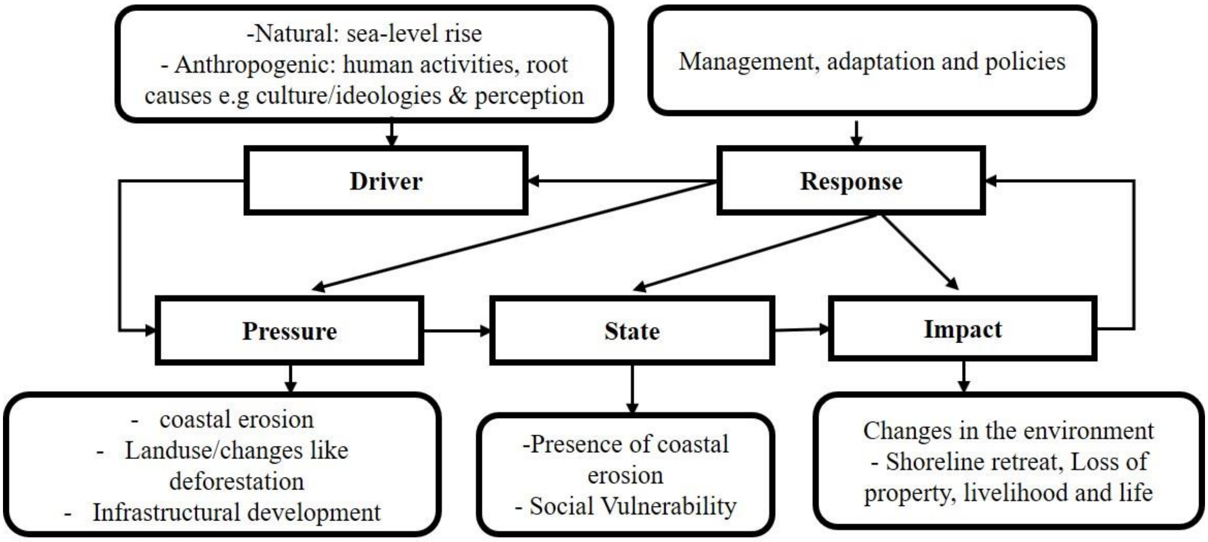


Figure 4.4: Example of the Driver-Pressure-State-Impact-Response (DPSIR) for coastal erosion. Adapted from Oesterwind et al. (2016).

Despite being successful and its potential in coastal management as it addresses the underlying issues that impact vulnerability and engaging stakeholders and policy makers, Lewison et al. (2016) notes that DPSIR has been under-utilised. Since the outcome of my research could impact policy at any level, having a comprehensible way of structuring the data which could be easily understood by the stakeholders irrespective of scientific background cannot be overemphasised. For this reason, I adopt this framework. The opportunities presented by the framework make it easy to incorporate different levels of indicators for different vulnerability assessments. To adequately explore the 'root causes' of vulnerability, this study will identify indicators that represent the 'root causes' as an integral part of the 'drivers' that contribute to the local scale of vulnerability which varies across the study locations.

4.3.2 Data Generation: building up the data resources

Although the scope of the entire research follows a mixed-method approach, this section will focus on the various culturally responsive and participatory approaches used, such as focus groups, direct observations, reflective journals, interviews alongside innovative and responsive methods, such as a walking interview around the sites of interest and participatory photo-taking exercises to generate the data used for the analysis of the socio-ecological assessment of coastal erosion.

4.3.2.1 My Pathway to the Coastal Communities: Reflections on Access and Negotiations

Before embarking on the fieldwork, I could not have envisaged the multiple levels of access points and negotiations that I would need to gain before the end of the fieldwork. One might think that access is something you get once at the starting point of your fieldwork, but that is not the case. It is a continuous process throughout the pre-field, during the field work and even when one is to give feedback to the community (Johl et al. 2010). The process of accessing the study area began with the approval of the Ethics proposal by the College of Science & Engineering Ethics Committee of the University of Glasgow. Before traveling to the study locations, I had sent letters ahead and remotely set up a research team that would assist me on arrival with the hope that it would smoothen my access pathway considering the limited time (6 weeks) I had for the fieldwork. That was not the reality I experienced. As a matter of fact, a considerable amount of time was put into gaining access because in the communities, there were no responses to the letters sent; rather they were verbal consent. The government officials did not attend to the letter until my arrival, while in some areas, access was a continuous process until the end of the fieldwork. Interestingly, some places never acknowledged my access request, making it impossible to access information in those areas. For instance, the top-down access approach I had initially adopted (figure 4.5) - to move from the state to the local Government before the communities - was not the pathway that was used in the field. Due to time constraints, I was given verbal approval by the ministry to proceed with my field work, in particular meeting with the stakeholders at the local and community levels, pending the state approval.

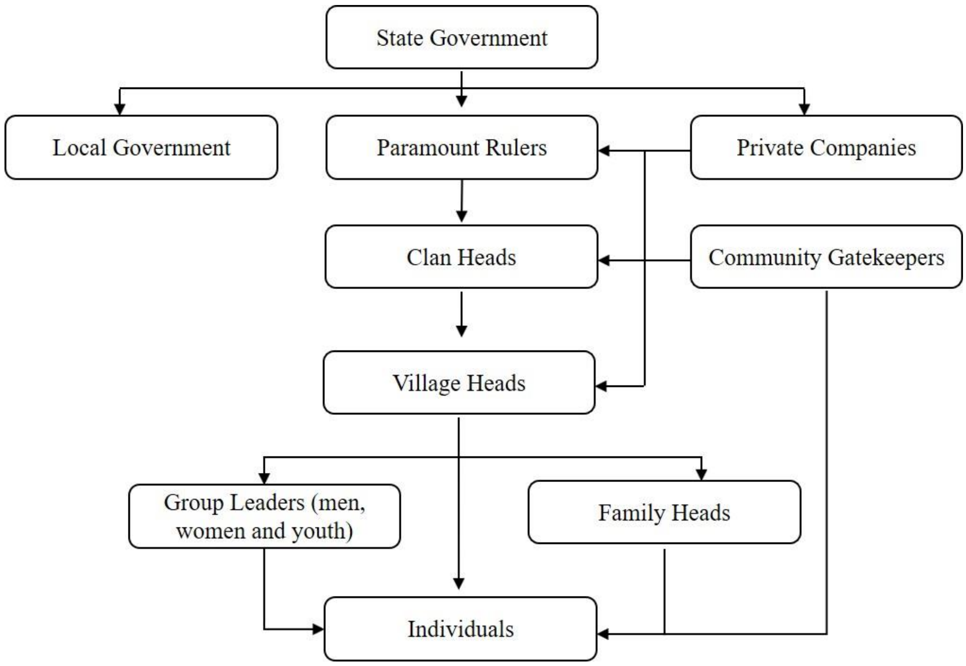


Figure 4.5: Governance Structure in Akwa Ibom State.

Having access to the study area entailed understanding the Governance structure in the area and knowing the leadership level from which permission could be obtained. My experience during the fieldwork made me understand that access is multidimensional and dependent on the social setting and the context surrounding the research. For instance, my obtaining access from the state or local government would not necessarily give me access to the coastal communities. As a matter of fact, it would have no impact on gaining local access as it did not matter to them. If anything, it would have raised dust or question as to what my relationship with the Government was. Community access is very important and is obtained at the clan head level or designated gatekeepers. Another dimension to access is engaging the gatekeepers. Gatekeepers, as observed in the field are not necessarily the leaders in the village but people who can influence decisions in the village. Permission and access to conduct the fieldwork was done on both formal and informal terms. The formal terms included the letters sent to the State ministry, Local government areas and village heads before the fieldwork began. While awaiting the formal response, informal approval was given that the work could begin by directly seeking permission from the gatekeepers of the intended communities. The gatekeepers refer to a person or people of influence in a community (McKenna et al. 2013; Co-ops 2015).

4.3.2.2 Engaging with the gatekeepers

Gatekeepers are influential members of the community; as such, when carrying out a community-based participatory approach, it is a necessary tenet to do substantial research before embarking there (Strand et al. 2003). However, the success of carrying out participatory research in a rural community is contingent on the successful entry into the 'community' and the cooperation of the participating community. Since the gatekeepers play a vital role and are the primary point of entry to a community, it is a crucial step for one seeking access to a new community to develop a relationship with the gatekeepers. Practically, the permission from the gatekeepers is as important, if not more important than getting approval from the Government because without their interest and approval, the fieldwork in those communities could be jeopardised and there would be no entrance to or co-operation from anyone in the community. In addition, different communities could have different cultures, and as such, the process of gaining access will vary from community to community (Wanat 2008). Cultural sensitivity is a key factor and should be taken into consideration by the researcher (Vuban et al. 2019). For this reason: *"Researchers must learn the social structure of a research site to successfully negotiate entry"* (Wanat (2008) p. 192). As important as the gate keepers may be, obtaining trust from members of the community is very important in getting them to be comfortable with you and cooperating with the research which has a role to play in the reliability of the data sets obtained.

4.3.2.3 Bridging the language barrier and trust-building

As earlier mentioned, data generation for this research was done with the aid of Nigerian fieldwork assistants. The assistants provided essential support to this research by gaining permission from the state government, local village leaders and policymakers in the local government. They also helped set up local (community) fieldwork assistants who provided help with translation, data collection and support in the communication of the research findings to the communities involved. Language would have been a huge limitation to carrying out this fieldwork, but this was surmounted with the help of the local fieldwork assistants.

There can be a concern of accuracy, pseudo-information and information being lost in translation (Lucas 2020). To address this issue, on arrival, I provided training for the Nigerian fieldwork and community assistant team to ensure a full understanding of the research and its approach. Secondly, being an indigene of the state enabled me to filter through the conversation and understand the trend of discussion. To a large extent, I made sure that an intensive discussion on the necessary cultural/traditional practices was also relayed to me by the local assistants.

4.3.2.4 Selecting the study locations

The research is aimed at understanding the perception of the coastal communities towards coastal erosion and coping mechanisms practised in the area. Therefore, communities directly along the coast were selected for the research. However, on getting to the field I realised that we had to also extend the research to some land communities. For instance, prior to the pre-field work, five focus group meetings were planned but on getting to the field, some clan heads advised us to involve all the villages in the clan, whether or not it is directly by the ocean to avoid inter-village rivalry or feuding (i.e., when news travels that some researchers came and met with only a few selected leaders of some villages). This was understandable and without which, access could be denied. However, this posed other challenges that I did not consider during the conceptualisation of the research, including the extension of my timeframe in a Local Government Area. This impacted the number of days spent in a Local Government area and my ability to reach and have focus group discussions (FGDs) in all the Local Government areas, which was paramount to my research. Due to time constraints and accessibility to communities, only 12 FGDs were held. Second, due to the practicality of gathering all of the clan's village heads in one location, we had to hold more FGDs than planned. We were forced to combine some of the villages along the coast in each Local Government Area (L.G.A) due to their proximity to one another or the time constraints on travelling to some remote areas. Because of this arrangement, some of the merged communities had only their leaders or representatives attend the focus meeting.

All these measures were necessary because we were informed that there had been past rivalries between villages. This happened because ‘left-out’ villages felt that they were being marginalised by the clan head and they had the perception that the researchers could influence policy and bring potential aid to the clan, of which they would be excluded. This provides an important insight to the less visible, but significant negative or unintended impacts of academic research on communities.

4.3.2.4.1 Traversing through the study locations

Due to the challenges of study location selection encountered in the field, the research covered twenty-three (23) communities along the Akwa Ibom coastline. The communities visited were all part of five Local Government Areas in the State which include Oron, Mbo, Ibeno, Eastern Obolo and Ikot Abasi. Within these communities, twelve FGD and thirteen interviews were conducted. The location of the communities where data had been gathered from can be seen in figure 4.6.

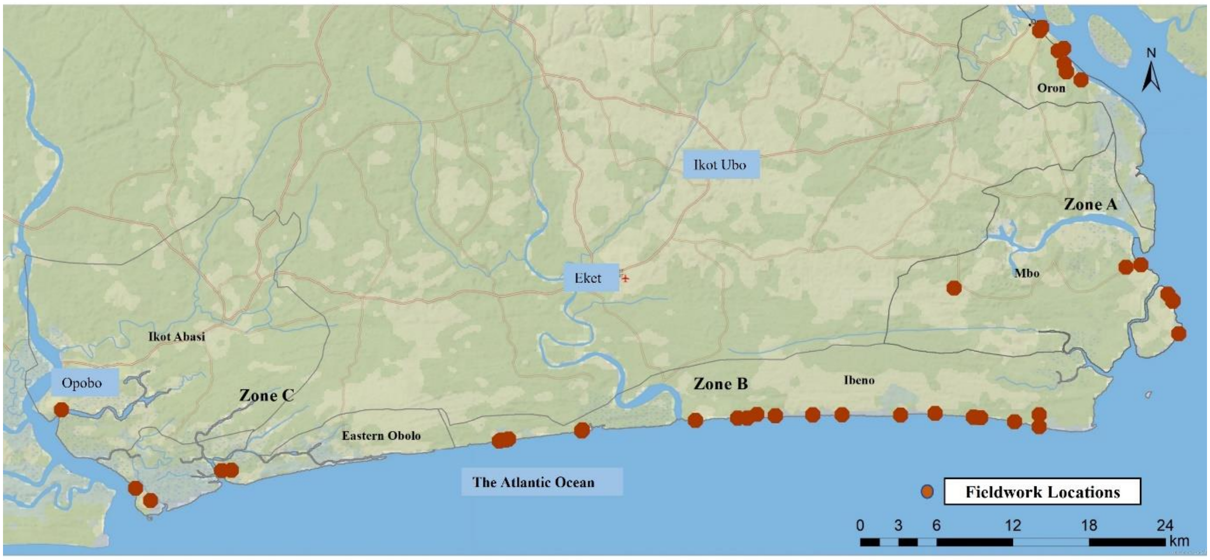


Figure 4.6: Fieldwork locations along the coast of Akwa Ibom State, Nigeria overlaid on overlain on an Esri Ocean basemap (Esri 2011)

Table 4.1 shows the type of data generation methods that were used at the different study locations along the Akwa Ibom State coast.

Table 4.1: Communities visited during the fieldwork.

State	Zone	Local Government Area	Communities	FGD (Focus Group Discussion)	FGD NO.	Interviews (Including Walk Around Interviews)	Interview No.
Akwa - Ibom	Zone A-1	**Oron**	Esin Uffot	*	FGD 1	-	-
			Idua Asang	-	-	*	INTVW 1
			Esuk Oron	*	FGD 2	*	INTVW 2
			Idua Afaha Eduok				
			Idua Ukpata	*	FGD 3	-	-
						*	INTVW 3
	Zone A-2		Ine Ekong				
		Mbo	Ibaka	*	FGD 4	*	INTVW 4
			Mben Ndoro	*	FGD 5	-	-
			Brama	-		*	INTVW 5
			Unyehe	*	FGD 6	*	INTVW 6
			Ibuot Utan	*	FGD 7	-	-
	Zone B	**Ibeno**	Itak Edim Ukpa	*	FGD 8	*	INTVW 7
			Atia				
			Itak Ifa	-	-	*	INTVW 8
			Ndito ekaiba	*	FGD 9	-	-
			Inua Eyet Ikot			*	INTVW 9
			Itak Esuk Ikim Akwaga	-	-	-	-
			Akata	*	FGD 10	*	INTVW 10
			Iwuo Okpom Okpolum	*	FGD 11	-	-
	Zone C-1	**Eastern Obolo**	Emereoke 1	*	FGD12	*	INTVW 11
			Agasa			*	INTVW 12
						-	-
			Obianga				
	Zone C-2		Ikonta	-		-	-
		Ikot Abasi	Uta Ewa	-		*	INTVW 13

Accessibility to most of these locations was a challenge as only a few of these locations were accessible via motor vehicle; others were accessed via boats and motorbikes (figure 4.7). For those accessible via road, our first point of contact was the paramount or village head's compound to inform him of our arrival.

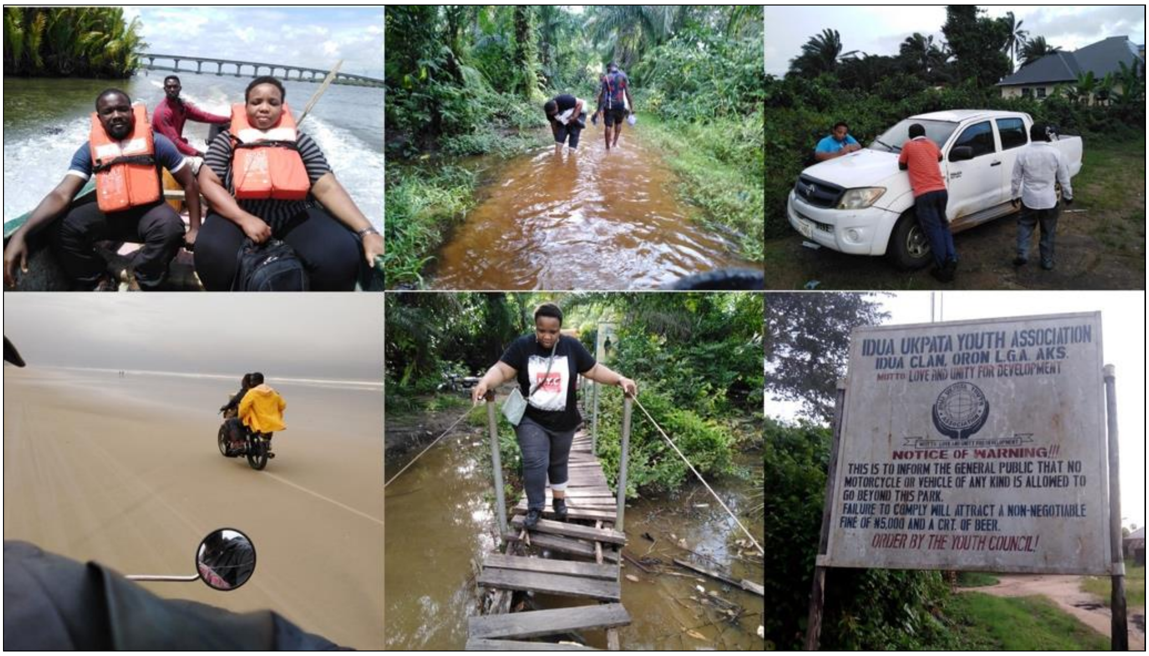


Figure 4.7: Types of accessibility to the Communities visited during the fieldwork.

4.3.2.4 Fieldwork and Ethical challenges

As highlighted earlier, before embarking on the fieldwork, approval of my research ethics was obtained from the ethics board of the College of Science and Engineering, University of Glasgow. This is important because there is a need for a guideline that is acceptable to both the researcher and the communities involved. It ensures cultural sensitivity where the culture of the research population is taken into consideration (Liamputtong 2008). As the research involved interviews, there were a few ethical concerns about the research that needed to be addressed. These include:

- *The issue of confidentiality and anonymity.*
- *The issue of participants not understanding fully what they are being asked to contribute to.*
- *There was a slight risk of participants becoming upset or distressed when talking about the challenges they have faced in their lives or problems within their communities.*
- *There was the concern of people feeling obliged to participate.*
- *There were also concerns that some people may not want to be filmed or photographed.*

(Please see appendix 4.1 for steps adopted in this research to address the ethical concerns, appendices 4.2 and 4.3 for the participant information and consent form).

4.3.2.4.1 The challenges of research misconception

Before embarking on the fieldwork, I did not envisage the potential challenge of the misconception that my research was associated with government agendas. On getting to the field, however, before proper access and cooperation during the FGDs could be given, the people questioned if I was working in conjunction with the government. With such orientation, the expectations they had of this research were extremely high. It became problematic initially trying to re-orient their expectations and negotiate my access. The youths in the village would not allow easy access and requested that we pay cash royalties to them before entering the village. The situation was worsened by the fact that I came in from a western country (known as "obio mbakara" by the villagers) for the research with financial resources. To ensure that the misconception was corrected, I heavily relied on the gatekeepers to help me convey the purpose of the research and convince the people in their communities that I was not working for the Nigerian government or any foreign government but that the work was purely academic. I also reiterated the fact that results of this research study will be used for my Ph.D. thesis output, in scientific reports and that the findings of this work may be presented at an academic conference, published in an academic journal and potentially as the basis for future research and may be used to help guide policies/future activities working with the local community, town committees and local government.

4.3.2.5.2 Incentives

The frameworks of PR and the culturally responsive methodology tremendously guided the FGDs. Cultural ethics came into play at every location of the fieldwork. Naïve expectations that cultural practices would be in any way similar were ruled out before embarking on the fieldwork and every community approached was unique in their ways of doing things. For this study, different forms of incentives were given to all participants. The local research assistants had informed me that giving incentives was unavoidable, especially working in rural areas. Incentives like drinks for the leaders are statutory and failure could hamper our access because it is deemed a sign of respect in paying homage. Then et al. (2014) noted that incentives such as free services, food or other forms of rewards used during FGD can be simply a way of appreciating the participants for their willingness to participate; they should never be used to coerce participants. However, Grant et al. (2004) noted that whenever incentives are to be used, it should be done in a proper ethical manner. Singer et al. (2013) is of the opinion that incentives are not used to coerce but to reduce non-response to participation, as it increases the rate of response. To eliminate the bias of coercion, the participants were unaware of the availability of refreshments until we reached the venue for the FGD.

During the fieldwork, monetary incentives were given as gifts to the value of 4000 naira (approximately £9-10 depending on the exchange rate and equivalent to a customary bottle of wine) to each paramount leader (who is the leader of clan heads and village heads in a given Local Government Area), clan head (head of a group of villages with individual village heads), the village head and family heads for their assistance in arranging the participants for the focus groups, surveys and walking around site information and for taking part in the survey. Incentives like pens, refreshments of drinks and snacks were offered to the participants while focus groups and mapping workshops were being conducted as compensation for their time.

4.3.2.6 Focus Group Discussions: Approaching the FGD Responsively

Prior to the FGD meeting, the criteria for participants were clearly communicated to the leaders. As such, the village head/clan head held the prerogative on whom to invite to the meeting and the local stakeholders present at the meeting could not be fully regulated by my team and me. I was made to understand that there are certain people that will have to be statutorily present which include

- The village heads
- The village council chairman
- The village council secretary
- Village council youth representative.
- The family heads.

Only after, can the group leaders (this refers to different demographics group leaders like the youth and women leaders) and any other person be invited. The snowball sampling enabled me to meet more knowledgeable people with the required information on changes in their environment needed to build up linkages that would give a deeper understanding of the phenomenon being studied, draw upon their belief of potential risks and to triangulate data.

The fieldwork was characterised with the challenge of scheduling and differing expectations of time. For instance, on getting to the first community, we met with the village head in his compound but on getting there, there were no stakeholders present. The following is a typical example of a scheduling challenge encountered in the field; the village head said that he could not ask Elders to come and wait for youths; rather now that we had arrived the FGD venue, he would send a word out to the Elders to come and meet with us. We had no option than to re-schedule the FGD with that village because my team had to catch up with the next team. This gave me more insights into the role of culture in this research. Time constraints have been noted by Then et al. (2014) to be a limitation of using this method. But the experience during the meetings was different and varied across the study locations. Initially, an FGD guiding outline on conduct/proceedings was co-produced with the local research assistant and translator to enable us to manage the time and dynamics of the meeting properly; *one begins with a proper/formal greeting. Declaration of intent. Await acceptance. Prayers. Entertain any questions. Proceed with the discussions. Entertain questions. Mapping exercise. Entertainment. Closing prayers.*

Although each of the elements on the list eventually came into play, apart from the initial formal greetings at the beginning, every other thing was snowballed; meaning, the next discussion is an offshoot of the previous. The moderator here who was one of the field assistants had to be sensitive to know how, when and what questions to continue with. For instance, in one location, the clan head began the meeting by receiving the drinks we brought and then proceeded to use them to make prayers to their traditional deities (figure 4.8) and that prayer lasted for almost twenty minutes. During this time, everyone had to be quiet as he was communicating with their gods. After the prayers, the drinks had to be given to everyone to drink to show acceptance on both parties. An interesting scenario came up here: I do not drink alcohol and my belief conflicts with that too, especially when dedicated to deities. As a researcher that could be the very end of your research in the community because it would be perceived as disrespect for their cultural/traditional beliefs. I had earlier discussed this with the local assistants, and they said that most of the time, the chiefs touch the honorary gifts of drinks and ask the researchers to drop them on either the table or the floor. But that was not the situation here. So, one of my local assistants immediately said that he would have the drink on my behalf. On the contrary: *The clan head just laughed and said, 'drinks shared with gods, cannot be shared with a woman'. As such, the drink was only for the men present.*

That was a relief, and I was thankful for such traditional beliefs as well as the very acceptance and welcome we received. Billson (2006) noted that the popularity of the FGD is because this data generation technique gives one access to information that is not easily derived using other methods. The use of FGD according to Rosenthal (2016), gives the researcher the understanding of the “why” behind what governs people's actions and local knowledge concerning the phenomenon of interest. Though it may seem like a simple process, Nyumba et al. (2017) noted that the role of the researcher is important as the researcher needs not only to plan, but to also have the skills and ability to facilitate the FGD.

Figure 4.8: A & B shows pictures of traditional drink presentation to the deities while C shows participants during the drink presentation.

During the focus group discussions, the interpreters were invaluable in mediating the questions and the responses and perspectives of the communities. Since focus groups are complex spaces of engagement, a good facilitator’s guide has to be in place with clear objectives of what needs to be achieved during the meeting (Then et al. 2014). In particular, participants are encouraged to discuss the subject with each other instead of just answering the facilitator's questions since the purpose is to understand people’s perceptions (Liamputtong 2015).

FGDs were carried out in twelve communities of stakeholders along the Akwa Ibom coast (see table 4.2). These discussions focused on the environmental challenges of coastal erosion in (though not restricted to) the area. During the FGD (see figure 4.9), a map-making exercise (participatory GIS) was carried out which involved participants mapping out the areas that have been affected by erosion in their community on a satellite map that was provided during the exercise. The generated maps based on local knowledge are then represented, stored and used in a Geographic Information Systems (GIS) for subsequent spatial analysis. The duration of the focus group discussions varied in the study locations and lasted between one to one and a half hours.

Figure 4.9: Photos A-F shows the focus group meetings in some areas along the Akwa Ibom coast.

The size of the FGD varied in the different communities. Liamputtong (2015) suggested that an FGD should involve a small number of participants of 6-8 of the same socio-cultural background and ideally, should be not extended longer than two hours. However, on getting to the field, some communities had twelve participants while others had either more than twelve (between 13-15 participants) or fewer (between 7-11 participants). In FGDs where there were more than 12 participants, the village leaders explained that a representative of all the groups and family head had to be present to avoid problems while the communities with less than 12 participants, could not gather the people in time as some stakeholders were away (e.g out fishing).

4.3.2.7 Participant observation/field notes

Throughout my fieldwork, I highlighted my challenges and wrote down my observations. This involved the documentation and description of interactions, events, and behaviour of the participants in their social settings. My observations were focused on the focus group discussions (figure 4.10) and the walking interviews in the communities. My experience during the observations allowed me to gain more understanding, not only about the local risk perception of coastal erosion, adaptive capacity and mitigation along the coast, but also the participants' responsiveness and behavioural signs. Participant or direct observation is commonly used in ethnography and is taken up variably depending on the theoretical framework that underpins the practice (Coffey 2006). I refer to participant observation and direct observation interchangeably, since my observation involved the participants and the state of the environment. The findings derived from first-hand experience in the field can significantly improve the social and scientific understanding of social behaviours (Coffey 2006). In the field, I experienced the necessity of being in situ in the location of study rather than just rely on spatially derived data because the findings varied among the individual research locations along the entire coast. A total number of twelve direct observations during the FGD were made during this research.

Figure 4.10: My observation during the FGD discussion and note taking in the field.

4.3.2.8 My approach with interviews/walking interviews

Two types of interviews were undertaken: the semi-structured and unstructured interview (interview done with volunteers while walking through the study area). Six semi-structured interviews were carried out with Government or company officials to solicit information about the role of the government or the companies in the area in order to mitigate the effect of coastal erosion along the coastline of Akwa Ibom State. The interviews were recorded with a hand-held digital recorder and included open-ended questions.

Walking interviews were carried out with stakeholder volunteers who took us to strategic locations that showed the prevalence of coastal erosion in the area. This was also done to access locations that have been affected by coastal erosion to gain an in-depth understanding of any physical damages and mitigation parameters put in place (figure 4.11). The observations here serve as one source of assessing the credibility of information generated during the FGDs. This walking interview needed just one to two community volunteers who had first-hand knowledge of the area and the changes that have occurred because of coastal erosion. The volunteers took the research team together with the local translators to locations that have been affected by coastal erosion and explained the extent to which the community has been affected by the situation. They also explained and showed the team the physical mitigation parameters that had been put in place such as stilts and sandbags. Thirteen walking interviews included the capture of video/audio recordings, pictures, descriptions, coordinates and field notes.

Figure 4.11: Walking interview around some areas along the coast. Pictures A-C shows parts of Eastern Obolo while picture D shows Ndito ekaiba in Ibeno LGA.

4.3.2.9 Inclusion/Exclusion Criteria

Sampling enables a researcher to get a representation from a smaller or target group that depicts or represents information of a larger population of the study. A combination of sampling strategies was used which included purposive random sampling that can readily provide the information needed by the research and as such is deliberate with the choice of participants, and snowball sampling which results from the initial primary sampling technique. These strategies meet the purpose of the research which targeted individuals that are knowledgeable about the environmental changes taking place. My inclusion criteria for the different data generation methods are represented in table 4.2

Table 4.2: Sampling Criteria used during the fieldwork

Type of survey (Data generation)	Inclusion Criteria
Focus Group	Participants were selected by the village head and included people who have lived there for at least 20years
Questionnaires	Any Adult willing to participate and have lived there for at least 15 years. This is targeted at a wider age spectrum of respondents.
Interview	Government or private company representatives who have the knowledge and are in the position to give information about Government policies and mitigation parameters.
Walking Interview	One or two adults appointed by the village leader who had lived there for at least 20years and has expert knowledge of the area would be able to detail the changes that may have taken place.
Direct Observation	Based on the researcher's daily observation throughout the fieldwork.

The inclusion criteria were targeted at adults (18 and above) who would possess first or second-hand knowledge about changes that may have taken place in the area over the past 15-20 years. Based on the inclusion parameters, people residing outside the study area, children, and those below 18 years of age were excluded.

4.3.3 Data Description using the Re-conceptualised DPSIR Framework

The data description for this research is done using an extended form of the DPSIR which was re-conceptualised (see figure 4.12) for this study. The extended DPSIR (figure 4.12) incorporates hazards as described by the FGD participants. This allowed the participants to explain the different hazards in the way they understand them. This method of involvement or entry gives the participants a sense of ownership of the information. The familiarisation of data was done through an iterative process where I read the data repeatedly to enable me to extract the indicators for each of the expanded DPSIR model's indicator components.

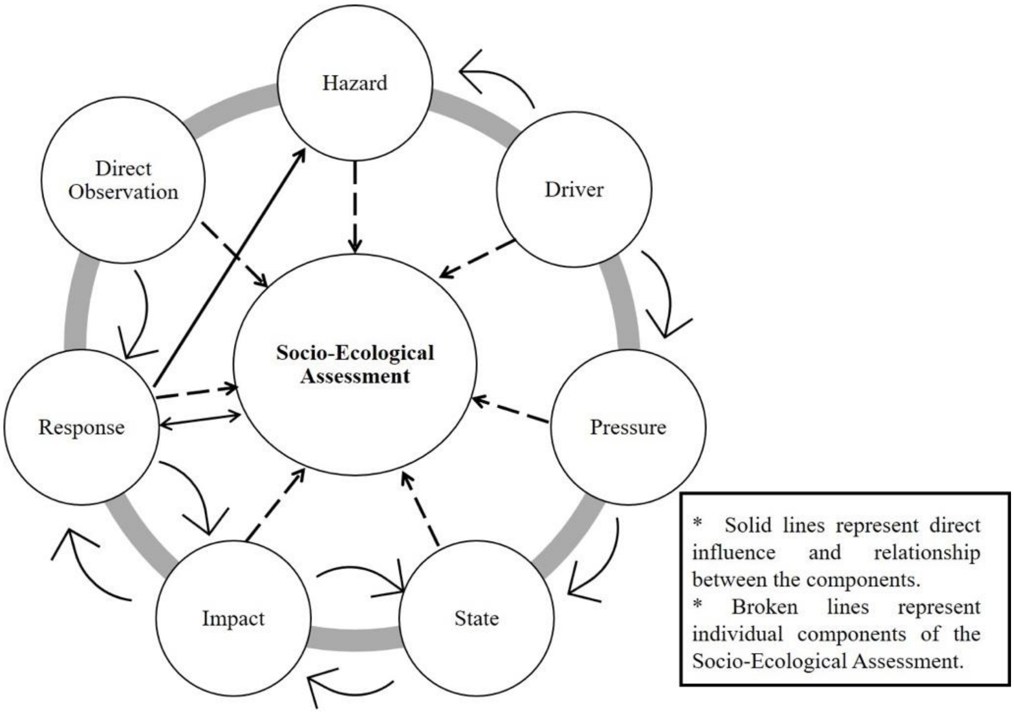


Figure 4.12: DPSIR Coastal erosion, an extended DPSIR model adopted by this study for data structuring and analysis by the researcher (European-Environmental-Agency 1999).

4.3.4 Data synthesis process

To contextualise the results of the extended DPSIR method, rhizoanalysis was used because of the multiplicity of data which is well embedded in the framework. Rhizoanalysis involves understanding and showing how the connections and movements can interrelate, and how data can be taken up to exhibit multiplicity, marking and unmarking territories or ideas, rupture pre-conceptions and form new connections (Deleuze et al. 1987). A rhizomatic process, is suited for this study because of the complexity of the human-environment system.

The rhizoanalysis disrupts conventional qualitative research analysis methods rooted in post-positivist paradigms or interpretivist paradigms by not generalising the results obtained in research or organising data into a pre-defined structure. Rhizomatic analysis acknowledges the multiplicity with multi-layered data that flow in different dimensions. Importantly, the rhizomatic process challenges the researcher to think differently while still in the process of analysis (Masny 2015) and interrupts and engages with the limiting factors in other research processes (Cumming 2015). This presents avenues for real-world data (RWD) that involves generating data from real-world interactions to create new lines of inquiry and insight. Rather than follow the traditional coding process which simplifies a complex set of interactions, and in some cases, as Elliott (2018) presents, may not give a full representation of the real world, the rhizoanalysis allows flexible connections of data where even the researcher experiences relationship with the data and perception can be adequately included in the analysis. A typical example is seen in Sellers (2015) whose study showed how rhizoanalysis allowed different ways of dealing with data instead of a definite process, thus addressing the gaps in what can be seen and reported, especially in a complex socio-ecological condition such as coastal zones. Sellers (2015) used rhizoanalysis to study the complexity arising from children's interrelationships presenting a continual possibility of multiple outcomes. Other studies that used rhizoanalysis successfully include Facca et al. (2021), who used it to re-evaluate ethical discernment in qualitative research and Sherman (2018) who used rhizomatic analysis to demonstrate understanding of a professional teacher-coach interaction.

4.3.4.1 Rhizo-analysis: Approaching the data Rhizomatically

Analysing the data was interesting because of the way the rhizoanalysis unfolded from the middle. It showed how local knowledge perceives environment change over time, and these changes prevented a single or linear sets of findings but prompted new connections and gave in-depth insights into how and why the vulnerability in these coastal areas has developed. For instance, during the FGDs, one realised that data was generated even before meeting and asking the participants about coastal erosion. There is no one starting or ending point to assess data but connections began presenting themselves through various sources (e.g. observations, casual interactions) which summarised the concept of rhizo methodology by Sellers (2015). In this way, the process could be endless and always changing in state.

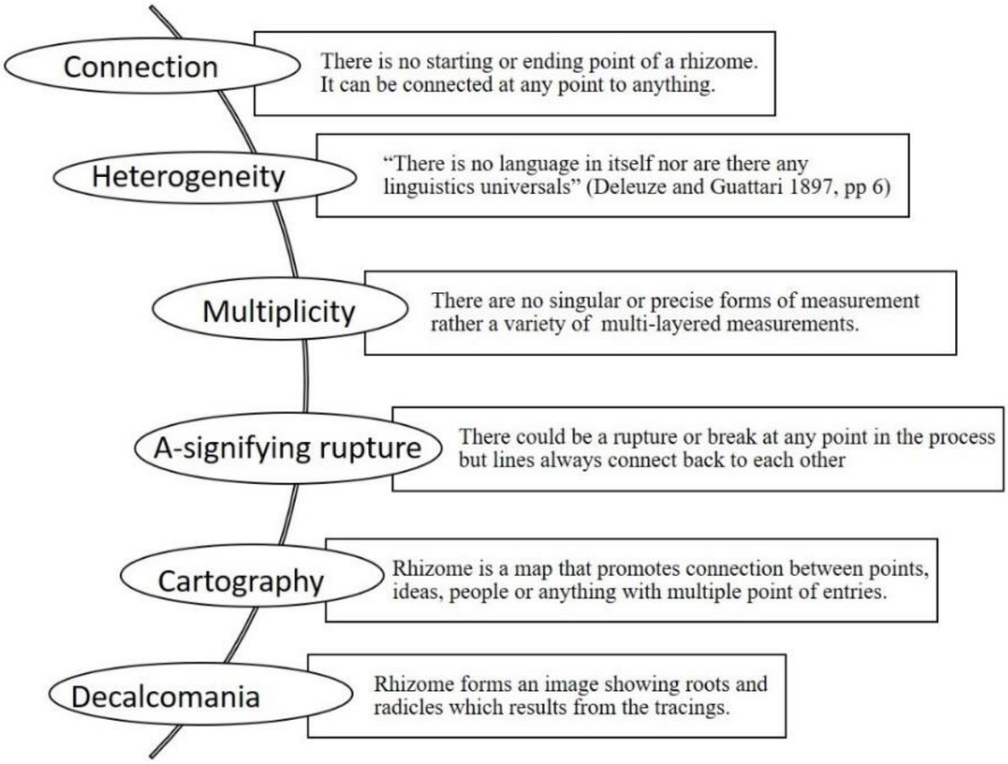


Figure 4.13: Deleuze and Guattari's Rhizomatic principles (adapted from Deleuze et al. (1987)).

The fundamentals of the rhizomatic principles are summarised in figure 4.13. It is essential to note that rhizomes do not have a start and end point, but start mid-point with linkages connecting different components and could arrive at an intermezzo but not a conclusion (Masny 2015). This process is continuous, deterritorialising (becoming) and reterritorialising (actualised) concepts to rupture and form new connections (Cumming 2015). A rhizome is clearly explained as: *"A rhizome ceaselessly establishes connections between semiotic chains, organizations of power and circumstances relative to art, sciences and social struggle" (Deleuze et al. (1987) pp 7).*

The analytical process is interesting as it gives a different, multiplicity, non-linear and multi-layered way approach to handling issues (Masny 2014). That means it helps unravel the 'what', understand the 'why' and gives connections to the 'how' which in the real world is multi-faceted which stems from the state or experience of those participating. This analytical process promotes the visual mapping of the encounters with data, connections and movements throughout the entire process (Hofsess et al. 2013). Sellers (2015) noted that Deleuzo-Guattarian rhizo-process also considers how the researcher wrote or assembled the 'what', the ‘why’ and the ‘how’ and that such lines of flight matter too and impact on the credibility of the research (Cumming 2015).

4.4 Results & discussion: Finding the connections within the data

The culturally responsive methodology within which this research lies, embraces non-traditional methods of expressing data in a way that many readers can resonate with (Berryman et al. 2013). As such, the integrated extended DPSIR and the rhizoanalytic approach is used in analysing the qualitative data to show connections, linkages, and mapping of the vulnerability of the Akwa Ibom coast to coastal erosion. The findings are guided by the research questions which comparatively analyse coastal erosion along the Akwa Ibom coast. There are multiple factors that contribute to the social vulnerability of a community to hazards. Reading and re-reading the data gives initial direction to what indicators to take up as patterns begin to emerge. The emerging indicators are used to describe the different components in the DPSIR model. These indicators provide in-depth knowledge of the driver-pressure-state-impact of coastal erosion and the management practices, if any, which cannot be easily derived from the physical data analysis only. A synopsis of the emerging indicators for the entire coast can be seen in figure 4.14.

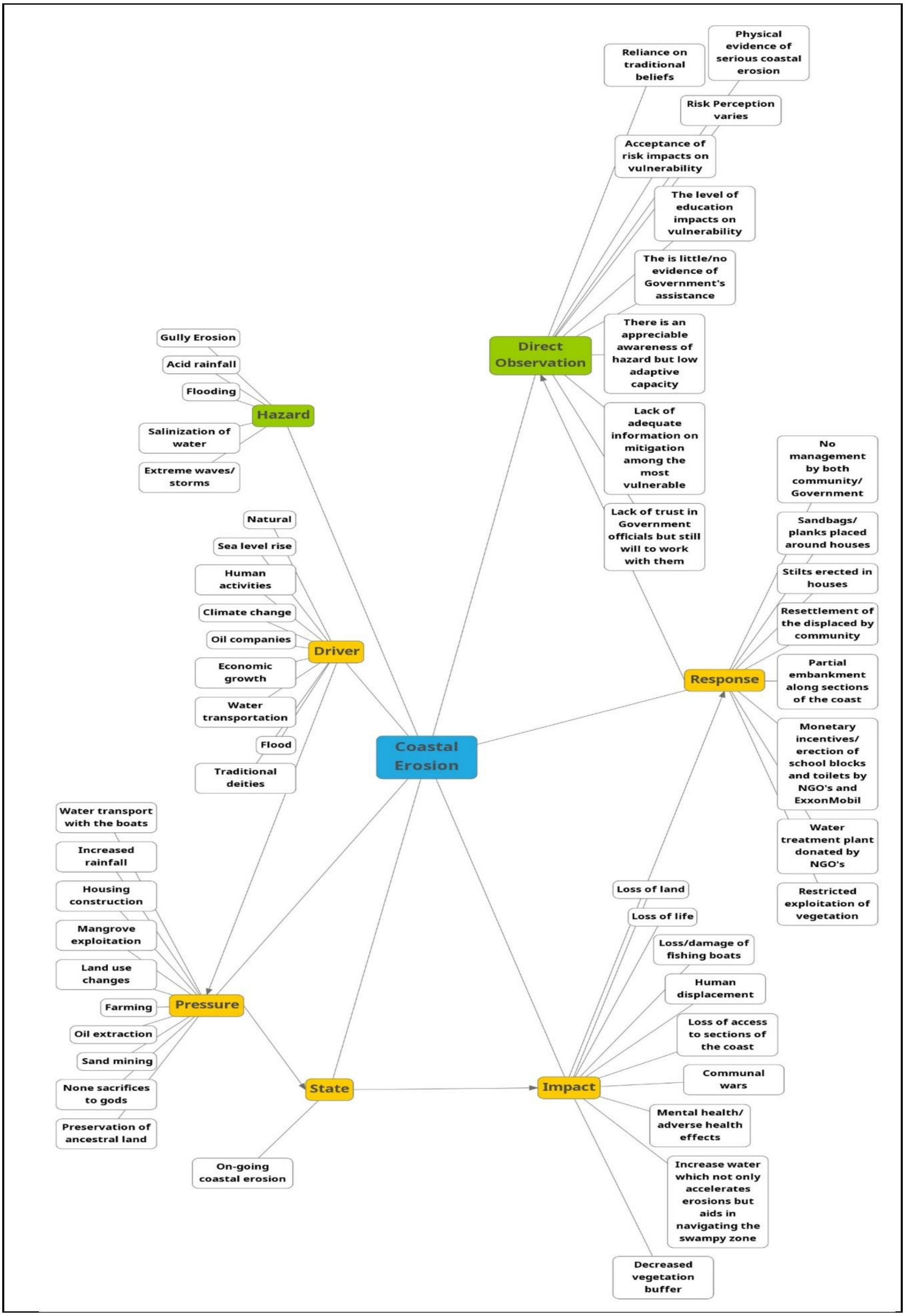


Figure 4.14: Rhizo-map of emerging indicators for coastal erosion hazard from the entire study area

4.4.1 Understanding the local knowledge on coastal erosion

- *What is the local knowledge on coastal erosion?*

The indicators of components - hazards and the drivers - in the extended DPSIR will be used to explain the local understanding of coastal erosion hazards. The participation of local stakeholders is depended upon by this study to access the vulnerability of the coast to coastal erosion. Their participation enabled multiple sources of data entries of information to access what locals understand by coastal erosion and how the human-environmental relationship either enhances or reduces the vulnerability in the area.

4.4.1.1 Perception of the hazards experienced along the coast

The results from the FGDs show that there is variability in the perceived hazards in the area (figure 4.15) and that there is an appreciable understanding of changes in the area. There are six major indicators of environmental hazards identified by the participants. These are coastal erosion, flooding, extreme waves/storm surge, salinisation of water, gully erosion and acidic rainfall (table 4.3). Below is an example of the perceived hazard along the coast:

Quote 4.1: *'...another thing that is disturbing us is gas flaring, it has disturbed even the rainwater that we used to drink. When you fetch it, the water will turn black within some minutes.' FGD 5 – male participant 4*

Despite the focus of this research, the qualitative and rhizomatic approach resulted in a much broader engagement with perceived hazards (see quote 4.1). This level of understanding is important for contextualisation concerning my research focus on coastal erosion. Also, the perceived hazards by the participants give a make-up of the environmental identity of study locations, and they could be referred to during the research, due to the inter-relationship with coastal erosion hazard and the human system in the environs.

A) Coastal erosion at Akata, Ibeno, L.G.A

B) Researcher at a flooded location in Ine Ekong, Oron L.G.A

C) Roof of a house destroyed at Ibuot Utan, Mbo L.G.A

D) Salinization of water at Ndito Eka Iba , Ibeno L.G.A

E) Gully erosion at Esuk Oron, Oron L.G.A

F) Metallic sign post corroded by acidic rain at Itak Idim Ukpa, Ibeno L.G.A

Figure 4.15: Pictures A-F shows the different hazards described by the participants at FGD along the Akwa Ibom state coast.

Table 4.3: Summary of Knowledge on the hazards experienced along the entire coast derived from the focus group discussions

Zones	**FGD/ Hazards**	**Coastal erosion**	**Flooding**	**Extreme waves/ storm surge**	**Salinization of water**	**Gully erosion**	**Acid Rainfall**
Zone A-1	FGD 1	*	*	-	-	*	-
	FGD 2	*	*	*	-	*	-
	FGD 3	*	*	*	*	-	-
Zone A-2	FGD 4	*	*	*	-	-	-
	FGD 5	*	*	*	*	-	-
	FGD 6	*	*	*	*		-
	FGD 7	*	*	*	*	-	-
Zone B	FGD 8	*	*	*	*	-	*
	FGD 9	*	*	*	*	-	*
	FGD 10	*	*	*	*	-	-
	FGD 11	*	*	*	*	-	-
Zone C-1	FGD 12	*	*	*	*	-	-
Zone C-2	No FGD	-	-	-	-	-	-

The approach undertaken by this research was not just based on finding answers to my research questions but allowed for the expression of views and voices of the participants about the ranges of environmental changes they experienced. The use of this approach enabled me to assess broadly what their primary concerns (i.e hazards) were, and the perceived level of concern for the changes. I believed that listening to the array of hazards they chose to discuss fostered trust and openness when eventually I narrowed down the discussion to coastal erosion. In that way, they understood that I was interested in listening to their plight and was not just there for my academic output which they were sceptical about because of their prior experience. For instance, a participant had this to say in response to their knowledge of hazards (see quote 4.2):

Quote 4.2: *'I want you people to promise us that when you are through with this work that we will have a copy of it and that you didn't just come here for your study alone. At least, with that, we can show the findings to the government or any other agency that wants to help us.' – FGD 3- Male participant*

'…People have been coming to our area to ask questions but never come back but since you say it's for educational purposes, we will comply since we don't know if one of you could be of help to this community.' – FGD 3- Male participant

From the quotes above, it is clear that participants have had researchers come to the communities with bogus promises and after the research, never return. Some of the participants were apprehensive initially. During our discussion, I told them that a copy of the findings will be given to them and that I do intend to collaborate further with the community based on the recommendations from the study. My response seemed to have paved the way for a less apprehensive meeting with them and the openness of mind towards our discussion. My observation is that the participants were willing to fully participate if there was something at stake for them. But I had to also be careful to ensure that the information given was reliable and not exaggerated because the participants knew that it would be documented, possibly published, and could also inform government stakeholders or other agencies. This is where contextualisation of data becomes necessary to ensure the reliability. Validation of the data used was a continuous process and will be seen throughout the data analysis stage. To access local knowledge on the environmental changes, questions were asked by the moderator of the group discussion. One such questions was:

Please can anyone tell us about your experiences living here in this area? Have there been any changes in the area from when you were born or moved here till now? And what are the noticeable changes if any?

Here are some of the responses the village heads gave us on their experiences living in the study area (see quote 4.3):

***Quote 4.3**: 'We are predominantly fishermen. .... Erosion washes way the surface soil that used to yields better foods before now and washes the soil into the ocean…' - FGD 2- Male participant 4*

'The big engine boats are a huge problem here. The waves from its movement send a lot of water to the land and this recedes taking sand away from the land. Over time, it has washed up a lot of shore land and loosens the soil in the area making it easy to be carried away by waves, flooding and even rainfall'. FGD 3- male participant 6

'This village is called Idua Ukpata - One of the ancient villages here. For me, I have seen many changes. I was born in 1947 and since I have known myself, significant changes have taken place. Today, this change is known as climate change. That is what scientists call it… The erosion washes away the nipa palm and then causes the land to fall off. This now makes the creek and the river to be extended into the land. The nipa palm does not have strong roots and when it is washed away by erosion, the water has the freeway to enter the land (villages) because now there is nothing to block it.' - FGD 3- Male participant 3

These quotes show that the participants have local knowledge of the different hazards because of their direct experiences and can distinguish between them. As earlier discussed, the study area was divided into three zones (A, B, C) where the communities along the coast were grouped into. For instance, zones B and C showed extreme concern for almost all the perceived hazards. Their understanding of the changes that have taken place over time is also drawn from changes/decrease in their resources such as washing away of nipa palms and poorer yields of food. The variation in understanding is influenced by their proximity to the coast (direct open waters) and topographical location of the participants and priority of what hazards they perceived as most threatening. This is also evident in the major flooding history memories they gave. Though they all had similar dates usually around October, except Zone B which also experienced a major flooding event in 2018 which occurred in September of that year and coincidentally, they all reported that these were also periods when coastal erosion in the area intensified (table 4.4). Following that, the perception of the different hazards will also differ.

Table 4.4: Major Flooding/erosional experiences along the study coast

Location	Major Flooding/Erosional episodes
Zone A: Oron/Ibeno L.G.A	2012, 2017
Zone B: Ibeno	2012, 2013, 2017, 2018
Zone C: Eastern Obolo	2012, 2017

Although participants were able to explain the different hazards they experienced, the communities in the uplands/hinterland seem to be more concerned about gully erosion than coastal erosion which affects the lowland. This highlights the impact of topography on the perception of coastal erosion. Interestingly, despite the experience of those in the lowlands, there seems to be more subject knowledge among the participants in the upland or hinterland (FGD 1, 2, 6 & 9 - refer to table 4.1 for more information on the FGD IDs). This may be credited to their access to education, more information, and social amenities. For those in the lowlands, their understanding is primarily based on experience and, to an extent, knowledge, which is received from members in the community that have attended higher institutions of knowledge (post-secondary school programmes) and are more exposed to the concept of coastal erosion and climate change. The participants in zone A where FGDs 1 and 2 took place discussed extreme concern about the gully erosion as it had affected their roads, houses, and environment upland in the area. Unlike the participants from Idua Ukpata community (FGD 3), who discussed that they experienced more hazards than in other locations in zone A. This could likely be explained by the fact that the area is low lying nearer the ocean than the other locations visited. It was also the case in zone A-2, Ibaka (FGD 4), Mben Ndoro/Brama (FGD 5) and Ibuot Utan (FGD 7) communities, which had been severely impacted by coastal erosion. However, Unyehe (FGD 6) discussed that although coastal erosion was present, it had not been seriously impacted by it, which could be explained by its location being the furthest away from the coast in this zone.

The results in zone B show that the hazards along the coast in this zone are similar. The communities demonstrated that coastal erosion, flooding, extreme waves, and water salinisation were unique to the entire zone, as opposed to zones A and C, and that these hazards were of extreme concern in the area. However, communities such as Itak Edim Ukpa and Atia (FGDs 8 & 9) revealed that they were experiencing more hazards such as acid rain fall and attributed it to the onshore gas flaring system from the oil company located nearby. They expressed extreme concern because it was slowly corroding the roofs of the houses, window protectors, door handles, and rails. They also highlighted that the taste and hardness of the water used in the area were affected. The results show that this location is the most affected region; up to five perceived hazards are of extreme concern. These risks vary along the coast and could be dependent on the proximity to the coast. For instance, regions directly opened to the Atlantic Ocean like zone B are seen to experience more hazards than other regions in zone A and C. Overall, there is a general agreement along the entire coast that coastal erosion is present. However, the level of concern about coastal erosion hazards varies along the coast.

4.4.1.2 Perception of the causes (drivers) of coastal erosion

Having shown a knowledge of the hazards prevalent along the coast, it is imperative to have an in-depth understanding of their perception of the drivers of coastal erosion. Table 4.5 gives a synopsis of the perceived drivers of the coastal hazards in each of the zones across the study coast. This shows that the variability of perceived hazards across the coast and their understanding contributes to the risk impacted by coastal erosion. The perceived drivers from all the study locations are summarised in figure 4.16.

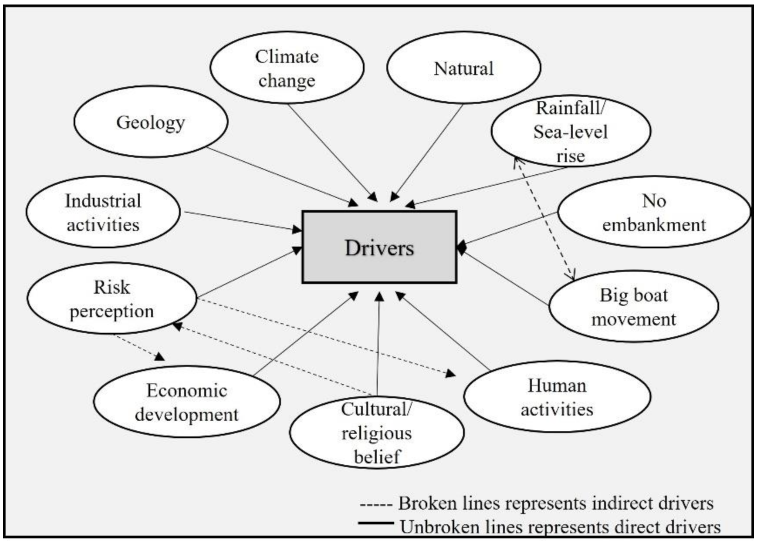


Figure 4.16: Perception of the causes of coastal erosion in the study area.

The FGDs enabled participants to identify various drivers of coastal erosion. It is important to note that the participants believe that the majority of the hazards have the same drivers. The arrows depict the perceived direct and indirect drivers of coastal erosion. For example, movement from large boats has a direct impact on the coast, and the impact of the waves from that movement may vary depending on rainfall/sea-level rise. In such a case, rainfall/sea-level rise becomes an indirect driver. Another example is risk perception because it influences how people and communities respond to the threat of erosion. People may be more likely to take actions to protect their houses and property, such as building seawalls or relocating, if they believe the risk of erosion is severe. On the other hand, people may be less motivated to act if they perceive the risk to be acceptable, which increases the possibility of erosion occurring. Furthermore, risk perception can impact policy decisions such as coastal erosion control funds and development limits in erosion-prone zones.

The understanding of the drivers of coastal erosion follows a similar pattern along the coast. I emphasise here that, even though this research is about coastal erosion, most of the participants had difficulty distinguishing the drivers of coastal erosion from other coastal hazards and, as a result, repeatedly provided the same drivers even after clarifications were made as to which hazard was of interest to the researcher. It is also noted that participants who live further away from the coast and are closer to town and social amenities have a different understanding of the drivers of coastal erosion. Participants were able to identify both climatic and non-climatic factors influencing coastal erosion during the discussion even though they did not focus on distinguishing them. For the natural drivers, participants were able to describe that sediments are progressively carried away during high and low tides, as well as when there are strong waves or a storm. However, if the responses were to be grouped, the categories seen in figure 4.17 can be deduced.

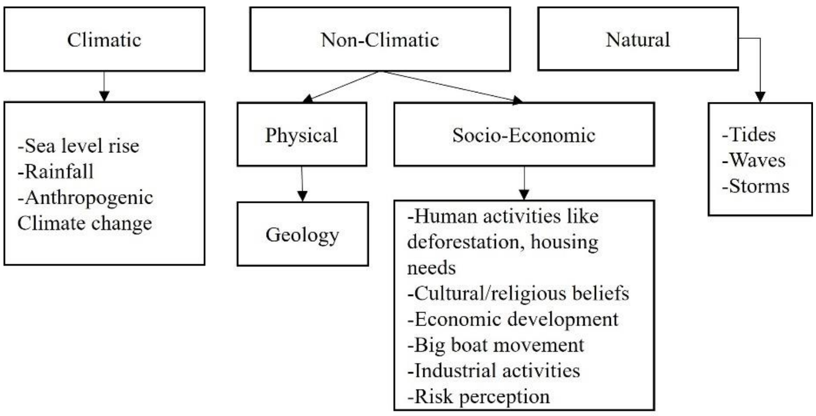


Figure 4.17: Categories of perceived drivers of erosion.

In Zone A (Oron and Mbo L.G.A), there is a similar understanding across the participants in all locations that the predominant drivers are natural, rainfall/sea-level rise, movement of big vessels/fishing boats, lack of embankment, no sacrifices to gods (traditional beliefs), and oil companies. However, in Zone A-1, Esin Uffot, Idua Asang, Idua Afaha Eduok and Ine Ekong communities, there seems to be a wider range of what the possible drivers were, including climate change, geology (slope), human activities and economic exploitation. It is understandable why the slope is a factor here because this zone happens to be the area with the most appreciable terrain height along the entire coast. The same is not the case in zone A-2 (Ibaka, Mben Ndoro, Brama, Unyehe and Ibuot Utan communities), the economic exploitation and slope factor (topography) were not mentioned, yet those are obvious drivers as observed during the fieldwork (figure 4.18). Only 25% of the participants acknowledged climate change and human activities as a driver.

Figure 4.18: Pictures A & B showing relatively flat terrain in some parts of the coast (Brama, Mbo L.G.A).

In zone B, the knowledge on the drivers is similar to that of zone A which indicates that the predominant drivers are nature, rainfall/sea-level rise, movement of big vessels/fishing boats, lack of embankment, cultural/traditional/religious beliefs and oil companies while in zone C, most factors in table 4.4, except cultural beliefs and the influence of risk perception, were acknowledged. Here are some responses during the FGDs by some participants on the perception of the causes of coastal hazards along the coast (quote 4.4):

Quote 4.4: *'...see, truth be told. Many years ago, our ancestors worshipped and sacrificed to the river goddess but with the introduction of Christianity, that practice has gradually faded away. So, it's their way of taking from us since we have not been giving them sacrifices again'. FGD 8- Male participant 6*

I do not totally agree with that. See it is natural and that's how God made it and water is a living thing, so it is growing just as we are growing too (laughing)- FGD 8- Male participant 7

In zone B, it is also interesting to note that 50% of the FGD locations that included climate change, economic development and slope factors have closer proximity to education and social amenities than the locations that did not include those factors. These locations, especially where FGD 9 took place, are relatively developed due to the presence of the ExxonMobil oil company. This understanding may result from the fact that two out of thirteen FGD participants had university degrees, five had college diplomas, three had secondary school certificates, one had primary school certificates while the remaining two had informal training. The level of education among leaders in the village, this study believes, has played an active role in understanding the hazards in the coast and the adaptive measures implemented. According to Muttarak et al. (2014), reduced vulnerability and increased resilience to disasters can both be achieved through education. They noted that it crucial to place more emphasis on education as a strategy of empowering individuals and communities.

Though there is an appreciable understanding of the causes of the change in the state of the environment, the way the communities, especially in the lowland, attach importance to the non-climatic and physical drivers such as cultural, traditional and religious beliefs will adversely impact the vulnerability in the area. This is so because change can only begin from within. Belief systems play a huge role here and if there is no influence on practices embedded in the tradition and cultural beliefs, there will be a state of continued pressure on the land without caution. The results also show that oil companies seem to be one of the most common drivers throughout the coast while drivers such as human activities, exploitation of the vegetation/mangrove which should have played a critical role in land cover are discussed by just 50% of the FGD. This reveals that despite the range of perceptions of drivers of erosion, there is a gap in awareness of the drivers of coastal erosion.

Table 4.5: Drivers of the hazards prevalent in the Akwa Ibom coast (Source; FGD).

Zone -	FGD/Driver	Climate change	Natural	Rainfall/ Sea-level rise	Human activities like deforestation	Movement of big fishing boats	No embankment	Cultural, traditional/ religious beliefs	Economic development: fishing, broom manufacturing, roofing sheets	Risk perception	Industrial: Oil companies	Geology (Slope)
Zone A-1	FGD 1	*	*	*	*	*	*	*	*	*	*	*
	FGD 2	*	*	*	*	*	*	*	*	*	*	*
	FGD 3	*	*	*	*	*	*	*	*	*	*	*
Zone A-2	FGD 4	*	*	*	*	*		*		*	*	
	FGD 5		*	*		*	*	*		*	*	
	FGD 6		*	*		*	*	*		*	*	
	FGD 7		*	*		*	*	*		*	*	
Zone B	FGD 8	*	*	*	*	*	*	*	*	*	*	*
	FGD 9	*	*	*	*	*	*	*	*	*	*	*
	FGD 10		*	*		*	*	*		*	*	
	FGD 11		*	*		*	*	*		*	*	
Zone C-1	FGD 12	*	*	*	*	*	*		*		*	*
Zone C-2	No FGD	-	-	-	-	-	-	-	-	-	-	-

4.4.2 How have the prevalent social-ecological interactions along the coast changed over time and what is the impact on the vulnerability of the area to coastal erosion?

This section uses the pressure-state-impacts components of the extended DPSIR model to describe the participants' understanding of how human activities and interactions with the environment have changed over time and what the resultant impacts are (see figure 4.19).

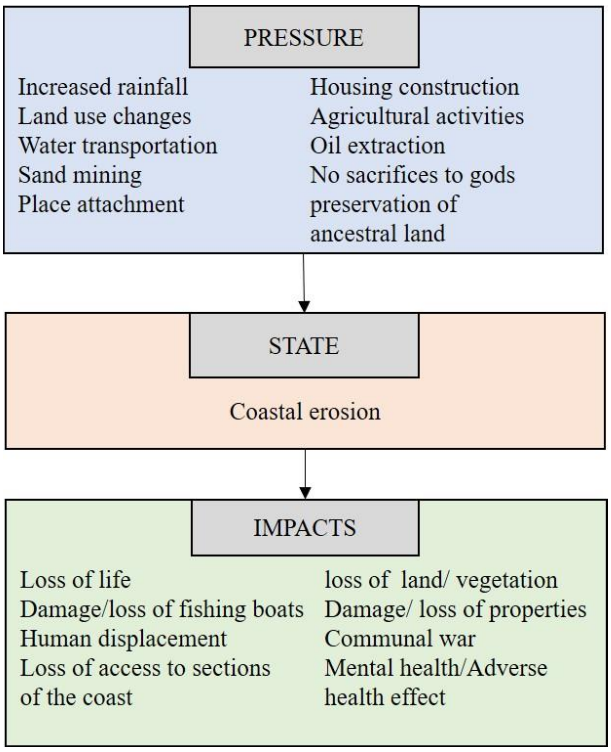


Figure 4.19: The pressure-state-impacts components of the extended DPSIR model illustrating the prevalent social-ecological interactions along the coast.

4.4.2.1 Pressure

There are direct and indirect activities that have led to the geomorphic changes in the state of the environment identified during the FGDs and observation. The responses on these activities are summarised in table 4.6 and give an understanding of the motivation of human activities which exert pressure on the environment even with the risk associated with prevalent hazards in the area. The pressures identified vary across the study locations and this research groups the identified pressures into natural, physical, economic, industrial, and cultural pressures (figure 4.20).

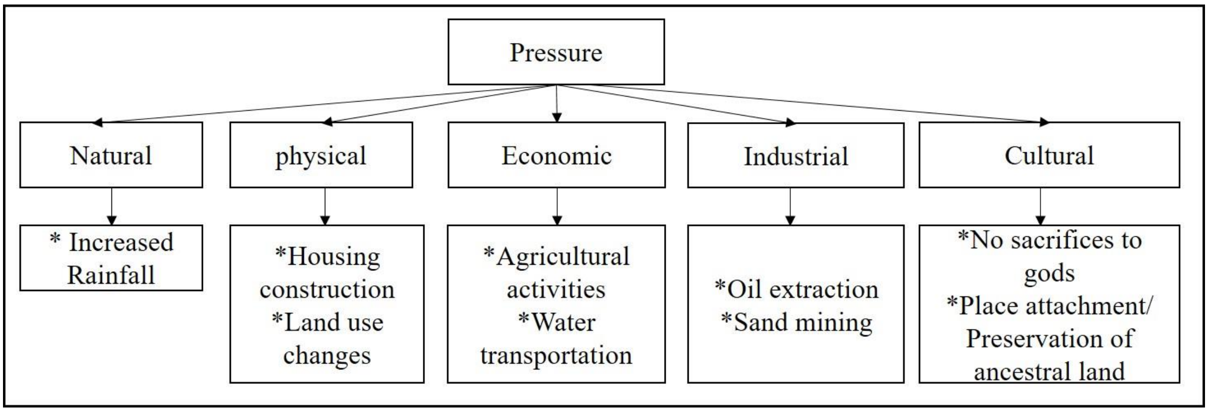


Figure 4.20: Categories of pressure in the study area.

Table 4.6 shows that the most common categories of pressure identified by participants in all the study locations were the natural (increased rainfall) and economic (water transport) components. The perception of increased rainfall in the area agrees with observed data reports by some publications like Amos et al. (2015) which show that there has been an increase in the amount of rainfall over the years using rainfall data from 1991 – 2010. According to the National Bureau of Statistic of Nigeria reports, Akwa Ibom State, where the study area is situated, had the fourth highest amount of rainfall recorded in Nigeria between 2012 -2015, ranging from 1912 to 2532 mm annually (NBS 2017). This also buttresses participants' earlier discussion represented in table 4.4 that periods of extreme rainfall events marked extreme erosional seasons in the area. From the results for the entire FGDs in zone A (Oron/Mbo L.G.A), there is a consensual understanding that increased rainfall, water transportation and belief systems/cultural pressures play significant roles in the state of coastal erosion in the area. Quote 4.5 is a response from an individual in FGD 3 which illustrates the belief system/cultural pressures.

Quote 4.5: *'…give to Caesar what belongs to Caesar…we stay in a coastal area and there are gods that govern the water. Before now, we use to appease the gods but now Christianity has made us stop all that but not everyone believes that should be the case. This has angered the gods and they have allowed all these issues to befall us and there is no protection again'. - FGD 3- Male participant 7*

The discussions also show that there is an appreciable understanding of the contribution of anthropogenic activities to the prevalence of coastal erosion in this area. Six out of the seven communities, where the FGDs were held in zone A, attributed the coastal erosion to water transportation, housing construction activities/land-use changes and removal of vegetation.

Two out of the six communities where the FGDs were held, related the pressure to include other anthropogenic factors such as agricultural activities such as crop farming and sand mining while five FGDs highlighted the pressure arising from oil extraction. Furthermore, six out of the seven communities where the FGD were held, highlighted place attachment/preservation of their ancestral land as a pressure.

Interestingly, in Zone B (Ibeno L.G.A), the participants' perception of the pressures varied immensely. However, there were similar responses from participants, which indicated that increased rainfall, water transportation and oil extraction are recognized factors in all the communities where the FGDs were held. Here are some responses from the participants on the perceived pressures in zone B (quote 4.6).

Quote 4.6: '…*heavy rain and longer rainfall. The rainfall we have now is more than we used to have before oooo. It rains too much'. - FGD 8- Male participant 4*

'…the sacrifices also play an important role. When they were done, our fathers did not have all these issues… even death from the water was scarce as the river goddess protected us'. FGD 8- Male participant 5

'…There are many reasons. I know that trees used to protect us, but flood and humans have destroyed all that. We use the mangrove for our houses and broom as you can see. It has been another source of livelihood for us'. - FGD 8- Male participant 4

Three out of the four FGDs locations indicated cultural factors as pressures. This illustrates that cultural beliefs/practices play an important role in vulnerability because believing that not sacrificing to ancestral gods induces coastal erosion and its consequences mean that any suggested preventive measure will be futile except returning to sacrifices. Apart from cultural beliefs, 50% of the FGD participants highlighted housing construction/land-use changes, removal of vegetation and agricultural activities as pressure factors. Only one location in this zone indicated sand mining activities as a pressure factor. This is understandable as this is the location that is most developed along this section of the coast and increased concrete buildings require 'sharp sand' for plastering of walls.

The participants from Zone C (Eastern Obolo L.G.A) said that the resulting environmental pressures are increased rainfall, water transportation, housing construction/land-use changes, removal of vegetation, oil extraction and place attachment/preservation of ancestral land. Factors such as agricultural activities, sacrifices to gods and sand mining were not considered because this location has most of its agricultural activities behind the backshore vegetation, and mud is mostly used for the construction of homes. The high educational level of most of the participants also indicates exposure to relevant information on climate change and other factors contributing to coastal erosion (see a participant's perception of pressure in quote 4.7).

Quote 4.7 : *'… Climate change has led to increased rainfall which supports erosion especially in places where there no vegetation'. FGD 12- Male participant 2*

Generally, in all the study locations, the most common perceived sources of pressure are the natural (increased rainfall) and economic (water transport) components. Apart from increased rainfall, water transportation is perceived by all FGD's to also be a major driver. They state that when speed boats are in motion, they usually send out strong waves which hit the shore and erode the environment. Unfortunately, speed boats are a major form of mobility there. From observation, boat drivers turn off the engine when they pass by each other to avoid capsizing but that is often not the case when passing through areas with accommodation. Despite that, these boat drivers do not act in isolation. There is the physical pressure that enables or accelerates natural or other drivers prevalent in the area.

The physical pressure which includes the construction of houses and land use changes is seen to be responsible for the removal of vegetation/deforestation. With the increasing population in those areas, there is huge competition for space to build. The houses, especially in the lowlands of the study location are usually thatch houses made from dry leaves/vegetation and sticks. This puts a demand on the vegetation, especially the mangroves in the area, to satisfy the housing needs. From the focus group discussion, it is realised that the dry vegetation used for the houses must be changed every year to avoid rainwater from entering the house. So, every year, most house owners in the area will have to cut down trees for sticks and vegetation to reinforce their house. This is a practice that has gone on for more than thirty years. The use of vegetation for housing purposes is not the only economic pressure exerted on the environment; the mangroves are also exploited for commercial purposes. The coastal area was known for its trade in brooms, and the raw material used for broom making is the mangroves. However, this trade is quickly fading since there was an over-exploitation of the mangroves which has left the area with just scarce pockets of mangroves. Unfortunately, there has also been an encroachment of nipa palms which they are not pleased with as the nipa palms are not as strong and economical as the mangroves.

Another perception of pressure on coastal erosion is oil extraction. Participants believe that they started experiencing changes after ExxonMobil started offshore drilling of oil along the coast in the 1960s.

Quote 4.8: *... I have seen many changes. I was born in 1947 and since I have known myself, significant changes have taken place. - FGD 3- Male participant 3*

This is a perception (see a participant's response on historical changes in quote 4.8) shared by all the communities where the FGDs were held in the study area. Most of the participants have lived in the study area all their lives and experienced these changes in their lifetime. Despite the experienced changes, the participants do not seem to be in a rush to relocate outside the location. The perceived place attachment/preservation of ancestral land could act as either a driver or pressure or both on coastal erosion. For instance, it could act as a factor influencing the legacy to live in the area, which drives the residents to either resort to cutting down trees to re-enforce their homes, or continued alteration of the environment to meet the needs of living in the area. However, their understanding of how to preserve their ancestral home or land is also the catalyst that has led to the removal of vegetation cover which in turn exposes the land, making it susceptible to coastal erosion. In general, the results of the participants' perceptions of pressure clearly show that the majority of participants understand the fact that coastal erosion is dependent on different determinants. Nevertheless, there is a huge concern here of how correct these perceptions are, especially of people who are most vulnerable living in areas highly susceptible to coastal erosion ("hotspots"). Coastal erosion hotspots here refer to locations that experience significant rates of erosion and impacts when compared to adjacent locations.

Table 4.6: Pressures on the Akwa Ibom coast (Source: FGD).

Zone -	FGD/ pressure	Increased rainfall	Water transport ation	Housing construction	Removal of backshore vegetation/ Mangrove exploitation	Agricultural activities	Oil extraction	Sand mining	No Sacrifices to gods	Preservation of ancestral land
Zone A-1	FGD 1	*	*	*	*	*	*	*	*	-
	FGD 2	*	*	*	*	*	*	*	*	*
	FGD 3	*	*	*	*	-	*	-	*	*
Zone A-2	FGD 4	*	*	*	*	-	*	-	*	*
	FGD 5	*	*	*	*	-	*	-	*	*
	FGD 6	*	*	*	*	-	*	-	*	*
	FGD 7	*	*	-	-	-	*	-	*	*
Zone B	FGD 8	*	*	*	*	*	*	-	*	*
	FGD 9	*	*	*	*	*	*	*	*	-
	FGD 10	*	*	-	-	-	*	-	*	*
	FGD 11	*	*	-	-	-	*	-	*	*
Zone C-1	FGD 12	*	*	*	*	-	*	-	-	*
Zone C-2	No FGD	-	-	-	-	-	-	-	-	-

4.4.2.2 Perception of the state of hazard

The state of hazard refers to the present condition of the environment as described by participants of the communities where the FGDs, walking interviews and direct observation took place. This condition or trend is a result of the pressure exerted on the environment. For the scope of this research, the state relating to coastal erosion will be discussed here. Results from the FGDs, walking interviews and direct observation show that coastal erosion is prominent in most parts of the coast (Table 4.7). However, the results show that there is a spatial variation in the level or degree of severity along the coast and the vulnerability associated with coastal erosion hazard. The participants in lower-lying sections of the coast attribute a very severe to severe state of the coastal erosion hazard.

Table 4.7: Status of the State of the environment.

Zone	FGD/ State	On-going Coastal erosion	Severity
Zone A-1	FGD 1	Present	Mild
	FGD 2	Present	Mild
	FGD 3	Present	Severe
Zone A-2	FGD 4	Present	Severe
	FGD 5	Present	Severe
	FGD 6	Present	Mild
	FGD 7	Present	Severe
Zone B	FGD 8	Present	Severe
	FGD 9	Present	Severe
	FGD 10	Present	Very Severe
	FGD 11	Present	Severe
Zone C-1	FGD 12	Present	Mild
	Walking Interview		Severe
Zone C-2	No FGD	-	-
	Interview	Present	Mild

The status summary in table 4.7 is a combined result derived from the perception of the participants, walking interviews and direct observation. In zone A (Oron/Mbo L.G.A), the status shows that the severity of the coastal erosion ranges from mild to severe, while the results for zone B (Ibeno L.G.A) ranges from severe to very severe which is consistent with the direct observation made during the fieldwork. The state of the hazard in zone C (Eastern Obolo/Ikot Abasi L.G.A) is perceived to be mild to severe which is also consistent with the observations made in the field. Though the community relocated behind the vegetation buffer, there are still evidences of previous impacts from coastal erosion. However, they believe that the effects have decreased since moving behind the vegetation buffer, which increases their resilience to coastal erosion. From the results on the severity, Zone B is perceived to have the greatest impact from coastal erosion which will be further discussed in the next section. This aligns with changes calculated from DSAS in chapter 3.3.2.1 which indicated that zone B had the highest average erosion rate of -5.23 m/yr from 1984-2020 (refer to chapter 3.3.2 for more details).

The widely held perception of the participants in all the FGDs, is that coastal erosion is an ongoing process along the coast. However, the level of severity varies along the coast. The results from the FGD analysis are combined with direct observations during the walking interview to develop a severity matrix to describe the state of the environment (refer to table 4.7). Based on results, the lowlands and areas closest to the coastline are the most affected by coastal erosion and they experience very severe coastal erosion while the upland was of moderate severity which is understandable since they are not directly affected by the impacts of coastal erosion. Overall, there is moderate to very severe coastal erosion prevalent along the coast. This general finding corresponds to results by Oyegun et al. (2016) that showed significant coastal erosion along the Akwa Ibom coast.

4.4.2.3 Perception on the impacts

This section discusses the perceived impacts of coastal erosion along the Akwa Ibom coast. There is a wide range of impacts that have been experienced by the participants which include loss of life, loss of land/vegetation, damage or loss of fishing boats, damage/loss of property, human displacement, loss of access to sections of the coast, communal war, and poor mental health (see figure 4.21).

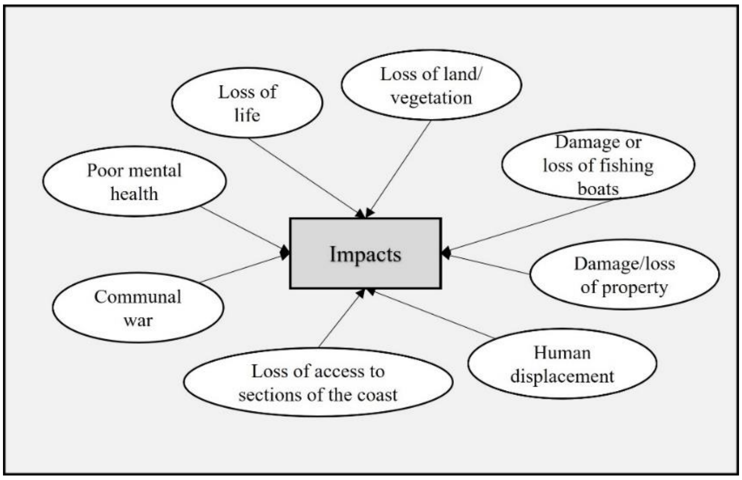


Figure 4.21: Perceived assemblages of the impact of coastal erosion in the study area.

With climate change exacerbated by human activities, these impacts will continue to be experienced in the future if proper precautions are not taken to increase resilience (see figure 4.22). Although the perception of the impact of coastal erosion varies across the different study locations (see table 4.8), it is observed that loss of land/vegetation, damage/loss of property and human displacements are the most common indicators of the impact of coastal erosion in all the study locations. Participants' perception of those in zone a-1 (Oron L.G.A), in addition to the most common indicators mentioned, highlighted loss/damage of boats which is their source of livelihood (FGD 2 and 3 - Idua Asang/Idua Afaha Eduok and Idua Ukpata/Ine Ekong), communal war (FGD 2 - Idua Asang) and mental health issues (FGD 1 – Esin Uffot). However, in zone a-2 (Mbo L.G.A), all the study locations mentioned loss/damage of their fishing boats with loss of access to sections of the coast as additional indicators of the impacts experienced by them. There was no mention of the loss of lives linking it directly with coastal erosion during the FGD, except with flooding. However, some participants had attributed the loss of lives to erosion too, because from their experience, they believe that the coastal flooding and erosion occur together and as such, they reference the impacts together. Since they were not able to establish a clear differentiation of the causation of death and lack accuracy, this research will exclude that information on impacts of coastal erosion in zone A except where there is a clear distinction on the cause of death. Though the findings on the perceived impacts in zone B are similar to the results from zone A in terms of loss of land/vegetation, damage/loss of property, human displacements, loss/damage of boats which is their source of livelihood (FGD 8, 9 and 11 – Itak Edim Ukpa/Atia, Ndito Eka Iba/Inua Eyet Ikot and Iwuo Okpom Okpolum), communal war (FGD 8 - Itak Edim Ukpa/Atia) and mental health issues (FGD 8 and 10 - Itak Edim Ukpa/Atia and Akata) indicators, the participants in zone B, have included loss of lives

(FGD 8 and 10 - Itak Edim Ukpa/Atia and Akata) which suggests a higher vulnerability of the area to coastal erosion than other areas along the coast with no fatalities. For instance, on the 30th of September 2018 where Akata community in zone B lost 8 lives arising from a multiple of coastal hazards (erosion, flooding and storm surge). Coastal erosion had been a lingering problem that the community was experiencing but this situation was compounded by the intense flooding and storm surge that took place on that day. The perceived impact from coastal erosion is different in zone C (Eastern Obolo L.G.A) which has FGDs study locations with the lowest indicated impacts along the coast. It was observed during the walking interview that most of the locations along the Eatern Obolo axis of zone C have most of the community settled behind a vegetation buffer (area protected by vegetation), especially the mangroves which contribute immensely to the reduction of erosion because of their engineering properties such as structure and depth of roots which enables them to reduce the energy fluid, wind and waves passing through them (Gracia et al. 2018; Brunier et al. 2019). The general perception shows that the major impacts in the area are loss of land, damage/loss of fishing boats, damage/loss of property and human displacement.

Figure 4.22: Photos A- D shows the impact of coastal erosion in zone B (Photo A and C show damage to property and land, photo C shows loss of access to other parts of the coast and photo D shows loss of land/vegetation).

Figure 4.23 (B and C) show the location of the remains of a building fence in zone C which the participants, during the walking interview, explained that the original fence was about 5 poles or more (a pole according to them is equivalent to 50m) away from the coastline about thirty years ago. This simply means that the regression of the coastline is about ≥250m from their understanding.

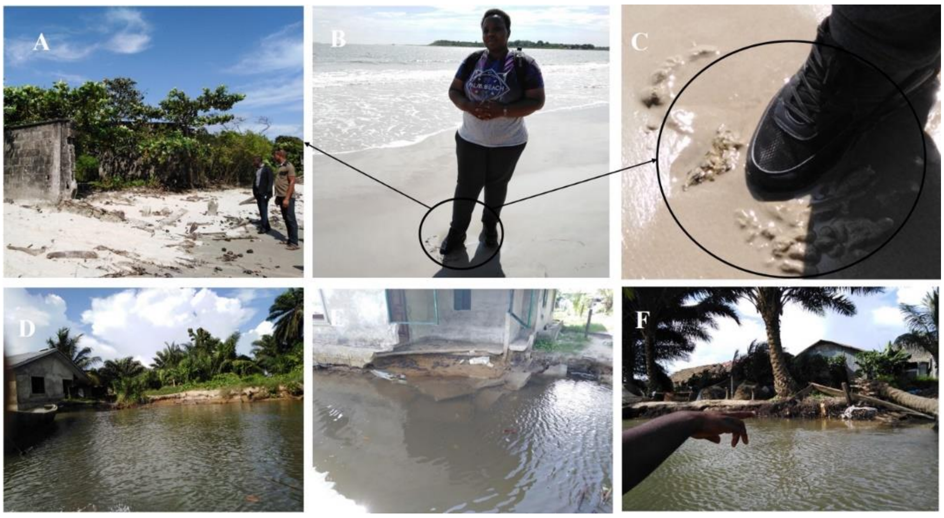


Figure 4.23: Figure A shows the remains of and erected property fence, figure B and C show the proximity of the location of the remains of the foundation for the fence, D and E shows property damage, and picture F shows trees falling.

Figure 4.23 gives an indication of the prevalence of coastal erosion in the zone which corroborates the results derived from the linear regression rate (LRR) computed for this section of the coast from Landsat satellite images spanning from 1986 to 2020 in chapter 3. The results showed a trend of coastal erosion with 80.66% (584 transects) of the transects being erosional and 61.44% of the erosional transects showing significant erosion. For this zone, the maximum erosion derived was -14.86m/yr while the average erosion in the area is -3.82±0.99m/yr which implies that the shoreline is experiencing a landward movement at a rate of not less than 3m/yr (refer to chapter 3.3.2 for more details).

The general perception along the entire coast indicates that coastal erosion has led to serious environmental degradation, loss of land, homes, farmlands, and loss of schools. Coastal erosion is also believed to have impacted adversely on the mental health of many people in the area; to have led to several deaths and have also caused inter-community wars in some areas because of land encroachment during relocation to the upland by those who lived down by the coast. This information and account on impacts such as communal wars and adverse mental health revealed during FGD, to my best of knowledge, has never been documented by previous researchers. This illustrates how important soliciting local knowledge can impact government policy for coastal management. There is also a significant impact on their source of livelihood which is primarily fishing. The mangrove that usually attracted fish, crayfish and crabs near shore has been destroyed and swept away by erosion and flooding. This, they believe has led to a decrease in the number of fish and a dwindling market because of the risk involved to sail inwards the Atlantic Ocean to catch fish and still with just a few fish to show for it. Also, the erosion and flooding activities have encouraged the growth of nipa palm, which is of low economic value to them, and does not encourage marine animals to come nearshore. The in-depth discussion reveals how the participants have experiential knowledge because they have felt the impacts first hand and is the crux of the matter to them (how coastal erosion has affected them).

Table 4.8: Impacts of the coastal erosion in the Akwa Ibom coast (Source; FGD).

Zone -	FGD/Impacts	Loss of life	Loss of land/ vegetation	Damage/Loss of fishing boats	Damage/loss of properties	Human displacement	Loss of access to sections of the coast	Communal wars	Mental health/Adverse health effect
Zone A-1	FGD 1	-	*	-	*	*	-	-	*
	FGD 2	-	*	*	*	*	-	*	-
	FGD 3	-	*	*	*	*	-	-	-
Zone A-2	FGD 4	-	*	*	*	*	-	-	-
	FGD 5	-	*	*	*	*	*	-	-
	FGD 6	-	*	*	*	*	*	-	-
	FGD 7	-	*	*	*	*	*	-	-
Zone B	FGD 8	*	*	*	*	*	-	*	*
	FGD 9	-	*	*	*	*	-	-	-
	FGD 10	*	*	-	*	*	*	-	*
	FGD 11	-	*	*	*	*	*	-	-
Zone C-1	FGD 12	-	*	*	*	*	-	-	-
Zone C-2	No FGD	-	-	-	-	-	-	-	-

4.4.3 How has the risk perception in the area influenced the emerging social - geomorphological patterns/processes in the area?

4.4.3.1 Risk Perception (RP)

Exploring the concept of coastal erosion risk is important as it allows elicitation of participants' ideas about the risk associated with coastal erosion. The risk perception varies across the study location and is usually controlled or influenced by several varying factors. There was no starting point or node, but the discussion entered at any point where they felt comfortable to talk. The major factors influencing the risk perception in the study area as observed and generated from the FGD include risk acceptance, belief system, culture, and education (see figure 4.24). The in-depth-understanding allowed in the RP conceptual framework enables the participants to highlight the reasons behind the human-environment relationship. A good illustration can be seen in Longueville et al. (2020)'s study which examined the perception of and responses to coastal risk in Cotonou, Benin. The study identified and analysed the responses of five different groups of people in the area, including wealthy individuals, people at risk, fishermen, individuals in vulnerable situations that are trapped and poor newcomers, providing insights into how each group responds differently to the risk of coastal erosion in the area. Such depth of understanding will inform or influence sustainable policies not easily represented in only empirical/physical vulnerability assessments. This also illustrates the advantage of combining the RP with the social-ecological system models which incorporate these complexities in its model, address and give tools on the organisation of findings, acquired knowledge and are well suited for comparative analysis.

Risk perception is not a straightforward concept, as seen in figure 4.24. Several factors are influencing each other, and it shows a continuum of risk perception indicators which means that risk perception is not limited to only the indicated factors but is a progressive sequence that keeps ongoing.

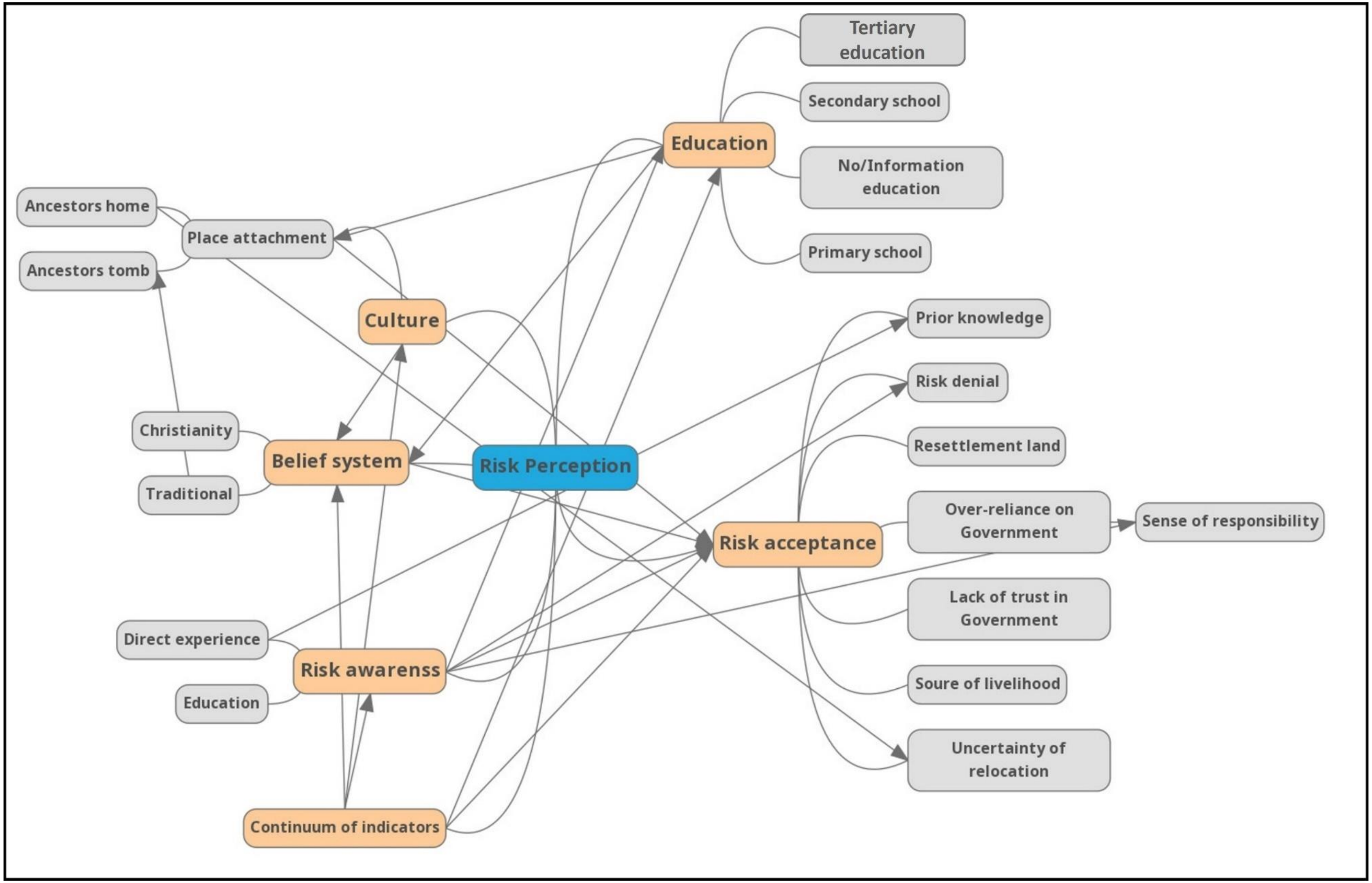


Figure 4.24: A continuum of the risk perception indicators adopted for this research. Themes generated from focus group discussion (adapted from (Rufat et al. 2015).

The understanding of the coastal erosion risk in the study area follows the rhizomatic principles where the discussion or concept of discussion does not have a start and endpoint, but could start mid-point with linkages connecting different components and could arrive at an intermezzo but not a conclusion (Masny 2015). It also demonstrates the fluidity of knowledge and that harnessing the different forms will adequately inform this research. Some emerging risk perception indicators includes:

I) Risk awareness

Risk awareness is simply the understanding of risk in one's environment; what it is, what it does and how it could be prevented. Awareness plays an important factor in understanding coastal risk (Rufat et al. 2015). However, Luís et al. (2016) suggest that risk awareness does not necessarily equate to a reduced coastal risk perception. This reflects my observations in the field. Quote 4.3 shows that there is an agreement that coastal erosion is taking place but quote 4.4 highlights a gap in awareness of the drivers of coastal erosion. The belief that coastal erosion is caused by the Gods of the land could conflict with any scientific or technical solutions to manage the problem. This belief can be a barrier to effective coastal erosion management because they may instead rely on traditional practices or rituals to address the issue. Also as seen in figure 4.24, awareness is not a stand-alone parameter which means that for a reduced perception of vulnerability to coastal erosion, a combination of several other factors come in to play. For a more detailed discussion on the perceived awareness, refer to 4.4.1.

II) Risk acceptance

The observation and responses from the FGDs show that risk acceptance plays a significant role in the vulnerability of the coast to coastal erosion. Figure 4.25 shows that there are several factors acting directly and indirectly on the level of risk perception. Definite conclusions are difficult to reach since varied factors give rise to one another and the context of the factors may be different depending on one's experience. Hence, I take up a continuum structure, that is, a continuous or limitless range of elements without clear dividing points[2]. An interesting discussion ensued during one of the FGDs when asked why they choose to remain in the area

[2] Cambridge Dictionary (2021): https://dictionary.cambridge.org/dictionary/english/continuum

despite the risk associated with coastal erosion. See the discussion on risk perception in quote 4.9 (P refers to the participant, while F refers to facilitator).

Quote 4.9:

P: *How did you come here today?*

F: *We drove down here.*

P: *Okay… Was there no risk involved in driving down here today? But you came did you not?*
F: *Yes! we did because it is necessary.*

P: *You see my sister, there is risk in everything in life, even sleeping at night, even if you stay in town. How do you know that you will not be robbed? What is the guarantee? If you follow all that, you will get nothing done. We stay here because 1) For the preservation of our culture (cultural belief). Our ancestors lived and died here with their graves. We cannot just pick up and leave them behind or leave our communities…. 2) Our great grandfathers can be angry with us if we leave their graves here. It is said that 'the dead only has their eyes closed not their ears' so, if we leave, they would be very angry with us saying why did you leave us. That is why I did what I did when we started, pouring the libation and saying the incantations calling on them…. So, we cannot leave the land and our ancestors. My grandparents were buried here, so were my parents and when I die, I will be buried here too. So, we have a strong belief that our ancestors are with us. The deities they put in place are watching over us….We will stay here until Jesus comes.*

This reasoning (see quote 4.9) demonstrates that the acceptance of the risk is governed by several factors including their denial of the risk itself or their over-reliance on prior knowledge of the risk to mitigate the impact of the risk. An example of such denial is a participant's comment on the fact that the deities there would not let anything happen to them (see quote 4.10).

Quote 4.10: *'We have deities here that protect us, protect every Idua person even if the boat sinks, they can swim out. It is not easy for us to die in the river because our deities protect us'. – FGD 2 – male participant*

Several factors influence risk acceptance, which include (though not limited to):

a) Prior experiences of the participants regarding different hazards along the coast, especially flooding, seem to affect the way they relate to coastal erosion issues. For instance, their understanding of weather and tidal variations enables them to plan their daily movements and temporary relocation, but coastal erosion is not governed by the ocean currents and waves but also by geology and geomorphology. This means that they could experience a serious impact from coastal erosion when they least expect it because they are only considering the wave factor. Apart from prior knowledge and risk denial, the participants showed understanding of a variety and relationships of other risk acceptance.

b) Uncertainty of relocation: This topic brought a lot of emotions because some of the participants reflected on the communal wars that had happened because of trying to resettle further inland. The majority showed displeasure for that and suggested that would rather stay and die than move and be killed by other community people (see quote 4.11 for some participants response on relocation). Though many were faced with the fear of the uncertainty that lies with re-location, some noted that they were open to it if the government could step in and facilitate that process and broker a peace treaty between them and the host community.

Quote 4.11:'*As the land gets washed away, we keep moving upland. That is why Eyoabasi village is fighting with us not to move up and we have to fight back that need to survive. Why should we go and die there?' FGD 3- Male participant 3*

'We cannot leave because we don't have anywhere to go to. The war that happened here was because of land when people were trying to relocate from the seaside inwards. The other people felt threatened and want to take whatever land we have left. The government did not come to our aid. Though they tried to discuss with the parties involved, it did not work. Our houses, property were destroyed, many people were killed. Till now, though we are not fighting now, there is no real cordiality between our village and the other village. It is the condition of things that has kept us here. No more to relocate, no place to relocate to, our business is here (fishing and fish selling), our family is here. This is where we have known all our lives. Sadly, we have to suffer like this. What did we do to deserve this?' FGD 2- male participant 8.

c) Source of livelihood: Though some participants indicated that they would love to relocate elsewhere due to the increased risk of living along the coast, however, such relocation is hindered because the coast is where they have their source of livelihood. From the discussion, more in-depth knowledge was gained that the reservation for those of them who do not have proper education is hinged on the question: *what jobs opportunities will be available for them, particularly those with no educational qualifications, if they relocate and forgo fishing as a source of income?* This concern shows that education also plays a vital role (directly or indirectly) in risk acceptance.

d) Over-reliance or lack of trust in Government: Some participants believe that there is actually nothing they can do about their situation other than accept the risk of staying there unless the government comes to their rescue.

Quote 4.12:'… *We are still hoping on the government to come to our aid. I just hope they can do an embankment to secure the coast.' FGD 4- male participant 4.*

The major appeal from them is the construction of an embankment along the coast (see quote 4.12). They made references to the little stretches of the coast that had embankments and concluded that those areas are protected now, and such benevolence should be extended to other areas, especially where there are human settlements. Another school of thought drawn from the discussion is that even if the government should ask them to relocate, they will not because the government will abandon them like it is at present.

e) Resettlement: The participants emphasised that resettlement had been used by the community to manage the risk of coastal erosion. They explained that when the lands where they lived directly by the coast were eroded, the community or those who had farmlands inland resettled in those areas. Unfortunately, the participants agreed that there are no longer enough lands available for community resettlement because more than half of the reserved farmlands have been used to resettle those impacted by coastal erosion. Participants stated that resettlement to the limited available land has had a significant impact on their food supply due to lower crop production and yield due to reclaimed farmlands for housing purposes.

III) Belief system and Culture

Interrelated with other factors, the belief systems help in understanding more about participants' perceptions and why they respond to risks in the way they do. Religious and traditional practices are driven by the major belief systems identified in the study area. Concerning traditional practices, here are some responses from participants on why coastal hazards take place (see quote 4.13).

Quote 4.13: *'…. they used to carry out sacrifice before now. They will say buy goat, cow, yam, and whatever have you and would even stop the movement for that but now the Ibibio brought in the gospel and do not allow those things to be done anymore… Apart from that, there is no money to buy all those things. So, it has become a problem when we can't sacrifice as before to protect our land and lives…' – FGD 9 - Male participant 2*

There was a situation where participants had different beliefs on what causes coastal erosion (see the last response in quote 4.13). Here the response from a participant was countering initial responses which suggested that the traditional gods were responsible. This illustrates that beliefs and culture are crucial in understanding the way of life of a group of people. Also, one seeks to understand how the culture in the area has influenced the sense of attachment to the location which makes it either difficult to mitigate the impact of coastal erosion or support a stronger resilience, as such, impacting positively or negatively on vulnerability. In my opinion, the cultural component of risk perception overlaps with the belief system in the area and is illustrated in quote 4.14 which displays the cultural and the traditional belief that they must stay there because their ancestors were buried there. This coincided with the need for maintenance and passing on of the family land/home.

Quote 4.14: *'Firstly, this is our home and land; our forefathers passed it down to us. Secondly, we are used to it. Where my grandfather built his house has been washed out into the sea. This place we are now staying was not the original place we stayed but it used to be our farmlands…We do not have any other place to go. Thirdly, our ancestors were laid to rest here and we can't leave them like that'. FGD 3- male participant 3*

The above quote demonstrates that place attachment perception in this context is influenced by a variety of factors, not just culture. According to quote 4.11, one interesting factor highlighted is communal wars, and to avoid conflict, they would rather stay in their land than die in a war.

IV) Education

Though this factor was not an essential requirement for participation, the observation and responses during the FGD show that there is a strong correlation between the education level and the perception of coastal hazards together with the risk associated with them. For instance, here is a response from one of the participants illustrating the role of education on risk perception (see quote 4:15).

Quote 4.15:'*This village is called Idua Ukpata. One of the ancient villages here. For me, I have seen many changes. I was born in 1947 and since I have known myself, significant changes have taken place. Today, this change is known as climate change. By this time, many years ago during Sept-Oct you only have to take your net to the river side, and you will catch fishes and prawns but now you cannot find them again. You will have to go deeper into the sea to find* *that…This is just one of the changes I have seen. Another one is that we used to have mangroves along the coast but now because of climate change, they are gone. FGD 3- Male participant 4*

'…People like me and few others were fortunate to be sponsored to school all the way to tertiary education with the proceeds from fishing.' - FGD 2- Male participant 4

The responses in quote 4.15 show that there is comprehensive knowledge about the environmental changes in the area through lived experience and gained knowledge facilitated by receiving a higher education. Based on the overall response, a risk perception matrix was developed by this study based on some key risk perception indicators considered to ascertain the level of vulnerability in the different study locations along the coast (see table 4.9). The matrix shows the vulnerability rank that equates the risk perception factors. The new developed risk perception matrix was sent to a third party with a background in Geography who is knowledgeable in coastal hazard assessments along the Akwa Ibom coast for verification and validation. This was done to ensure that the risk perception matrix is objective and devoid of biases, as well as provide an independent evaluation, which can help in identifying any areas for improvement. As a result, the risk perception matrix gains credibility and reliability, and can be used to enhance decision making.

Table 4.9: Risk Perception matrix of coastal erosion in the study area.

Risk Perception Vulnerability Index	Ranking	Direct Experience Due to Proximity	Risk Acceptance/ Denial	Risk Awareness	Education	Belief System/ Culture	Sense of Responsibility	Severity of Impact	Responses
Very Low	1	Property > 1km No Experience/ not Heard about it	Unacceptable	Highly/strongly Aware	Tertiary Education	Climate change/Human activities	Easy- Management practices implemented	Mild	Partial/full embankment and unexploited vegetation along coast
Low	2	Property >500m off the coast. Heard about it but not affected by it.	Acceptable with controls	Moderately aware	Secondary Education	Environmental (geology), require only Government assistance (for embankment)	Not difficult	Moderate	Restricted exploitation of vegetation/mangroves and replanting of mangroves
High	3	Property within 100-500m of the coast. Significant damages to property, roads	Acceptable	Fairly Aware	Primary Education /Informal Education	Controlled by ancestral gods control it, little can be done about it e.g appease the gods	Very difficult	Severe	Sandbags and planks placed around houses individuals
Very high	4	Property within 0-100m of the coast. At least one fatality, major damaged to property with relocation	Little/No risk	Not aware/poorly aware	No Education	Natural e.g. Oceans are dynamic systems, nothing can be done about it	Not at all possible	Very severe	No response by Government, local Government and other agencies. There is nothing that can be done by the Communities.

4.4.4 How do the coping mechanisms currently used mitigate the impact of coastal erosion?

The 'response' component of the extended DPSIR, interviews and direct observations were analysed to give more understanding of the coping mechanisms and resilience implemented in the area (see figure 4.25).

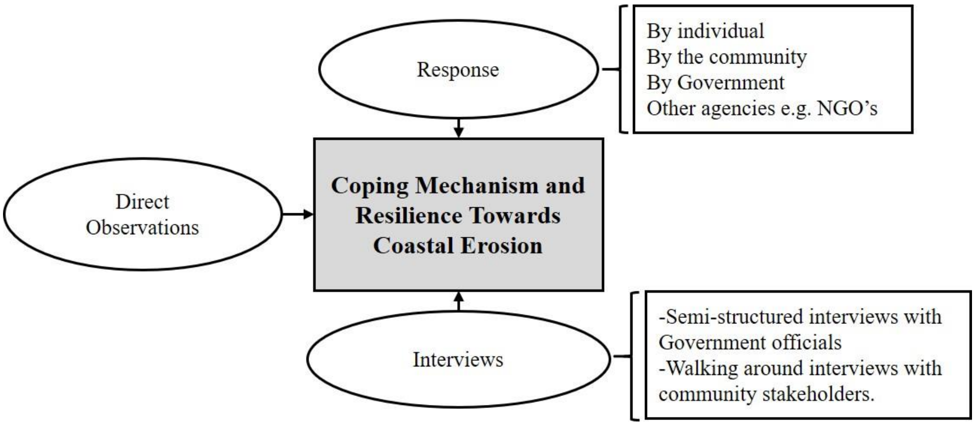


Figure 4.25: Coping Mechanisms and resilience towards coastal erosion.

4.4.4.1 Perception on the responses

Responses in the DPSIR framework refer to measures taken by the government or community stakeholders to mitigate the impact of hazards or adapt to the changes caused by them.

4.4.4.1.1 Responses from Government

From field observation and responses from the communities where the FGDs were held, little or no government interventions have been carried out along the coast (see table 4.10 and figure 4.26) except along specific sections of the coast – the museum at Oron, the seaport at Ibaka, Mbo and the fuel station at Ikot Abasi L.G.A's (see figure 4.26).

Figure 4.26A-C**:** Cement embankment at a) Ibaka, Mbo L.G.A B & C) Ikot Abasi Local Government area.

Most of the participants believe that embankments by the Government would be the solution to coastal erosion (see quote 4.16). However, they feel let down by the Government who have not provided that despite numerous pleas for help. The participants of the FGDs suggest that there is no organised form of communication between the village and the government because most of the FGD participants said that the village has written many letters to the government but have not had any responses or help from them. These are highlighted in the responses by some participants in quote 4.16, on their perception of the response of the Government. All the communities visited cry neglect and say they only hear from the government during election periods.

Quote 4.16: *'…we need serious embankment, concrete is very strong, the one we are having was since 1987 but it just at the seaport'. FGD 4 -Male participant 1*

'…Yes! Most especially children. We have suffered a lot here and the government has neglected us. This is the largest coastline in West Africa. Yet no one comes to our aid. Our land has been destroyed, swallowed up, our farms (look at that…pointing to somewhere), houses and even our boats have not been spared'. FGD 8- Male participant 1

'…but we usually cry to the government. In fact, there was a time they said they will come to do the land reclamation, yet they never came. The government has done absolutely nothing to salvage the situation. FGD 10- Male participant 1

'…what the government has done is this borehole that they drilled for us and the water is not even good, even schools, we do not have for children. This one you are seeing here is the village head that ordered the building to be used as a school'. FGD 5- Male Participant 6

Participants further explained that even the communities in the study location that have a good source of drinking water have had it donated from the assistance of non-Governmental organizations (NGOs). While most of the community agreed that the Government had done nothing to alleviate the impact of the risk, one community acknowledged that the government had provided a borehole for them but further mentioned that the water coming out is not good (see the last quote in quote 4.16) and had nothing to do with the plight they were facing with coastal erosion.

4.4.4.1.2 Responses by individuals/village council

The responses highlighted by the participants in walking interviews and observation are shown in table 4.10 and figure 4.27. The most common form of coping mechanisms by community stakeholders are the use of sandbags, planks and sticks to reinforce their homes. 83% of the FGD participants highlighted that this is the best practice for them to secure their homes and farmlands. Other than that, 100% revealed that the village council has ensured that affected individuals are relocated as soon as there are lands available. The responses derived from the FGD across the study locations show that apart from impact-response at the individual level, there are inadequate or inappropriate mechanisms put in place to mitigate the impact of coastal erosion.

Figure 4.27 A-F**:** Pictures A – E show individual responses to the change of state of the environment and picture F show the response by the village council to relocate the affected individuals to a new village site.

Hence, the severity of the impact especially at the lowlands zone. At the community level, resettlement of affected individuals to available lands is carried out. However, it is not always feasible due to the shortage of land reserves. The community attempts to relocate the affected group of people to available farmland or community land, but if this is not possible, the people must relocate outside the area. In the past, encroachment on nearby villages had resulted in communal wars, resulting in the loss of lives and property. It is worth noting here that another perception of the participants that could increase vulnerability is the understanding they cannot do anything to mitigate the impacts of coastal erosion except the Government. Unfortunately, the embankment facilitated by the Government is only completed on the strip that serves the areas of Government's interest, such as the tourist Museum in Oron, the floating mega gas station in Ikot Abasi, and at the Ibaka seaport in Mbo Local Government areas.

Having been to the field and from the FGDs, I understand the people's plight in demanding embankment and the definite need for one, because in areas where embankment has been implemented, such as the shoreline near the Oron Museum in Zone A, the coast appears to be protected from erosion and the shoreline stabilised. According to Rangel-Buitrago et al. (2018), while hard erosion measures such as embankments have received significant attention as one of the best approaches to curbing coastal erosion, they are not without limitations such as high construction and maintenance costs. A possible approach to addressing coastal erosion at the community level would be to preserve backshore vegetation and to stop or reduce mangrove exploitation. Surprisingly, only one community (FGD12 - Emeroke 1, Eastern Obolo L.G.A) has relocated most of its residents behind the backshore vegetation. This response is facilitated by academic knowledge and understanding. Here, one of the village advisers is a geology graduate and has played key roles in management policies in the village. While coastal erosion is prevalent in that location, the impact level is lower than in the zone B study location. The vulnerability is also heightened by beliefs that coastal erosion is a divine act and the work of local deities. This means that nothing can be done about the situation except to accept the risks. And with the conflict between religious views now overwhelming traditional views on sacrifice to gods, they believe they will be washed away in a matter of years unless they return to traditional ways of sacrificing to the marine and land gods Here, sacrifices to the gods are more than just a discrete act that solves other problems; they indicate a very different and deep interconnection between humans (communities) and non-human environments. Meaning that in the world, both the visible and the unseen are connected and interdependent (Van Beek 2017). As a result, a return to that level of interdependence (including sacrificial practices), would also mean a return to a more widespread understanding and appreciation of how the human and non-human worlds are connected and depend on each other. All of this means that, it is an indication of a distinct relationship with the earth, rather than simply a token or instrumental "exchange" of products.

During the fieldwork, I had 6 interviews with representatives from three state government agencies representatives and three local Government offices. The interviews gathered that awareness campaigns were created mostly in the city but not in coastal areas. However, according to the representative of the State Ministry of Environment and Mineral resources, that these communities have been visited and advised to relocate from those areas, but they refused. When I requested a previous report of hazards/risk assessment, it was observed that the ministry did not have a comprehensive knowledge of the different hazards occurring and the extent of devastation caused by coastal hazards in these areas and was referred to another unit, the NEWMAP office (Nigeria Erosion and Watershed Management Project) (see quote 4.16 for Interview excerpts from a state ministry officer on availability of coastal erosion reports).

Quote 4.17: *'…Most of the information you want, you know this new mark is a world bank sponsored program and you know that before the world bank starts anything, they must do a lot of studies. So, a lot of studies have been done along the coastline, a lot of pictures and maps have been taken, but it is all with NEWMAP office. - INTERV 1- Female participant 1*

Unfortunately, the NEWMAP project, which is a World Bank project partly funded in Nigeria on erosion assessment and rehabilitation, is primarily focused on gully erosion and did not have any information on coastal erosion. As such, there was no past or ongoing report that I could access from them. This probably explains why the representative from the ministry indicated that the commissioner was interested in my findings and that they would be open to any collaborations with me on coastal erosion based on my research. For most local Governments, the officers say that there is little or nothing that can be done for these communities with the limited resources they have and rely greatly on the State and Federal Government for any mitigation plans.

Table 4.10: Responses to coastal erosion in the Akwa Ibom coast (Source; FGD)

Zone -	FGD/ Responses	No management by both local/State Government	Sandbags and planks placed around house by individuals	Stilts erected in houses by individuals	Re-settling of displaced by the village	Embankment along some sections of the coast	Monetary incentives / erection of toilets and boreholes by NGOs and ExxonMobil	Water treatment plant donated by individuals	Restricted exploitation of vegetation/ Mangroves and replanting of mangroves
Zone A-1	FGD 1	-	-	-	*	*	-	-	-
	FGD 2	-	-	-	*	*	-	-	-
	FGD 3	-	*	*	*	*	-	-	-
Zone A-2	FGD 4	*	*	*	*	*	-	-	-
	FGD 5	-	*	*	*	-	-	*	-
	FGD 6	-	*	*	*	-	-	-	-
	FGD 7	-	*	*	*	-	-	-	-
Zone B	FGD 8	-	*	*	*	-	*	-	-
	FGD 9	-	*	*	*	-	*	*	-
	FGD 10	-	*	*	*	-	*	-	-
	FGD 11	-	*	*	*	-	*	-	-
Zone C-1	FGD 12	-	*	-	*	-	-	-	*
Zone C-2	No FGD	-	-	-	-	-	-	-	-

4.4.4.3 Interviews with Government Officials

The interviews with the state government officials revealed that there are conflicts between the government and community stakeholders. For ethical issues, I will not mention the name or the units within the Government ministry. When asked if they were aware or visited the Akata community at Ibeno that just recently suffered an intense case of coastal erosion and flooding that consumed about 40 thatch houses killing 8 people; quote 4.17 shows the response from the state government official on the situation in the coastal area.

Quote 4.18: *'…No, but we have not been there been at Akata and several others. These are communities that should have moved, but because of ancestral attachments, they said that their gods are there and all that. Like when we went there two years ago, you saw economic trees that were planted with people's houses right inside the water. So, flooding in Akata is something that happens almost every year'- INTERV 2- male participant 1*

The response in part explains the frustration among the community stakeholders when they discussed intervention from the government. They did acknowledge that the government has asked them to move. However, the big question is: to where? In their opinion, the government has not made any concrete arrangements for them like securing land for them or negotiating with the neighbouring villages to accommodate them. They further disclosed that in time past, moving upland was not an option for them except for those who had relatives or friends that could accommodate them. In time past, such movements have caused communal wars, as previously mentioned. When asking if adequate awareness campaigns were carried out, another state official said that most of the awareness campaigns, for the time being, were done in the metropolis. This indicates that the most vulnerable groups to coastal erosion are not in receipt of such awareness.

4.4.4.2 Reflections based on direct observation

To successfully adopt culturally responsive methodologies, the researchers and the participants are expected to allow their identities, culture and belief systems to influence the way the research is viewed and implemented to collectively create authentic new knowledge representative of all involved in the research (Bhabha, 1994; Soja 1996). On getting to the field and seeing the impact of coastal erosion in the area, the participants were asked if the

Government did not know that this area was part of their jurisdiction because it was sad seeing how some houses were eroding and yet still occupied by people. I, however, quickly added that the burden of management and mitigation lies on everyone instead of the government alone so that the participants do not get biased and feel only the government has to ensure environmental sustainability. This kind of outburst of emotion was not repeated throughout the fieldwork. Another situation I encountered was trying to redirect the discussion during the FGD. There were few instances when the participants in the communities further inland kept referring me to the gully erosion in the area. I acknowledged their information which was part of the general discussion but had to re-direct the focus of the discussion to coastal erosion which is of interest to me. After that, I had to have a brief re-training of the interpreters and assistant because I was not sure if they just wanted me to know of their other plights or they simply were not aware of the area of my interest. This greatly improved because, in the last inland community of the study, they discussed more coastal erosion.

As a researcher, reflexivity was established to ensure that my opinions or prior knowledge about the subject of interest did not influence the interview process (Breen 2006). For instance, before the fieldwork, remote sensing/GIS was used to do a preliminary change analysis along the coast between 1984 – 2015 (see section 5.5.4). Reflections enabled me to familiarise myself and re-familiarise myself more with the emerging assemblages and be critical about the data. Approaching my data in a non-linear form has enabled me to unravel the 'why' behind the relationship of the community stakeholder and the environment even with the realization of the risk involved. Understanding the risk perception adequately informs the vulnerability of the community to coastal erosion. The different and multiple sources of data used for this study enabled me to triangulate my data (see figure 4.28) and demonstrate rigor in my analysis. The fascinating thing about this research is that this chapter (qualitative) gives an in-depth understanding of the different factors that influence vulnerability along the coast which explains the results derived in my quantitative chapters (chapter 3 & 5). This agrees with Wilson (2014) that triangulation of data approach gives a richer data resource and enables the researcher to give a fuller picture of the phenomenon under observation and also increase the confidence or reliability of findings.

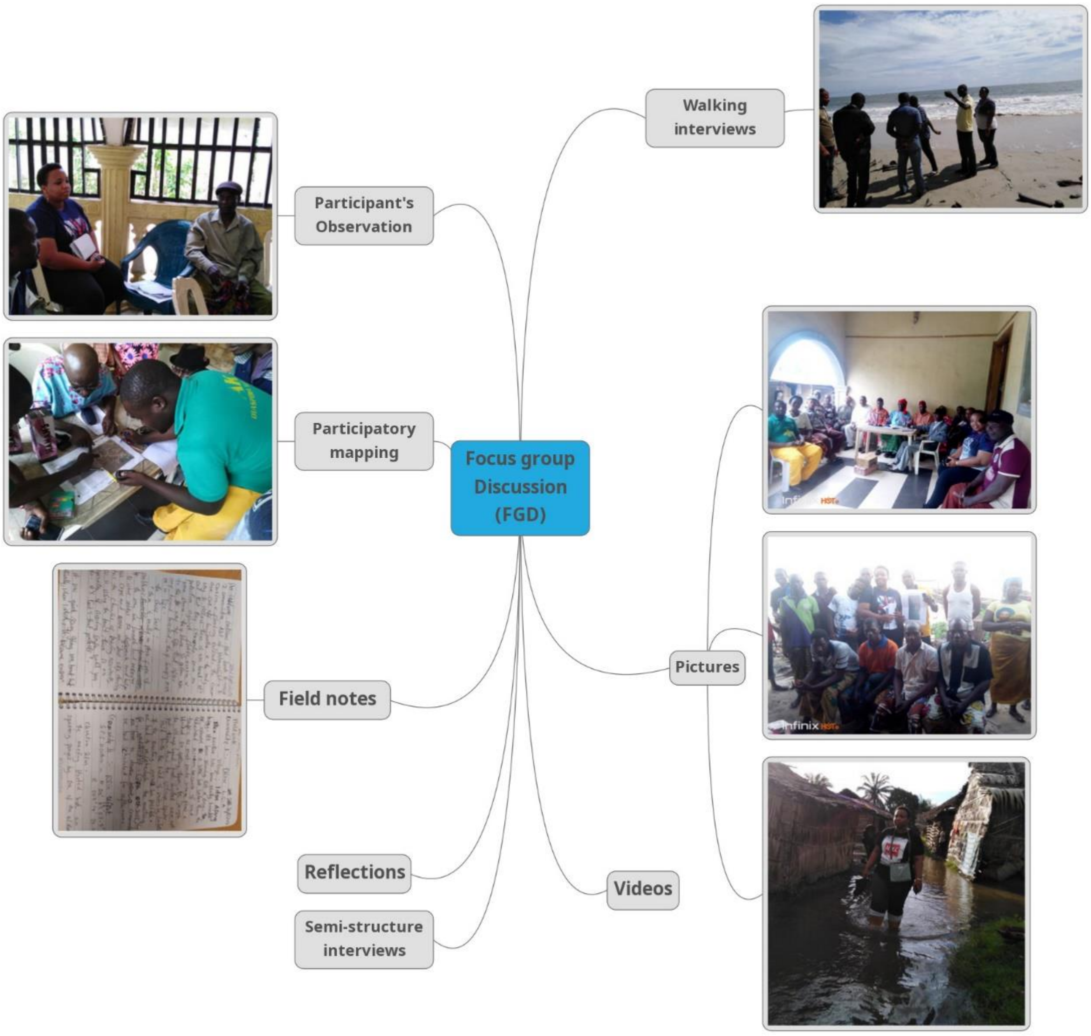


Figure 4.28: Triangulation of data used for this research (researcher, 2021)

Direct observation is useful for establishing credibility. Ground truthing is simply the collection of real-world data to support the accuracy of remotely sensed data, such as satellite images. Prior to fieldwork, desk research was conducted, and a quantitative change analysis was performed, which revealed that coastal erosion is the dominant process in the study area. The triangulation of data enabled me to know the degree/extent of coastal erosion taking place there as perceived by the stakeholders and the areas experiencing the most erosion. However, on getting there for the FGD/interviews, I did not disclose that I had information already of preliminarily assessed coastal erosion from satellite images; rather I allowed the group to discuss the extent of loss of land and the impact coastal erosion has on them. Local knowledge on the coastal erosion hazard should not be neglected or undervalued. The entire process of the fieldwork and analysis has been a continuous, deterritorialising (becoming) and reterritorialising (actualised) of concepts to rupture and form new connections (Cumming 2015).

4.5 Conclusion

Results show that the strand coast of Nigeria, once a natural geological paradise which served as a home to many, a source of plenty of food and land for farming, is now a place of rapid fading landforms with increased susceptibility and vulnerability to coastal hazards. The changes, which were initially slow but are now accelerated, have in recent times led to the disappearing coastline by coastal erosion, which is one of the key issues faced every day along the coast. This chapter analysed social-ecological data using qualitative methods including interviews, walking interviews and focus group responses to assess the local risk perception of coastal erosion, adaptive capacity, and threat/hazard mitigation. To assess the spatial variability of the social-ecological drivers and impacts of coastal erosion along the Akwa Ibom State coast, the findings show that perception of coastal erosion along the entire coast varies spatially. Although there is an appreciable knowledge about coastal erosion hazards, this does not correlate with the high levels of vulnerability assessed via their overall risk perception. The diversity in the range of perceptions on the drivers, pressure, impact, and responses shows that adequate awareness of each factor and their causes is limited and that relates with their level of knowledge which is more adequate in the upland/hinterland than in lowlands which are directly posed with the coastal hazard threats.

Participants, due to lack of trust in the government’s assistance, have resorted to individual /community level coping mechanisms/adaptation strategies such as sandbagging, stilting, resettlement among others to enhance community resilience to coastal erosion impacts. Apart from impact-response at the individual level, there are no other adequate or proper mechanisms put in place to mitigate the impact of coastal erosion; hence, the severity of the impact, particularly at the lowlands zone and as such, the very high levels of vulnerability. The key findings and risk perception assessment matrix developed from this analysis will inform the development of an integrated coastal erosion vulnerability index of the study coast presented in Chapter 5.

To increase resilience and adaptive capacities which can reduce the impact of coastal erosion, there is a huge need to create a tailored management/environmental awareness which centres around the needs of the different coastal areas. As such, no one-size-fits-all approach should be used. The findings here can inform policies on coastal management. Vulnerability can also be reduced, and resilience increased if the different stakeholders in both Government and the local communities work together rather than individually. Community engagement is highly recommended for sustainable management implementation. Coastal hazards programs should be organised at the community level to enlighten and improve knowledge on coastal erosion/hazards, causes, the drivers, pressures, and potential impacts of coastal erosion/hazards.

Chapter 5: Coastal Erosion Vulnerability Assessment Along the Akwa Ibom Coast Using a combined Geospatial and PGIS based approach

Chapter five identifies the optimum approach for assessing coastal erosion vulnerability in a data scarce region. Historical change rates in coastal erosion susceptibility using the Digital Shoreline Analysis System (DSAS) linear regression rates, a vulnerability model - Coastal Vulnerability Index (CVI) and participatory GIS and focus group discussions are integrated to assess socio-ecological vulnerability to coastal erosion.

Chapter 5

5.1 Introduction

In order to mitigate the risk associated with coastal erosion, a coastal assessment analysis for coastal susceptibility and vulnerability to climate change caused coastal erosion is required to meet the significant need for adaptation within the coastal zone. As a result, the first step in assessing the coastal erosion risk must be to identify the causes of coastal erosion in the area. Climate change has both natural and anthropogenic origins, but we already know that our climate is fast changing, particularly because of human activity (IPCC 2022). Consequently, it is critical to comprehend the interplay of both physical and social elements in the coastal environment.

With increased population in coastal areas (United-Nations 2017), people's exposure to coastal risks and impacts from SLR (such as flooding, erosion, loss of biodiversity, and ocean acidification) is expected to increase (IPCC 2018). To this end, it is vital to examine the state of coastal vulnerability in coastal areas. Several ways of assessing coastal vulnerability have been developed into models based on physical elements that contribute to shoreline change. Coastal vulnerability assessments have been widely utilised to evaluate vulnerability to several coastal hazards (refer to section 2.2.3) which includes erosion (Jana et al. 2013). Globally, these interactions contribute to vulnerability-related repercussions, which are visible along the low-lying shoreline of Akwa Ibom State in Nigeria's Niger Delta region, necessitating further investigation at this local scale. Mclaughlin and Cooper (2010) and Lopez Royo et al. (2016) also explored the advantages of measuring vulnerability at various spatial scales. To understand the vulnerability associated with the dynamism and interaction of various natural and human components along the coast at various spatial scales, Ramieri et al. (2011), highlights that several approaches such as index-based approaches (Gornitz 1990; Murali et al. 2013; Oloyede et al. 2022), indicator-based approaches (Balica et al. 2012), GIS-based decision support approaches (Casini et al. 2015; Torresan et al. 2016), and dynamic computer models (Flax et al. 2002; Vafeidis et al. 2004; Nicholls et al. 2011) could be used. The most widely used, is the index-based methods (Roukounis et al. 2022) because of its simplicity and flexibility to adapt to a wide range of parameters. Adding as many parameters for assessing coastal vulnerability is possible but not mandatory nor recommended, since most variables are closely correlated (Mclaughlin et al. 2010). Rather, Mclaughlin et al. (2010) advised that it is important to select parameters that are most suitable for the scope of vulnerability studied and also accessible at the spatial scale of interest. The index-based method was adopted in this current study because of its adaptability for a wide range of parameters. The novelty of the approach in this study is the addition of local risk perception data to assess the vulnerability of the Akwa Ibom State coast to coastal erosion which to the best of my knowledge has never been done.

5.2 Aim

The aim of this chapter is to use a modified Coastal Vulnerability Index (CVI) approach to assess the vulnerability of the Akwa-Ibom coast along the Niger Delta region of Nigeria to coastal erosion. Spatio-temporal analysis of shoreline changes (1984-2020) of the study area (please see chapter 3.3) show that coastal erosion is prevalent in the area. The shoreline change data from chapter three and risk perception data from chapter four, served as input parameters for the overall integrated coastal erosion vulnerability index which is the focus of this chapter. To proffer recommendations useful for coastal planning, monitoring and decision-making at both governmental and village level; an assessment of the vulnerability and possible identification of areas of the coast that are most vulnerable to erosion is vital.

5.2.1 Research questions

To achieve the aim, the following questions are addressed:

- How vulnerable is the physical coast and coastal communities of Akwa Ibom State to coastal erosion? (Discussed in section 5.5.1)
- What are the benefits of including social risk perceptions and participatory GIS (PGIS) in assessing coastal erosion? (Discussed in section 5.5.2)
- Does the integration of physical, socio-economic and social-risk perception characteristics contribute to an improved vulnerability assessment? (Discussed in section 5.5.3)
- Can this approach be generalised for use in other data scarce regions? (Discussed in section 5.6.3)

5.3 Conceptual Framework and Research Approach

This current research draws upon the Working Group II contribution to the IPCC's sixth Assessment Report (WGII AR6) (IPCC 2022) as a conceptual framework for vulnerability and risk (see figure 5.1).

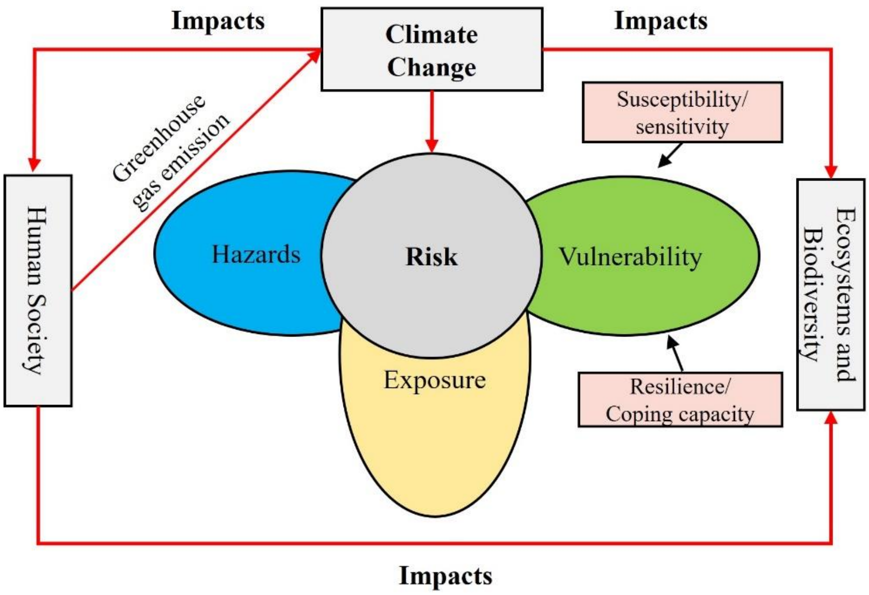


Figure 5.1: Adapted from the Working Group II contribution to the IPCC's Fifth Assessment Report (WGII AR6) (IPCC 2022).

According to the IPCC (2022), climate change is caused by human activity, which creates hazards that might have serious impacts and risk when combined with exposure and vulnerability of both the human society and the ecosystem (see figure 5.1). It suggests that exposure, susceptibility/sensitivity, and resilience/coping capacity can have a substantial impact on human vulnerability. However, the nature of the associated vulnerability differs depending on the in-situ conditions (both social and physical) in the region (IPCC 2014). The concept of vulnerability used in this study lies within the definitions by Benassai et al (2014) which simplifies vulnerability as the susceptibility of a coastal area to be affected by inundation or erosion. Mclaughlin et al. (2010) defines vulnerability as the sum of coastal characteristics (resilience and susceptibility), coastal forcing, and socio-economic factors; Meur-Ferec et al. (2011) describes vulnerability as a combination of hazards, the assets at risk, management measures emplaced and perception of risk. These definitions are appropriate for this study situated in Nigeria since it aims to determine the degree to which the human-environment system is susceptible to coastal erosion. Please see sections 2.1.3 and 2.15, for a more detailed explanation of vulnerability employed in this study.

In this study, the vulnerability assessment is carried out using three different approaches (see figure 5.2): index-based, participatory-GIS, and social learning which draws on the local perception of coastal erosion and how it impacts on both the environment and humans in the coastal area. These approaches were chosen due to their versatility to accommodate the availability/lack of data for the study area.

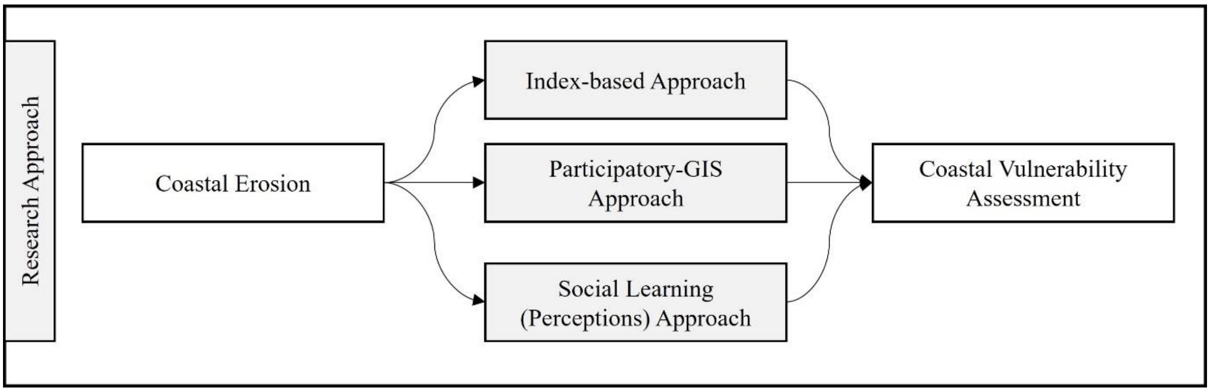


Figure 5.2: Research approach adopted for this study

5.3.1 Index-based approach - Coastal Vulnerability Index

The most widely used index-based approach is the coastal vulnerability index (CVI) originally developed by Gornitz (1990). Due to its simplicity, the use of the coastal vulnerability index (CVI) is often adopted to assess coastal vulnerability to sea-level rise (SLR) driven erosion (Koroglu, et al., 2019). Palmer et al (2011) noted that it is a rapid method that could be used in the assessment of coastal vulnerability using crucial but few parameters such as beach width, distance of vegetation behind the back beach, dune width, distance to 20m isobath and percentage outcrop. The important parameters, however, are determined by the scope of the investigation. Though few parameters could be used, there are also some CVI assessments that are data intensive with high volumes of data being used (e.g. see Table 2.4). As Koroglu et al. (2019) discussed, the information acquired through the use of CVI is often adopted in long term coastal planning and management, and subsequent decision making. The ability to adapt and vary the parameters used in the CVI makes this method well-suited for data scarce regions such as the study area in this research.

The original CVI, though widely used, is not without its limitations. Gornitz (1991) observed that the main limitation of the CVI is its lack of incorporating demographic and economic parameters which are essential for a more rigorous assessment. Other limitations include the weightings that are used for parameters, often these being subjective and entirely based on the user. Ramieri et al. (2011) suggested that the simplicity of the CVI may not adequately reflect the complexity of the coastal system and as such, should integrate indices that properly model these complexities like considering the human contribution/exposure to erosion risk (see table 2.4 for some modified versions of the original CVI model). Exposure variables are recognised as those predominantly exposed and vulnerable to the impact from a hazard or threat (Musa 2018). Interestingly, though exposure is important to determine risk, it is not always sufficient on its own (Cardona et al. 2012). With coastal vulnerability analysis, shorelines are often exposed to several variables, leading to the importance of understanding shoreline exposure when calculating the CVI. In simple terms, shoreline exposure refers to how much of the shoreline is exposed to the energy of waves; it is a crucial factor to consider when determining susceptibility (Suganya et al. 2015). Susceptibility refers to the degree to which a coast could be impacted by hazards as a result of the physical parameters (Fitton et al. 2018). It is important to note here that apart from scientific understanding of the physical parameters that contribute to coastal vulnerability, it is crucial to understand the social components (Corell et al. 2014). However, designing such research models can be tasking but vital since the results can impact environmental policies, adaptation and mitigation measures (Kelly et al. 2013).

This research assessed both the physical and social vulnerabilities of the Akwa Ibom coast in order to identify areas that are vulnerable to coastal erosion. The first stage of this study applies the coastal vulnerability index (CVI) to assess the physical vulnerability of the study area to coastal erosion. The original CVI by Gornitz et al. (1994) calculates the physical vulnerability as the square root of the product of the parameters divided by the number of parameters used (equation 5.1):

$$\boldsymbol{CVI} = \sqrt{\frac{\boldsymbol{a * b * c * d * e * f * g}}{\boldsymbol{n}}} \tag{5.1}$$

where *a, b, c, d, e, f, g* are the different physical parameters used and *n* is the total number parameters used.

These physical parameters (such as slope, geomorphology, elevation, shoreline displacement, tidal range and wave height) are calculated using both traditional and numerical models, as well as remote sensing and GIS as tools (Kunte et al. 2014). According to Sudha Rani et al. (2015), most vulnerability assessments approaches/parameters were adapted from Gornitz (1990) depending on availability of data and also the geographical area where it is being applied.

5.3.2 Socio-Economic Vulnerability Index

The CVI method by Murali et al. (2013) is used in the second stage to measure both the physical and socio-economic vulnerability. The CVI approach by Murali et al. (2013) uses the Analytical Hierarchical Process (AHP) derived weightings (AHP approach is discussed in detail later in this section) to calculate both the physical vulnerability (PVI) and socio-economic vulnerability (SVI) in equation 5.2 and equation 5.3;

$$PVI = W1X1 + W2X2 + W3X3 + W4X4 + W5X5 + W6X6 + W7X7 + \cdots \ldots WnXn \quad (5.2)$$

$$SVI = W1X1 + W2X2 + W3X3 + W4X4 + \cdots \ldots WnXn \quad (5.3)$$

Where *Wn* is the weight of the parameter and *Xn* is the vulnerability score of the parameter. For this study seven physical parameters were used namely: slope (%), geomorphology, elevation (m), proximity to the coast (m), shoreline changes(erosion/accretion) (m/yr), mean tidal range (m) and sea level change (mm/yr). Additionally, five socio-economic parameters were used namely: landuse/landcover, road network, coastal defence, cultural heritage and population density (persons per km^2).

The coastal vulnerability index (CVI) is (equation 5.4):

$$CVI = \frac{PVI+SVI}{2} \quad (5.4)$$

According to Murali et al. (2013), both components contribute equally to coastal vulnerability, hence the division by 2. Murali et al (2013) incorporated both the physical and socio-economic parameters of the Puducherry coast, India, using the vulnerability maps that were based on the weights and scores derived from the AHP for sub-indices of both PVI and SVI. There are many examples of how vulnerability maps based on AHP weights, and scores were used to compute the CVI and Murali et al (2013) is a good example. The weights for the PVI and SVI were calculated separately using the AHP weights and then combined to calculate the vulnerability of the area. Here, the weights derived are used to distinctively calculate the PVI and SVI separately and then summed up to determine the vulnerability along the coast. The combined results are divided by two which indicates the number of sets of parameters considered to get the final vulnerability. The results suggests that AHP-derived weights included in the CVI provided better vulnerability estimations than the original CVI, which would be more effective in making management decisions. However, one major drawback to this approach is that expert knowledge is still required to apply weights to the parameters, despite the inclusion of the SVI and PVI. As a result, it is probable that the outcome of the vulnerability will fluctuate depending on the individual or collective opinion of the experts, assuming they assign various priorities of importance. It is important to bear in mind that though the AHP weights improved on the outcome of the CVI, it does not overcome the limitation of subjectivity in the original CVI.

Studies using the Analytical Hierarchical Process (AHP) to improve CVI parameter weightings (e.g (Cozannet et al. 2013; Murali et al. 2013; Bagdanaviciute et al. 2015) have been conducted in numerous areas (see Table 2.4) and for different types of research. According to Canco et al. (2021), the AHP technique can be applied to both qualitative and quantitative issues with realistic bounds based on scientific and mathematical principles for setting priorities, evaluation, and decision-making, especially in complex situations. Many variables contribute to coastal erosion, each with varying degrees of impact. Because of this, AHP can be incorporated into the vulnerability assessment because it will provide a well-informed evaluation that can be used for management objectives, making it ideal.

The AHP technique uses a pairwise comparison to define the problem and construct a hierarchy of criteria to be used in making decisions to address the problem. Using a scale of absolute assessments on how much one element dominates another with respect to a certain attribute, pairwise comparisons are done (Saaty 2008). Stakeholders benefit from AHP's hierarchical structure, which helps them to make educated and informed decisions (Awang et al. 2017). In environmental research, it is often used alongside the Coastal Vulnerability Index to build a more comprehensive understanding. It has also been widely utilised in coastal vulnerability research to identify and prioritise the most vulnerable places along the coast (Awang et al. 2017; Sandhyavitri et al. 2020; Ahmed et al. 2021). Given its effectiveness in fostering qualitative decision-making (Partovi et al. 1990) and its adaptability and versatility for use in various fields and industries to facilitate decision-making (Awang et al. 2017), the AHP developed by Saaty (1987) continues to gain popularity in today's research and academic environments (Anfuso et al. 2021). The approach does have some limitations. Palcic et al. (2009) indicated that AHP involves significant work to break down the problem and assign hierarchies, assigning values and numerical scores to each element and variant as well as doing pairwise comparisons, and as such requires significant effort and can also be time consuming. Furthermore, AHP does not account for the interrelationships and co-dependency of the vulnerability variables along the coast through comparisons and hierarchy assignment.

Despite the limitations, several studies suggests that the AHP assigned weights improves the CVI. According to Özyurt et al. (2011), AHP provides weights and values to each coastal vulnerability index component, increasing AHP-CVI accuracy. Özyurt et al. (2011) also points out that assigning values to each variable through expert opinion reduces the chances of discrepancy from the subjectivity of the users and stakeholders. The improvemnents of the CVI using the AHP is likely to come from the the fact that AHP uses both technical and non technical criteria while the CVI uses only technical criteria (Sandhyavitri et al. 2020). Awang et al. (2017), emphasise the advantages of utilising the AHP technique to assess coastal erosion risk effectively by evaluating diverse and complex risk factors. Based on the advantages of integrating the AHP, it is a reasonable approach to assessing the Akwa Ibom coast's vulnerability to erosion because it allows coastal researchers with first-hand knowledge of the study area to contribute their expert knowledge, which is particularly important given the lack of adequate and recent data for analysis (Lin et al. 2017).

The AHP method was implemented using the following process:

i) Developing a criteria hierarchy which involves outlining the goal and structuring the selected criteria and sub criteria for decision making (Awang et al. 2017).

For this study, the parameters were selected based on data availability. The different parameters (see figure 5.3) were generated using ArcGIS 10.8 software and all vector maps were transformed into raster maps to have the same format making it easy for calculations and analysis.

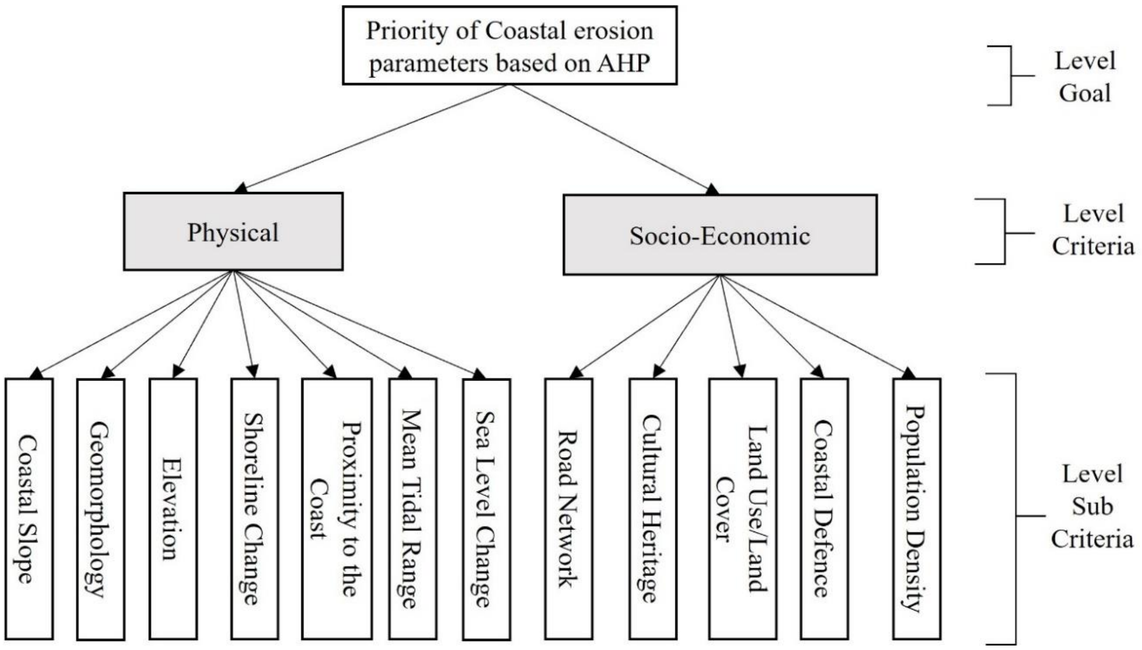


Figure 5.3: Hierarchical priority of parameters used for the physical and socio-economic vulnerability index in this study

ii) Allocating weights to the developed criteria to determine the relative importance of the attributes in a pairwise comparison and assigning numerical values to the attributes to derive the normalised weights for each attribute used.

The pairwise comparison for the parameters selected for this study was performed by the researcher and two other experts. Expert 1 is a lecturer/researcher within the Geology Department of Akwa Ibom State University while expert 2 is a researcher within the Geography Department of the University of Uyo, Akwa Ibom State. Both experts have adequate knowledge of the area and have carried out coastal research in the area. The expert knowledge was applied using the Saaty's fundamental scale of importance (Saaty 1987) (see table 5.1).

Table 5.1 Saaty's fundamental scale of measurement (Saaty 1987)

Intensity of Importance on an absolute scale	*Definition*
1	Equal Importance
3	Moderately more important
5	Strongly more important

7	Very strongly more important
9	Extremely more important
2,4,6,8	Intermediate values between the two adjacent judgements
Reciprocals:1/3, 1/5, 1/7, 1/9	If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i

iii) **Calculating the consistency ratio for the derived normalised weight of all the criteria.**

The reliability of the AHP method lies in the consistency of the pairwise comparison of the relative importance of elements. Ideally, according to Saaty (1987), the consistency ratio calculated should not exceed 0.1 (10%) and if it does, should be very marginal meaning that the inconsistency in the expert knowledge is about 10% which is tolerable. Consistency index which is a ratio of the consistency index and the random index generated by Saaty (1987) is given as equation 5.5 and equation 5.6;

$$Consistency\ ratio\ =\ Consistency\ Index\frac{CI}{Random}Index\ (RI) \qquad (5.5)$$

$$Where\ consistency\ index\ (CI) = \frac{ƛ\max\ \ -n}{n-1} \qquad (5.6)$$

Where ƛmax is the weighted sum of the normalised weights and n is the number of criteria/attributes used and RI is the random index.

RI (see table 5.2) was generated from a number of experiments and data entries of randomly generated reciprocals (sample size of 500) using the Saaty's scale to see if the matrix has a consistency index of 0.1 or less (Saaty 1987) which is acceptable.

Table 5.2: Saaty's Random consistency index (Saaty 1987)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

iv) Combination of all the expert's pairwise comparison to obtain the final weights indicating the level of importance of the parameters.

The final weights for each attribute derived from using AHP pairwise comparison methods were used to multiply the CVI values of the selected attributes for this study at the final stage of the vulnerability assessment (see section 5.4.3).

5.3.3 Social Learning Through Participatory Geographic Information System (PGIS)

As earlier mentioned in 5.3.1, the CVI model is limited in its ability to assess and analyse complex parameters such as the human contribution/exposure to erosion risk (Ramieri et al. 2011), which primarily facilitated the need for another approach of assessment. The third stage presented in this study, involves the use of social learning through a Participatory Geographical Information Systems (PGIS) approach to assess, understand and incorporate local knowledge in the coastal vulnerability assessment (refer to detailed discussion in section 2.3.2). The participatory GIS approaches used to generate the coastal erosion risk maps and the risk perception parameter used in this study were derived from focus group discussions, map-making exercises, walking interviews and photographs-taking (refer to section 4.3.2 for discussion on sampling techniques and data generation). The results from the PGIS were analysed in a descriptive process and presented in two stages;

1) The first stage which extensively discusses and analyses the risk perception of erosion along the study is presented in chapter 4 (refer to the socio-ecological assessment of coastal erosion in chapter 4)

2) The second stage which is presented as a case study where these data (social learning data) are used to create a participatory coastal erosion risk map along the the Akata section of Ibeno Local Government Area situated in the zone B of the study coast is discussed in this chapter 5.

3) Lastly, information from the local mapping of the coastal erosion hazard (refer to the section 5.5.4), the physical and socio-economic parameters in this chapter (refer to sections 5.5.1 and 5.5.2) and risk perception data generated in chapter 4 are all combined to evaluate the overall coastal vulnerability index of the selected case study area – Akata section of the Akwa Ibom coast (outlined in section 5.4.5).

Haklay et al. (2017) recognised that local stakeholders participation and mapping provide multiple data which facilitate a more holistic approach of vulnerability assessment where data from perceptions, memories and other qualitative aspects could be assesed and presented; but they also noted that such integration of local knowledge and quantitative scientific measurement can be complicated if not assessed structurally or properly. This means that where a coventional vulnerability assessments or survey methods are limited due to data availability, PGIS can address issues, such as lack of data for vulnerability assessment, by allowing for local generation of multi- parameter information, through stakeholder participation. The thematic layers from local knowledege (Chapter 4) can then be combined with GIS which is a powerful tool in vulnerability (Meenar 2017). These can be useful for vulnerability assessments, especially in developing countries, where spatial data quality are not a priority according to Brown et al. (2015) and where quantitative data availability (for example SLR), one of the key datasets for assessing and modelling the coastal system, is greatly limited (Musa et al. 2016) (refer to 2.3.2 for more details on PGIS). For instance, local knowledge of flooding, as demonstrated in the Senegalese municipality of Yeumbeul Nord (YN) by Sy et al (2016) is crucial for accessing reliable information required for understanding flood hazard and vulnerability. They also demonstrated how this local data can improve GIS and remote sensing data by adding context to it.

Sy et al (2016) examined flood risks using PGIS and demonstrated how local knowledge can improve interpretation and analysis of remote sensing data, especially when satellite images are covered by clouds or not available. According to Sy et al (2016), local knowledge offered new and more accurate information on vulnerability patterns, hazard intensity and exposure, suggesting that it can be used in place of expensive high-resolution satellite images. Gorokhovich et al. (2014) used three methodologies to assess past and future physical coastal changes caused by sea-level rise and coastal erosion in the Kotzebue Sound region of Northwest Alaska. Firstly, they assessed it using a GIS-index based coastal vulnerability index (CVI); then through a participatory GIS mapping of community subsistence resources developed in colloboration with the local experts and finally, through representative local surveys to establish the relevance of each subsistence resource and to identify particularly vulnerable locations. The purported benefits of their techniques of combining all three methods including the identification of regions most vulnerable to coastal erosion, the provision of relevant information to coastal managers on how coastal development had exacerbated coastal erosion in the area, which information serves as a guide for coastal management plans, provides the rationale for intergrating CVI, PGIS mapping and risk perception in assessing coastal erosion vulnerability in this study.

5.3.3.1 Risk Perception Vulnerability Index

As earlier discussed, PGIS offers a variety of benefits, multiple forms of data generation and a pathway to accessing local knowledge. For this study, the knowledge of risk perception was elicited through the stakeholder's coastal erosion hazard awareness, their understanding of the severity of the impacts and from the management response/measures taken by the government or community stakeholders to mitigate the impact of the hazards or adapt to the changes. During the PGIS exercise, stakeholders were asked (1) to identify and map areas currently at risk of erosion and (2) questioned to understand their risk perception on the coastal erosion and the impacts it has on both the physical environment and the community as a whole. An example can be found in section 4.4.2, where participants in the various FGDs were asked to rate the severity of erosion in their local communities. Their answers which were based on a likert scale with mild as the lowest rank and very severe as the highest, were utilised to form the ranking used in creating a GIS layer on the severity of risk. This layer served as an input parameter in the overall vulnerability assessment in section 5.5.5. Risk is the possibility of adverse impacts (Reisinger et al. 2020) and changes depending on circumstances (Cardona et al. 2012), meaning it may be necessary to quantify the uncertainty associated with it but quantifying it gives information of the nature and degree which will be necessary for assessing and managing it (Reisinger et al. 2020). It becomes more important when population and economic resources are present (Cardona et al. 2012). In analysing a system's vulnerability, it is critical to take into account factors such as the risk awareness, emotional attachment to a place, the willingness to accept or deny risk, the underlying cultural attitudes about risk, the adaptive capacity and other social factors are important in assessing a systemic vulnerability (Meur-Ferec et al. 2011). This understanding or percieved risk is known as risk perception (refer to 4.4.3 for discussion of the findings on risk perception in the study area).

This study is not suggesting that risk perception has not been considered in previous studies rather, previous researchers addressed it largely in a single discipline, but not as part of a multi-disciplinary approach. For example Sullivan-Wiley et al. (2017), used only risk perception index to understand how the people of Eastern Uganda perceived multi-environmental hazards. In their study, single index values were derived to represent the parameters used to assess each hazard. The responses on the perceived likelihood of experience, the perceived severity and concerns based on responses on a 5-point scale from 0 to 4 (0 = no likelihood, not severe, and no concern which progresses to 3 = definite likelihood; 4 = extremely severe, and extreme concern) hazards suggests that it is vital to consider public perception of risk impacts on the way people adapt or respond to environmental threats. In the study, they further suggested that if reducing vulnerability is the goal, engaging with those affected and understanding their risk perception is crucial especially in developing nations as their findings showed a significant relationship between risk perception, self-efficacy (belief in one's abilities) and protective actions. Also, Kunte et al. (2014) showed that when social variables were excluded from the studies, a large underestimation of vulnerability is likely. Though, the results suggests an improvement on the CVI result, their study did not offer adequate information on whether the results reflected the true vulnerability circumstances on ground, Hence, incoporating local knowledge through risk perception could improve on the results.

Having established the significance of risk perception, this study adapts the vulnerabiliy index approaches by Murali et al. (2013) and incorporation of PGIS in a CVI by Gorokhovich et al. (2014), in an index-based method which is simple, adaptable and has a wider application, to assess risk perception and used it to represent a newly proposed risk perception of erosion represented by RPIerosion, for the case study area. The data used for this index is generated based on the local knowledge gained during the focus group workshops along the study area. The steps taken included:

1. Using the reconceptualised driver-pressure-state-impact-response, DPSIR (H-DPSIRO) model by the European-Environmental-Agency (1999) to select parameters needed for this index. The risk indicators and explanation follow the data description done using the re-conceptualised DPSIR framework (refer to section 4.2.3). The original DPSIR is extensively discussed by the European-Environmental-Agency (1999). The DPSIR model adopted by the European Environmental Agency is a causal framework that distinguishes and shows a chain of causal links from driving forces (for example, human activities) through pressures (for example, land-use changes) to states (for example, coastal erosion) and impacts on the environment, human health and functions, which ultimately lead to responses (by stakeholders or government agencies).

2. The risk perception indicators derived from the focus group discusisions were ranked on a scale of 1-4, with 4 being the highest risk perception class and 1 the lowest (see table 5.3).
3. The indicators were grouped into three sub-indices following the IPCC (2022) where risk is a product of hazard, exposure and vulnerability.

$$Risk = hazard * exposure * vulnerability \quad (5.7)$$

   For more details on risk, hazard and vulnerability, refer to section 2.1 For this study, perception of hazards is broken down in to two; a) knowledge of the hazard, the drivers of the hazard, and b) knowledge of severity of impact; exposure represents either the presence or absence of human population in the hazard prone area while vulnerability indicates the responses (the coping capacity/resilience) of that community/government to the manage, resist and recover from the impact of that hazard.
4. The calculation of the risk perception of coastal erosion by substituting indicators from the results of the reconceptualised DPSIR (H-DPSIRO) from chapter 4 that describe the components of equation 5.7 to give equation 5.8 and equation 5.9:

$$RPIerosion = Hazards * Impacts * exposure * Responses \quad (5.8)$$

   So, equation 5.8 can be represented as

$$RPIerosion = X1 * X2 * \dots Xn \quad (5.9)$$

where RPIerosion is the coastal erosion risk perception index

Where Xn is the vulnerability score of the selected risk parameters.

The generated RPIerosion is combined with the physical vulnerability index and socio-economic index and applied in a case study location along the study coast to assess the applicability of integrating coastal erosion risk perception index in an overall vulnerability of the study area to coastal erosion.

The method proposed here to integrate the physical vulnerability index, socio-economic vulnerability and coastal erosion risk perception into an integrated coastal erosion vulnerability index (ICEVI) adapts the Murali et al. (2013) and Gorokhovich et al. (2014) approaches to include the risk perception on coastal erosion. The proposed integrated coastal erosion vulnerability index (ICEVI) (equation 5.10) combines equation 5.2, 5.3 and 5.8 and to give the final vulnerability and is presented as:

1) $ICEVI = \frac{PVI+SVI+RPIerosion}{3}$ (5.10)

where PVI is the physical vulnerability index

SVI is the socio-economical vulnerability index

And RPIerosion is the risk perception vulnerability index.

Following Murali et al. (2013), all three components contribute equally to coastal vulnerability, hence the division by 3. Moreover, as all three components can be used to assess coastal vulnerability individually, combining them should not underestimate the potential of each separate component. To justify the inclusion of the risk perception in a coastal vulnerability index, it is reasonable to question the addition of another dimension of a social layer when previous studies (Mclaughlin et al. 2010; Murali et al. 2013; Tano et al. 2018) have already incorporated socio-economic parameters. Most of the coastal vulnerability index studies that included socio-economic parameters have failed to consider how the social learning/ risk perceptions of the coastal communities affects their vulnerability. Thus, risk perception should be an integral component of a coastal vulnerability assessment especially when mitigation and management is the end goal.

Though previous studies suggest that the inclusion of social parameters is crucial in a hazard vulnerability assessment, the gap recognised by this study is that parameters like risk perception are not hardly considered as coastal vulnerability indices. An example of such is the CVI produced by Kunte et al. (2014) for the state of Goa, which included data only population density and tourist density as social data in addition to seven physical and geologic risk indicators. Though it included one socio-economic dataset, it overlooked the fact that other social thematic layers that can be derived through participatory mapping (for example, knowledge of the severity of impacts and understanding the resilience/coping capacity) could improve vulnerability results proffering better information that could impact policy (Gorokhovich et al. 2014).

According to Cutter et al. (2003), it is common for environmental vulnerability studies to remove social factors due to their difficulty in quantifying them, despite their critical role that contributes to the overall susceptility and resilence. Another difficulty, according to Cutter et al. (2003) is defining justifiable weighting factors for social dimensions while keeping in mind that not all features are equal. While one may argue that social vulnerability parameters have been incorporated into the coastal vulnerability index, risk perception and coping capacity are essential components in social vulnerability, and are rarely measured (refer to chapter 2.3.3)

Risk perception scoring is widely used in many fields, including health care (Rehani 2015). Uncertainty, according to this study, creates potential for perception differences. This is why the value of this parameter is crucial. Risk perception is subjective, Rehani (2015) defines it as a person's subjective assessment of a risk's features and severity.

> As rightly described "risk perception is the area that has received the least attention and where the majority of the problem exists"- Rehani (2015) pp 8.

To adequately address the vulnerability condition in coastal areas, the physical indicators alone are not sufficient because the coastal area is not only affected by the physical parameters that reveal susceptibility but also by other elements, such as the social and economic, cultural issues. This chapter's methodology (see figure 5.6) has various advantages, among which are:

- The approach is interdisciplinary which explores local knowledge by using PGIS mapping techniques to show locations of coastal hazards and exposure, focus group workshops to gather information on risk perception, making inference from the resulting map produced, walking interviews, photography, structured interviews and empirical data, and structured interviews to assess the coast's vulnerability to coastal erosion. This method helps to clarify where (location) and to what extent (impacts) coastal erosion is occurring, as well as why (causes) and how (pressure) it is occurring. These not only enhance the vulnerability assessment, aligning with previous studies that emphasise the necessity to incorporate coastal communities and other stakeholders in vulnerability assessments (social inclusion) (Kundu et al. 2011; Horita et al. 2013; Islam et al. 2013; Gorokhovich et al. 2014; Labib et al. 2017; Bevacqua et al. 2018; Haworth 2018) but it provides a simple indicator-based approach on how risk perception can be integrated into a coastal vulnerability index which can be very useful in data-scarce regions.
- The different sources of data enable triangulation of data, exhibiting rigor in the analysis. This accords with Wilson (2014) who suggests that using a triangulation of data techniques provides a richer data resource, allowing the researcher to provide a

more complete picture of the phenomenon under study while also increasing the confidence or dependability of conclusions.

There will be more details on the use of participatory GIS and focus group talks later in this chapter (5.5.4). In addition, when the community is included in the evaluation of vulnerability, adaptation and mitigation techniques are more effective. Even though this approach is not as straightforward as modelling the physical characteristics alone, Bitsura-Meszaros et al. (2019) discussed how important PGIS is in informing mitigation and adaptation efforts in their study that involved stakeholders in a climate change risk assessment along the NorthShore of Lake Superior in Minnesota.

Figure 5.4 shows the workflow implemented by this study to estimate the coastal vulnerability index (CVI) for the entire study coast and the ICEVI of the selected case study location, Akata, which is along the Akwa Ibom coast. In general terms, this chapter systematically assigns relative priorities for both the physical and social parameters in a structured process based on the AHP method as detailed in Palcic et al. (2009) to determine the integrated coastal erosion vulnerability of the study area which is contingent on the physical vulnerability index (PVI), socio-economical vulnerability index(SVI) and risk perception index (RPIerosion).

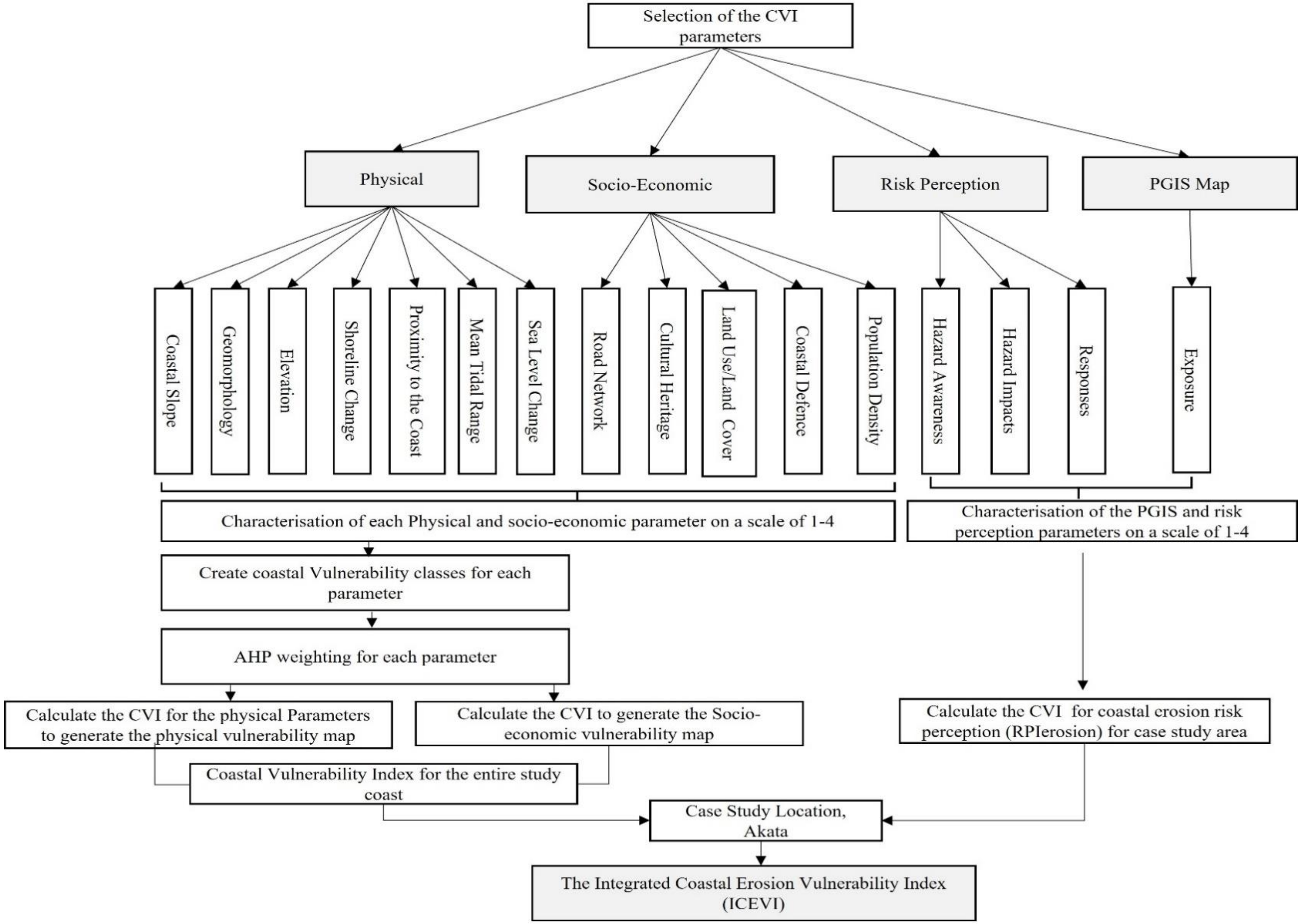


Figure 5.4: The workflow implemented to calculate the CVI

5.4 Datasets

The data used for this study is divided into two broad categories (see table 5.3): firstly the coastal vulnerability index data which use both the geo-physical parameters (refer to section 5.4.1), of which the shoreline change parameter was derived from chapter 3 and socio-economic parameters (refer to section 5.4.2) which apply to the entire area of the study; secondly, the PGIS (refer to section 5.4.3) and risk perception data (from chapter 4) used in the case study area to calculate the risk perception together with an exposure map used in the proposed integrated coastal vulnerability index. Although there is a possibility of upscaling the risk perception dataset from chapter 4 to the entire coast, the results will increase the amount of ambiguity and error in the interpretation because the perception for the locations where the focus discussions were held may differ from other locations where there are no communities or the locations along the coast that are relatively stable due to the presence of either vegetation or coastal defences. As a result, the decision was made to simply test the integration of risk perception data for the case study location.

The selection of geo-physical and socio-economic parameters used for the coastal vulnerability assessment in this chapter is dependent on the data availability that could be accessed/derived remotely. There are seven geo-physical parameters which include a) coastal slope (%), b) geomorphology, c) elevation (m), d) shoreline changes (mm/yr), e) tidal range (m), f) sea-level change (mm/yr), and e) proximity to the coast (m). These geo-physical parameters were derived from geospatial analysis and existing numerical datasets and the index ranges were adapted from previous research (Murali et al. 2013; Musa et al. 2014; Lopez Royo et al. 2016; Tano et al. 2018). The five socio-economic dataset used for this study were generated from both geospatial analyses; land use/landcover generated from Landsat 8 data of 2015; road network; cultural heritage; population density (persons per km^2) and from the PGIS; coastal defences (management) after Mclaughlin et al. (2010), Jana et al. (2013) and Kantamaneni et al. (2022). Furthermore, the four indicators used for generating the risk perception index and exposure map were obtained from PGIS through the focus group discussions and mapping exercise and include: (a) hazard awareness (b) severity of impact (c) exposure (exposure mapping) and (d) responses.

Table 5.3: Vulnerability data and ranking criteria used for this study. Geo-physical parameters adapted from Murali et al. (2013), Lopez Royo et al. (2016), Tano et al. (2018), Musa et al. (2014) and socio-economic parameters after Mclaughlin et al. (2010), Jana et al. (2013) and Kantamaneni et al. (2022).

Parameters	Variables	**Vulnerability ranking**				**Data source**	**Data Period**	**Data Format**
		Very low (1)	**Low (2)**	**High (3)**	**Very High (4)**			
Geo-Physical (PVI)	**Coastal Characteristics**							
	Coastal Slope (%)	> 9	6-9	3-6	<3	SRTM DEM (30m)	2014	Raster
	Geomorphology	Rocky coast	Embayed/ Indented coast	Dunes/Estuaries and lagoons	Mudflats, mangroves, beaches, barrier spits	Fieldwork/Literature review	2018	Vector converted to raster
	Elevation(m)	> 9	6-9	3-6	<3	SRTM DEM (30m)	2014	Raster
	Shoreline Change (m/yr)	Accretion >2	Accretion < 2	Erosion < 2	Erosion > 2	Calculated from Landsat images downloaded from Earth Explorer (https://earthexplorer.usgs.gov/)	1984-2020	Vector converted to raster
	Proximity to the Coast (m)	>1000	500 -1000	250-500	<250	Generated in ArcGIS using shoreline extracted from Landsat images downloaded from Earth Explorer (https://earthexplorer.usgs.gov/)	2020	Raster
	Coastal Forcing							
	Tidal Range (m)	>4	2-4	1-2	<1	Ines Oceanographic services, Nigeria. Nigerian Navy https://www.nnho.ng/NavPub.php	1988-2020 2020	Excel (Nigerian-Navy 2020)
	Sea Level Change (mm/yr)	<1	1-2	2-3	> 3	Ines Oceanographic services, Nigeria And Literature review	1880-2015 1993-2010	Excel (Musa et al. 2014)

Socio-Economic (SVI)								
	Road Network	Absent	Minor road	N/A	Present	Field work/ Generated from Landsat Images using ArcGIS 10.8)		Raster
	Cultural Heritage	Absent	N/A	N/A	Present	Fieldwork/ Literature review		Raster
	Landuse/Land Cover	Water Bodies	Mixed vegetation, mangroves, and other trees	Cultivated land/fallow land	Settlement/Build-up	Generated from Landsat Images using ArcGIS 10.8)	2015	Raster
	Coastal Defence	Hard/Soft: embankment: seawall, embankments, groynes, and vegetation (>50%)	Hard/Soft Engineering: embankments, vegetation, sandbags (20-50%)	Soft Engineering: Sand bags/sticks/planks/ vegetation, sandbags, tilts (<20%)	None	Fieldwork/PGIS	2018	Raster
	Population	0-500	500-1000	1001-1500	>1,500	Government website (AKS-Government 2014)	2013	Excel

5.4.1 Geo-physical Vulnerability Parameters used in the Physical Vulnerability Index (PVI)

The geo-physical parameters are divided into two main categories; the coastal characteristics and coastal forcing based on the definition of vulnerability by Mclaughlin et al. (2010) where coastal characteristics assesses the potential susceptibility of any coast to morphological changes. Coastal characteristics refers to the elements or variants considered when evaluating coastal vulnerability or sensitivity (Anfuso et al. 2021). Different authors consider different coastal characteristics in their research, however, variants such as geomorphology, coastal slope and shoreline change, among others, are typically consistent. The coastal characteristics employed in this study are: coastal slope (%), geomorphology, elevation (m), shoreline change (mm/yr) and proximity to the coast (m). The rationale for using them lies in the successful application of these parameters in previous studies (refer to section 2.2.3 for more details). Coastal forcing simply refers to the natural occuring and dynamic agents that are present in coastal areas; which includes but is not limited to wind, sea level, tidal waves (Kamal 2021), storms and significant wave heights (Zhu et al. 2019). Zhu et al. (2019) refers to them as the external forces acting on the coastal system. Based on availability of data for the entire study coast, the mean tidal range and sea level change are considered in the current vulnerability assessment.

5.4.1.1 Coastal slope

The coastal slope for this study was generated from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) from the year 2000 with a spatial resolution of 30m. The vulnerability zoning was done using ArcGIS 10.4 software. The entire Akwa Ibom coast was covered by two DEM tiles (1-arcsecond each) which were mosaiced together and clipped to the study area extent. The slope values were classified into four vulnerability classes, adapted from Lopez Royo et al. (2016) because of similarities in geomorphological features(barrier coast, low lying sandy beaches) with the study area. The slope values used in the classification were derived from the study DEM which indicates that areas with slope > 9m are of a very low vulnerability; areas with slope between 6-9m of low vulnerability; those between 3-6m as high vulnerability and those < 3m as very high vulnerability (see Table 5.3 and appendix 5.1a). The rationale for this parameter is that areas with low coastal slopes are considered extremely sensitive to penetrative marine waves and sea-level rise because they are thought to retreat faster than steeper regions. Areas with the lowest slope ranges were classified as higher vulnerability than those within the higher range.

5.4.1.2 Geomorphology

The geomorphology of the study area was assessed from both fieldwork, past literatures and Google Earth®. This study follows Murali et al. (2013) which qualitatively divides the geomorphological features into a representative numerical index of 1 - 4 for coastal vulnerability with rocky coast as very low vulnerability; embayed/indented coast as low vulnerability; dunes, estuaries and lagoons as high vulnerability while mudflats, mangroves beaches and barrier spits as very high vulnerability (see Table 5.3). Approximately 79% of the coast is classified as beaches, while 21% is classified as estuaries (see Table 5.3 and appendix 5.1b). As earlier discussed in section 5.1, the study's coastal stretch is made of the alluvial plains (Ekpoh (1994) which are easily eroded, especially along zone B which is primarily low-lying with mostly loose, fine and unconsolidated sediments (Inim et al. 2017).

5.4.1.3 Elevation

The SRTM DEM was used to extract elevation for the study area and selected due to its availability and reasonable level of detail (30m resolution). The DEM was manually classified into 4 classes based on the vulnerability ranking where elevations > 9m represents very low vulnerability; elevation values between 6-9m are low vulnerability; elevation values between 3-6m are classified as high vulnerability and those less than 3m as very high vulnerability. This classification was adapted to the values derived for the study area following Murali et al. (2013) (see Table 5.3 and appendix 5.2a).

5.4.1.4 Shoreline change

The vulnerability ranking is adapted based on the derived values for the study area following Murali et al. (2013) where accretion > 2m are classified as very low vulnerability; accretion < 2m as low vulnerability; < 2m erosion an high vulnerability and erosion > 2m as very high vulnerability (see appendix 5.2b). A comprehensive analysis on the shoreline change in the study is presented in chapter 3 that assesses the spatio-temporal analysis of shoreline changes along the Akwa Ibom coast (Strand coast). The results obtained from the shoreline change were used here to assess the vulnerability of the coast to erosion. The results showed a range of shoreline changes between -24.8m/yr as maximum erosion and a maximum accretion rate of 38.9m/yr within the 36-year interval (1984-2020) considered for the analysis.

5.4.1.5 Proximity To The Coast

The proximity to the coast used in this study was calculated using the euclidean distance tool in ArcGIS 10.4. The ranking used here was adapted from Musa et al. (2014) and was considered based on the scope of the research to assess the settlements that are directly affected by coastal erosion along the coast. Most of the settlements affected were within 500m of the the coast while those farther inland were not. Hence, the study considered the following distances: 250m of the shoreline, 250-500m from the shoreline, 500-1000m and areas above 1000m from the shoreline. These distances from the shoreline were ranked into four classes as seen in Table 5.3. It indicates that areas farther in distance from the shoreline (marked with green colour) are less likely to be affected by the impact of coastal erosion while those closest (marked with red colour) will be more exposed to/impacted by coastal erosion (see Table 5.3 and appendix 5.3a). The vulnerability ranking for the proximity parameter has areas within 250m of the coast as very high vulnerability, 250-500m as high vulnerability, 500-1000m as low vulnerability and those > 1000m as very low vulnerability.

5.4.1.6 Mean Tidal Range

In estimating the mean tidal range for the Akwa Ibom coast, a tidal prediction dataset was obtained from the nearest tidal stations in the Nigerian Navy tidal predictions for Nigerian ports and river channels report (Nigerian-Navy 2020), and data from one tidal station at Ibeno from 1988-2020 obtained in an excel format from Ines Oceanographic services in Nigeria was used. The vulnerability ranking was adapted from Lopez Royo et al. (2016) which suggests that based on storm surges with rising tides, there is an increased likelihood of storm surge and rising tide along the microtidal coast (tidal range >1m) because sea level is almost the same as the high tide (Anfuso et al. 2021), making it more vulnerable than other areas with increased tidal ranges. Here, the mean tidal range vulnerability is ranked; tidal range <1m as very high vulnerability, between 1-2m as high vulnerability, between 2-4m as low vulnerability and >4m as very low vulnerability (see Table 5.3 and appendix 5.3b).

5.4.1.7 Sea Level Change

Church et al. (2011) estimated that the global mean sea level (MSL) has been rising since the 1900s. Such increases in the sea level could suggest acceleration in coastal erosion processes. Despite the relative importance of sea level statistics, the study area lacks sufficient data. A likely explanation is given by Musa et al. (2016) which suggests that it could be due to a lack of measurement equipment citing the fact in Nigeria, the contouring map begins at 40 metres above sea level which excluded the low-lying regions such as this study area. Because of a paucity of data, the value employed in this study's vulnerability ranking was derived from previous literature and applied to the entire coast. The Eustatic sea level change rates used in this study ranges from 3.03 to 3.39mmyr[1] along the the Niger Delta coast (Rosmorduc, 2012 as cited in Musa et al. (2014). These values were used as a proxy for the Akwa Ibom coast and the data shows that the study area falls into the "very high vulnerabiity" category, according to the ranking ranges in table 5.4.

Table 5.4: Summary of the vulnerability ranking distribution for the physical parameters

Parameter	**Physical vulnerability ranking (%) along the study coast**				**Classification adapted from literature**
	Very low (1)	**Low (2)**	**High (3)**	**Very High (4)**	
Slope (%)	7.03	11.54	34.39	47.04	Lopez Royo et al. (2016)
Geomorphology	-	-	21.02	78.98	Murali et al. (2013)
Elevation (m)	38.64	28.08	29.79	3.49	Murali et al. (2013)
Shoreline change (m/yr)	3.2	18.42	21.81	56.57	Murali et al. (2013)
Proximity (m)	-	14.9	40.69	44.4	Musa et al. (2014)
Mean Tidal Range (m)	-	-	33.71	66.29	Lopez Royo et al. (2016)
Sea Level Change (mm/yr)	-	-	-	100	Musa et al. (2014)

Table 5.4 summarises the results of the vulnerability ranking for the physical parameters in the study coast. In general, the afforementioned rankings in Table 5.4 were used to create

vulnerability maps for the physical paramters and a summary of the percentage coverage of each class of vulnerability for the physical parameters can be seen in Table 5.4.

5.4.2 Socio-Economic Parameters used in the Socio-Economic Vulnerability Index (SVI)

The existence of humans and economic activities is reflected in socio-economic indicators (Balica et al. 2012) which depicts the extent to which these socio-economic parameters puts pressure on the coastal areas (Tano et al. 2018). In section 5.3.3, the addition of social elements in determining coastal vulnerability is examined. Several studies have utilised various factors to estimate the coast's vulnerability to threats. This study adapts and uses socioeconomic characteristics of Mclaughlin et al. (2010), Kantamaneni et al. (2022) and Jana et al. (2013).

5.4.2.1 Land use/Land cover (LULC)

Mahapatra et al. (2015) noted that land use/land cover is an important factor in highlighting areas that are considered more vulnerable to coastal hazards. The land use/landcover map used for this study was generated from the Landsat image 8 (30m) of 2015. To generate the LULC used in this study, a supervised image classification was carried out on the Landsat image in the ArcGIS 10.4 software. Here, training samples for each LULC were selected and used to generate a signature file for LULC used in classifying the image into four classes representative of the vulnerability indexes, namely, water bodies (very low vulnerability - 1); mixed vegetation which includes mangroves and other trees (low vulnerability - 2); cultivated land/fallow land (high vulnerability - 3); and settlement/built up areas (very high vulnerability - 4) (see appendix 5.5). The ranking categories show that locations with infrastructure/settlements are most vulnerable, ranking 4 because this represents human presence and activities that expose the coastal area to increasing vulnerability (Murali et al. 2013); cultivated areas loosen up the soil particles leaving them vulnerable to erosion and fallow land exposed with little or no crop coverage to protect the soil, is ranked 3; while locations with vegetation cover is ranked 2 and considered a low vulnerability because the vegetation serves as buffer protecting the soil and areas, where water is present is ranked very low vulnerability because, such areas have no human presence and activities, as such, decreasing vulnerability. Table 5.3 shows the vulnerability ranking of this parameter in the study area while the spatial distribution of the land use/land cover vulnerability ranking along the Akwa Ibom coast can be seen in appendix 5.4a.

5.4.2.2 Road Network

The importance of the road network in coastal vulnerability has been highlighted by Ahmed et al. (2021), who stated that it is a critical component of communication, as well as a means of carrying goods and attracting tourists. Oloyede et al. (2022) discussed its importance in terms of proximity to the coast, where a road network that is very close to the water could quickly be flooded, posing major threats to the coastal population, while Mclaughlin et al. (2010) notes that the presence of major roads would indicate high vulnerability because they are expensive to build. The road network vulnerability ranking used for this study shows that where roads are absent, the vulnerability is very low; where there are minor roads, the vulnerability is low and where there are major roads, the vulnerability is very high (see Table 5.3 and appendix 5.4b). The ranking used here is adapted from Mclaughlin et al. (2010) to reflect the road network obeserved and generated from field work (October, 2018). The data generated in the field is used because there is no comprehesive road network map of Akwa-Ibom State that extends to all the locations along the coast.

5.4.2.3 Cultural Heritage

The impact on locations with cultural heritage along the coast are considered to be more severe than areas where it is absent. This is because such locations (for example, tourist locations) are of more economic value (Murali et al. 2013). The data used here were generated in the field and from the review of past literature (Akpan 2021). This study adapts the rankings from Mclaughlin et al. (2010) which assigns the highest vulnerability to locations with cultural heritage and the lowest vulnerability ranking to areas without such locations (see Table 5.3 and appendix 5.6a).

5.4.2.4 Coastal Defence

Coastal defence refers to both soft (e.g. coastal protection vegetation, beach nourishment) and hard (e.g. sea walls, offshore breakers, embankment, groynes) approaches used in protecting the coast from the impacts of flooding, erosion and other coastal hazards (Anfuso et al. 2021). The vulnerability ranking adopted for this study is adapted from Kantamaneni et al. (2022). However, since adequate information on coastal defence in the study area is limited, for the scope of this study, coastal defence here refers to areas where partial or full hard/soft engineering structures are located. The use of mangrove mapping along the coast could be a useful dataset for defence. However, from the Landsat satellite image used in this study, there is no clear distinction between mangroves, nipa palm and palm trees which would have given an indication of the degree to which the plants can attenuate the wave action, as such serving a buffer for the coast. Hence, vegetation data were excluded from coastal defence assessment. The information on coastal defence that was generated in the field during the PGIS session and walking interview, was information on the partial or full hard/soft engineering structures present in the area (see figure 5.5). Here, areas that have more than 50% of hard engineering structures such as sea wall, embankments and groynes along the coast are classified as very low vulnerability; areas with hard engineering between 20-50 % of the coast are classified as low vulnerability: areas with 10-20% of hard engineering or soft engineering such as sand bags/sticks/planks and sandbags as high vulnerability while areas with lesser than 10% of hard engineering or no form of coastal defence are classified as very high vulnerability (see Table 5.3 and appendix 5.6b).

Figure 5.5: Coastal defence structures along parts of the study coast.

5.4.2.5 Population Density

Population density is important because it indicates not only the size of the population likely to be affected by coastal erosion (BalaSundareshwaran et al. 2019), but also the extent of the impact (Murali et al. 2013) and pressure on the environment by people living along the coast trying to mitigate/adapt to the likely impacts from erosion (Jana et al. 2013). The population vulnerability ranking used in this study is adapted from Jana et al. (2013). The vulnerability ranking used is areas with <500 persons per km^2 as very low vulnerability, areas with 501-1000 persons per km^2 as low vulnerability, areas with 1001-1500 persons per km^2 as high vulnerability and areas with >1500 persons per km^2 as very high vulnerability. Since this study was unable to collect population density at ward level along the coast to give a more realistic picture of the coastal population, as such it was unable to distinguish between inhabited and uninhabited locations. The population density data used from this study was downloaded from (AKS-Government 2014). The average population density in the State is 680 people per square kilometres (sq.km). However, in each Local Government Area where the study area is situated, population was as follows; Oron – 2688 people per sq.km, Mbo – 385 people per sq.km, Ibeno – 381 people per sq.km, Eastern Obolo - 648 people per sq.km and at Ikot Abasi- 381 people per sq.km (see appendix 5.8).

In general, the socio-economic parameters in Table 5.3 were used to create vulnerability maps (see appendices 5.4, 5.6 and 5.7) and a summary of the percentage coverage of each class of vulnerability for the socio-economic parameters can be seen in Table 5.5. In the socio-economic vulnerability maps, an insert of one of the locations visited is highlighted to give a clearer picture of the distribution of the vulnerability ranking along the study coast.

Table 5.5: Summary of the vulnerability ranking distribution for the socio-economic vulnerability (SVI) parameters.

Parameter	**Socio-Economic vulnerability ranking (%) along the study coast**				**Classification adapted from literature**
	Very low (1)	**Low (2)**	**High (3)**	**Very High (4)**	
Land use/Land cover	1.51	65.13	17.99	15.37	(Mclaughlin et al. 2010)
Road Network	-	83	17	-	(Mclaughlin et al. 2010)
Cultural Heritage	22.48	-	-	77.52	(Mclaughlin et al. 2010)
Coastal Defence	17	4.38	78.62	-	Kantamaneni et al. (2022)
Population Density	56	27	-	17	Jana et al. (2013)

5.4.3 Participatory GIS - Risk Perception parameters for the case study location

The social metrics from PGIS are the risk mapping and risk perception. This study offers a methodology for assessing the risk perception parameter based on the index-based method (refer to section 5.3.3 for explanation), where participants' mapping and representative perceptions of coastal erosion were retrieved using qualitative methodologies during the fieldwork for this study. This technique is critical because it is adaptable and promotes user confidence in the method for describing complicated social vulnerability issues (Huang et al. 2012). Given that the weight is primarily established by expert knowledge, it is also critical to evaluate the risk of bias in this technique. However, since the data primarily rely on local knowledge/experts, further weights will not be applied here on the assumptions that their voices or perceptions are given equal importance in the assessment of coastal erosion.

The data used were derived from focus group discussions about the past and current situation of erosion, the impacts and coping/adaptive capacity in place; interviews conducted during fieldwork from chapter 4, and mapping exercises to delineate areas most exposed and affected by erosion (see section 5.5.4). The data generated from the discussions were transcribed, transformed by extensively reading the transcribed work, highlighting and extracting answers that best reflect the research questions, reflecting over the discussion to establish credibility of data used (not just what was said but the context in which it was said and how it was said), writing the main ideas resonating from the process to find patterns in the data, reviewing and grouping the indicators from the data that best described the risk parameters for the study and re-assessing the risk parameter indicators, establishing the ranking parameters (derived from the mean value of the responses for an indicator) included in the RPIerosion vulnerability index. For the mapping exercise, the locally generated maps produced during focus group discussion process (chapter 4) were scanned and stored electronically, then the scanned maps were imported into the ArcGIS 10.4 software where they were georeferenced into the UTM WGS 84_(32N) co-ordinates to have the same geographic coordinate system as the rest of the data used (refer to section 5.5.4). Thereafter, a shapefile was created for the case study area to show areas identified by the local populations with settlement exposure and areas without.

The vulnerability indices used here ranged from one to four, with one indicating very low vulnerability, two indicating low vulnerability; three indicating high vulnerability; and four indicating very high vulnerability to be consistent with the ranking used for the physical and socio-economic parameters (refer to chapter 4 for an extensive discussion on the data generation and analysis of risk perception). To the best of my knowledge, this study is the first to include the risk perception parameter in a coastal erosion vulnerability index assessment.

Figure 5.6: Maps A & B show mapping exercise at Esin Offot community and maps C & D show the focus group discussion and mapping exercise at Idua Ukpata community.

Based on the inclusion/exclusion from the different data generation in section 4.3.2.9, the inclusion of the risk perception vulnerability generated from the focus group discusion is that :

- All the respondents must live in close proximity to the coast (not more than 500m inland)
- Must include people who have lived there for at least 20 years and had first hand knowledge of the impacts of the hazards.

This criterion was deliberate to allow the research to evaluate individuals who are knowledgeable about the environmental changes that are occurring and have firsthand knowledge of the hazards that are occurring there, the perceived severity of the impact, the areas along the coast most vulnerable to erosion, and the responses implemented to mitigate the impact of hazards or adapt to the changes caused by them. In chapter 4, several risk perception factors are examined in depth in order to thoroughly analyse coastal erosion in the research area. However, four main categories are employed in this chapter to convey the risk perception on coastal erosion in the study area: hazard awareness, severity of impact, response generated through qualitative analysis in chapter 4 during the focus group discussions (refer to 5.3.3.1 for details) and exposure which is based on the risk map from the PGIS mapping in this chapter. The hazard awareness parameter utilised here refers to knowledge of the types of hazards that are present, as represented by the hazard-component (H) of the H-DPSIRO model, the drivers-component (D) of the H-DPSIRO model, and the pressure component (P) of the H-DPSIRO model (refer to section 4.3.3 for description of the different components). Higher numbers for awareness signify reduced vulnerabilities, implying that the hazard is well understood in that location. The re-conceptualised DPSIR (H-DPSIRO) model was used to estimate the severity of the impacts of coastal erosion in the research area. The current condition of the coastal hazard, which represents the H-DPSIRO model's state-component (S), and the impacts of the hazards, which represent the H-DPSIRO model's impact-component (I), were used to describe the severity of the impacts from coastal erosion in the research region. In this case, areas with more accretion than erosion and lower mean severity values suggest lesser vulnerabilities, and vice versa. Human settlements were utilised as an indicator of exposure in this study, and the data used here was generated through the PGIS mapping effort. The response vulnerability index was created by the R- component of the re-conceptualized DPSIR (H-DPSIRO) model, which evaluates the management/measures taken by government or community stakeholders to minimise the impact of hazards or adapt to the changes caused by them. The oberservation-component (O) is used throughout the course of the fieldwork as a way of triangulating the data collected from the field that will be beneficial in the course of the discussion.

The ranking process created for this study was adapted from Gorokhovich et al. (2014); if a predetermined ranking scale was used during the FGD to generate data, the ranking score or the mean of the ranking score (if more than one ranking score) is utilised in the matrix. However, in cases where a specified ranking scale was established in generating the indicator data during the FGD, the following technique was used:

1) Assign a point to each indicator that demonstrates understanding and knowledge of the hazard, natural and anthropogenic drivers and the pressures of the hazard.

2) Aggregate the points and compute the average of the total scores generated.

3) The ranks were determined by representing the mean score on a scale of 1 to 4 (meaning that the mean score is total divided by 4).

For this study, during the field work, several hazards were described by the participants. However, because coastal erosion is the primary hazard in this study and based on the adopted re-conceptualised DPSIR (H-DPSIRO) model; if coastal erosion is the current state of situation (area of interest), then the perceived severity of impact described by the FGD participants is accepted; otherwise, the perceived severity of impact described is not used for this matrix. For example, if the hazard impact is caused by floods rather than coastal erosion, no hazard impact is recorded for that segment of the coast. This is crucial because it avoids misrepresenting the effects of coastal hazards connected with a specific hazard or providing a misleading representation of its perceived social impacts.

5.4.3.1 Hazard Awareness

Here, the locations where the participants show an excellent knowledge or can strongly demonstrate the knowledge of the hazard taking place and are able to distinguish between the natural and anthropogenic drivers/pressure are ranked as 1 representing very low vulnerability; those that moderately demonstrates good awareness of the hazard and shows fair knowledge on both the natural and anthropogenic drivers/pressure are ranked as 2 representing low vulnerability; those that fairly demonstrates the awareness of the hazard taking place, fairly understand the causes of the hazards are ranked 3, categorised as high vulnerability while those that show poor understanding of the hazard taking place with no knowledge on both the natural and anthropogenic causes or drivers are ranked 4 showing a very high vulnerability (see Table 5.6).

5.4.3.2 Severity of impact

For severity of impact, the locations that did not show the significant coastal erosion but rather experienced significant accretion, suggests no injury to humans or damage to property and requires no attention at present are classified as very low vulnerability. The ranking here is similar to the ranking of the shoreline changes seen in Table 5.3 that assigns location with more than 2m accretion as very low vulnerability except that, this is based on the information provided by the locals which includes information on percieved casualities. Areas that are predorminantly accreting but have mild or minor damages to property caused by erosion are classified as low vulnerability class; and areas predominantly eroding with significant damages to property falls within the high vulnerability class while areas with severe impacts of coastal erosion that require immediate attention and have recorded at least one death are classified as very high vulnerability (see Table 5.6).

5.4.3.3 Exposure

During the focus group discussion, participants were able to distinguish locations with settlement, erosion and accretion. Participants were able to identify sites that were particularly prone to erosion. An example of the map developed during the fieldwork experiment is shown in Figure 5.7. The maps were scanned and geo-referenced in the ArcGIS 10.08 software. Reference co-ordinates taken in the field were used to in geo-referencing the map into the same coordinate system as other maps used in this study. The now geo-referenced maps were digitised, and the shapefiles created representing the different features delineated on the maps. The exposure used in this study adapted from Mclaughlin et al. (2010), simply refers to locations with human population exposed to the potential impacts of erosion as high vulnerability and areas where the human population is absent, as very low vulnerability.

5.4.3.4 Responses

In this study, areas with partial/full embankment along coast fall within the very low vulnerability class; areas with restricted exploitation of vegetation/mangroves and replanting of mangroves fall within the low vulnerability class; areas with sandbags and planks placed around houses of individuals are tagged high vulnerability and areas with no form of management/response by State Government, local Government, the communities and other agencies were designated the very high vulnerability class (see Table 5.6).

Table 5.6: Vulnerability data and ranking criteria used for risk perception in this study. Adapted from Mclaughlin et al. (2010).

Parameters	Variables	**Vulnerability Ranking for Risk Perception (RPIerosion)**				**Data source**	**Data Period**	**Data Format**
		Very low (1)	**Low (2)**	**High (3)**	**Very High (4)**			
PGIS								
Focus group discussions	**Perceived Hazard Awareness**	-Excellently/ strongly demonstrates the awareness of the hazard. -Excellent knowledge on the Natural and anthropogenic drivers/pressure	-Demonstrates moderately good awareness of the hazard -Shows fair knowledge on both the natural and anthropogenic drivers/pressure	-Fairly demonstrates the awareness of the hazard -Fairly understands the causes of the hazards	-Poorly demonstrates the awareness of the hazard -Shows poor/have no knowledge on both the natural and anthropogenic causes Or the drivers	Focus group discussion (FGD)/Interview	2018	Transcription from Audio to Ms-Word
	Perceived severity of Impact	- No significant coastal erosion -Significant accretion, -No injury to humans or damage to property and requires no attention at present.	Accretion is more prominent than erosion but have mild or minor damages to property caused by erosion.	- predominantly erosion with significant damages to property severe impacts of coastal erosion that requires immediate attention.	- Very severe impacts of coastal erosion that requires immediate attention and has recorded at least one death.	Focus group discussion (FGD)/Interview	2018	Transcription from Audio to Ms-Word
	Response	-Partial/full embankment and unexploited vegetation along coast.	-Restricted exploitation of vegetation/mangroves and replanting of mangroves.	-Sandbags and planks placed around houses individuals.	-No response by Government, local Government and other agencies. -There is nothing that can be done by the Communities.	Focus group discussion (FGD)/Interview	2018	Transcription from Audio to Ms-Word
Mapping	**Exposure**	Absent	-	-	-Present	Participatory mapping	2018	Scanned maps into GIS

5.5 Results

Twelve parameters (12) were used in deriving the coastal vulnerability ranking seen in Table 5.3. Each parameter was ranked, evaluated for a weighted scoring and was categorized into classes based upon the relative vulnerability. Different classes have been used in past literatures. Majority of the studies ranked the indicators on a scale of 1-5 following after the original CVI by Gornitz et al. (1994) with 5 representing the most vulnerable value and 1 the least vulnerable (Ago et al. 2021; Ahmed et al. 2021) while others like Murali et al. (2013) and Jana et al. (2013) ranked the indicators on a scale of 1-4 (with 4 being the most vulnerable value and 1 the least vulnerable) which was entirely based on expert opinion. Additionally, a scale of 1-3 (high, medium and low) has been used by studies like Kumar et al. (2012) based on 25, 25-50 and 50 %ile values suggesting that the scale is adequate enough to highlight areas where physical changes were most likely to occur. This study chose to adopt the 1-4 scale by like Murali et al. (2013) and Jana et al. (2013) due to lack of adequate data across the entire study coast, as well as the homogeneity of the available data for the study coast.

5.5.1 Geo-Physical Vulnerability Assessment (PVI)

The first steps, as earlier stated, involved ranking of the physical parameters (Table 5.3) and the resultant vulnerability maps based on the selected physical parameters are seen in section 5.3. The next step involved assigning weights to these physical parameters using the AHP approach. The weights used for the physical parameters were derived from three experts knowledgeable in coastal hazard assessments along the Akwa Ibom coast used in the calculation of the physical vulnerability index. The AHP weighting based on expert knowledge can be seen in Table 5.7. The matrix shows the subjective assessment of the experts based on the importance of each physical parameters in respect to one another. The individual rankings via expert knowledge (see appendix 5.8) were analysed using AHP priority calculation software by Goepel (2018) to derive the aggregated weightings used for this analysis.

Table 5.7: Consolidated decision matrix for the physical vulnerability parameters. Calculated using AHP following (Goepel 2018).

		Coastal slope	Geomorphology	Elevation	Shoreline Change	Proximity	Mean Tidal range	Sea level change
		1	2	3	4	5	6	7
Coastal Slope	1	1	0.38	0.69	0.28	0.38	1.82	1.82
Geomorphology	2	2.62	1	3.56	0.79	0.69	3.11	3.11
Elevation	3	1.44	0.28	1	0.38	0.32	2.71	2.29
Shoreline Change	4	3.56	1.26	2.62	1	2.62	3.78	3.56
Proximity	5	2.62	1.44	3.11	0.38	1	1.82	1.82
Tidal Range	6	0.55	0.32	0.37	0.26	0.55	1	0.63
Sea Level Change	7	0.55	0.32	0.44	0.28	0.55	1.59	1

The consistency ratio for the AHP result for physical parameters is 0.04 which is acceptable. This means that consistency ratio is less than 10% and as such is consistent because CR which is <0.1 is acceptable (Saaty 1987; BalaSundareshwaran et al. 2019). The results shows that shoreline change was ranked highest with a weight value of approximately 0.28, indicating that it has the highest influence/relative importance in the analysis when compared to other parameters used for the coastal erosion assessment, while it suggests that tidal range had the least influence on the physical vulnerability (see Table 5.8).

Table 5.8: The consolidated experts weightings used for the physical parameters

Weights	Coastal slope	Geomorphology	Elevation	Shoreline Change	Proximity	Mean Tidal range	Sea level change	Consistency Ratio
Expert 1	0.08	0.21	0.10	0.27	0.17	0.08	0.09	0.08
Expert 2	0.10	0.18	0.10	0.26	0.22	0.07	0.07	0.07
Expert 3	0.08	0.24	0.12	0.31	0.18	0.04	0.05	0.07
Aggregated Weights	**0.08**	**0.21**	**0.10**	**0.28**	**0.19**	**0.06**	**0.07**	**0.04**
Aggregated ranking	**5**	**2**	**4**	**1**	**3**	**7**	**6**	

The physical parameter weights were used to calculate the PVI using the weighted sum tool in ArcGIS 10.04 software. To assess the physical vulnerability index, both the original coastal vulnerability index approach by Gornitz (1991) and the approach by Murali et al. (2013) were used for analysis. For the CVI by Gornitz (1991), no weights were involved since it assumes that all the physical parameters contribute equally to the overall vulnerability results (see figure 5.15b). The resultant CVI map was classified into four vulnerability classes using the equal interval method (commonly used for CVI) which grouped the CVI values 2.64 -12.45 as very low vulnerability, 12.45 - 22.26 values as low vulnerability, 22.26 - 32.08 values as high vulnerability and 32.08 - 41.89 as very high vulnerability. It further indicates that 24.66% of the coast falls into the very low vulnerability category; 37.29% is within the low vulnerability category; 31.04% of the coast falls into the high vulnerability category and only 7.01% of the coast falls into the very high vulnerability category.

For the PVI by Murali et al. (2013) where experts weights were incorporated (see 5.15a), the resultant PVI map was also classified into four vulnerability classes using the equal interval method. The results show that 0.98% of the coast is classified as very low Vulnerability (PVI values between 1.87-2.38); 19.65% is classified as low vulnerability class (PVI values between 2.38-2.90); 33.9% falls under the high vulnerability class (PVI values between 2.90-3.41) and 45.47% falls within the very high vulnerability class with PVI values between 3.41-3.93. This approach indicated that only a very small section along the coast fall within the very low vulnerability class. It can be seen in Table 5.9, that the overall result for PVI Murali et al. (2013) and CVI by Gornitz (1991) have different values in each class except for the high vulnerability class that shows some similarity in values. However, they both show that the study area has a wide range of vulnerability classes, from very low to very high vulnerability classes. The PVI results showed that it was largely influenced by the shoreline changes in the area. However, since this study relies on expert knowledge for assessing other components of the integrated coastal erosion vulnerability index, the PVI by Murali et al. (2013) is adopted by this study. In general, as seen in figure 5.7, zone B (Ibeno L.G.A) is seen to have the highest widespread of the very high vulnerability class, indicating that it is the most susceptible to coastal erosion. Zone B is a barrier coast and is relatively flat when compared to other sections of the coast. This is similar to the western section of the Accra coast, which is highly vulnerable to erosion because it is a barrier coast, low lying, made up of loose sediments and open to inundation due to sea-level rise (Addo 2013).

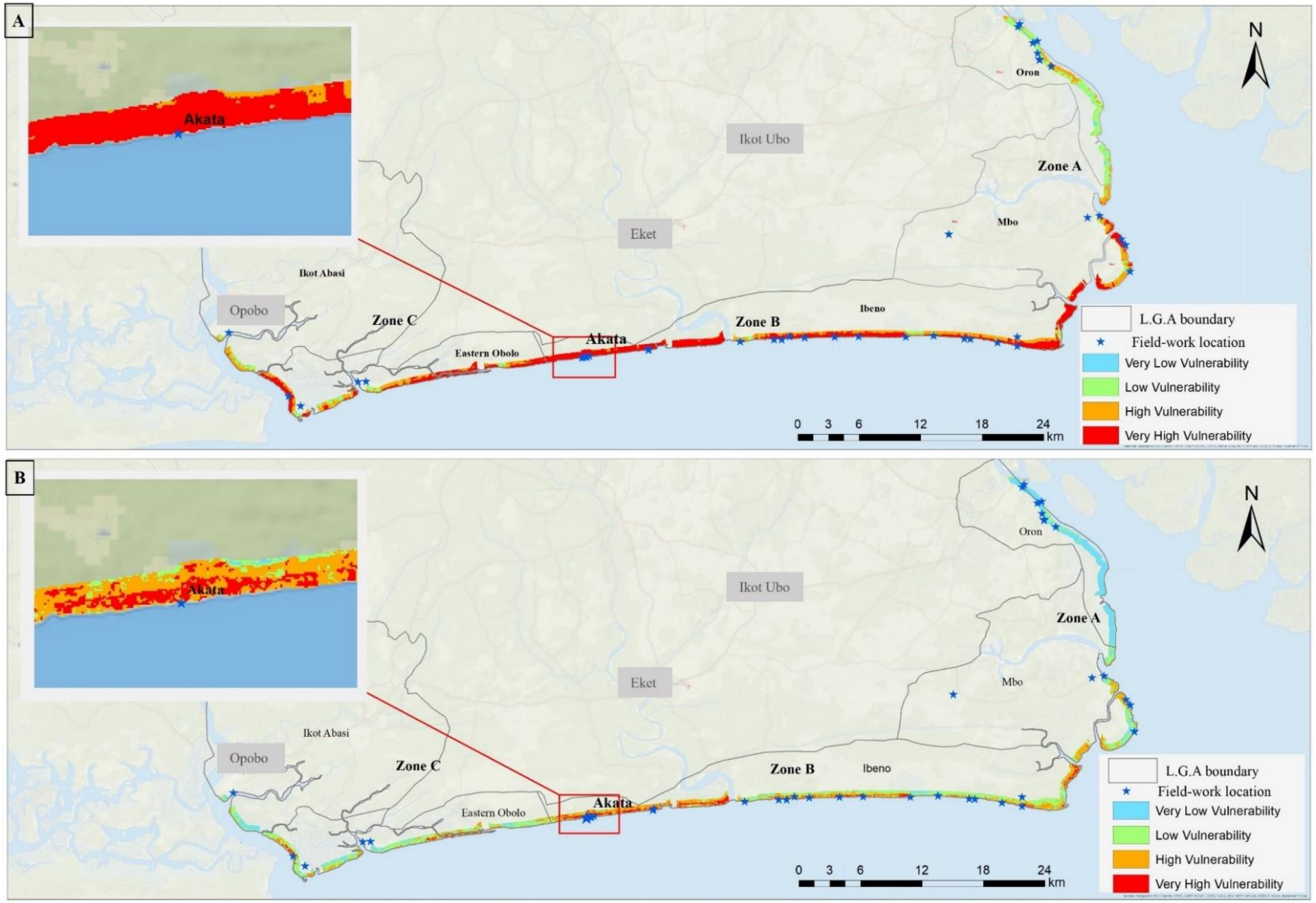
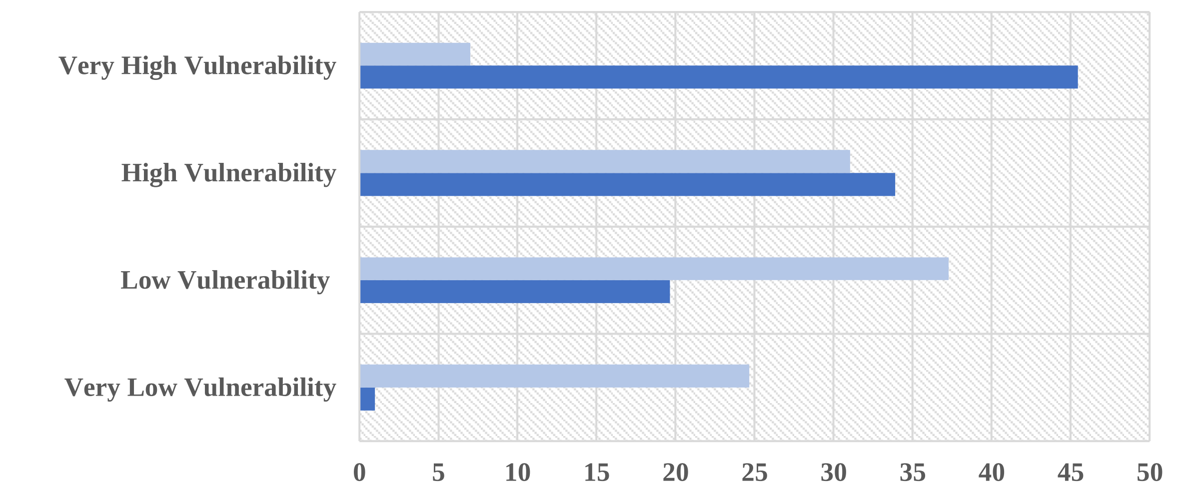


Figure 5.7: Map A shows the physical vulnerability index (PVI) assessment for study area based on Murali et al. (2013) and map B shows the coastal vulnerability index assessment for the physical parameters in the study area based on Gornitz (1991) overlain on an Esri Ocean basemap (Esri 2011)

The summary of the distribution of the physical vulnerability indices and result are seen in tables 5.9 and figure 5.8.

Table 5.9: A summary of the distribution of the physical vulnerability indices used in the study area

% Coverage	Very Low Vulnerability	Low Vulnerability	High Vulnerability	Very High Vulnerability
Slope	7.03	11.54	34.39	47.04
Geomorphology	0	0	21.02	78.98
Elevation	38.64	28.08	29.79	3.49
Shoreline Erosion/ Accretion	3.2	18.42	21.81	56.57
Proximity to shoreline	0	14.91	40.69	44.4
Mean Tidal Range	0	0	33.71	66.29
Sea Level Change	0	0	0	100
PVI (weighted sum) by Murali et al. (2013)	0.98	19.65	33.9	45.47
CVI for physical parameters by Gornitz (1991)	24.66	37.29	31.04	7.01



	Very Low Vulnerability	Low Vulnerability	High Vulnerability	Very High Vulnerability
CVI (Physical) by Gornitz	24.66	37.29	31.04	7.01
PVI	0.98	19.65	33.9	45.47

Figure 5.8: Ranked CVI results for the physical vulnerability assessment (Based on Murali et al. (2013) and Gornitz (1991)

5.5.2 Socio-economic Vulnerability Index (SVI)

The socio-economic parameters were analysed to assess the socio-economic vulnerability index of the study area to coastal erosion using the Murali et al. (2013) approach, following the same process as the PVI in which experts' weightings are applied to each parameter used in the vulnerability calculations (see table 5.10 for the consolidated matrix).

Table 5.10: Consolidated decision matrix for the socio-economic vulnerability parameters. Calculated using AHP following (Goepel 2018)

		Land Use/ Land Cover	Cultural Heritage	Road Network	Coastal Defence	Population
		1	**2**	**3**	**4**	**5**
Land Use/ Land Cover	**1**	1	2.62	3	0.44	0.79
Cultural Heritage	**2**	0.38	1	3	0.44	0.44
Road Network	**3**	0.33	0.33	1	0.44	0.35
Coastal Defence	**4**	2.29	2.29	2.29	1	1
Population	**5**	1.26	2.29	2.88	1	1

The spatial distribution of socio-economic vulnerability index can be seen in figure 5.16 and the summary of the socio-economic vulnerability consolidated matrix and ranking is seen in Table 5.11.

Table 5.11: The consolidated experts weightings used for the socio-economic parameters

Weights	Land Use/ Land Cover	Cultural Heritage	Road Network	Coastal Defence	Population	Consistency Ratio
Expert 1	0.21	0.13	0.08	0.27	0.31	0.07
Expert 2	0.22	0.15	0.08	0.28	0.27	0.04
Expert 3	0.22	0.13	0.08	0.35	0.23	0.07
Aggregated weights	0.22	0.14	0.08	0.30	0.26	0.05
Aggregated ranking	**3**	**4**	**5**	**1**	**2**	

The results show that the socio-economic vulnerability of the Akwa-Ibom coast to coastal erosion lies between very low- very high vulnerability classes. The result (see Table 5.12) shows that 1.22% falls within the very low vulnerabily class with SVI values between 1.79-2.10; 57.85% of the study area falls in the low vulnerability class with SVI values between 2.10-2.40; 26.74% of the coast is within the high vulnerability class with SVI values between

2.40-2.71 and 14.18% of the coast is classified as very high vulnerability with SVI values between 2.71-3.01. Though coastal defence has the highest ranking, it can be seen in the map (figure 5.9), the landuse data greatly influence the final SVI assessment.

Table 5.12: Summary of the vulnerability rankings in the socio-economic index assessment (Based on Murali et al. (2013)

% Coverage	**Very Low Vulnerability**	**Low Vulnerability**	**High Vulnerability**	**Very High Vulnerability**
Land use / Landcover	1.51	65.13	17.99	15.37
Cultural Heritage	22.48	0	0	77.52
Road Network	0	83	17	0
Coastal Defence	17	4.38	78.62	0
Population	56	27	0	17
SVI	1.22	57.85	26.74	14.18

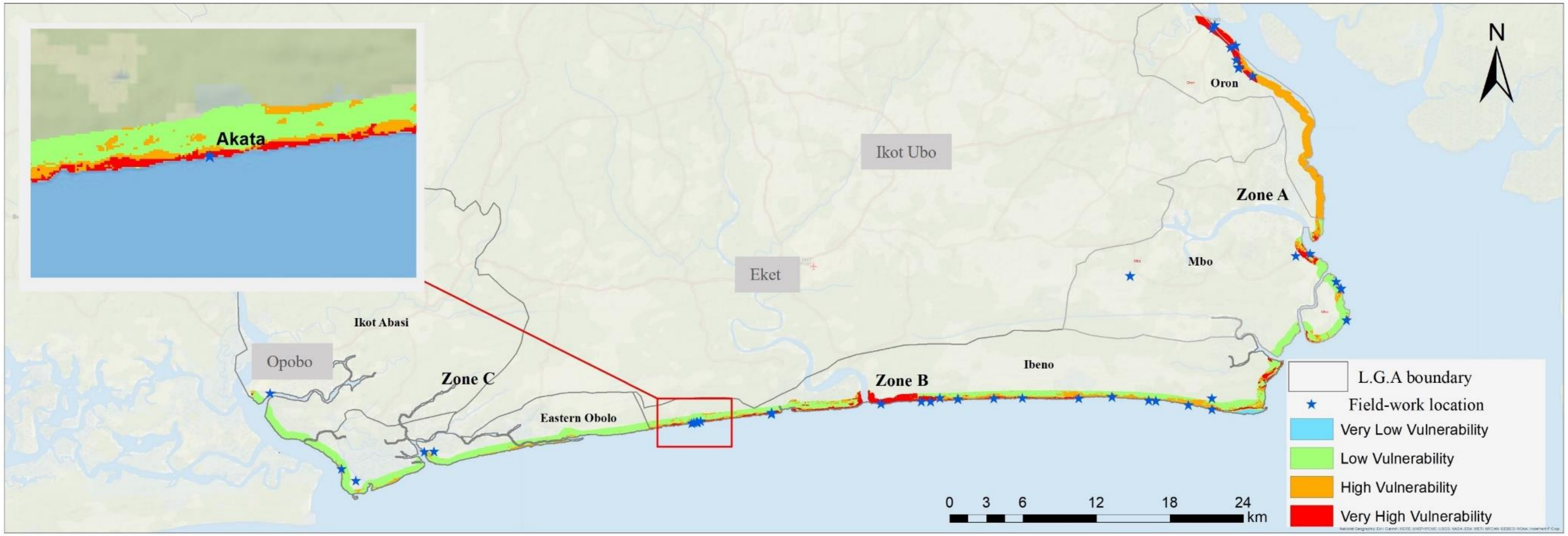
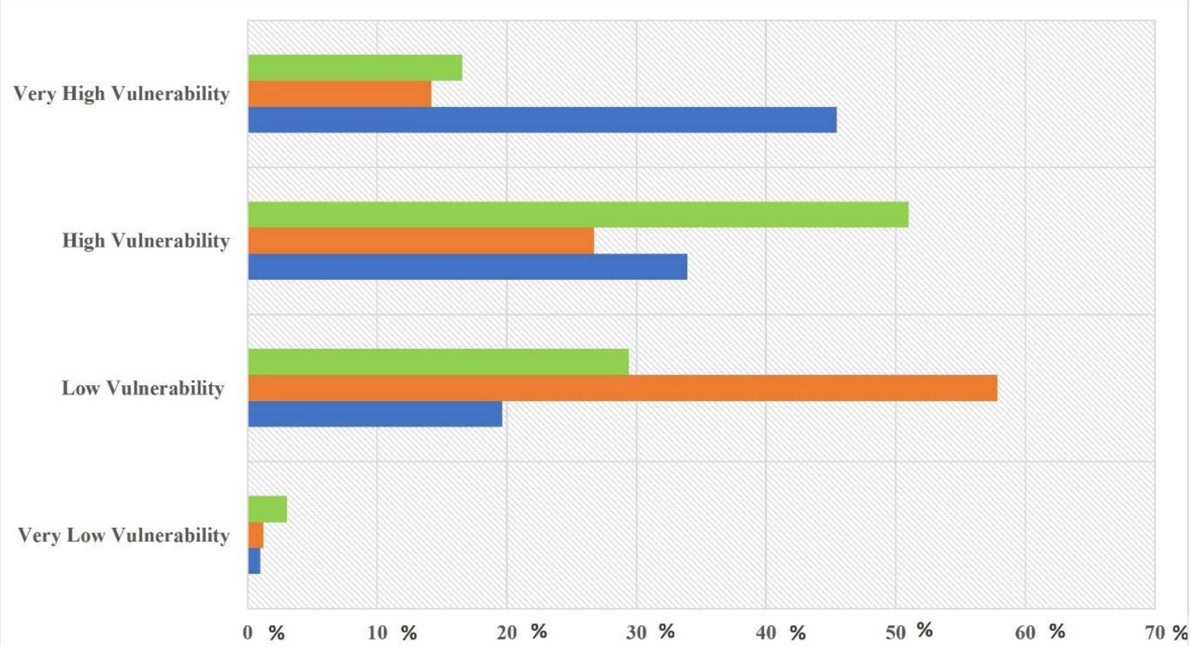


Figure 5.9: Socio-economic vulnerability index (SVI) assessment for study area based on Murali et al. (2013) overlain on an Esri Ocean basemap (Esri 2011)

5.5.3 Coastal Vulnerability Index Assessment (CVI)

Based on Murali et al. (2013), the coastal vulnerability index for the entire study coast was calculated using equation 5.4 to integrate both the weighted physical vulnerability (PVI) and weighted socio-economic index (SVI) to obtain the vulnerability index across the study region. The resultant CVI results which ranged from 2.22 to 3.32 were divided into four classes using the equal interval classification method on ArcGIS. The results shown in Table 5.13, suggest that 3.04% of the study coast is in the very low vulnerability class; 29.41% is in the low vulnerability class; 50.98% is in the high vulnerability class and 16.57% falls within the very high vulnerability class. This finding suggest that coastal erosion is the predominant process along the study coast with about 67.55% of the coast eroding and 32.45% of accretion taking place (see figure 5.10).

Table 5.13: Chart showing the coastal vulnerability index (combination of the PVI and SVI) of the study area to erosion



	Very Low Vulnerability	Low Vulnerability	High Vulnerability	Very High Vulnerability
CVI	3.04	29.41	50.98	16.57
SVI	1.22	57.85	26.74	14.18
PVI	0.98	19.65	33.9	45.47

CVI SVI PVI

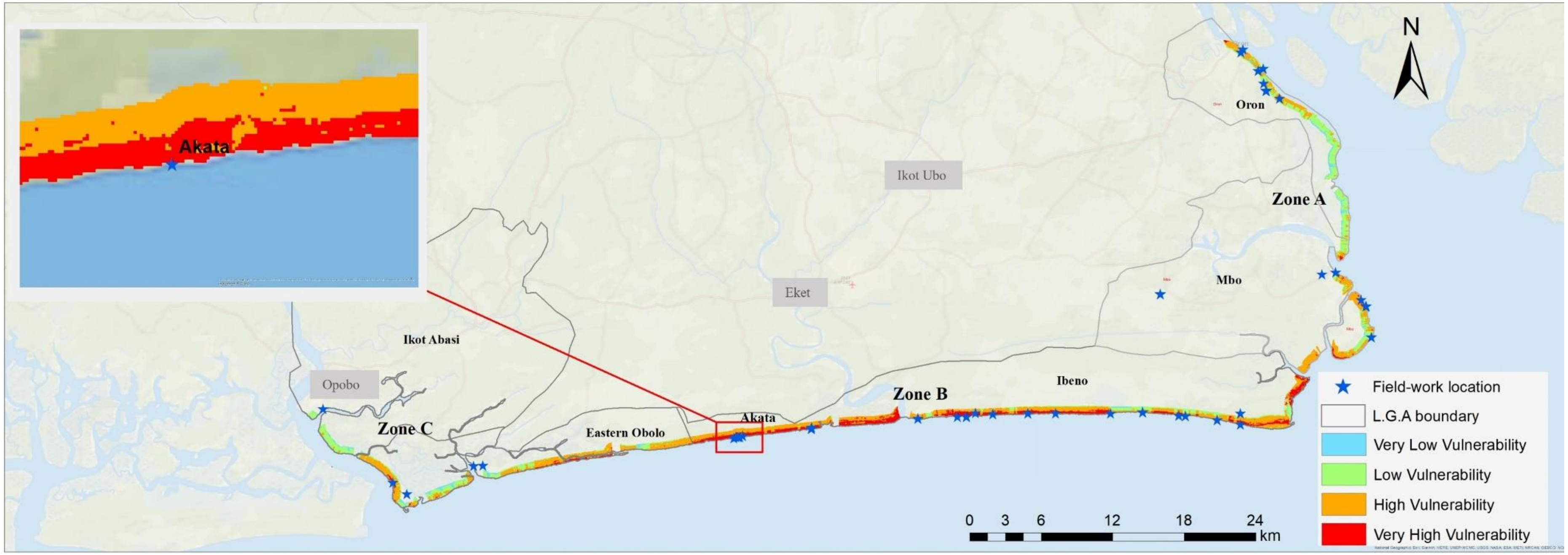


Figure 5.10: Coastal vulnerability index (CVI) which is the product of the mean of the PVI and SVI, derived from the study area because of coastal erosion (insert; Akata, case study location) overlain on an Esri Ocean basemap (Esri 2011).

5.5.4 Participatory GIS Case Study: Akata Community, Ibeno Local Government Area

Akata is a community located in Ibeno L.G.A and situated in the zone B section of the study area and has experienced adverse impacts of coastal erosion. Figure 5.11 depicts active erosion in the Akata section of the coast.

Figure 5.11: Pictures A-D show the eroded section of the study coast along Akata (zone B) which is a serious situation needing urgent response**.**

The risk perception index was integrated for coastal erosion investigation along the Akata stretch of the coast. This region was chosen as the case study area based on;

(1) A preliminary evaluation of the study coast was conducted for chapter 3 before heading to the fieldwork exercise which took place between September-October 2018. A thirty-year shoreline change detection using a 1984 shoreline and comparing it with a 2015 shoreline delineated from Landsat (30m) images obtained from United States Geological Surveys (USGS) to identify areas that showed rapid shoreline changes and identify communities within such locations. Pre-field work, six locations were identified, and it included the Akata community which is labelled D (see figure 5.12).

(2) A fieldwork evaluation conducted during the field mapping exercise. Akata was selected for the case study because it was actively experiencing severe erosion and had the exposure of human population at risk. Through the PGIS, the community also contributed appropriate knowledge on the effects of coastal erosion and their coping ability, as well as thoughts on future consequences in the area.

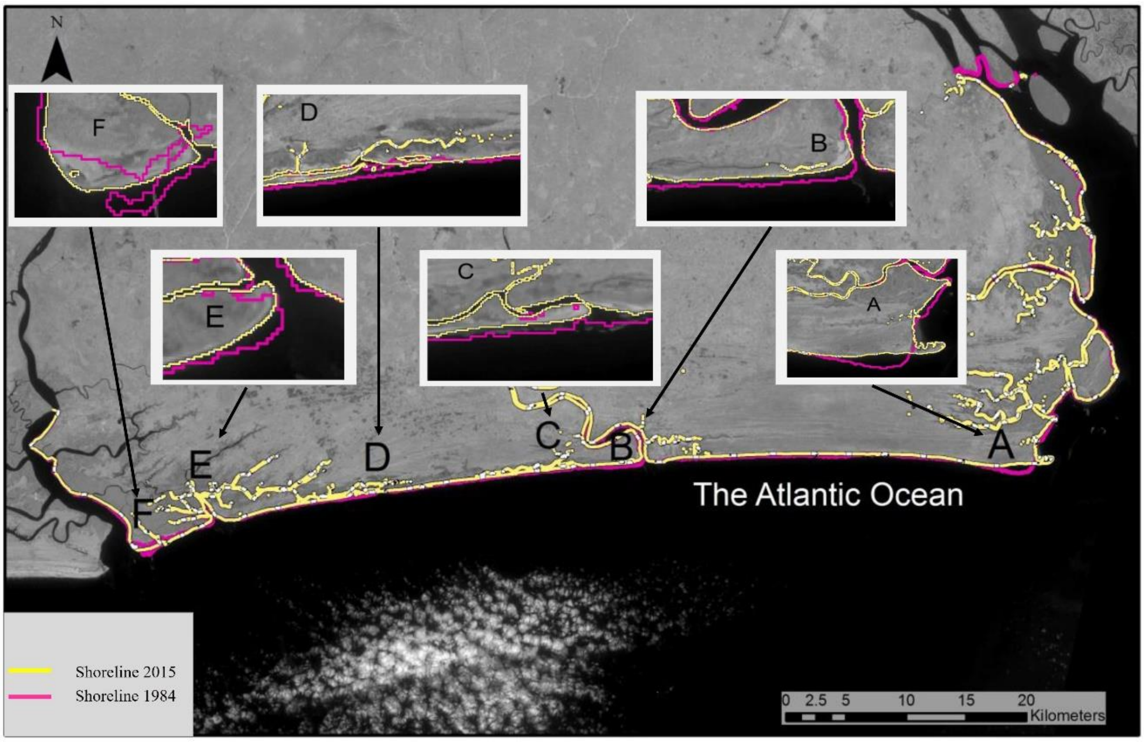


Figure 5.12: Pre-fieldwork assessment of the Akwa Ibom using Shoreline changes from chapter 3 to identify the areas showing significant shoreline changes between 1984- 2015 overlain on a Landsat (band 5) image of 2015.

As previously indicated in section 5.4.3, the PGIS was divided into three steps: 1) focus group discussions about the past and current condition of erosion, the impacts, and the coping/adaptive capacity in place; 2) fieldwork interviews; and 3) mapping exercises with the focus group participants to delineate regions most vulnerable to coastal erosion.

5.5.4.1 Focus Group Discussion

During focus group discussion (refer to chapter 4.4.1), questions such as what is your opinion of any changes to the landscape in your community along the coast? What is your view on the coastal changes that have occurred here? What is opinion on the causes of the changing coastal land? Can you give any information on how these changes have affected the community? Are there any concerns about the coastal changes? What activities has been carried out by the community or government in managing the situation? (See appendix 5.9 details). It should be mentioned here that, the question did not follow any particular order; rather they were presented as follow-up questions to the participant-led discussion (refer to chapter 4 for extensive details of the FGD).

5.5.4.2 Coastal erosion Risk Perception Index ($RPI_{erosion}$) for Akata Community

This metric indicates the level of vulnerability based on the risk perception of Akata community to coastal erosion. For this section, data used were generated from: **(1)** The focus group discussion where the perceived hazard awareness, the perceived severity of the risk and the responses to mitigate the impact of the hazard were generated for the entire study area (derived from chapter 4). **(2)** PGIS mapping exercise where the perceived exposure was assessed from the map produced by the FGD participants.

The outcome here is based on the ranking assigned to the perceived hazard awareness, the perceived severity of the risk, exposure and the responses to mitigate the impact of the hazard. The perceived risk data presented here were based on community-level assessments conducted in Akata community which is along the zone B section of the study coast (see section 4.3). Owing to the complexity of coastal hazards, these social data make it possible to examine coastal erosion holistically, adding to our understanding of its causes and effects. Since, coastal erosion is greatly exacerbated by the presence of human elements, it should not just be assessed using physical or socioeconomic criteria as do the conventional approaches but should also make inferences from social learning. These parameters were selected because they best describe the re-conceptualised DPSIR approach of assessing hazards (refer to section 5.3.3 for more details). Table 5.14, show that the Akata Community falls into the low vulnerability class for perceived hazard awareness; for perceived severity of impacts, it falls into the very high vulnerability class; for exposure, it falls into the very high vulnerability class; and for ranking response, it falls into the high vulnerability class.

Table 5.14: Summary of the vulnerability ranking distribution for the Risk perception index (RPIerosion) parameters.

% Coverage	Very Low Vulnerability	Low Vulnerability	High Vulnerability	Very High Vulnerability
Perceived awareness	-	100	-	-
Perceived Impacts	-	-	-	100
Perceived Exposure	-	-	-	100
Perceived Responses	-	-	100	-

The risk perception index to coastal erosion was calculated based on equation 5.8. This RPIerosion for Akata was then combined with previously derived physical vulnerability (see section 5.5.1) and socioeconomic vulnerability (see section 5.5.3) indexes to generate the final integrated coastal erosion vulnerability index for the Akata section of the study coast in equation 5.10.

5.5.4.3 PGIS mapping

During the fieldwork, a pre-field work was conducted on the 22nd of September 2018 to inform and educate the community of the intended research and to invite/solicit permission to carry out a focus group workshop. At the time of the initial visit, visible and substantial impacts of erosion were observed. However, it was reported that on the 30th of September 2018, a section of the coast that was already eroding was totally undermined due to a storm event that happened that night. Though erosion has been a major problem, on the said day, there was an extreme storm that hit the village at night, flooding the area and eroding a section of the community. It is estimated that about fifty houses were affected, and the community recorded eight fatalities while leaving many homeless, according to participants in the focus group discussion. Regrettably, such fatality discoveries usually go unnoticed and were not included in any coastal vulnerability index assessments. Given their capacity to affect policies and responses, one question that has to be addressed, or possibly the real issue, is whether or not the conventional findings or estimates of vulnerability without a more in-depth social learning about the current situation are being exaggerated or understated.

The map generated by the focus group participants in field where the participants indicated specific areas of active erosion, location of exposed settlements, locations of high and low risk of erosion, present shoreline and in some case, drew the past shorelines on the maps sheets that were provided using coloured pencils and pens (this can be seen in figure 5.13a and 5.17). The map depicted locations where erosion and accretion were perceived to be the dominant processes, as well as showing how vulnerable the settlements in those locations are to coastal erosion. These drawings were scanned, geo-referenced using coordinates generated during the walking interviews with the stakeholders and presented in ArcGIS shapefile format.

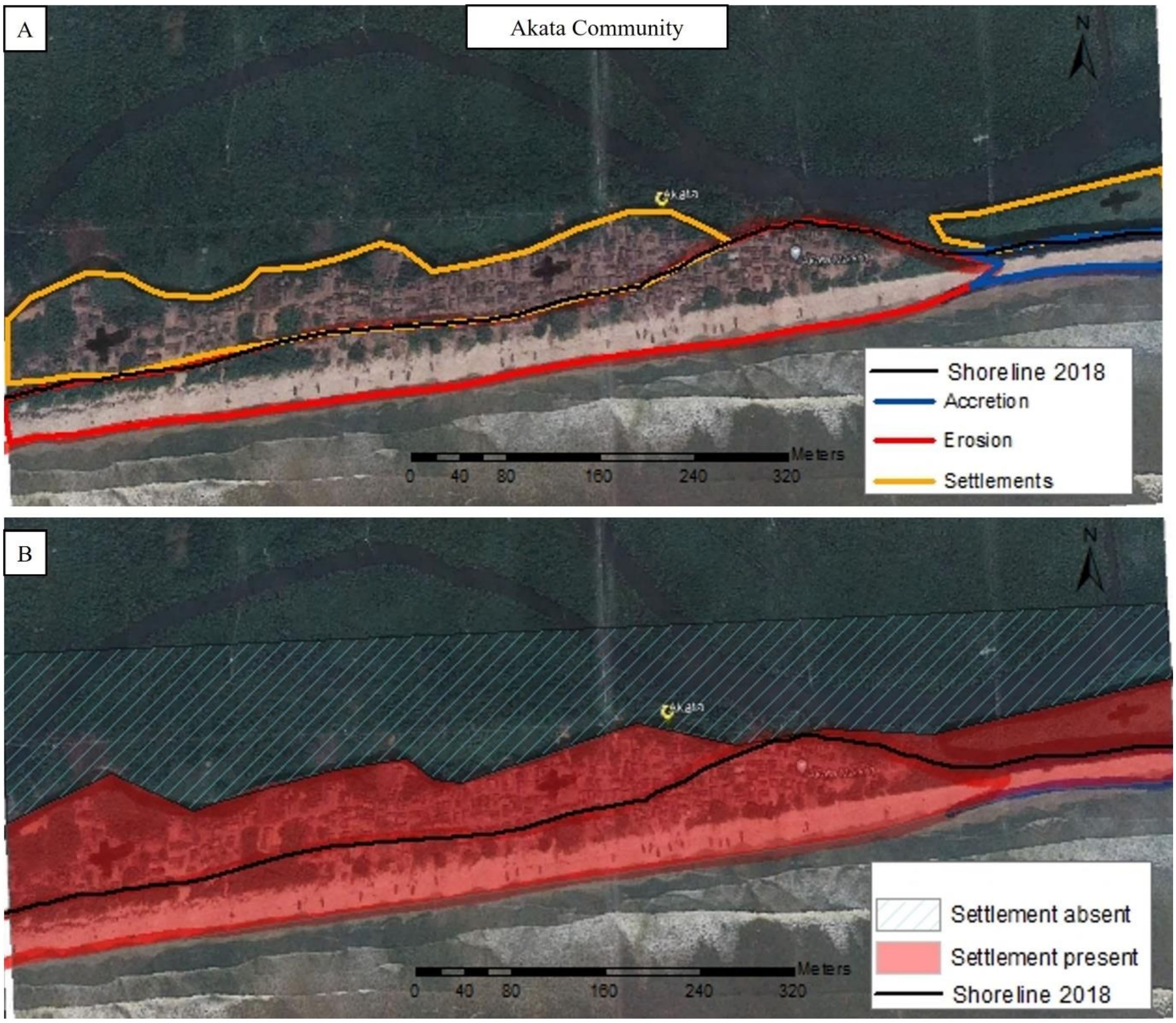


Figure 5.13 A-B**:** Picture A shows the PGIS map generated by the participants at Akata community showing areas eroding and accreting (2018). Picture B shows the georeferenced classified PGIS map showing exposure of the settlement to coastal erosion**.**

5.5.5 Integrated Coastal Erosion Vulnerability Index (ICEVI) along the Akata axis of the Akwa Ibom coast

The proposed ICEVI was carried out only in the case study area to assess the suitability of integrating a risk perception into a coastal vulnerability index. The final vulnerability map was generated by integrating the major parameters selected for this study through the novel approach provided in this work, the integrated coastal erosion vulnerability index (ICEVI) which extends Murali et al. (2013)'s CVI approach. The ICEVI was calculated as:

$$ICEVI = \frac{PVI + SVI + RPIerosion}{3} \qquad (5.11)$$

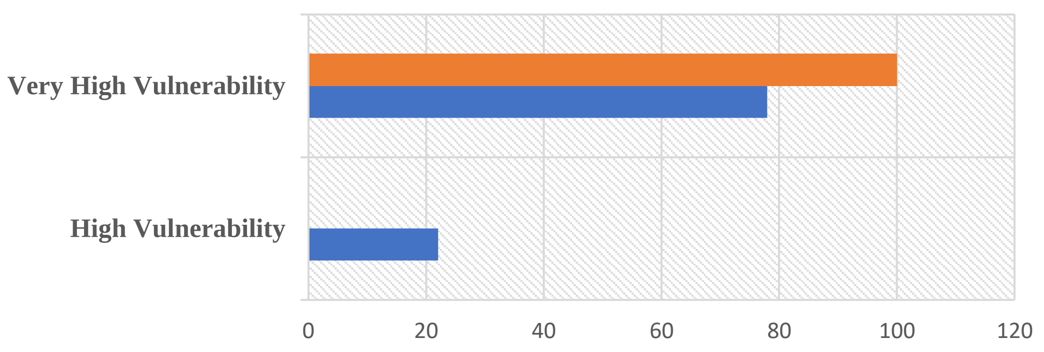
Where *PVI* is the physical vulnerability index

SVI is the socio-economic vulnerability index

And *RPIerosion* is the risk perception vulnerability index for erosion for the study area.

The final ICEVI value assumes that all the criteria employed here contribute equally to coastal vulnerability (see equation 5.11). The final ICEVI for the case study area was calculated using sixteen variables (see appendix 5.10 for a list of variables).

Table 5.15: Comparison of the ICEVI (which had the integration of the RPIerosion with the PVI and SVI) with the CVI which used only the PVI and the SVI for assessment



	High Vulnerability	Very High Vulnerability
ICEVI Akata	0	100
CVI Akata	22.05	77.95

ICEVI Akata CVI Akata

The result of the final calculation of the ICEVI can be seen in table 5.15. Figure 5.14 also compares the final ICEVI (which integrated the RPIerosion with the PVI and SVI) (figure 5.14a) to the CVI, which just employed the PVI and the SVI (figure 5.14b). The ICEVI results suggest that 100% of the Akata section coast is very highly vulnerable to coastal erosion while the CVI (i.e PVI+SVI/2) suggests that 22.05% of the Akata coast is highly vulnerable to the coastal erosion and 77.95 % of the Akata coast lies within the very high vulnerability class.

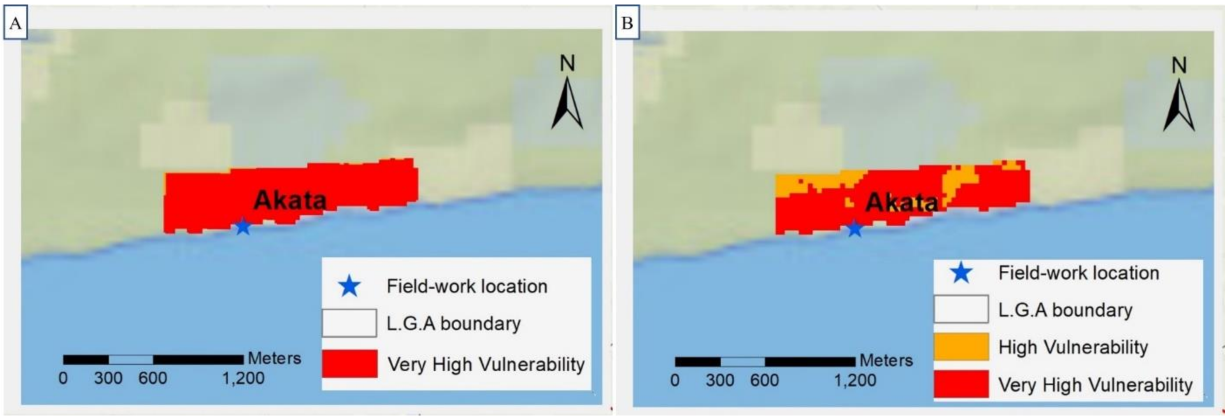


Figure 5.14: Map A shows the integrated coastal erosion vulnerability index (ICEVI) assessment for the case study area and map B shows the CVI (combined PVI and SVI) based on Murali et al. (2013) which excludes the risk perception parameter overlain on an Esri Ocean basemap (Esri 2011).

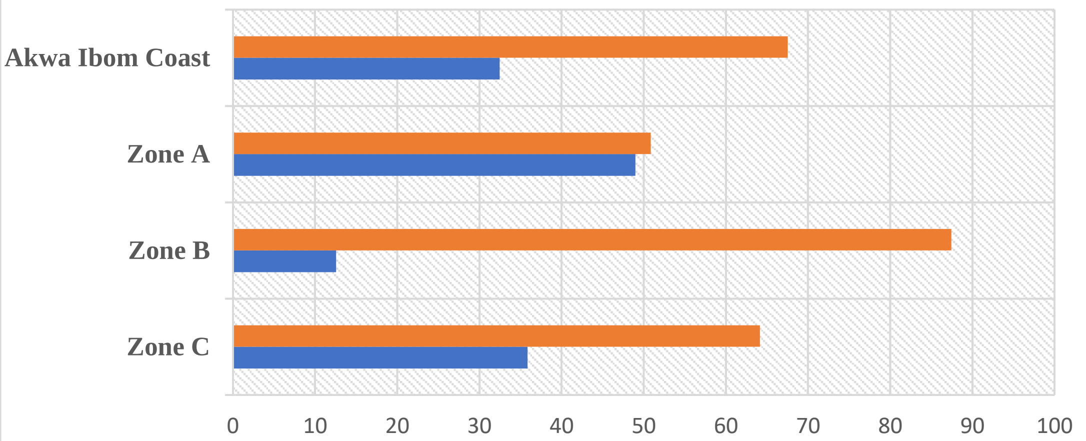
5.6 Discussion

First, the coastal vulnerability index of the study area to coastal erosion was assessed in this chapter using both physical and socioeconomic parameters. Then, to assess final coastal erosion vulnerability in the study area, an integrative technique (mixed-methods) was used, which combines quantitative (chapter 3) and qualitative (chapter 4) methodologies in a single study. The use of multiple sources for assessing erosion vulnerability is critical because it promotes data triangulation and increases the dependability of the outcome (Cox et al. 2012). The findings of the coastal vulnerability assessments are used to answer the research questions for this chapter.

5.6.1 How vulnerable is the Akwa Ibom coast to coastal erosion?

The coastal vulnerability assessment results were divided into four categories: very low, low, high, and very high. According to the CVI results, 67.55% of the entire study coast falls within the high - very high vulnerability class while 32.45% falls with the very low-low vulnerability class (see Table 5.13) indicating that coastal erosion is the predominant process along the coast. A summary of the coastal vulnerability assessment of the Akwa Ibom coast to coastal erosion can be seen in Table 5.16.

Table 5.16: Variability of coastal erosion and accretion along the entire Akwa Ibom State coast



	Zone C	Zone B	Zone A	Akwa Ibom Coast
% Erosion	64.15	87.43	50.84	67.55
% Accretion	35.85	12.57	48.99	32.45

% Erosion % Accretion

The study area as previously stated, is divided into three zones; zone A, zone B where the case study is situated and zone C, which enables a more comphrehensive understanding and comparison of coastal erosion taking place along the coast. This study's findings are consistent with those of Oloyede et al. (2022) that identified parts of the study coast (Strand coast) as having a high risk to coastal hazards. Also table 5.16 indicates that zone B, is the most vulnerable section to coastal erosion with about 87.43% of the section eroding while 12.57% indicates accretion. According to a recent study by Amangabara et al. (2021), Ibeno L.G.A which is located in zone B, experienced a 4.25% increase in erosion and 2.91% accretion between 1986 and 2016. Their findings corroborate the results presented in chapter 3 of this research, which demonstrated that zone B was the most dynamic and vulnerable section of the coast to coastal erosion when compared to other sections. The results revealed an average erosion rate of -5.23m/yr and an accretion rate of 3.44m/yr from 1984 to 2020. The shoreline change rating revealed that 56.57% of the coast is very highly vulnerable to shoreline changes, implying that erosion rates greater than 2m/yr occur in certain locations within this zone.

Figure 5.15 depicts a visual assessment of the Akata, along zone B (2013-2019). Figure 5.15a shows that the location within the black rectangle in 2013 has been significantly eroded by 2019 (figure 5.15b). The evidence in Figure 5.15 suggests that the Akata section along zone B is eroding rapidly. It also depicts the shorelines' landward migration from 2013 to 2019, indicating erosion.

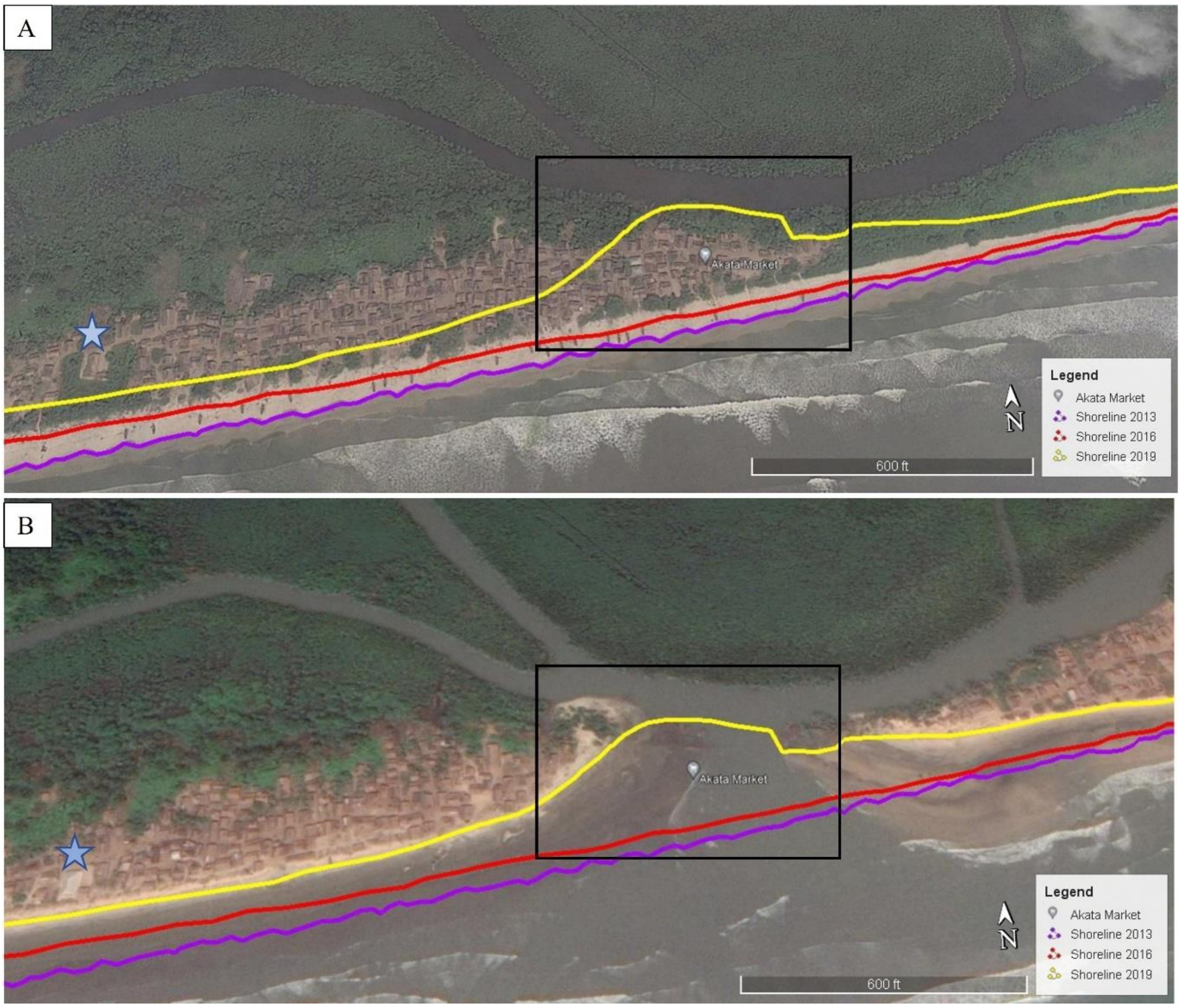


Figure 5.15: Picture A shows shorelines for 2013-2019 extracted from Google Earth and overlain on a Google Earth (2013) image. Picture B shows the same shorelines overlain on a Google Earth (2019) image showing the extent of coastal erosion in Akata community.

There are several possible explanations for the high rates of erosion observed in zone B, which could be attributed to a variety of contributing factors, taking into account that different factors contribute to the study coast's vulnerability to coastal erosion. The PVI results show that the Akwa-Ibom coast falls into the very low to very high vulnerability classes, with 45.47% of the coast classified as very high vulnerability; 33.9% as high vulnerability; 19.655 as low vulnerability and 0.98% as very low vulnerability. The PVI results show that, for shoreline changes, the coast falls within the very low vulnerability to very high vulnerability range, implying that the coast is undergoing both erosion and accretion processes, with around 21.62% of the coast accreting and 78.39% of the coast is eroding . Despite the accretion, the results indicate that coastal erosion is the dominant process along the coast. Aside from shoreline changes, a number of other physical factors are known to influence coastal erosion. The slope factor has a significant impact on the rate of coastal erosion (Athanasiou et al. 2019). According to the United-Nations (2017), the low-elevation coastal zone (LECZ) - coastal areas less than 10m above sea level are regarded as home to 10% of the world's population (about 750 million people). According to Barbier (2015), 28 % of the global population resides within 100 kilometres of the coast in places with elevations less than 10 metres above sea level and developing countries' LECZs are the most vulnerable to sea-level rise, coastal erosion, and other coastal hazards. Because coastal erosion is highly influenced by site-specific circumstances (Masselink et al. 2020), the slope values and other parameter ranges used here were tailored to the values derived for the study coast. As a result, applying international ranges may not be relevant. The PVI for slope in the study area shows that 47.04% of the coast has slope values of less than 3% which falls within the very high vulnerability class, 34.39% have slope values between 3-6%, which indicates high vulnerability, 11.54% have slopes between 6-9% which indicates low vulnerability when compared to other areas along the coast; and 7.03% have very low vulnerability because these areas have slopes greater than 9%. Going by Barbier (2015), the entire coast is vulnerable to coastal erosion. The results show that the most vulnerable areas are mostly located along the Ibeno L.G.A axis of the coast, which is directly exposed to the Atlantic Ocean (see figure 5.5a). The gentle slopes and openness to the coast are possible explanations for the very high vulnerability levels of erosion, which could be easily impacted by SLR (Musa et al. 2016) and the disturbance from the waves and currents, which could be due to its proximity to the open coast (Fitton et al. 2016) which should be expected to be higher along the estuaries.

Proximity to the coast is an essential parameter in this study. Proximity to the coast also presents significant problems for countries where many of the industrial facilities, commercial buildings and other social and economic infrastructure are located close to the coast, such as the case in Australia (DepartmentOfClimateChange 2010). This report also highlights that there has been increased property damage, rise in costs of maintenance and repair of infrastructure because of their proximity to the coast and the persistent effects of climate change (DepartmentOfClimateChange 2010). It was additionally reported by the Australia’s Department of Climate Change that in the coming years, from 2031-2070, the severity of the damage will reach moderate to high levels, and by the end of the century, it is expected to reach high to extreme for several coastal communities. The report further pointed out that between 1967 and 1999, approximately $28.6 billion was spent repairing damage from coastal hazards, pointing out that the success costs of repairing the impending damage will be certainly significant. This is also similar to Varela, North western Guinea-Bissau in West Africa which has experienced about 700m shoreline retreat in the past 40 years, eroding several infrastructures including tourism resorts posing serious threats to the economic hubs there (CILSS 2016). This simply indicates that vulnerability is directly impacted by proximity. Meaning that the farther away from the shoreline, the lower the vulnerability and vice versa (Rocha et al. 2020). Owing to this type of significant damage that could result from coastal hazards due to their nearness to the shoreline, the inclusion of this parameter in assessing coastal erosion vulnerability along the Akwa Ibom coast cannot be over-emphasised. The PVI ranking for proximity to the coast shows that the study area falls within the low – very high vulnerability class with 44.4% of the study area in very close proximity of less than 250m to the shoreline, making those areas very highly vulnerable to erosion. About 40.49% lie within 250-500m of the shoreline, indicating high vulnerability and only 14.91% fell within the low vulnerability class with a distance between 500-1000m of the shoreline. The results indicate how vulnerable the coast is to coastal erosion because the exposure of coastal communities due to a close proximity to a shoreline, determines the severity of impact arising from sea level rise and climate change (Milfont et al. 2014). As Milfont et al. (2014) further point out, though all types of regions experience the effects of climate change to varying degrees, the coastal communities experience more serious threats from the impact of climate change.

Another plausible explanation for the vulnerability of the coast to coastal erosion is the geomorphology of the coast. The research area is distinguished by sandy beaches and barrier systems comprised of unconsolidated loose sediments. Also, because the barrier system indicates that the research region is wave-dominated, the rate of movement of the loose sands will be greatly accelerated. Because of the geomorphology, about 78.98% of the coast shows a very high vulnerability whereas only about 21.02% falls in the high vulnerability class. As a result, the Akwa Ibom coast is classified as falling within the high - very high vulnerability class. Its significance is discussed by Naylor et al. (2017) on how it controls flooding and erosion with illustrations along the United Kingdom coast. With different geomorphic units, it is expected that the degree of erosion and vulnerability would vary (Serio et al. 2018). Rao et al. (2008) further explain that while rocky cliffs, for instance, provide sufficient resistance against coastal hazards, dunes and mudflats, among other sandy and muddy constructs, are considerably vulnerable to sea-level rise. This means that geomorphological features are either erosional or depositional in nature (Evelpidou 2019), which is facilitated by increasing SLR due to climate change. As such, accelerated vulnerability of the geomorphology of coastal areas to erosion should be expected. A typical example of such an accelerated climate-change impact on coastal geomorphology around the United Kingdom is discussed by Masselink et al. (2020) who explained that global rate of sea level rose from 1993 till 2017 which it was recorded to be 3 ± 0.4 mm/yr and accelerating at 0.084 ± 0.025 mm/yr^2 but it was noted that there were multiple sites along the English Channel that showed significantly higher rates than the average global trend. This means increased vulnerability to coastal erosion in such areas unless adaptation measures are put in place to combat the effects of coastal erosion (Masselink et al. 2020). Also, Masselink et al. (2020) extensively discuss how geomorphology influences the rate of erosion along the United Kingdom and Ireland's coasts with the soft coast eroding at a much faster rate than the hard coast. They also discussed how elevation played a huge role in the 2013/2014 storm that caused significant shoreline changes. Though no lives were lost, the impact that took place was severe.

The elevation rankings for the study area suggests that 38.64 % of the coast is classified as very low vulnerability, meaning that those locations had elevations greater than 9m while 28.08 % are classified as low vulnerability with elevations between 6-9m and about 29.79 % are classified as high vulnerability with elevations between 3-6m and only 3.49% of the coast show elevations lower than 3m (very high vulnerability). Elevation is significant in coastal erosion studies. For instance, coastal elevation serves as a barrier to the ability and extent to which ocean flood can inundate and overwhelm the land (ClimateCentral 2019). Unsurprisingly, though, communities and ecosystems at low lying elevations are particularly vulnerable to the effects of climate change and SLR and are at risk to lose their natural capital such as agricultural lands, among others (Edward 2017), while locations at higher elevations are less likely to be adversely impacted by SLR and related hazards (Murali et al. 2013). As such, this makes the more elevated coastal areas less vulnerable than the low lying coastal areas (Serio et al. 2018). According to Kamal (2021) increase in sea levels contributes to flooding, storms and hazard events along the coast. Despite studies linking coastal erosion to SLR, Cozannet et al. (2014) argue that these studies do not show that recent sea-level rise has been a major factor in coastal retreat. Due to lack of data availability, sea level change was generalised along the coast using data derived from past study which indicated that the coast falls in the very high vulnerability class because of the range from 3.03 to 3.39mmyr^1 along the Niger Delta coast (Rosmorduc, 2012 as cited in Musa et al. (2014). As Lee et al. (2017) highlight, coastal communities are at risk of coastal inundation as repeated flooding from high tides poses a significant problem along the coast. Interestingly, there is an increase in tidal range if it hits along a hard coast and tends to decrease along low lying soft coasts (Lee et al. 2017). A study by Pongsiri et al. (2020)

found that trends regarding tidal levels were almost consistent to the increasing trends relating to mean sea level. This is understandable because tidal range is used to determine the vertical location of the local mean sea level, and also plays a role in coastal flooding and total water levels (Hill 2016). This creates the need for more understanding of the many facets of tidal range, such as mean, spatial distruibution and temporal variation but at the moment, direct observations of tidal changes are limited by the available data (Hill 2016).

Apart from the results from the physical vulnerability, which illustrates how vulnerable the physical coast is to coastal erosion, the observation vulnerability of the coast could be attributed to the socio-economic parameters along the coast. The socio-economic vulnerability index suggests that the research region falls into the very low- very high vulnerability category. According to the findings in this study, 1.22% falls into the very low vulnerability class; 57.85% falls into the low vulnerability class; 26.74% falls into the high vulnerability category and only 14.18% falls into the very high vulnerability class. It should be noted that the majority of the social-economic data used were predicated on the existence or absence of an indication rather than actual measured data. Although socioeconomic characteristics do not indicate the coastal erosion sites, including them in the vulnerability assessment is crucial as they will determine the level of vulnerability or impact that the hazard can produce (Mclaughlin et al. 2010). But these results should be interpreted and discussed with caution. Land use/land cover, which was generated from the Landsat image for 2015, indicated that 1.51% falls into the very low vulnerable class, 65.13% is classified as low vulnerability, 17.99% is classified as high vulnerability and 15.37% falls into the very high vulnerability class. The very high vulnerability rank shows areas where there are settlements/build up because these are places with a human population, while areas with protection from vegetation and water bodies are assigned the lower vulnerability ranking. Interestingly, the land use and landcover factor indicates several things. For example, it depicts areas that should be protected from erosion (Mclaughlin et al. 2010) and highlights areas which have high impact use that alters and destroys natural vegetation which would have served a buffer in protecting the coast from eroding (Huang et al. 2012). Agricultural/cultivated and bare soil are also vulnerable because they impact the removal of soil with increased disturbance to the land, and bare unprotected land tends to increase the amount of erosion (Oloyede et al. 2022). Also, coastal villages or locations considered to be home to significant assets for the communities are considered to be more vulnerable (Jana et al. 2013) and likely to be affected by coastal erosion (Ahmed et al. 2021). Apart from highlighting the area most vulnerable to coastal erosion, Oloyede et al. (2022)

indicate that land use/land cover is a proxy for understanding the extent of human disturbance of the natural environment around the coast. Having 15.37% of the area showing settlements is understandable because during the fieldwork for this research, it was observed that the settlements in that region are sparsely located.

Another socio-economic factor used in this study to assess the vulnerability to coastal erosion is the road network. Murali et al. (2013) points out that roads serve as linkages between areas and that if such important roads erode, the impact on the economic status of that area, particularly during disasters, could be exacerbated. The road network for this research region falls into the low-high vulnerability category. The presence of minor roads in 83% of the study area reduces the vulnerability of the area to erosion. However, while, that may be understandable, 17% of the area have major roads which leaves such locations highly vulnerabile to coastal erosion, especially if there is the presence of economic activities, tourism and cultural heritage. The data for cultural heritage was generated during the fieldwork exercise for this study and the results show 77.52% of the coast falls into the very highly vulnerable class and 22.48% area classified as very low vulnerability. These results can be explained because the rankings only indicate places with/without cultural heritage. The Cultural heritage locations along the Akwa Ibom coast include tourism sites in;

- Esuk Oro, Oron: which is home to Africa's oldest wood carving and other ancestral figurines (masquerades), as well as a historical museum founded in 1958.
- Mbo: Ibaka sea port is located here. This place serves as a trading hub and host to an annual sea regali event.
- Ibeno: home to famous Ibeno beach which is not only a tourist destination but also a fishing business hub.
- Ikot Abasi: This is where the Women's War Cenotaph was established in 1929. It is also the site of the slave prisons and the famed bridge of no return, which was a significant slave trading route during the slave trade era. In 1914, Lord Lugard, the colonial administrator of Northern Nigeria, merged the Northern and Southern Protectorates, creating Nigeria as a single geographical entity in the Amalgamation house located in the area of the study coast (NDEBUMOG).

It is interesting that most of the locations with the presence of cultural heritage have partial coastal defences (embankment) which serve as defense from coastal erosion. This study's results show that 78.62% of the coast falls into the high vulnerability class, indicating that soft engineering forms (sand bags/sticks/planks/, tilts) of managment were implemented which are not adequate enough to cushion the effects of coastal erosion. It also revealed that while 17% falls into the very low vulnerability category, 4.38% of the study area is classified as low vulnerability. It is almost certain that areas with little or no coastal defence not only leave the area susceptible to erosion but also increases the vulnerability of the human population in such areas to coastal erosion. This simply means the densely populated the area, the more vulnerable the area is to coastal erosion and vice versa (Cao et al. 2022). According to Mclaughlin et al. (2010), coastal erosion at locations without human population will have a no-to-low vulnerability index since it just reflects the susceptibility of the land to erode with no negative repercussions. The population density ranking for the study shows that 56% of the study area had fewer than 500 people per km^2, which indicates very low vulnerability, 27% had between 250-500 persons per km^2, indicating low vulnerability and 17% showed very high vulnerability with more than 1000 persons per km^2. Understanding how the population along the coast impacts on either accelerating erosion or managing it can be assessed in various ways. One such way can be through the risk perception in the affected regions.

Generally, the findings revealed that coastal erosion is predominant along the three zones highlighted in this study. This finding agrees with results from chapter 3 and 4 which highlights the presence coastal erosion along the study coast. In zone A, 50.84% of that section of the 38 km length of coast is predominantly erosion while 48.99% experiences accretion. One reason for the observed erosion and accretion in zone A may be linked to the role played by the hard engineering structures put in place along sections of this coast (refer to chapter 3.4.1.1 for more discussion about that). In zone B, 87.43% of the 55km length of coast is undergoing erosion while 12.57 is accreting which agrees with the finding in chapter 3 (see 3.section 4.1.1 for more explanation) which suggests that zone B is the most dynamic and susceptible section along the entire study coast to coastal erosion. And in zone C, which is about 37km long, a similar erosion trend is observed with 64.15% of the coast undergoing erosion and 35.85% of the coast accreting making this zone the second most vulnerable zone along the coast which is corroborated results derived in chapter 3 (refer to section 3.4.1.1 for discussion).

5.6.2 What is the benefit of participatory GIS (PGIS) in assessing coastal erosion?

It is important to note here that the use of local knowledge cannot be overemphasied. The data generated through qualitative analysis in chapter 4 and the PGIS described here, does not only compliment scientific research but also validates the output by increasing its reliability (Haklay et al. 2017; Cochrane et al. 2019). For instance, the coastal defence data used in the coastal vulnerability inde assessment was obtained during the course of the PGIS surveys where protected areas were delineated. Without the coastal defence data, the socio-economic vulnerability would be increased. The coastal defence in this study assigns low vulnerability for areas with hard erosion control. Although some studies, such as Eurosion (2004) and Balaji et al. (2017) argue that altering the natural shorelines with hard coastal defence structures increase the cross-shore erosion. The observation and finding from the PGIS methods suggested that there has been a stability in areas with coastal defences as zone C. However, the likely effects along the down drift side of the coastal defence were not considered in this study because the scope of work of the PGIS was limited to areas where focus group discusions were held. PGIS have been successfully applied globally and in data scarce regions (Gorokhovich et al. 2014; Meenar 2017; Klonner et al. 2021). This method has proven to be a good source of not only data generation but also for community participation in effective coastal management (Baldwin et al. 2014; Cochrane et al. 2019). The PGIS approach is essential, especially in environments in which little or no data exists. The advantages and benefits of this approach are evident in my study area, where not only are community stakeholders willing to take proactive management steps where necessary, but the Akwa Ibom state Ministry of Education has shown interest in the findings of this research, as it will be the first comprehensive mixed-method assessment of coastal erosion along the Akwa Ibom coast, with the potential to support mitigation measures and proper coastal management policy.

Though effective, there are challenges with the approach. For instance, during the fieldwork, only a few people understood and were willing to participate in the mapping exercise. Majority of the coast are predominantly fishermen and during the day were out to sea and those around were enagaged with their businesses. So after the focus group discusions (discussed in chapater 4), the mapping exercise was not of priority to most of them. Also, the scale and clarity of the satellite maps used in the mapping exercise played a major setback in the process. A more detailed physical map or digital maps would be ideal but because the scope of the work focuses on data available in poor data region, these google earth map were used as better information could be generated than the Landsat 2018 available. However, these did not allow for clear delineation of most locations and boundaries. An improvised approach used applied where plain sheets of paper were used to carry out the risk mapping in some locations along the study coast (see figure 5.16). For example, the risk map generated for Ndito Eka Iba, which is approximately 1.9km along the Ibeno section zone B (see map 5.16), provided details on areas of very low to very high risk of coastal erosion in only its immediate environs which could be useful for only localised planning and management.

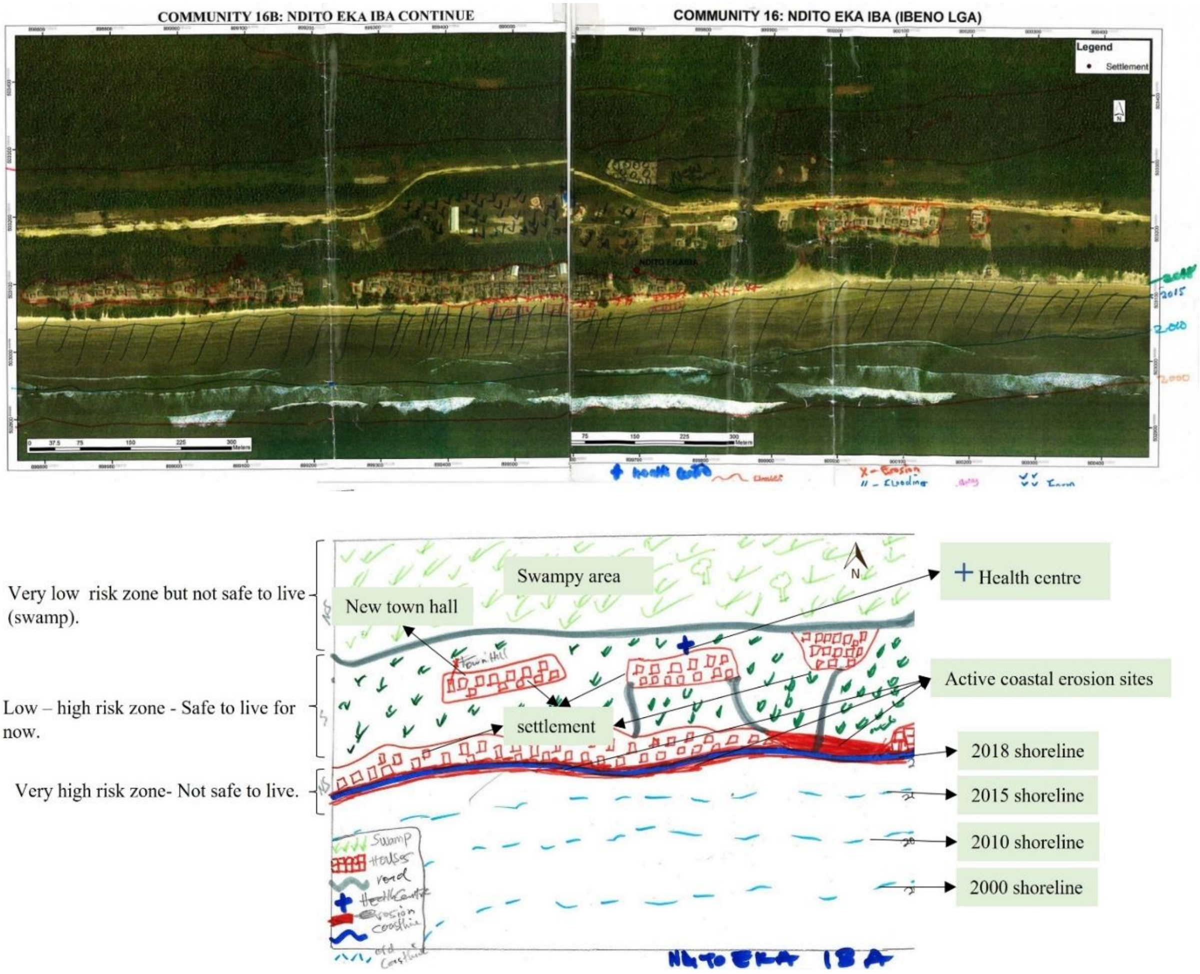


Figure 5.16: Coastal risk map created by the focus group discussion 9 (Ndito Eka Iba) along zone B of the study coast

Another drawback to PGIS encountered, is the lack of interest in mapping by most of the stakeholders which means the mapping is done by a fewer number of people and as such, is completely based on the individual’s subjectivity, mapping understanding and skills (Hasanzadeh 2021). To tackle this, the researcher or facilitator has to seek alternatives sources to validate the details given in the risk map like organising a delibration and feedback session or could buy-in from scientific data to verify the maps (Burdon et al. 2020). However, due to time constraint during the fieldwork and owing to the Covid-19 pandemic, a feedback and deliberation session was not feasible. Despite these limitations, PGIS offers a great tool to assess current situation about coastal erosion in the area and foster stakeholder participation, which is good for adaptation and management practices. An example is the case study area used in this study, community mapping of the elements and extent of exposure to coastal erosion, information of the impacts, casualities and the management practices implemented which should form a more holistic vulnerability assessment could only be easily generated during a PGIS session/sessions (refer to section 5.5.4 for results).

For instance, during the fieldwork, though the Eastern Obolo community in zone C acknowledged the occurrence of coastal erosion and even minor damages to property, but they described its impact as "mild" because they had emplaced hard and soft management techniques to reduce the impact of coastal erosion across a significant stretch of that zone. Example of such management includes communities being relocated behind the vegetation backstop that runs majority of the coast (see figure 5.17).

Figure 5.17: Pictures A and B show the vegetation backstop used as buffer against coast erosion in Eastern Obolo L.G.A (zone C)

Apart from additional data generation, with the advancement of technology and the common use of mobile phones in the coastal communities, mobile GIS could be a better technique of mapping and sharing information. A good example is the use of mobile GIS for field survey where detailed spatial dataset of flora and fauna was collected in the Kujawy Mining Site in Bielawy Lafarge Cement S.A company Poland by Nowak et al. (2020). This method proved useful in sharing the data generated in the field between researchers and enable a more efficient way of creating reliable maps of the species distribution in the area.

5.6.3 How does the integration of physical, socio-economic and social-risk perception characteristics contribute to a better vulnerability assessment?

Complex environmental challenges like coastal erosion, which are affected by a variety of factors, necessitates the use of a more rational and holistic strategy. The effectiveness of a coastal vulnerability index's results is determined by the user and the purpose of the coastal vulnerability (Murali et al. 2013). For example, if the goal is to understand the coast's susceptibility to physical elements, then the physical vulnerability index is essential. However, when it comes to assessing the relative influence of humans, the socioeconomic vulnerability index would help. However, to understand how the coastal human-environment system affects coastal erosion, this study recommends integrating physical, socioeconomic, and risk perception data to holistically analyse erosion using the ICEVI proposed by this study.

In this research, a case study location, Akata community, was used to implement the more holistic approach developed by this study (refer to section 5.3.3. and section 5.5.5 for rationale and reliable results). The final results from the proposed ICEVI were compared to the coastal vulnerability data produced from the CVI (PVI and SVI) without including risk perception. The findings revealed a similarity between the two vulnerability outcomes (see figure 5.14). However, the ICEVI data approach, demonstrates and suggests that entire Akata coast which is about 2.5km long along the study coast falls within the very high vulnerability class which is not the same for the CVI. The CVI predicts the zone falls between the high-very high with 22.05% falling into the high vulnerability class and 77.95% falling with the very high vulnerability class. The ICEVI result is supported well by the state of erosion observed during the field work which is also evidenced by figures 5.15 and 5.16 which show how the disappearing coast and how rapid the coastal process is taking place. The evidence from this study suggests that the newly proposed method, ICEVI, gives a better representation of Akata communities perception of risk along the Akwa Ibom coast and provides adequate information that can be useful for management and policy making.

Although this approach gives a better representation in Akata community, with one location and a small sample size used, caution must be applied, as the findings might not be representative of the entire coast especially areas with no human settlements. Secondly, the approach relies heavily on qualitative data from stakeholders and an as such, there is a bias on the reliability of information especially where there is no proper documentation of hazards and impacts. Moreover, the interpretation of results should be done with caution because of the element of bias from the experts that may be present during the PGIS workshops. Also, from the difficulties that arose during this study, where the study relied mainly on data generated from the focus group discussion, which could have elements of bias from either those attending because views may not represent the communities since only selected people based on the criteria (refer to section 4.3.2.9) were invited to the FGD or error the researcher during the process of transcribing and interpreting the data. However, it is important to note here that as a researcher, I made certain that I established reflexivity in order to ensure that my ideas or prior knowledge about the issue of interest did not impact the interview process (Breen 2006). Reflexivity simply implies being conscious of one's effect, and it requires researchers to present their whole dialogue and interaction with the participants in the report, demonstrating the level of influence (or lack thereof) that it had on the participants (Begoray et al. 2012). Also, qualitative data from questionnaire could represent individual perceptions of coastal erosion, preventing over-exaggeration of interpreted results. Despite, the drawbacks, this simple index method can be applied to any other sector if the ranks for the indicators are assessed by more expert knowledge in the field and are applied within reasonable and acceptable rationales.

5.7 Summary

Vulnerability ranking is an excellent way to express relative vulnerability, especially in low data environments and due to its ease of use (Koroglu, et al., 2019). This approach has proven to be particularly beneficial when examining complicated phenomena and in mixed-method investigations. Although beneficial, implementing a mixed-method approach can be time-consuming, capital-intensive, and stressful. According to Molina-Azorin (2016), a researcher must determine whether the integrated data will provide more information or advance the research more than using qualitative or quantitative results independently or drawing from both results separately without integration. It is vital to emphasise that mixed-method research, which this study does, provides far more than simply integrating quantitative and qualitative results in a single research effort (Halcomb et al. 2015). Adopting this research methodology provides not only an added advantage in terms of research validation because it incorporates multiple recognised research methodologies in a comprehensive analysis of the elements of research (Doyle et al. 2009), but it also promotes community participation, which is a key element in adaptation. And also provides adequate information for policy making to understand the coastal erosion risk and adaptation measures at a more local scale. That not withstanding how vital the intergrated approach, the trade off of combining the physical, socio-economic and risk perception maps into a single assessment, implies that the granularity that can be obtained from each map assessed alone is lost.

Chapter 6: Discussion

Chapter six discusses the findings from Chapters 3 to 5 in relation to the thesis aims and objectives. It provides an overview of the challenges faced by the coastal regions in Akwa Ibom State, Nigeria to risks from coastal erosion, as well as the implications for policymaking, practical measures and methods of community engagement to improve local coastal resilience and the study's contribution to coastal erosion vulnerability assessments in data scarce regions more broadly.

Chapter 6

6.1 Discussion

The purpose of this thesis was to assess the Akwa Ibom coast's vulnerability to coastal erosion at a scale (i.e the local community scale) that can be used for village planning and decision making. An integrated approach combining quantitative physical vulnerability mapping of recent coastal change and predictions of anticipated future risks (Chapter 3), social vulnerability from secondary data sources (Chapter 5), and qualitative analysis of community knowledge of climate change, erosion and their risk perception obtained through a community-based participatory approach (Chapter 4) was used to address the coast's vulnerability to coastal erosion holistically (Chapter 5). The thesis is organised in such a way that each empirical chapter discusses its own findings, and this chapter elaborates and synthesises these findings in order to cohesively address the thesis's main aim.

First, a spatio-temporal analysis of shoreline changes along the study coast was conducted in Chapter 3, with historical changes assessed and future predictions made using both, medium and high-resolution satellite datasets. The shoreline change analysis provided insights into the study area's susceptibility to coastal erosion over a 36-year investigation period (1984-2020). Second, in Chapter 4, a culturally responsive approach was used to understand local perceptions and impacts of coastal erosion in Akwa-Ibom State. The chapter investigated the complex human-human and human-nature relationships in a stressed and vulnerable socio-ecological system by gaining knowledge of the local community’s risk perception of coastal erosion, the spatial variability of the social-ecological drivers, and the physical and social impacts of present-day coastal erosion along the Akwa Ibom state coast. Furthermore, the coping mechanisms used by local communities found in the twelve villages studied within the wider study area (i.e. the Akwa Ibom region’s coast) were investigated in order to provide well-informed, place-based and culturally grounded recommendations on potential adaptation strategies to improve community and ecosystem resilience to the effects of coastal erosion in this region. Thirdly, an assessment of the vulnerability of the Akwa Ibom coast to coastal erosion was carried out using widely used Coastal Vulnerability Models (CVI) and a newly conceptualised ICEVI (Integrated coastal erosion vulnerability index) to investigate whether the use of social data can improve erosion vulnerability assessments in data poor countries. The shoreline change analysis from chapter 3 shows that coastal erosion is the predominant trend along the study coast. A similar conclusion was drawn from the participants' risk perceptions along the study coast in chapter 4, which showed that the region was experiencing significant coastal erosion. The shoreline change result from chapter 3 served as an input parameter assessing the coastal vulnerability of the entire study coast to coastal erosion. To determine the newly conceptualised Integrated Coastal Erosion Vulnerability Index (ICEVI) in the Akata axis (case study location) of the Akwa Ibom coast (chapter 5), the risk perception data from chapter 4 was combined with the PGIS exposure parameter and coastal vulnerability index determined in chapter 5 (see figure 6.1).

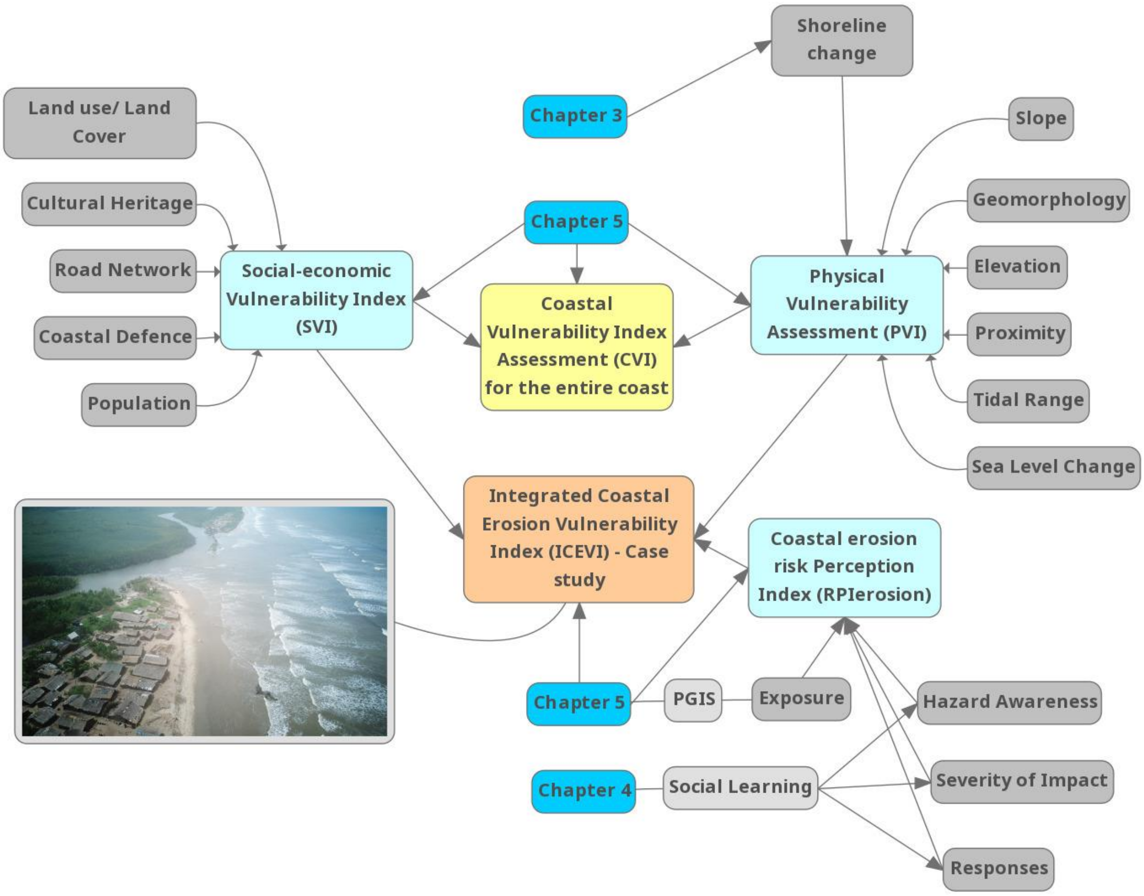


Figure 6.1: A Conceptual diagram showing the synthesis of this study's empirical chapters

6.2 Shoreline evolution along the Akwa Ibom coast and its implication for coastal erosion hazards

Understanding the changes in the shoreline is critical for understanding how the coast has changed over time and is considered necessary for improving coastal resilience to climate change hazards (Correll-Brown et al. 2022). Previous research has highlighted the importance of detecting shoreline changes in determining the locations and rates of erosion/accretion.

According to Dewi et al. (2020), with increasing human population pressure along the coast, constant monitoring of shoreline changes is critical for planning and development. Tamassoki et al. (2014) suggests that the viability of the coastal region will be threatened if the locations susceptible to constant shoreline changes are not continuously monitored. Monitoring is not only beneficial for understanding the present situation, but can also help with future prediction (Melet et al. 2020) and a better understanding of the spatial and temporal changes occurring along the coast (Niang 2020). Although monitoring of shoreline changes is critical, the spatial and temporal assessment may be constrained by the lack of data, particularly in data-poor countries (Sunder et al. 2017). This study uses remotely sensed data to evaluate the shoreline evolution of the Akwa Ibom State shoreline over a 36-year period (1984 -2020). This method was chosen not only because it is widely used, but also because of its success (Barik et al. 2019), transferability (Temiz et al. 2016) and accessibility (Thomas et al. 2018).

6.2.1 What is the trend of the Shoreline change analysis in the study area?

As discussed extensively in chapter 3, the susceptibility of the Akwa Ibom coast to erosion was assessed using the Landsat 5 multispectral scanner (MSS) and Landsat 8 Operational Land Imager (OLI) together with high-resolution Pleiades and SPOT imagery (refer to chapter 3 for discussion on image processing and analysis). Different temporal scales were used to understand the dynamics of erosion (represented by negative values) and accretion (represented by positive values) along the entire coast: long-term (1984-2020) and short-term shoreline change analysis (2015-2020). From 1984-2020, the overall average LRR was -2.7±0.18m/yr and from 2015-2020, the overall average LRR was -3.94 ±1.28m/yr, indicating an erosional trend across the entire study coast. Although the rate of erosion derived from the results varies along the study coast, the linear regression rate (LRR) results show that there is a predominant trend of erosion along the study coast in both the short and long term.

6.2.2. Where are the most susceptible areas of the Akwa Ibom shoreline in the Niger Delta to the impacts of coastal erosion and how rapid are the geomorphological changes?

The shoreline analysis in chapter 3, revealed that zone A was the least susceptible location to coastal erosion, with an average LRR of -0.54±0.13 m/yr, followed by zone C with an average LRR of -2.44±0.99m/yr while zone B had an average LRR of -4.46±0.34 m/yr, indicating that it is the most dynamic and susceptible location to coastal erosion along the study coast. These results are corroborated by the findings from the social-ecological assessment in chapter 4 on the perceived prevalence of coastal erosion along the coast, as well as observations made during the research fieldwork from September to October 2018. In chapter 4, all the FGDs indicated that coastal erosion was not only prevalent, but they classified the severity of present state of the hazard based on a scale ranging from mild, moderate, severe to very severe, with mild being the lowest ranking and very severe being the highest (see section 4.3.2.2 and table 4.9). For zone A, three of the seven FGDs indicated that the severity of erosion was mild, while four indicated that it was severe; for zone B, all of the FGDs indicated that coastal erosion was severe - very severe and had recorded fatalities as a result of the impacts of coastal erosion, making zone B more vulnerable to coastal erosion when compared to other zones that indicated no fatalities; and for zone C, the severity of coastal erosion was described as mild - severe. The findings of chapters 3 and 4 contributed to and influenced the overall vulnerability of the coast by explaining how and why the study area is vulnerable (refer to chapter 5). While chapter 3 indicates the locations that are the most and least susceptible to shoreline change, chapter 4 provides possible explanations for why these locations are least/most susceptible to coastal erosion from the social standpoint.

As previously stated, Chapter 3 suggests a progressive rate of increased erosion along the coast from 1984 to 2020, with more rapid rates recently experienced (based on the results from 2015-2020 analysis). There are several possible explanations for the long and short-term shoreline change analysis results. These could be caused by a combination of natural and anthropogenic factors found along the coast (Kantamaneni et al. 2022). Rainfall, for example, was mentioned by participants across the study area as a cause of coastal erosion. Locals reported that erosion rates have recently increased, particularly in the last decade, and have rapidly worsened since 2012, suggesting that these periods coincide with increasing high rainfall amounts and duration, flooding, increased waves, wind, and storm surges in the area. Participants indicated that major erosional periods coincided with major rainfall periods in recent times between 2012 and 2018 (refer to chapter 4.4.1.1). According to the participants' discussions, zone B experienced four major erosional episodes with very severe impacts along the coast (2012, 2013, 2017, and 2018), whereas zones A and C indicated only two major erosional episodes in 2012 and 2017, which could explain why the perceived severity of coastal erosion in zone B is higher. Aside from the social understanding of coastal erosion along the coast, results from Chapter 5.6.1 show that zone B is the most vulnerable section of the coast to erosion based on physical and socio-economic parameters, with 87% of that coast eroding and only about 12.57 % accreting (more on the vulnerability of the coast to erosion is discussed later on in this chapter).

As discussed in chapter 3.4.1.1, the zone B coast is more prone to flooding, increased waves, wind and storm surges, and erosion than other sections of the coast due to its direct exposure (openness) to the Atlantic Ocean (see figure 6.2).

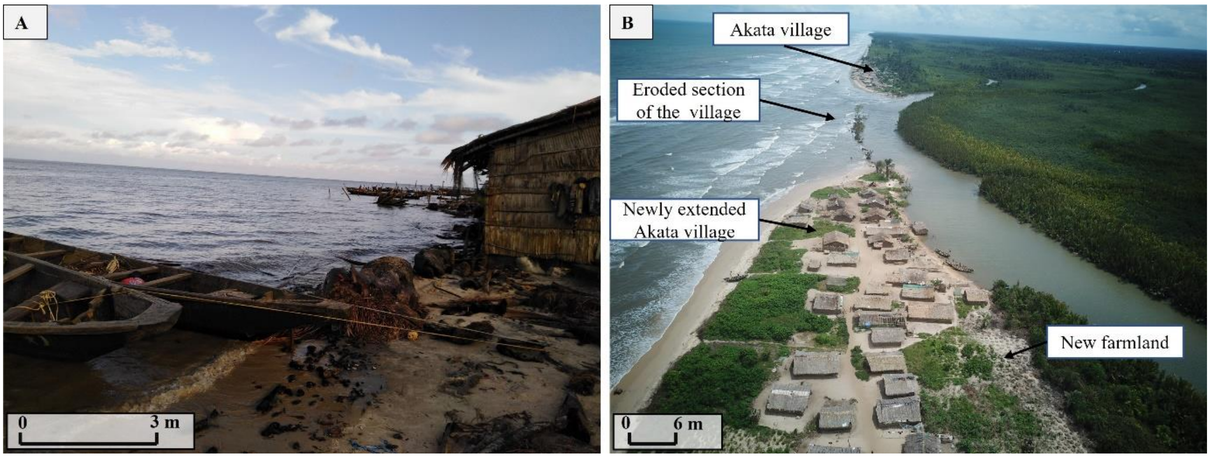


Figure 6.2A-B**:** Picture A shows the openness of the Brama section of the coast (zone A) to the Atlantic Ocean. Picture B shows a drone photograph of the Akata section of the coast (zone B) showing its openness to the Atlantic Ocean. (Picture A taken by the researcher on the 26th of September 2018 and picture B taken on the 27th of May 2019 via drone by the researcher's fieldwork assistant).

The results of the short-term analysis from 2015-2020 confirm the observations made during the walking interview and the participants' responses from the FGD (chapter 5), that more severe impacts from coastal erosion have been felt along the entire coast recently, particularly from 2012. This suggests that higher rates of coastal dynamism were recorded when compared to the results of the long-term analysis. Figure 6.2b is an illustration of these rapid rates, showing how the barrier ridge that the Akata community inhabits was cut through (eroded) by storm waves between September 2018 and May 2019 and how this caused the community to be split into two separate communities. In addition to the openness of communities to the Atlantic Ocean, communities like Brama (see figure 6.2a) in zone A have also been affected by downdrift erosion (see 3.4.1) which is probably a consequence of the construction of the embankment at Ibaka seaport. During the FGD at Brama, participants highlighted the fact that over forty years ago, the shoreline used to be more than 150 metres away from where it is currently, with vegetation between the settlements and the sea, but that now it is open and exposed to the sea. Serious erosion can also be seen in Akata (see figure 6.2b) where a section of the village has been eroded, forcing affected families to relocate to the adjacent lands which were previously used for agricultural purposes. Unfortunately, most of these areas are only able to relocate to horizontally adjacent lands because the area is bounded by the Atlantic Ocean in the front and the river at the back. And given the current condition of climate change, things are only going to worsen.

Climate change, as reported by the National Oceanic and Atmospheric Administration, has contributed to a steady increase in the global mean sea level, which in 2020 was about 9.1cm increase from 1993 and was also the highest yearly average in the satellite record as at 2020 (Lindsey 2022). In addition to increasing sea level, the WorldWeatherOnline (2021) reported an increase in rainfall events between 2010 and 2021 in Akwa Ibom state which could contribute to increase in the rates of coastal erosion along the susceptible study coast. During the FGD exercise, the participants indicated that wave action (wave strength and direction) played a significant role in coastal erosion, landform evolution and associated sediment transport along the coast. Significant landform changes were observed during the fieldwork exercise where the barrier ridge along Akata axis of the coast was cut through during this PhD fieldwork period between September and October 2018 (refer to chapter 3.4.2 for pictures showing the changes and Figure 6.2b above). The perception of the locals generated during the FGD shows that there is a strong link between the increase in rainfall, wave action along the coast and coastal erosion (see chapter 4.4.2.1), highlighting the fact that the local knowledge can as well inform a coastal erosion assessment. Focus group participants in all twelve FGD locations stated that the strong waves and storm from the sea were major drivers of coastal erosion. Interestingly, they added that when speed boats are in motion, they usually send out strong waves which hit the shore and they believe that the waves also contribute to the erosion because speed boats are a major form of daily mobility. However, from field observation, these boat waves do not act in isolation. They are simply another physical pressure that accelerates natural or other drivers of wave intensity prevalent in the area. The local perception of waves as coastal erosion drivers is consistent with findings from Udo-Akuaibit (2017), who attributes tidal currents and wave action to coastal erosion that resulted in the permanent submergence of parts of Itak Abasi fishing village, Ibeno in zone B (this is highlighted further on in the chapter). A study by Fourie et al. (2015), can be referred to for further discussion on the relationship between wave action and coastal erosion conducted along the Monwabisi, Northern shoreline of False Bay in Cape Town showing that waves have a significant impact on coastal erosion.

Apart from rainfall, Chapter 3.4 highlights several physical and human factors including the role of vegetation, geology and geomorphology in influencing the susceptibility of the sedimentary coast to hydrodynamic drivers that in combination influence erosion. Erosion, for example, may proceed more slowly in regions supported by harder sedimentary rocks than in regions supported by less cohesive sedimentary strata (Esteves 2018), which was the case in the study area with zone B underlain by loose coastal plains sands (see figure 6.3a-b) unlike zone A which is a more consolidated weathered lateritic soil (see figure 6.3c-d) (refer to 3.4.1.1 for more discussion). Another factor that serves as an important factor influencing shoreline changes is vegetation cover. As a result, mapping vegetation along the coast would provide more information about the coast's susceptibility to shoreline dynamism. However, that was not possible in this study due to the difficulty in distinguishing between features such as settlements and vegetation along some sections of the coast with the poor quality 30m spatial resolution data that were available. The impact of data resolution on temporal and spatial variations along the study area was previously discussed in chapter 3.4.3.2, where a comparison of short-term shoreline changes between 2015 and 2020 was performed using both Landsat (30m) and SPOT (6m) images. While the rates of shoreline change differed, there were similarities in the patterns of shoreline change, and the linear regression analysis performed suggests that the results derived have a good correlation. The findings indicate that an overall erosional trend was observed along the study coast for both processes, with zone B being the most dynamic zone. However, one of the study's limitations in using high-resolution data is data availability, limiting the ability to study long-term coastal changes and the spatial extent of the analysis. Herein lies the advantage of using medium resolution (30m resolution) images with a longer temporal coverage (e.g minimum of 30 years) that can be used to understand past changes and provide insight into what future changes are likely to occur.

6.2.3 What anticipated future risks will likely occur along the Akwa Ibom coast?

Future shorelines change analysis was carried out using historical rates of change using the Beta forecasting methodology available within the DSAS v5.0 software (see discussion in chapter 3.4.5). In Chapter 3, the future trend of coastal dynamics by 2040 was predicted using historical shoreline data from 1984 to 2020. The results show that by the year 2040, the coast will experience an average accretion and erosion rates of 1.79 m/yr and - 4.17m/yr respectively. The maximum accretion of 28.77 m/yr and erosion of -22.58 m/yr are also predicted along the coast by the year 2040. Notwithstanding the limitation and uncertainties of the prediction using the Beta method, the results show locations that are likely to erode in the future based on historical shoreline change data, which could be useful information for coastal management. Although this model was not previously used to predict absolute erosion rates but rather the probable future erosion locations due to potential and uncertainty about the contributing factors to erosion in the future. This study’s attempt to quantify the anticipated future risk by 2040, shows an overall average LRR of -2.73$\pm$ 0.99 m/yr which anticipates that coastal erosion will still be prevalent along the coast by 2040. Given the current global climate change situation and based on the rapid rates of erosion observed in recent times, as well as the current impacts on the Akwa Ibom coast, there is a likelihood that the shoreline change rates, particularly for coastal retreat by 2040, should be expected to be much higher than the current forecasting. Also, more severe and increased vulnerability should be expected in the future if current climatic conditions and human activities along the coast continues as status quo. Furthermore, future acceleration of coastal erosion in coastal regions worldwide is expected due to SLR (Barik et al. 2019), as are the associated impacts. This means that the impacts of these potential future erosional trends would exacerbate the risk that is already threatening the communities, infrastructure, and natural resources along the study coast.

Figure 6.3: Shows some impacts of coastal erosion in the study area. Picture A shows the foundation of a thatched house eroded at Akata, zone B. Picture B shows plantain farms destroyed at Itak Idim Ekpe, Zone B. Picture C – D shows a hotel destroyed at Esuk Oron, zone A (Source: pictures A, B, C and D were taken by the researcher during the September-October 2018 fieldwork in the study area).

According to the IPCC (2022), loss of land, loss of assets, community disruption and livelihood, loss of environmental resources, ecosystem, loss of life, or adverse health impacts are all potential risks along the coast due to climate change – the results show these risks are already occurring today. These impacts are already seen along the Akwa Ibom coast (see figure 6.3). Social learning from coastal residents indicates that there are many risks associated with coastal erosion. Chapter 4 has comprehensively discussed the social perspectives of the physical changes and the impact of coastal erosion which include loss of lives, property, farmlands, roads, and source livelihood (refer to section 4.4.2.3).

6.3 Social learning of coastal erosion along the Akwa Ibom state coast

According to Pollard et al. (2018), for a viable coastal risk management policy, it is essential to take into account how human activities influence coastal erosion. Despite the growing recognition of diverse forms of knowledge such as the inclusion of local knowledge to scientific knowledge in climate change assessments by IPCC (2022), there are still few studies that represent this inclusion. This is the first study providing a novel lens in establishing a link between social factors and the intensifying coastal erosion along the study coast. According to Thinh et al. (2017), understanding the stressors or drivers of shoreline change is as important as assessing the rates of shoreline change. The study's social contribution to coastal erosion and vulnerability was assessed using two approaches: a) eliciting local knowledge about coastal erosion in the study area through participatory approaches in the field (chapter 4), and b) measuring social vulnerability through social and economic indices using data gathered from pre-constructed sources (chapter 5). Surprisingly, the results of both approaches are essentially identical, indicating the prevalence of coastal erosion in the study area.

In chapter 4.3, the risk perception of coastal erosion in the study area is examined using Deleuze et al. (1987)'s rhizoanalysis approach. As previously discussed (refer to section 4.3.3.1), due to the complexity of coastal erosion and the human-environmental system, this approach proved useful in obtaining a multiplicity of data that informed a more holistic presentation of information on coastal erosion because it disrupts the traditional paradigm of what qualitative research should be (Cumming 2015) and the pre-defined ways of obtaining and analysing data. This approach has no starting or ending nodes to data entry but unravels layers of underlying information throughout the research establishing social-ecological patterns and relationships observed in the study area which influence the vulnerability of the study area to coastal erosion hazards (Sellers 2015).

There are multiple factors that contribute to the social vulnerability of a community to hazards. These variables were discussed using a re-conceptualised DPSIR model (European-Environmental-Agency 1999) which demonstrates causal relationships between the driver-pressure-state-impact-response to hazards (see section 4.3.3 for more explanation). The communities' ability to explain the various hazards experienced along the coast demonstrated adequate knowledge and understanding of the coastal erosion taking place along the coast. Interestingly, most knowledge on coastal erosion is gained through personal experience rather than academic education or other sources of information. When asked about their understanding of coastal erosion, quote 4.3 (see in section 4.3.1) states, *'We are predominantly fishermen... Erosion washes away the surface soil that used to yield better foods before now and washes the soil into the ocean'* showing how personal experience plays a huge role in understanding the social-ecological interactions.

However, Sambrook et al. (2021) points out that personal experience may not necessarily facilitate management response action along the coast. Management responses could be hinged on a variety of factors. For instance, the beliefs and values could influence an individual or communities' response to coastal erosion. An interesting finding that emerged, suggests that cultural/traditional and religious beliefs significantly influence their knowledge of the drivers, their attachment to the coast, and the response and adaption measures that can be implemented. In zone A of the study, some participants believe that the only response they have is to revert to the animal and food sacrifices that their forefathers did to the ocean gods for protection which has long stopped because of the introduction of Christianity in their community (refer to section 4.4.3.1). Such a strong belief could facilitate a lack of concern and an acceptance of the risk because they feel that it is beyond their control. According to the discussions in Chapter 4, the interactions could be passive due to a lack of adaptive capacity or a lack of concern about the hazard; reactive as a response to the eroding coast; or pro-active in advance to mitigate the impacts of coastal erosion.

According to the findings of the interviews, personal experience can have a positive or negative impact on responses to mitigate the effects of coastal erosion. For example, when asked, what measures the communities were implementing to mitigate the impacts of coastal erosion (see chapter 4), a participant in FGD 3 (Iduak Ukpat and Ine Ekong communities) in zone A noted that the gods of their forefathers would protect them and that whatever is happening along the coast, was allowed by the gods and who are they to question the gods but just accept the situation as it is which is also known as risk acceptance. On the other hand, the Eastern Obolo axis of zone C of the study coast is a good example of proactive management practice. Here, there is a restriction on exploitation of the vegetation along the coast, and the majority of settlements have been relocated behind the vegetation barrier to mitigate the effects of coastal erosion and climate change, which Brown et al. (2017), believes is a more useful management measure than the reactive and passive methods. A great example of proactive approaches in coastal regions can be seen in the sustainability measures suggested by Lynch (2022) where rigid structures like sea walls used to protect the coast against coastal storms are prohibited. Lynch (2022) advises that more open space should be created along the coast which will allow for natural and healthy beach-dune systems to emerge, hence increasing the resilience of coastal areas to storms.

Chapter 4 provided an overview on how human activities and interactions with the environment have changed over time, resulting in the impacts of erosion observed along the study coast. The field assessment during the walking round interviews, revealed that the degree and perception of exposure varied along the coast. The evidence of anthropogenic factors, such as the removal of vegetation cover/backstop for both residential and agricultural purposes reported in chapters 4 and 5, as well as field observations, indicates that human activities significantly contribute to the study area's susceptibility and vulnerability to coastal erosion in addition to oceanic and climate change drivers such as SLR and storminess. Moser et al. (2012) extensively discuss the increasing social stress in coastal regions and the urgent need to change how people interact with the environment to reduce coastal risks. Along the study coast, it is quite convincing that human interference combined with the natural processes along the study coast has led to rapid changes of the shoreline (see figure 6.3). Figure 6.3 depicts a historical data observation that explains why rapid shoreline changes are occurring in some zones along the coast. One of the primary reasons could be attributed to vegetation/mangrove over-exploitation which was a common observation in human-populated areas. The FGD participants discussed several reasons for the exploitation and encroachment of previously vegetated areas, including relocation for families whose homes have been affected by erosion or flooding, agriculture, firewood for cooking, as roofing and building materials for their thatch houses, economic firework and broom making, and building and reinforcing stick defences around their homes. Unfortunately, this has had negative impacts accelerating the rate of erosions. The vegetation backstops, particularly mangroves, contribute significantly to erosion reduction due to properties such as root structure and depth, which allow them to reduce the energy fluid, wind, and waves passing through them (Gracia et al. 2018; Brunier et al. 2019). Mangroves support biodiversity and a home to a variety of different fish species but due to over-exploitation, the number and variety of fisheries has decreased, negatively impacting the coastal zone's economic sector[3].

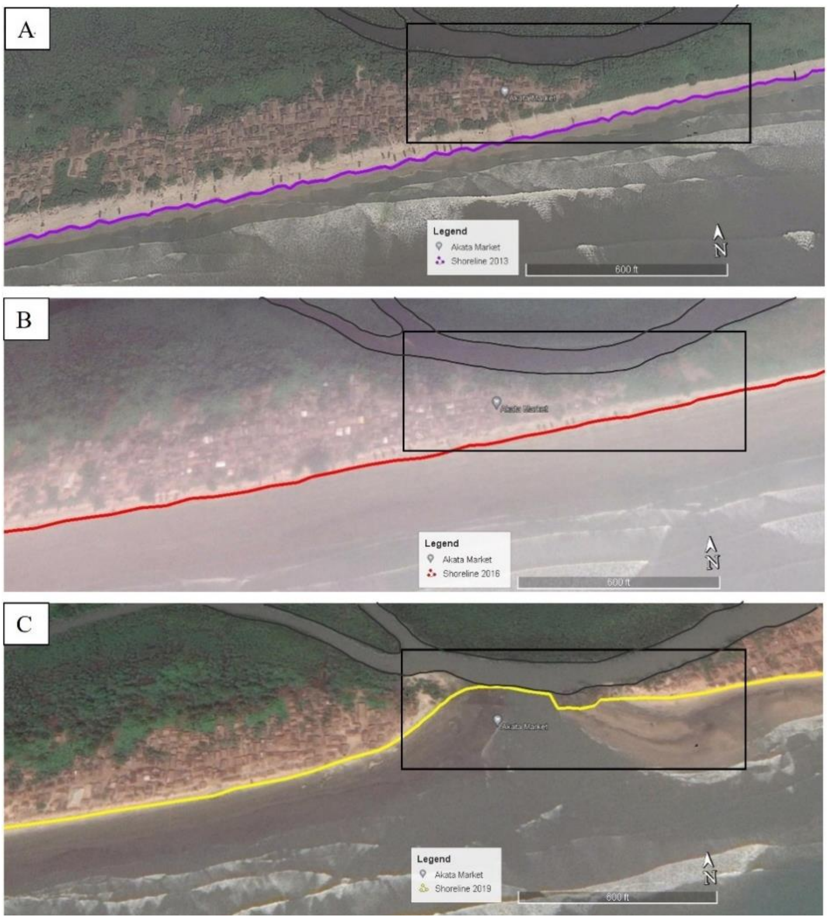


Figure 6.4: The progressive influence of human activities to shoreline changes. Picture A shows Akata community in zone B in 2013 while B shows same location in 2016 and picture C shows the same location in 2019. Inserted box shows how removal of vegetation and settlement expansion exacerbated the susceptibility of the area to coastal erosion (source -Google Earth (2019).

Surprisingly, it is not as if the role of the vegetation backstop in preventing erosion is unknown in the communities. Despite the awareness and observed negative economic impacts of mangrove exploitation in combination with other factors on fishing industries, as it is believed to be one of the contributing factors in a declining catch, evidenced by a participant's response: *'...before now, we had enough fish to catch, but now there are little, or no fish left in the ocean.' - FGD 9 - male participant;* it was discovered that over-exploitation of mangroves cannot be avoided. The interviewees stated that the immediate social needs of a source of income, building materials, and creating space for agriculture outweigh any future benefits of coastal sustainability and management; consequently, they did not feel the pressure or need to engage

[3] UN Environmental Programme (UNEP) 2022. https://www.unep-wcmc.org/en/news/5-facts-about-mangroves-and-why-we-must-protect-them.

in the conservation of the coastal resources like the mangroves which could be a source of meeting their immediate needs (see figure 6.5). In other words, what good will it be to preserve the mangroves if the people who live there are unable to meet their basic needs? This agrees with Luís et al. (2016) in that risk awareness does not always imply a reduced coastal risk. Nchimbi et al. (2019) reported a similar situation in Zanzibar in Tanzania where increased population in coastal areas and reliance on mangroves as a source of livelihood facilitated the exploitation of mangrove resources, which in turn had negative socio-ecological impacts on the community.

Figure 6.5: Picture A shows a drone picture of new thatch houses constructed for relocation of the affected families in Akata community in zone B. Picture B shows the exploitation of the vegetation for firewood and building materials. Picture C, the use of exploited vegetation stomps to guard against SLR and waves while picture D shows the use of exploited vegetation trees for home defence (Sources: picture A was taken on the 27th of May 2019 via drone by the research's fieldwork assistant while pictures B, C and D were taken by the researcher during the September-October 2018 fieldwork in the study area).

This is not to say that natural losses of mangroves do not occur; however, a global study by Goldberg et al. (2020) identified human activities as the primary driver. The study examined both natural and human drivers between 2000 and 2016, concluding that land use change from aquaculture to agriculture was responsible for 62% of the mangrove losses. Considering the importance of mangroves as buffers against hydro-dynamic forces acting along the coast (Asari et al. 2021), such over-exploitation of mangroves will expose the coast, making it vulnerable to sea-level rise, storms surge and waves which in turn will lead to or exacerbate the current state of erosion.

According to Udo-Akuaibit (2017), part of Itak Abasi fishing village was lost to the Atlantic Ocean between the years 2002 and 2013 which they noted was accelerated by climate change. He went on to explain that during the assessment period, there was a storm surge that hit the Strand coast in 2011, causing massive flooding, loss of land, and a fishing village (Itak Abasi) to be displaced 600m landwards of its 2002 position leaving many homeless. In this study, participants in FGD 8 along the Ibeno axis of the study area, noted that the relatively flat slopes and the loose coastal sediment in zone B (refer to figure 4.6 to see location) where the Itak Abasi village is also located, were key underlying factors increasing coastal erosion risks. Here is what the participant had to say*; "...and because the land is flat and almost the same height as the sea, it makes it easy for water to enter and wash away the soil. As you can see, the sand here is not sticky, it is separated…" FGD 8 - male participant.* This participant's perception from during the FGD workshop, supports the results in chapter 5 which showed that the areas with very high vulnerability to coastal erosion are due to relatively flat slopes and elevation (see section 5.4.1 for the physical vulnerability results). Unfortunately, these areas mostly rely on sandbags, sticks, planks and sand in protecting both their homes and land along the coast, as well as to protect the land from hydrodynamic conditions that could exacerbate coastal erosion (see figure 6.5). These practices, while useful in reducing the impacts of coastal erosion on a local scale are also the primary drivers for vegetation exploitation and sand mining which exacerbates the erosion process. This appears to be a case of causing more environmental problems while attempting to solve one and could as well be attributed to a lack of proper awareness.

As discussed in chapter 4, though there is awareness of coastal erosion, adequate knowledge on how these drivers contribute to the intensified state of erosion is lacking in most areas along the study coast, particularly along zone B, which is the most vulnerable section of the coast to coastal erosion (see section 4.3.1.2). Furthermore, some areas where sticks and planks were used to construct sea defences were also used as dumping grounds in an attempt to provide an extra layer of protection. Unfortunately, this becomes a major source of water contamination, negatively impacting human health conditions in the area. This seems to be a common adaptation practice in developing countries. In western Ghana, Freduah et al. (2019), demonstrated how this adaptation strategy of dumping refuse with locally constructed seawalls implemented in coastal communities led to maladaptation.

The significance of Chapter 4 cannot be overstated. Coastal erosion is a complex issue that necessitates multisource data to be adequately assessed, which is the primary goal of this research. Chapter 4 captured the underlying values and socio-cultural influences on the vulnerability of the study area that explains the spatial variation of shoreline changes observed in Chapter 3. This information could not be assessed solely by analysing the physical and socioeconomic parameters. This chapter thus, demonstrates that involving local stakeholders through the participatory GIS enables access to information on social factors influencing vulnerability, which is critical in providing additional information into possible actions that could increase coastal resilience, management practices and foster a pathway for change. Participatory approaches, according to Hofmeester et al. (2012), provide an in-depth awareness of socio-cultural underpinnings, allowing for alternative and flexible responses to complex issues such as climate change. An example of such responses is planned relocation. The benefits of managed retreat (MR) has been discussed by Hino et al. (2017) (see figure 6.6).

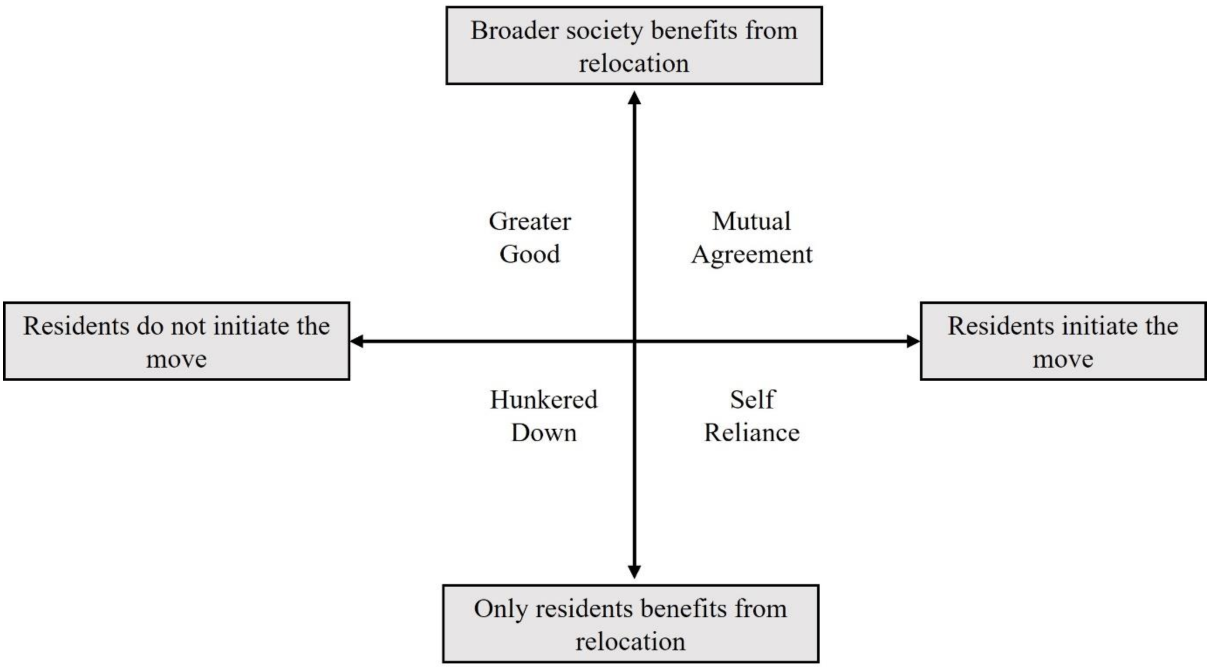


Figure 6.6: conceptual model of managed retreat by Hino et al. (2017)

Managed retreat usually involves both the government and the community (Wilkinson et al. 2016; Hino et al. 2017). Wilkinson et al. (2016), subdivided climate movement (CM) of people into three classes; (1) migration (2) displacement and (3) Planned relocation, indicating that displacements is as a result of an intensive risk that results from sudden high impact events like hurricanes while migration and planned relocation are driven by an extensive risk associated with a more frequent and lower impact events like periodic local flooding. Ajibade et al. (2020) stated that migration and retreat are sometimes used interchangeably due to similarities (e.g being the last resort), but there is a distinction between them, highlighting amongst others, the managed retreat is usually co-ordinated and funded by the government while migration is self-funded. In any case, they stated that everyone involved must come to an agreement for it to be successful (example; the affected communities, government, and the receiving communities). The conceptual model of managed retreat by Hino et al. (2017) provides a good illustration of this understanding or motive. This managed retreat model was adapted by this current research (see figure 6.7) to include and understand the factors influencing the migration and non-migration of the affected communities which in turns either reduces or increases the vulnerability to coastal erosion.

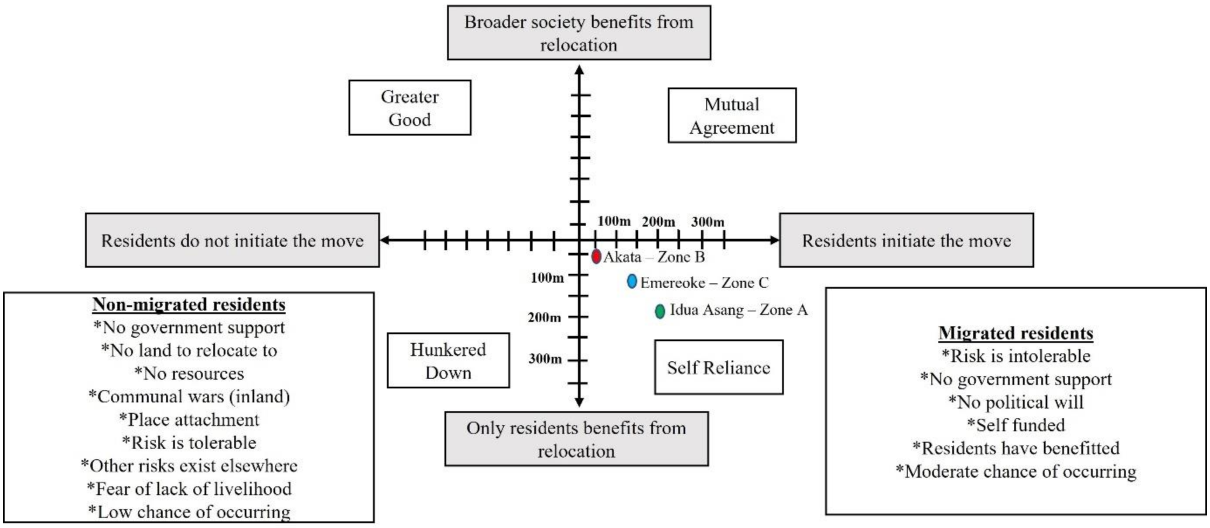


Figure 6.7: An adapted conceptual model of managed retreat by Hino et al. (2017) used to define managed retreat in the studied coastal communities – Idua Asang (zone A), Akata (zone B) and Emereoke (zone C).

Figure 6.7 illustrates the complexity, the variability and the motivation for migration/planned retreat and for non-migration from the study area's coastal erosion risk zones. The research's findings reveal that the study coast falls within the Hunkered Down and Self Reliance quadrants. For this study, the Self-Reliance quadrant indicates that the migration of people from the risk zone was initiated by the residents, self-funded, with no support from government, no retreat plans. Three study locations are plotted on the managed retreat model to illustrate migratory and planned retreat for the study coast where relocation has already occurred due to coastal erosion. At Idua Asang in zone A, some of affected residents relocated inland (about

150-200m from the coast). The move was self-funded and dependent on availability of resources and land (such as person/family farmlands that were situated farther inland). As such, those who cannot afford the move, remain within the affected area. For Akata in zone B (case study in chapter 5 is located), those who had the resources or relatives in other rural communities or in urban areas relocated permanently, but other affected residents who fulfilled any of the criteria listed for non-migrated residents in figure 6.7 moved laterally to the adjoining farmlands, which is within 50 metres of the eroded location. One unanticipated finding was that zone C, though on a small scale (community level) than usually expected for a planned retreat, they had relocated the settlements directly open to the Atlantic Ocean along the Emereoke community about 100-150m inland, behind the vegetation backstops in response to coastal erosion. Such relocation is commendable and should be encouraged along the rest of the coast. However, this is only feasible if there are available resources and land to relocate to, which was not the case in other locations or zones along the study coast (Rennie et al. 2021). Table 6. 1 shows the recommendations on relocation as an adaptation measure for the study coast.

Table 6.1: Summary of recommendations for the observed factors affecting relocation along the study coast

Issues affecting relocation	Action	Impact	Reference
*Lack of political will *Lack of government support	*Support relocation actively.	*Enabling conditions/ open window for relocation *Encourage social culture, network, and consistency *Move to the either the greater good or mutual agreement quadrant *Mitigate communal conflicts borne out of coastal erosion adaptation	Brown et al. (2017) Hino et al. (2017)
*Fear of loss of livelihood	*New skill acquisition training. *Government fundings/loans for start-up businesses. *Government stipends to enable adequate settling in the new location *Provide alternatives for livelihood		Piggott-McKellar et al. (2019)
*No resources or land to relocate	*Government to create incentives and make available land.		Duvat et al. (2022)
*Land conflicts/war	*Government should engage, initiate, and oversee the relocation process in a participatory approach.		Froese et al. (2019)
*Place attachment	*Systems to support build a new community. *Relocating the whole community.		Bukvic et al. (2022)
*Risk perception	* Understand the perception of risk and place attachment since they can influence relocation decisions. *Engage with the communities on coastal management plans, alongside enlightenment programs.	*Bridge the gap of awareness of coastal erosion drivers and risk.	(Domingues et al. 2021) (Quinn et al. 2018)

For the Hunkered Down quadrant, this study illustrates some reasons why residents choose to remain in the coastal hazard risk zone rather than relocate despite the significant impacts of coastal erosion in the community. For the those in the Hunkered Down quadrant, it will take the initiation and intervention of the government/environmental agencies to relocate them. Table 6.1 gives a summary of some action plans that may be useful in transitioning the coastal residents to the upper quadrants of the model. This indicates that resilience to coastal erosion is largely dependent on adaptive capacity and support from the government, and if there is a physical window of opportunity to provide room for relocation (Brown et al. 2017). This would create a shift in the managed retreat model for the study area, where residents from the Hunkered Down and self-reliance quadrants move to either the greater good or mutual agreement quadrant, indicating an increased resilience to coastal erosion risk.

This study observed a disconnect between the tiers of leadership from villages, local governments, state governments, and the federal level that should be implementing management policies. Unfortunately, the issues with multilevel governance is not only limited to developing nations. Naylor et al. (2019) presents a good illustration of how the disparity between the multi-level governing bodies affect coastal management practises and policies in Cornwall, United Kingdom. The need to improve communication and involvement between the government and the impacted communities and stakeholders was also suggested as a strategy to go forward with managing the United Kingdom's coast with respect to growing climate change risks (CCC 2018). The coastal area of this study shows the effects of this disconnect in governance (refer to section 4.4.4), which has exacerbated the erosion problem as coastal communities are observed addressing the coastal erosion problem anyway, as they see fit, resulting to maladaptation. For instance, in an effort to protect their homes from coastal erosion, they cut down trees along the coast to use as barriers. This exposes the coast to hydrodynamic forces, increasing erosion.

Interventions from the state or federal government are seen as possible if there is a federal or state presence that needs to be preserved, such as in the case of the Esuk Oron community in Oron L.G.A situated in Zone A of the study coast, where a seawall is being built to protect the cultural heritage there, which includes Africa's oldest wood carving and other ancestral figurines (masquerades), as well as a historical museum founded in 1958. Some of the cultural heritage along the study coast is highlighted in section 5.6.1. On the other hand, while the local government representative indicated that they did not have the financial capacity to intervene with the coastal erosion situation along the coast, indicating that it was capital intensive and required the State government or Federal government to step in, the State government claimed that the communities along the coast are well aware of the risk of staying there but choose to stay anyway, and thus nothing can be done about it. From the discussion, the participants across the study area expressed dismay and as well highlighted the fact that they felt abandoned by the government and that only the mainland communities benefit from government intervention of environmental hazards. However, despite the current situation, the participants showed the willingness to improve their resilience to coastal erosion and to implement recommended management strategies if it is within their capacity to do so. I strongly believe that planned relocation facilitated by both the government and village stakeholders would address the issue, reducing the vulnerability in the area. Overall, the social layer data enhanced the quality of the research providing results that could positively inform management policies (See section 7.4).

6.4 Vulnerability of the Akwa Ibom coast to coastal erosion

According to Milfont et al. (2014), while different regions experience varied effects of climate change, the coastal communities experience more serious threats from the impact of climate change. Due to the lack of data for a more comprehensive assessment, chapter 5 relied on AHP-derived weightings from coastal researchers with first-hand knowledge of the study area to contribute their expert knowledge in calculating both the physical vulnerability (PVI) and socio-economic vulnerability (SVI), which influenced the overall CVI calculated for this study. According to the findings, 67.55% of the entire study coast falls within the high - very high vulnerability class, while 32.45% falls within the very low - low vulnerability class (see Table 5.16). As discussed in chapter 5, vulnerability can be attributted to a variety of factors. Seven physical parameters and five socio-economic parameters were utilised in this study to determine the locations most vulnerable to coastal erosion. The results from both the physical and socio-economic vulnerability demonstrated a similarity in the vulnerability classes across the three zones with more than 50% of the study coast exhibiting high to very high vulnerability to coastal erosion.

The physical vulnerability, which took into account the coastal slope, geomorphology, elevation, shoreline change, proximity to the coast, the mean tidal range, and sea level change (refer to section 5.5.1 for individual vulnerability assessment), demonstrated how these physical factors influenced the study's vulnerability to erosion. Physical factors primarily determine the susceptibility of the coast to either erosion or accretion with or without interference from human activities. The degree of susceptibility of the coast to erosion is determined by the interaction of coastal driving elements (e.g., waves, tides, etc.) and coastal characteristics (e.g., slope, elevation, geomorphology, etc.). Human activities, unsurprisingly, tend to exacerbate these rates and the vulnerability to coastal erosion. As physical susceptibility to erosion varies along different geomorphic units, it is expected that the degree of erosion and vulnerability would vary too (Serio et al. 2018). The study areas are made up of coastal plains sands which are highly erodible (see section 2.5 for details on the physical setting of the study area). Rao et al. (2008) explains that while rocky cliffs, for example, provide sufficient resistance against coastal hazards, dunes and mudflats, among other sandy and muddy constructs, are considerably vulnerable to sea-level rise. This means that geomorphological features are either erosional or depositional in nature (Evelpidou 2019) and increasing SLR due to climate change could influence its nature. Understanding the extent to which different characteristics influence the hazard, according to Zhang et al. (2021), is crucial to establishing coastal management plans to increase resilience to climate change hazards. Chapter 5 illustrated and provided sufficient understanding on how each of the physical and socio-economic factors utilised in this study influenced the vulnerability of the coast.

In general, the findings in chapter 5 are consistent with results from chapters 3 and 4 which emphasise the prevalence of coastal erosion along the study coast. In zone A, 50.84% of that section of the 38 km length of coast is predominantly erosional showing high-very high vulnerability while 48.99% experiences accretion indicating low-very low vulnerability. As established in chapter 4 and chapter 5, vulnerability emerges from a variety of factors and understanding how these different factors contribute to the overall vulnerability could effectively inform management policy. One obvious reason for the observed erosion and accretion in zone A could be linked to the role played by the hard engineering structures installed along sections of this coast (refer to chapter 3.4.1.1 for full discussion). In zone B, 87.43% of the 55km length of coast indicated high-very high vulnerability while 12.57% suggests low-very low vulnerability which agrees with the finding in chapter 3 (see 3.4.1.1 for more detail) indicating that zone B is the most dynamic and susceptible section along the entire study coast to coastal erosion. In zone C, which is about 37km long, a similar erosion trend is observed with 64.15% of the coast falling within the high-very high vulnerability and 35.85% of the coast falls within the low-very low vulnerability, making this zone the second most vulnerable zone along the coast which is also corroborated by results derived in chapter 3 (refer to 3.4.1.1 for discussion).

Furthermore, as observed during the fieldwork, the zone A has higher elevations (up to 35m above relative sea level (RSL) when compared to other zones along the coast that are relatively flat (mostly < 10m above RSL), making Zones B and C more exposed to hydrodynamic forces that exacerbate coastal erosion, particularly Zone B which is the most vulnerable. Aside from the elevation, the zone A also had the most coastal defences along the study area, explaining its low vulnerability to coastal erosion. A similar pattern was observed in southeast coast of Guangdong Province, China, where the coastal erosion vulnerability was highest in the low elevation areas and locations lacking coastal defence (Cao et al. 2022), supporting the evidence that locations in the low-lying regions of the study coastal area has been significantly impacted by coastal erosion.

During the fieldwork, the researcher witnessed first-hand, the extent of the devastation and swiftness of coastal erosion (see figure 6.8) in the low-lying regions. Figure 6.8 depicts the relatively flat topography along the study coast and the risk of coastal erosion hazards in the area. The rapid rates of erosion in zone B derived from the short-term shoreline changes (2015-2020) in chapter 3 is similar to Amangabara et al. (2021)'s observation of a relative increase of 4.25% in the coastal erosion along zone B between 1986 and 2016. In the absence of effective management, the impact from such exposure could be adverse, thus increasing vulnerability. While the chapter illustrated how vulnerable the research coast is to coastal erosion, chapter 4.4.2.3 provided insights on the various repercussions of coastal erosion that exacerbate the study coast's vulnerability to erosion. Across the study coast, a wide range of impacts were identified, including loss of life, loss of land/vegetation, damage or loss of fishing boats, damage/loss of property, human displacement, loss of access to sections of the coast, communal war, and poor mental health. However, the magnitude and degree of perceived impact varied across the coast.

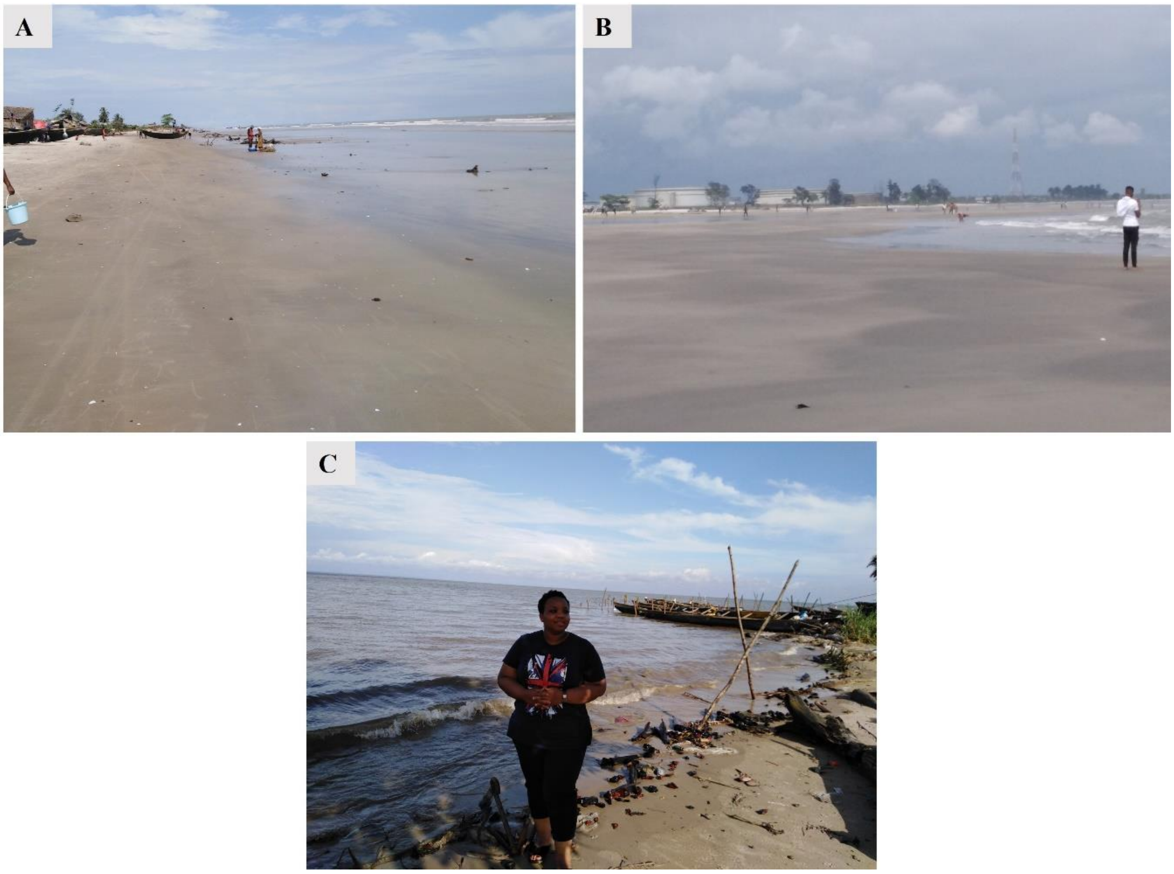


Figure 6.8A-C**:** Picture A is at Akata, zone B, picture B is along the Inua Eyen Ikot axis of zone B and picture C is the Bram axis of zone A. They show the relatively flat topography along the Strand Coast of Akwa Ibom State, Nigeria. Pictures were taken during the September-October 2018 fieldwork by the researcher in the study area (the images are published with consent of the subjects).

Communal war was an unanticipated impact reported during the focus groups, which is a risk less mentioned in past literatures and is one of the primary concerns that arises when relocation is considered as a mitigation measure. Communities would risk remaining in their current location rather than relocate to die in a local communal conflict resulting from their migration inland. This appears to be one of the perceived severe impacts of coastal erosion along the study coast. Here is a participant's response on why they have remained in that location despite the risk: *'…we cannot leave because we do not have anywhere to go to. The war that happened here was because of land when people were trying to relocate from the seaside inwards. The other people felt threatened and also want to take whatever land we have left'*. - *FGD 2 – male participant.* Sadly, despite severe impacts as communal war, participants reported that the government did not come to their aid at any point in time.

Integrating PGIS and local knowledge provides a more holistic evaluation of coastal erosion. This mixed-method approach could highlight the plights of the coastal communities, provide more understanding on the underlying causes influencing the current state of erosion, inform the management practises currently in place along the coast, provide information on the physical and social drivers which might inform government intervention, encourage a new or a revision of the current management practices and in the long run, increase coastal resilience. Though the PGIS approach has its limitations (see chapter 5.6.2 for more discussion), it has proven to be a viable source of not only data generation but also community participation which is effective for coastal management (Baldwin et al. 2014; Cochrane et al. 2019). This study has demonstrated the benefits of a PGIS approach and how essential it can be, particularly in data scarce environments in which little to no data exists.

6.5 Novelty of current study

The contributions of this thesis are highlighted in two stages: the general contribution to coastal erosion knowledge along the Akwa Ibom coast and the development of feasible and useful mixed-methods approach in assessing coastal erosion in data scarce regions.

6.5.1 Contribution to coastal erosion knowledge along the Akwa Ibom coast

This study, to the best knowledge of the researcher, is the first to assess the susceptibility and vulnerability of the entire Akwa Ibom coast to coastal erosion on a local scale, which can be useful for coastal planning by integrating physical vulnerability, social vulnerability, and risk perception generated through a community based PGIS approach. It covers a comparative study of the variability of coastal erosion along the different zones in the study coast, providing a more in-depth knowledge on the physical, socio-economic and underlying social and cultural factors that accelerate coastal erosion and influences on adaptation responses, combining both preconstructed data and perspectives of local communities. In doing so, it provides a comprehensive community-based perception of the evolution and impacts of coastal erosion, highlighting areas most vulnerable without having to generalise the result across the entire zone. It re-conceptualised the DPSIR method to include the hazard component and the direct observation of the state of hazard in the model creating the re-conceptualised DPSIR (H-DPSIRO) model for assessing coastal erosion. Although it was tested and developed here for coastal erosion, the H-DPSIRO approach is simple, yet effective, and could be readily adapted to various types of hazards and can be applied elsewhere too.

6.5.2 Integration of local community risk perception in a coastal vulnerability index assessment

This study introduced two novel approaches in assessing the vulnerability of the coast to coastal erosion; the development of a risk perception index to coastal erosion (RPIerosion) and the integration of the RPIerosion into a coastal vulnerability index called the integrated coastal erosion vulnerability index (ICEVI). The findings of the case study evaluation conducted in Akata community of zone B revealed an improvement in the overall vulnerability assessment to closely reflect the real-world situation which was consistent with data generated during the field observations. The Akata community, which is currently experiencing very severe impacts of coastal erosion including rapid loss of land, loss of settlements, loss of lives, limited alternative lands to accommodate planned retreat, very high exposure to hydrodynamic forces, over-exploitation of vegetation and lack of adaptive capacity, appeared to be an ideal location to demonstrate the potency of using a mixed-method or an interdisciplinary approach to assess the vulnerability of the coast to erosion. The methodology for including risk perception in a coastal vulnerability index is adaptable and can accommodate additional data. Although this method has its limitations (as discussed in section 5.6.3 and in section 7.3), from the standpoint of decision support, the findings can contribute to informed decision making by stakeholders, to enable prioritisation of coastal areas needing immediate measures to promote coastal sustainability.

6.6 Summary

The primary goal of this research was to identify and understand where coastal erosion is currently occurring along the coast, the evolution of the process using historical data, why and what has led to the exacerbation of the process and comprehend the degree of vulnerability of the coast to coastal erosion. The mixed-method approach used and the findings of this study could provide information from data-scare region like the study area that could feed into a global assessment of long term shoreline changes like that of Sabour et al. (2020) which assessed global shoreline changes along natural world heritage sites (NWHS). The findings reveal a prevalence of coastal erosion across the study area that has adverse impacts of coastal erosion, particularly in zone B of the study coast and that more than half of the study area falls within the high-very high vulnerability class. Figure 6.9 shows the disappearing section of Ibeno - zone B axis of the coast in Akwa Ibom State, Nigeria. This chapter highlights the need of employing mixed/interdisciplinary methods approach to analyse the coast's vulnerability to erosion. As previously discussed, coastal erosion is a complicated issue; thus, while single methodologies like physical and socioeconomic vulnerability assessment models in data scarce regions produce vulnerability assessments of somewhat limited value, this study has shown how local knowledge gathered through participatory methods can bridge this data gap – improving our understanding of coastal erosion risks and vulnerability in data scarce regions, such as the one studied here.

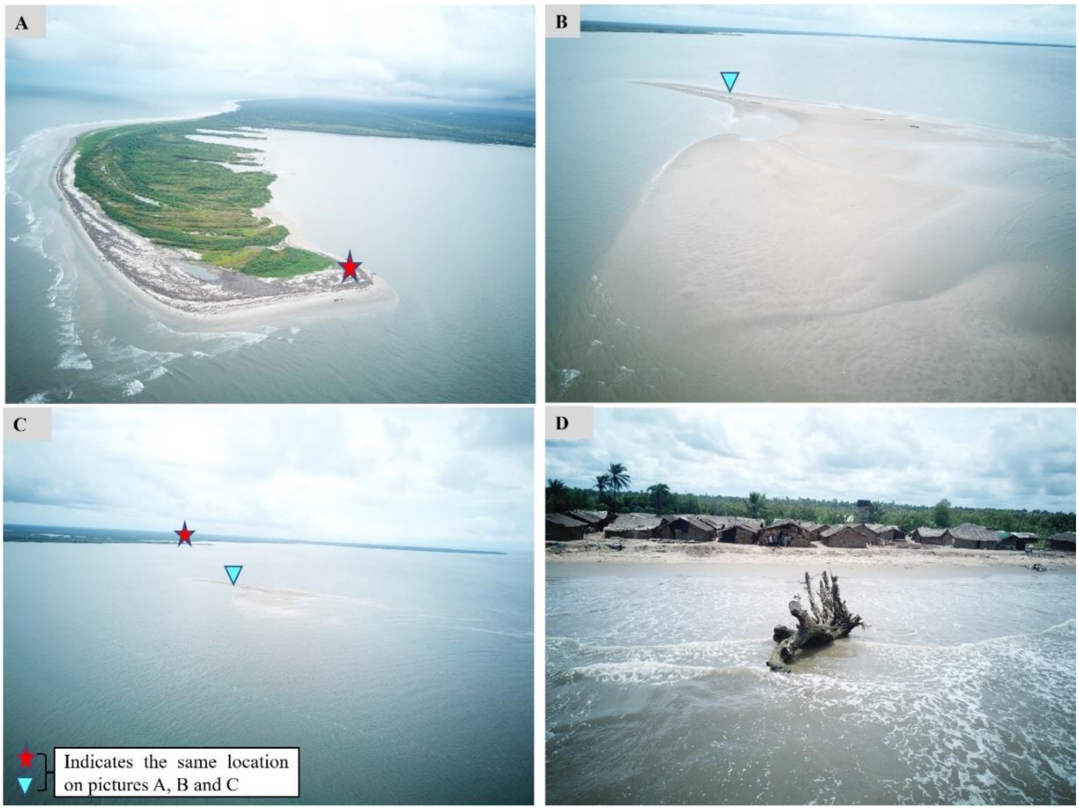


Figure 6.9: Pictures A-C shows the disappearing section of Itak Idim Ekpe in zone B, while picture D shows that disappearing coast of Akata, Ibeno L.G.A - zone B axis of the coast Akwa Ibom State, Nigeria (Source – drone photographs taken by the research fieldwork assistant on the 27th of May 2019).

The IPCC (2022) in the factsheet for Africa, observes with high confidence that, indigenous knowledge or local knowledge systems, particularly in the African context, provides a strong foundation for local adaptation measures. The local knowledge used here informs the scientific risk assessment by addressing underlying issues that contribute to the coast's vulnerability to coastal erosion. It demonstrates a link between casual agents (drivers) responsible for the pressures on the coast that are escalating the rates of coastal erosion observed in chapter 3, the impacts of shoreline changes described in chapter 4 and an understanding of the degree to which the coastal system is vulnerable to erosion (chapter 5) based on the perception of those at risk. The importance of this technique cannot be overemphasised if correctly applied. The findings thus demonstrated not only the presence of coastal erosion in the research area, but also the value of local community /stakeholder involvement, showing the potential for the perspectives from the lived inhabitants of these regions to inform understanding of the resilience capacity of the people impacted, and importantly to inform future co-design and/or selection of effective adaptation methods, to better support coastal climate change resilience in these communities. The research showed that although there is knowledge about coastal erosion and the risk posed by it in the study regions, it is notably insufficient to support long-term management solutions. This is because of a lack of strong awareness that the drivers of coastal erosion are climate change, rather than an act of the gods and lack of sacrifices amongst others which is created by a gulf of understanding the science.

Furthermore, because some of the current management responses to coastal erosion are the main drivers of coastal erosion (i.e. maladaptation), such as cutting down the mangroves to use as build barriers round about their homes, there is a need to improve coastal erosion and adaptation options awareness in the region, from local communities through to national government levels, to increase understanding and financing of adaptation measures to improve resilience of the communities to the impacts of coastal erosion and other coastal climate change impacts (e.g. intense storms and flooding). This research fills a key gap in our knowledge by analysing the hazards, impacts and vulnerabilities of the Akwa Ibom coast, which is threatened with high rates of coastal erosion, but has received relatively little attention from the Local, State, Federal government and other environmental organisations to date.

Chapter 7: Conclusions

Chapter seven summarises the main findings of the thesis relative to each research question and provides insights on the limitations of the study and adds suggestions for future research.

Chapter 7

7.1 Addressing the Research Aims and Objectives

This concluding chapter summarises the findings of the research, addressing the following objectives:

7.1.1 Research Objective 1

The first objective of this study was to identify the susceptibility of the Akwa Ibom coast to coastal erosion using remote satellite image analysis and identifying sections of the coast that are most susceptible to coastal erosion using shoreline change detection. The following are the main conclusions from Chapter 3:

- The overall average linear regression rates -2.7±0.2m/yr for the long-term shoreline changes revealed that from 1984-2020, there has been a progressive landward movement of the shorelines, indicating a prominent coastal erosion trend. Zone B was found to be the most susceptible zone of the three delineated zones.
- Along the Akwa Ibom coast, particularly in zone B, geomorphological changes are occurring at an unprecedentedly high rate. The short-term analysis average LRR of -3.9±1.3m/yr also demonstrates that erosion is prevalent along the coast. When compared with the results derived from the long-term (36 years) results which was -2.7±0.2m/yr, it indicated that the rate of change for the short-term (5 years) is higher than of the long-term analysis. This suggests that the magnitude of changes within recent years, 2015-2020, was higher than that of the longer-term indicating high dynamism along the coast. Evidence from chapter 4 confirms that human interference in combination with the natural processes along the studied coast has led to these rapid shoreline changes. The most likely main factor contributing to coastal erosion in the region is the remarkable change of land use/landcover type; from vegetation to settlements in order to accommodate the lateral movement of settlements affected by either flooding or erosion.
- In order to evaluate the suitability of using free, medium resolution (30m) imagery in a data-scarce region, a comparison of the results obtained from high-resolution SPOT image data (6 m) and medium resolution Landsat imagery (30 m) was conducted for a selected section of the research area. A positive correlation was found between the two rates produced by corresponding sections of the coast using the LRR results derived for

both methods. The results suggest that the Landsat data provided adequate shoreline positional accuracy for assessing the coastal changes over the 5 year timescale with r^2 values of 0.88 for zone A, r^2 value of 0.98 for zone B and r^2 is 0.86 zone C.

- Coastal erosion is likely to continue in the future as indicated by the expected shoreline changes for 2040, which shows an overall average LRR of -2.73$\pm$ 0.99 m/yr. The forecast method and analysis presented here should be used with caution because it does not take into account other erosion contributing factors (such as human activities, sea-level rise, geology, or wave height). Given current climate change and established SLR, this study can assume that the presented predicted erosion result is likely to be underestimated. Nonetheless, the future trend provides a picture of what is expected and can be very useful for policymakers by informing management practices. However, to improve on the forecast, this study recommends incorporating other factors and climate-change variables such as sea rise for future susceptibility to coastal erosion assessment. As illustrated by Rennie et al. (2021), modelling anticipated coastal erosion with future SLR scenarios, is an effective tool for monitoring, management and enhancing resilience.

7.1.2 Research Objective 2

Objective 2 focused on assessing the spatial variability of the socio-ecological drivers and impacts of coastal erosion along the Akwa Ibom state coast and examining the coping mechanisms prevalent along the coastal areas to develop informed recommendations on possible adaptation strategies to enhance resilience to the effects of coastal erosion. The following are the key findings from Chapter 4 and the future research needs that have been identified:

- Communities' ability to explain the various hazards along the coast demonstrated adequate knowledge and understanding of the coastal erosion occurring along the coast, but they lack accurate information about the coastal erosion risk which is evident in the continuous pressure they exert along the coast. Interestingly, most knowledge on coastal erosion along the study coast is gained through personal experience rather than academic education or other sources of information. Though there is awareness of the hazard risk, it may not necessarily facilitate proper management response action along the coast.

- Currently, there are no coastal management policies implemented along the study coast. With no coastal policies in place and if proper awareness and community/stakeholder engagement are not implemented, the risk of coastal erosion will likely continue to rise. Therefore, there is an urgent need for Akwa Ibom State government to create coastal management policies. Consequently, this study strongly supports and recommends coastal resource management (CRM), as demonstrated by Baquiano (2016), which promotes stakeholder engagement through a participatory approach to not only understand coastal resources but also to use and manage them appropriately.
- The notion that a lack of knowledge about coastal risk contributes to a lack of risk perception is a key characteristic of the deficit model (Ziman 1991). Our data, in a similar manner to Luís et al. (2015), showed that it is not always the case. This was evident in the study area, as it was noted that coastal erosion issues are complex since its management practice is hinged on a variety of factors, e.g, belief and government, amongst other factors. For instance, findings show that majority of communities along the coast belief that they lack the capacity to mitigate the impacts and that management measures can only be carried out by the government. This indicates that resilience to coastal erosion is largely dependent on adaptive capacity of local communities not necessarily awareness and that the limited support from government received thus far has, in most cases, led to maladaptation. In addition, there a few other communities that believe that nothing can be done about coastal erosion, since it is an act of the gods.
- Chapter 4 captures the underlying values and socio-cultural influences on the vulnerability of the study area which also provided an explanation for the geographic variation of shoreline changes as seen in Chapter 3. This type of information could not be evaluated solely by analysing the physical and socioeconomic parameters.
- Evidence from chapter 4 concurs with the World Bank's findings, that one of the impacts of climate change (erosion and flooding) is the separation of coastal inhabitants during relocation which alters the social fabric not just for the present community but also in the future (World-Bank 2019). This study recommends managed retreated (Hino et al. 2017) with intervention and involvement of government to engage, plan and facilitated the move which will still allow the option of communities to stay together.
- Overall, the social layer data enhanced the quality of this research, providing results that could positively inform management policies.

7.1.3 Research Objective 3

Objective 3 focused on integrating the human (using a PGIS approach) and physical/environmental vulnerability assessments to assess the vulnerability of the Akwa Ibom coast to coastal erosion using the widely used Coastal Vulnerability Models (CVI) compared with a newly conceptualised ICEVI (Integrated coastal erosion vulnerability index) and explore whether the use of social data can improve erosion vulnerability assessments in data poor countries. The following are the main conclusions from Chapter 5:

- According to the CVI results, 68% of the entire study coast falls within the high - very high vulnerability class while 32% falls with the very low-low vulnerability class. indicating that coastal erosion is the predominant process along the coast. Zone B is the most vulnerable section to coastal erosion with about 87% of the section eroding while 13% indicates accretion. These high vulnerability rates require immediate attention and intervention.
- With 45.47% of the coast being classed as very high vulnerability, 33.9% as high vulnerability, 19.65% as low vulnerability, and 0.98% as very low vulnerability, the physical vulnerability index (PVI) data demonstrate that the Akwa-Ibom coast falls into the very low to very high vulnerability classes. The PVI results indicate that the coast is experiencing both erosion and accretion processes, with about 21.62% of the coast accreting and 78.39% of the coast eroding.
- According to the socioeconomic vulnerability index (SVI), the research region is classified as very low to very high vulnerability. The study shows that only 1.22% falls into the very low vulnerability class; 57.85% falls into the low vulnerability class; 26.74% falls into the high vulnerability category and only 14.18% falls into the very high vulnerability class.
- The PGIS approach is crucial, particularly in settings with little or no data. This chapter demonstrates how involving local stakeholders via participatory GIS makes it possible to access data on social factors that influence vulnerability, as well as essential in providing additional information into potential actions that could increase coastal resilience, management practises, and foster a pathway for change.
- Community stakeholders are not only willing to take proactive management measures when necessary, but importantly, so is the the Akwa Ibom state Ministry of Education. They have expressed interest in the research findings as well as recommendations. This

study will be the first comprehensive interdisciplinary assessment of coastal erosion along the Akwa Ibom coast, and it has the potential to support mitigation strategies and robust coastal management policy. This evidence supports that PGIS offers a great tool to assess current situation about coastal erosion and foster stakeholder participation, which is good for adaptation and management practices.

- The integrated coastal erosion vulnerability index (ICEVI) developed by this research integrates the physical, socio-economic, local knowledge and PGIS to holistically assess coastal erosion in the study area and gives a better representation of communities' perception of risk along the Akwa Ibom coast.

7.2 Evaluation and Contribution to Knowledge

- As previously discussed, coastal erosion is a complicated issue; thus, while single methodologies like physical and socioeconomic vulnerability assessment models in data scarce regions produce vulnerability assessments of somewhat limited value, this study has demonstrated how utilising local knowledge obtained through participatory methods can bridge this data gap – enhancing our understanding of coastal erosion risks and vulnerability in data scarce regions, such as the region studied in this research.
- At the local scale, there was a lack of detailed rates of erosion and risk for the entire coast that this study has now provided.
- A new index method for assessing risk perception of coastal erosion was presented - ICEVI. Although tested in Akata-Akwa Ibom State, it could have global scale application if the limitations are addressed and could be widely applied to a range of global contexts and hazards/vulnerabilities.
- While this research provides the first analysis of the shoreline changes of Akwa Ibom State coast, indicating a seriousness of the shoreline loss, it also offers a methodology that can be used to investigate other coastal regions combining field survey and numerical modelling. Finally, the present research will enable decision makers to identify the zones with a higher risk and find better solutions to the existing coastal erosion problems.
- Academically, this study bridges the gap of incorporating participatory GIS and local knowledge with the physical and socio-economic parameters in a coastal vulnerability index study. Importantly, this has shown the applicability and reliability of this

approach, which is vital to understanding coastal erosion, particularly for data scarce regions such as the case study area, and holistically addressing coastal hazards.

- This academic output will be available online and accessible to the academic society and more importantly, it will be available to the Akwa Ibom coastal communities, The Federal and State government stakeholders, as well as coastal community projects funders such as World Bank for climate change induced hazard monitoring, planning, adaptation, resilience and mitigation purposes.

7.3 Limitations of the Research

- First, contrary to expectations, development of risk perception into indices for simpler quantification and aggregation in a coastal vulnerability index did not result in a significant difference between the CVI derived from combining just the physical and socio-economic parameters against including the risk perception index. This could be due to the small sample size used to test run the newly formulated method of combining scientific, local knowledge and awareness into vulnerability assessments. Also the risk perception indices can only provide an overview of the present condition and with the coast and human practices changing, this social indices will also change and as such, may not be sufficient enough to use on a long term sustainability management program (Jozaei et al. 2022). Notwithstanding this limitation, risk perception indices offer valuable insights that can inform short-term management interventions and decision-making.

- Second, although the ICEVI approach gives a better representation in Akata community, caution must be applied, as the findings might not be representative of the entire coast especially areas without human settlements.

- Third, the ICEVI approach relies heavily on qualitative data from stakeholders and as such there is a bias on the reliability of information especially where there are no proper documentation of hazards and impacts. Moreover, the interpretation of results should be done with caution because of the element of bias from the experts that may be present during the PGIS workshops. Also, from the difficulties that arose during this study, where the study relied mainly on data generated from the focus group discussions, which could have elements of bias from either those attending because views may not represent the communities since only selected people based on the criteria were invited to the FGD or by the researcher during the process of transcribing and interpreting the data.

- Vulnerability ranking is an excellent and easy way to express relative vulnerability, especially in low data environments (Koroglu, et al., 2019) and has proven to be particularly beneficial when examining complicated phenomena and in mixed-method investigations. Notwithstanding how vital the intergrated approach is, the trade-off in combining the physical, socio-economic and risk perception maps into a single assessment implies that the granularity that can be obtained from each map alone is lost.
- A sensitivity analysis of the newly development model is lacking in this study which could give more undertsanding of the degree of infleunce of each parameters in the ICEVI approach.
- Modelling of future vulnerability with changing climate-change scenerios would provide more comprehensive information and recommendation for coastal management and policies.

7.4 Recommendations

This research was conducted to holistically assess coastal erosion hazard and risk along the Akwa Ibom State coast. Based on the findings on the prevalence of coastal erosion, increased impacts of risk, low adaptive capacity and the current management measure implemented along the study coast, the research recommendations have been divided into both scientific and stakeholder recommendations.

7.4.1 Academic Recommendations

This study recommends that more academic research is carried out through mixed-method approaches which will engage the stakeholders at both the community level and government level. Scientific research through participatory methods has the potentials to create awareness, change the risk perception of the coastal residents, foster and impact coastal management practices. A summary of academic recommendations can be seen in table 7.1.

Table 7.1: Summary of Academic Recommendations

Recommendations	**Key Actors**
This study recommends carrying out a robust accuracy assessment to avoid either under or over exaggerating the risks associated with coastal erosion and/or undermining implementation of best protection practices.	Researchers
This study encourages collaboration and more participatory research by academics, government and coastal stakeholders which could serve as a pathway for creating more awareness on coastal hazards and local scale (at village level) monitoring along the study coast.	
The impacts of climate change can be felt everywhere. Such impacts, particularly in developing nations can be severe; which according to Adelola et al. (2017) is due to their lack of resources for local scale monitoring and low capacity to manage the risk associated with the hazards along the coast. This study encourages impactful research collaborations along the study coast which can provide evidence and improve awareness of the local stakeholders, allowing a window of opportunity for the government or environmental agencies to improve on coastal management policies and increase resilience.	Researchers/ coastal communities/ environmental agencies/ government
This study recommends collaborative research between the academia, the Government and the coastal communities to continuously monitor and gather data on coastal erosion and how it affects the land along the coast which is vital for coastal development and management.	

7.4.2 Stakeholders' Recommendations

The findings and discussions in chapters 4 and 6 show that some of the current management responses to coastal erosion are the main drivers of coastal erosion (i.e., maladaptation). As such, there is a need to improve coastal erosion and adaptation options awareness in the region, from local communities through to national government levels, to increase understanding and financing of adaptation measures to improve resilience of the communities to the impacts of coastal erosion and other coastal climate change impacts (e.g., intense storms and flooding). Based on these results, the following recommendations (see table 7.2) are made for all stakeholders; from the coastal communities, Nigerian Government at all 3-tiers, coastal environmental agencies, key funders of coastal community projects like World bank (World-Bank 2018), African development bank amongst others:

Table 7.2: Summary of Stakeholder's Recommendations

Scale	Recommendations	Key Actors
Community level	Community policies to avoid exploiting mangroves and other vegetation directly	Village leaders and community residents
	Designated vegetation zone where no one cuts down trees.	
	Encourage regular assessment of coastal erosion in the community.	
Local Government	Serve as a liaison officer between villages and state Government on coastal issues	Community /village stakeholders and local Government authorities
	Monitoring and documentation of coastal processes.	
State /Federal Government	Engagement with all stakeholders on coastal management Measures (CRM) approaches.	Community /village stakeholders and all tiers of Government, environmental agencies
	This study encourages stakeholders' engagement where the communities and policy makers work together on viable and sustainable management practices and polices	
	Restoration of coastal vegetation. Create and implement Mangrove conservation and sustainable exploitation policies along the study coast as these mangroves serve as natural buffers to the coast.	
	Regular monitoring and Evaluation of the coastal hazards	
	Encourage and sponsor soft measures like a vegetation restoration	
	To prevent erosion, hybrid shorelines like sills should be encouraged.	
	Set minimum setbacks regulatory measures.	
	This current study believes that planned relocation facilitated by both the government and village stakeholders would to a large extent address the place attachment issue, reducing the vulnerability in the area	
	Relocation, as an adaption measure is recommended by this study. Government should engage with the coastal communities, initiate and oversee planned retreats.	

In summary, the study's recommendations are vital for monitoring and gaining understanding on how the coast is evolving over time, particularly in response to coastal erosion. The recommended collaborative research between academia, government and coastal communities is crucial for coastal planning since it will enable up-to-date information on coastal erosion, paving a pathway for more informed coastal management practices. It will also provide more insight and understanding of the impacts from coastal erosion, which will inform adaptation and mitigation measures, as well as increase resilience along the study coast.

Appendices

Appendix 3.1: Research aims and objectives

Research Objectives	**Research Questions**	**Data**	**Data Analysis**
1) Identify the susceptibility of the Akwa Ibom shoreline to coastal erosion using remote satellite image analysis and identify sections of the coast that are most susceptible to coastal erosion using shoreline change detection.	*What is the trend of the shoreline change analysis in the study area?*	*Long-term coastal changes: Shorelines 1984, 2015, 2018, 2020 (30m Landsat)*	*Long-term coastal Change analysis (1984-2020) using DSAS- Linear regression rate method*
	How rapid are the Geomorphological changes in the study area?	*Short-term coastal changes: Shorelines 2015, 2018 & 2020 (30m Landsat)*	*short-term coastal changes (2015-2020) using DSAS- Linear regression rate method*
	What are the temporal and spatial variations along the study area and which data resolutions are best suitable for the study area?	*Long-term coastal changes: Shorelines 1984, 2015, 2018, 2020 (30m Landsat)* *Short-term changes: Shorelines 2015, 2018 & 2020 (30m Landsat)* *Shorelines 2015 & 2020 (1.5m SPOT)*	*1) Comparing the long-term and short-term changes along the coast.* *2) Comparing the short-term coastal changes (2015-2020) using 30m Landsat data and short-term coastal changes (2015-2020) using 1.5 m SPOT data*
	How susceptible is the Akwa Ibom Shoreline in the Niger Delta to the impacts of coastal erosion and where are the most susceptible areas of the coast?	*Long-term coastal changes: Shorelines 1984, 2015, 2018, 2020 (30m Landsat)*	*The susceptibility and 'hot spot' analysis for the coastal Change was carried out on the long-term data (1984-2020) using DSAS- Linear regression rate method*

2) Model future shoreline changes using historical data	*What future coastal changes will likely occur, using historical rates of change in the area applying the DSAS-Beta forecasting methodology?*	*Measured shorelines for 1984, 2020 and predicted shorelines for 2030 and 2040*	*Long-term coastal Change analysis (1984-2040) using the beta forecasting tool to predict the future shoreline trend*

Appendix 3.2: Description of baseline and shoreline attribute fields

Baseline attribute fields		**Shoreline attribute fields**	
Field name	Data type	Field name	Data type
OBJECTID	Object identifier	OBJECTID	Object identifier
SHAPE (alias: Shape)	Geometry	SHAPE	Geometry
SHAPE_LENGTH (alias: Shape_Leng)	Double	SHAPE_LENGTH	Double
ID	Long integer	DATE_ (DSAS_date)	Text (length = 10 or 20)
Group (DSAS_group)	Long integer	UNCERTAINTY (DSAS_uncy)	Any numeric number
Search_Distance (DSAS_search)	Double	SHORELINE_TYPE (DSAS_type)	Text

Appendix 3.3: Table showing the average shoreline change envelop (SCE) between the extracted shorelines for this study and the Pleaides 2015 reference shoreline.

Reference Shoreline	**Extracted shorelines**	**Average shoreline change (SCE)**
Pleaides extracted shoreline (2015)	Manually digitized shoreline from Landsat (2015)	34.22m
Pleaides extracted shoreline (2015)	Semi-automated shoreline from Landsat (2015)	39.47m

Appendix 4.1: Fieldwork and Ethical challenges

As the research involved interviews, there were a few ethical concerns about the research that needed to be addressed. These include:

- The issue of confidentiality and anonymity where the focus group participants feel wary of disclosing information about sensitive issues or activities (Sim et al. 2019). To ensure their privacy and anonymity, all participants and their responses are anonymized and coded with serial numbers assigned to each. There, however, were exceptions in some locations during the FGD, where clan leaders and village head waved off rights to anonymity. For those scenarios, their office title was used rather than their actual names like “Clan head” or “village head”.
- The issue of participants not understanding fully what they are being asked to contribute to. To minimize this risk, written and verbal communication consent was required of the participants. Though most the villages, believe that being present for the FGD meant their approval and in some cases, did not want to sign their names. In such cases, a verbal consent was sought and documented.
- There was a slight risk of participants becoming upset or distressed when talking about the challenges they have faced in their lives or problems within their communities. To curb that happening, participants were told ahead of the FGD, that if at any point during the meeting, they became upset or distressed, the research process could be paused or terminated, that information could also be given off the record by participants, giving the participants free choice about whether to continue or not.
- There was the concern of people feeling obliged to participate, for example, due to peer pressure to participate. Again, this was made clear to participants of the choice they had to participate or not and to the ‘gatekeepers’ to ensure that they do not pressurize people into participating especially when their presence may shape the way participants shared their knowledge. Most of the communities showed ready acceptance to participate and gave me and the team their cooperation.
- There were also concerns that some people may not want to be filmed or photographed. For this, we ensured that key contacts for each location put out the word with local contacts that filming will be taking place prior to the fieldwork. Thus, giving people the opportunity to avoid it as much as possible if they prefer. Also, consent was obtained formally or verbally from anyone appearing close-up on the camera. Interestingly, they always seemed happy to participate in the photography sessions.

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Plain Language Statement (or Participant Information Sheet)

Research Project: Vulnerability of the Nigerian coast to climate change induced Coastal Hazards

Researcher: Uduak Affiah

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you.

What is this project about: The purpose of the study is to identify the vulnerability of the Akwa Ibom Coast, Nigeria to the impact of coastal erosion and to identify the sensitivity and adaptive capacity of that system to sea-level change. This will be coupled with a community-based coastal hazard analysis based on local knowledge in an attempt to identify possible adaption strategies to mitigate the effects of climate change-driven erosion. ***In other words,*** this research wants to find out if coastal erosion is happening here, understand why it is happening and know the extent of damage it has caused to the land and the people in the community. This work also wants to know if the people in the community are aware of what is happening, why it is happening and if there are any measures put in place to reduce the effects of this hazard.

What do we require from you: You have been chosen to take part because you live in the Akwa Ibom coastal area and we believe you can provide us with information about the coastal erosion happening in your village. We would like to learn what you know about coastal erosion, what causes this and how it has affected the environment where you live, properties, roads and livelihood as a whole. We would also like you to give us information on how you cope with damages caused by the erosion and what you have done to lower the risk caused by it. To do this, we would appreciate if you can partake in one or more of our surveys. You do not have to take part (it is voluntary) but if you agree to take part, you will be asked to participate in one or more of the following activities in which you are free to withdraw at any time without giving any reason:

1) Focus group or questionnaire survey to discuss and answer questions on the prevailing effects of coastal erosion in your community to understand the vulnerability of your coastal area to climate-change induced hazards. To find out if coastal erosion is happening here, understand why it is happening, the extent of damage it has caused to the land and the people in the community and to know/understand the measures you have put in place to reduce the effect of this hazard. The focus group discussion will include at least 10 -12 members of the

1

community and should not take us more than 45 minutes. This will take place in the village town hall or any official space designated to us by the village.

2) Participate in a walking interview to show locations (if accessible and stable) that have been affected by coastal erosion and gain understanding of any physical mitigation parameters put in place to mitigate the hazard in these coastal areas. This exercise will involve just 1-2 Community volunteers and should not take more than 20 minutes and it will not require travel by vehicle. It involves walking to and showing the sites of nearby erosion while the researcher takes video (if consent is given) /audio recordings, pictures, coordinates and also take field notes at each location if more than one area.

3) Participate in a map-making exercise during the focus group discussion to locate and delineate areas in your community that have been affected by coastal erosion. This exercise will be done during the focus group discussion and will include at least 10 -12 members of the community. During the exercise, participants will be given satellite maps of their community together with pencils and asked to show or trace on the maps areas that are really affected by erosion and areas where people in your village had to relocate due to the effects from coastal erosion. This map-making exercise will also enable us to avoid visiting or accessing any unstable and precarious terrain as these areas will only be indicated on the map during the map-making exercise.

For the government and company stakeholders: You will be required to partake in an open-ended question interview on government and company`s roles in mitigating the effects of coastal erosion through the policies in place and how effective that has been in Akwa Ibom State where the study area is located. This interview should not take more than 15 minutes.

- It is possible to remain anonymous if you choose to do so. Please indicate on the accompanying consent form if you are happy to be identified. If not, you will not be identified in the research, and any identifying statements will not be used.
- All data will be stored on an encrypted laptop while in the field and subsequently stored on a password-protected computer at the University of Glasgow.
- **Please note that assurances on confidentiality will be strictly adhered to unless evidence of swrongdoing or potential harm is uncovered. In such cases the University may be obliged to contact relevant statutory bodies/agencies.**
- The results of this research study will be used in scientific reports, the findings of this work may be presented at an academic conference, published in an academic journal and potentially as the basis for future research and maybe be used to help guide any future activities working with the local community, town committees and local government.

Tertiary Education Trust Fund, Nigeria, funds this PhD research.

Contact for Further Information:

Researcher:	Uduak Affiah;	u.affiah.1@research.gla.ac.uk
Lead Supervisor:	Dr Brian Barrett;	brian.barrett@glasgow.ac.uk

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If you have any concerns regarding the conduct of this research project, you can contact the Secretary of the College of Science and Engineering Ethics Committee: Miss Louise McFadzean, email:
Louise.McFadzean@glasgow.ac.uk

Appendix 4.2: Participant information sheet

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Consent Form

Title of Project: Vulnerability of the Nigerian coast to climate change induced Coastal Hazards

Name of Researcher: Uduak Affiah

1. I confirm that I have read and understand the Plain Language Statement for the above study and have had the opportunity to ask questions.
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.
3. I wish / do not wish (delete as applicable) to be photographed or filmed.
4. I agree / do not agree (delete as applicable) to take part in the above study.
5. I wish / do not wish (delete as applicable) to remain anonymous.
6. I agree / do not agree (delete as applicable) to be recorded.

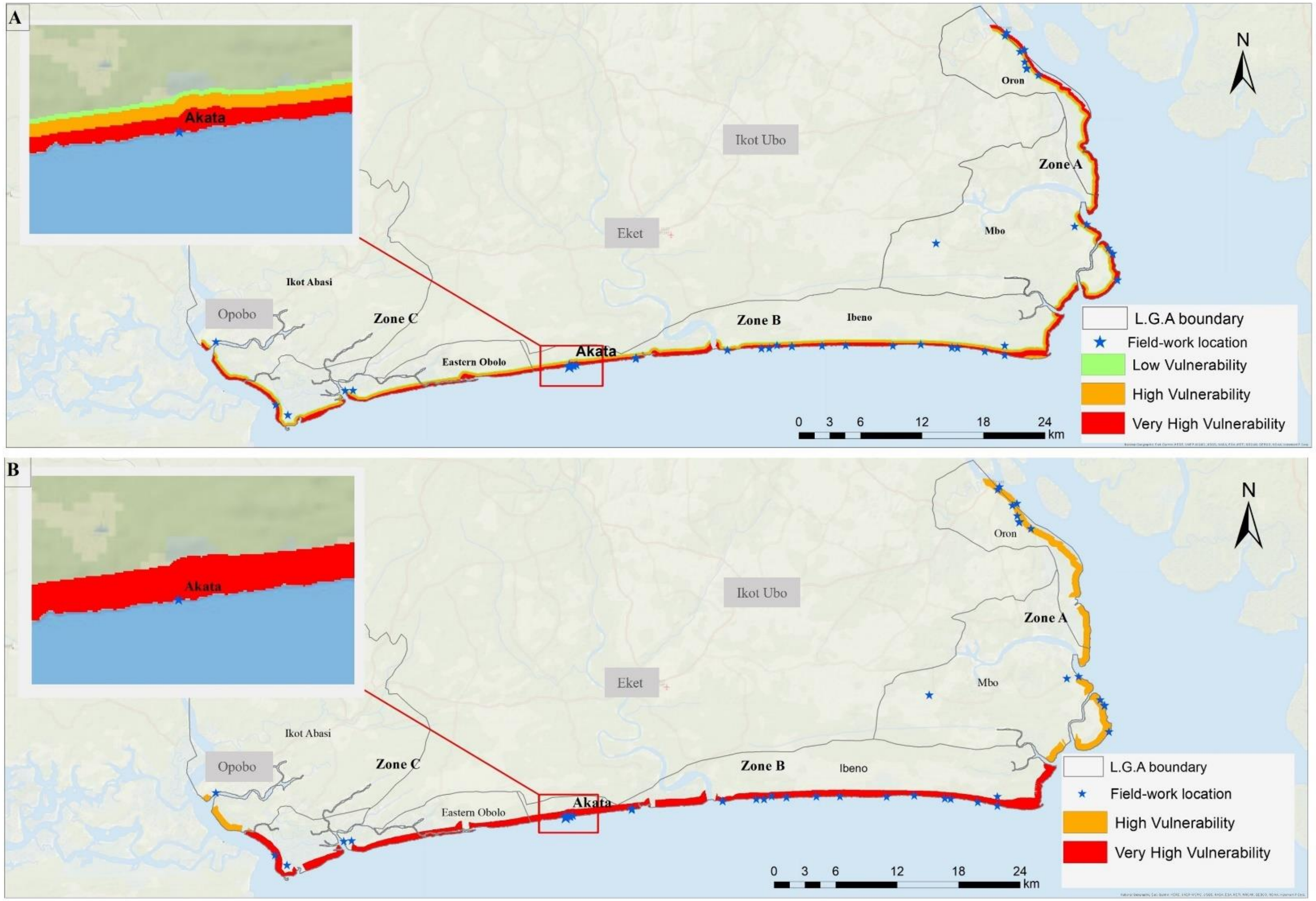
Name of Participant	Date	Signature

Uduak Affiah Researcher	Date	Signature

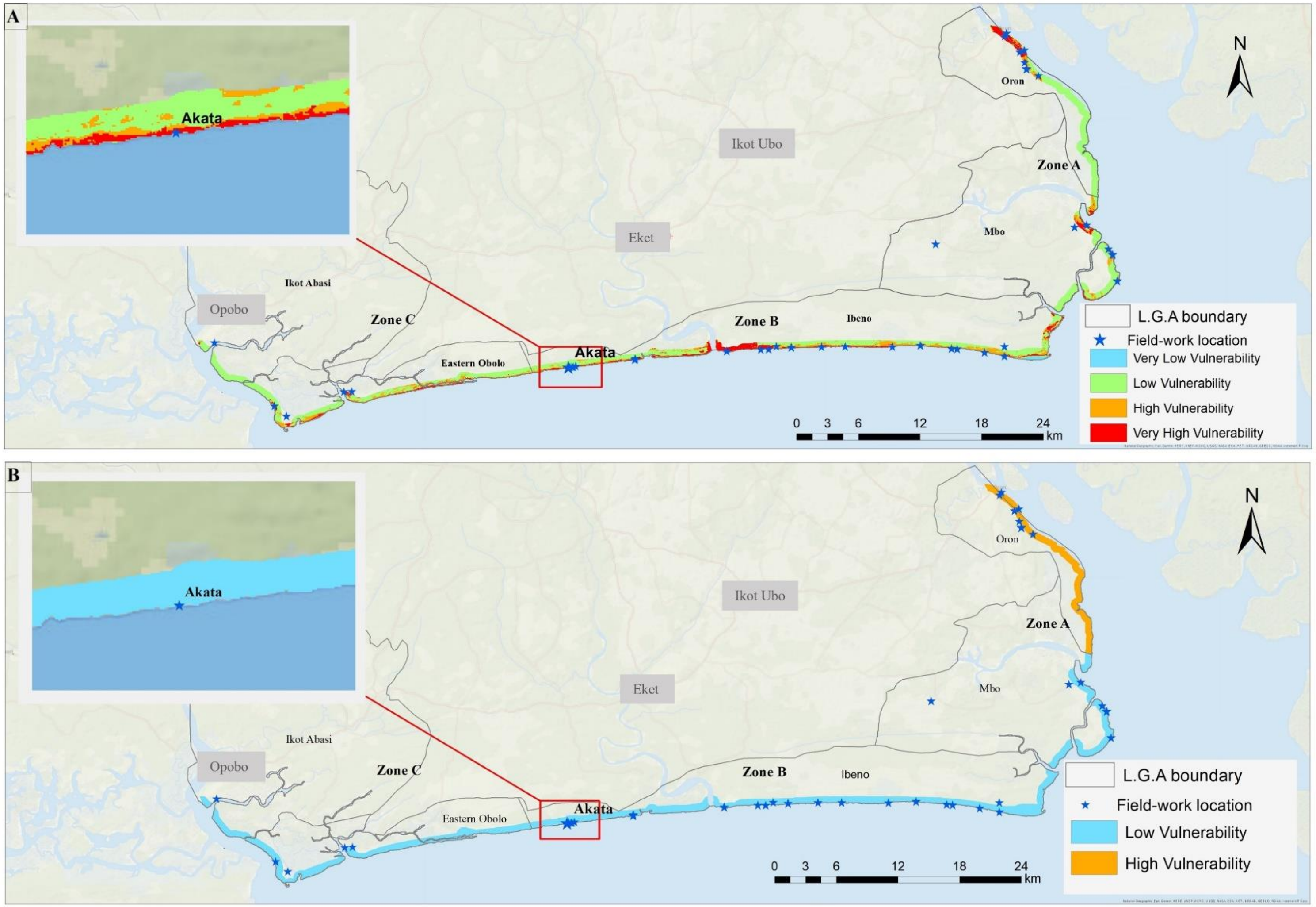
Appendix 4.3: Consent form for Participants

Appendix 5.1A-B: Map A shows the classified Slope distribution and map B shows the Geomorphological distribution within the study area overlain on an Esri Ocean basemap (Esri 2011).

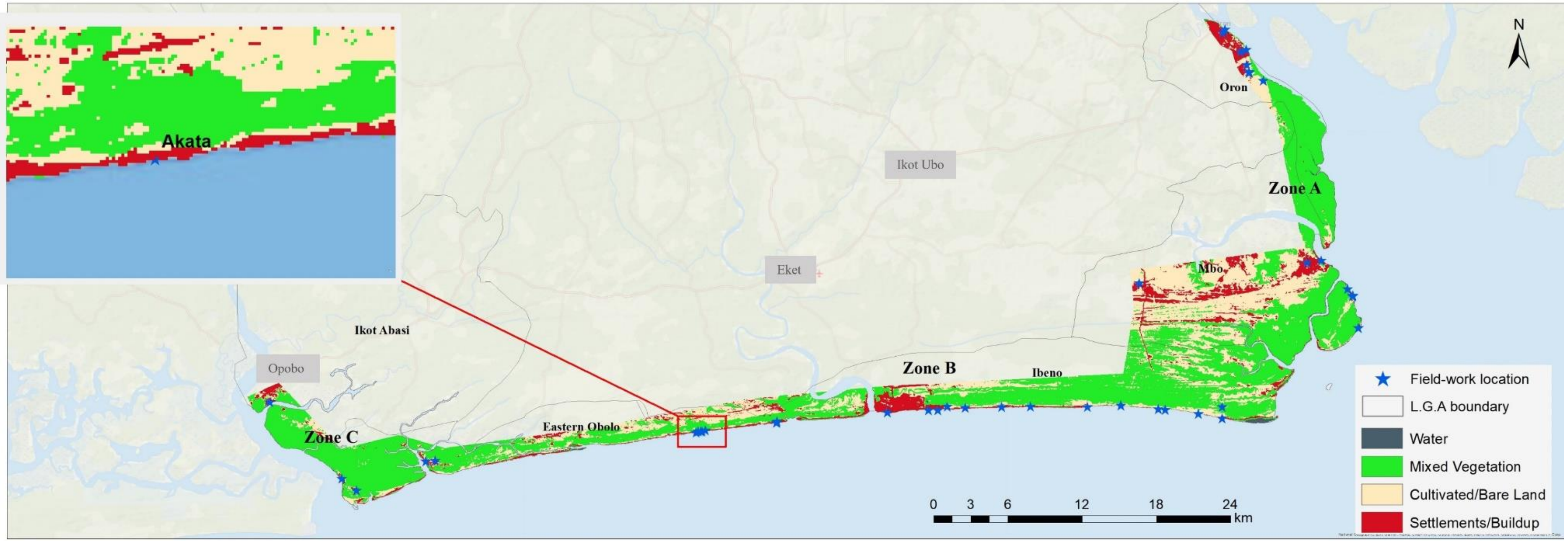
Appendix 5.2A-B: Map A shows the classified ranking of the elevation and map B shows the shoreline change distribution ranking within the study area overlain on an Esri Ocean basemap (Esri 2011).



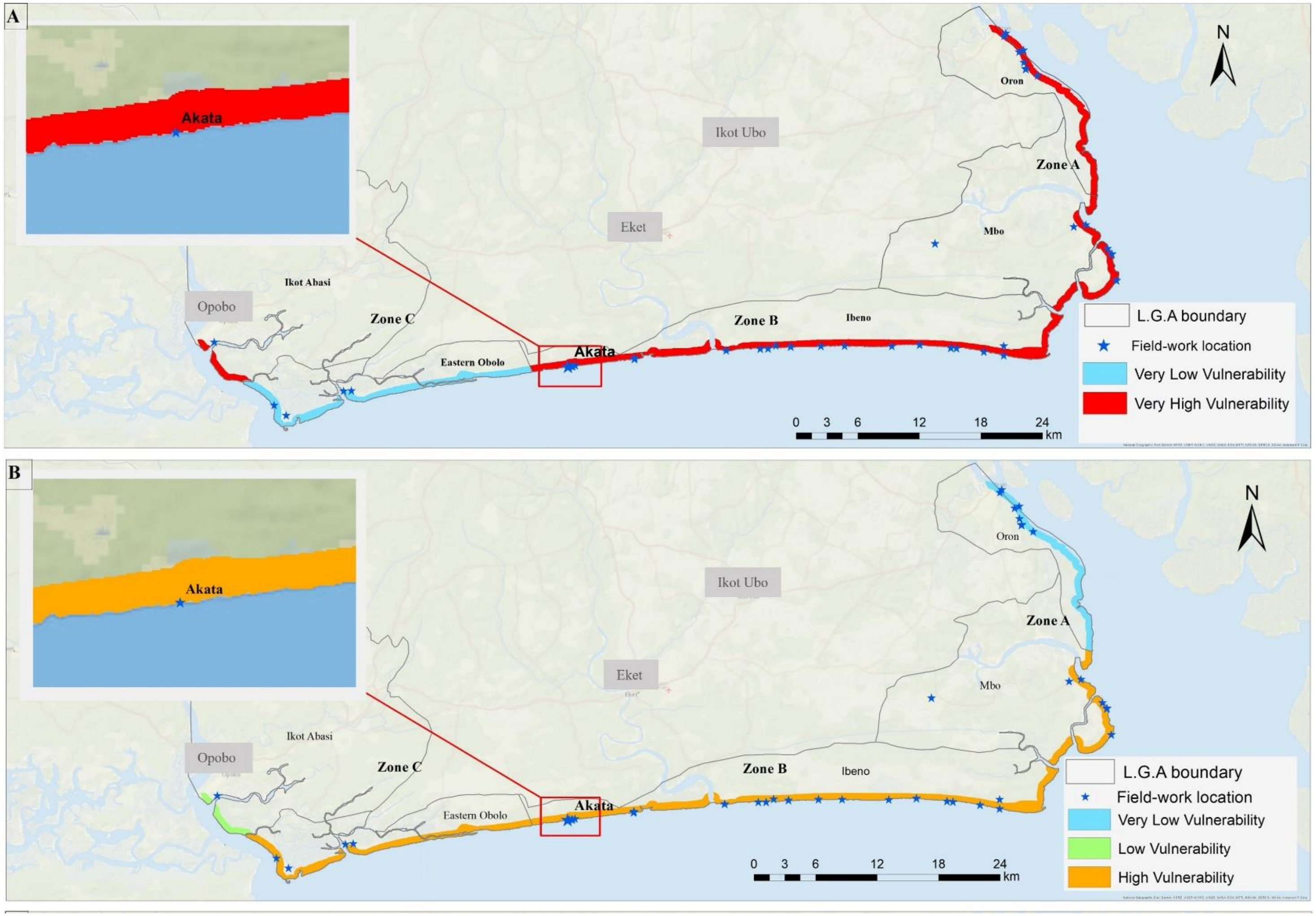
Appendix 5.3A-B: Map A shows the classified proximity to the coast and map B shows the mean tidal range distribution within the study area overlain on an Esri Ocean basemap (Esri 2011).



Appendix 5.4A-B: Map A shows the classified land use/land cover and map B shows the road network distribution within the study area overlain on an Esri Ocean basemap (Esri 2011).



Appendix 5.5: Classified Land use/ Land cover map for the study coast generated from Landsat 2015 Image.



Appendix 5.6A-B: Map A shows the classified cultural heritage and map B shows the coastal defence distribution within the study area overlain on an Esri Ocean basemap (Esri 2011).

Appendix 5.7: Map shows the classified population distribution within the study area overlain on an Esri Ocean basemap (Esri 2011).

Appendix 5.8: Summary of the parameters used in the Integrated Coastal Erosion Vulnerability Index (ICEVI).

	Sub-parameters	**Vulnerability Class**	**% Coverage**
Major parameters			
Geo-Physical parameters	**Slope (%)**	Very Low	7.03
		Low	11.54
		High	34.39
		Very High	47.04
	Geomorphology	Very Low	0
		Low	0
		High	21.02
		Very High	78.98
	Elevation(m)	Very Low	38.64
		Low	28.08
		High	29.79
		Very High	3.49
	Shoreline Change (m/yr)	Very Low	3.2
		Low	18.42
		High	21.82
		Very High	56.57
	Proximity to the Coast (m)	Very Low	0
		Low	14.91
		High	40.69
		Very High	44.4
	Mean Tidal Range (m)	Very Low	0
		Low	0
		High	33.71
		Very High	66.29
	Sea Level Change (mm/yr)	Very Low	0
		Low	0
		High	0
		Very High	100
Socio-Economic parameters	**Road Network**	Very Low	0
		Low	83
		High	17
		Very High	0
	Cultural Heritage	Very Low	22.48
		Low	0
		High	0
		Very High	77.52
	Landuse/Land Cover	Very Low	1.51
		Low	65.13
		High	17.99
		Very High	15.37
	Coastal Defence	Very Low	17
		Low	4.38
		High	78.62
		Very High	0
	Population	Very Low	56

		Low	27
		High	0
		Very High	17
Risk Perception Variables for Akata	**Hazard Awareness**	Very Low	0
		Low	100
		High	0
		Very High	0
	Severity of Impact	Very Low	0
		Low	0
		High	0
		Very High	100
	Exposure	Very Low	0
		Low	0
		High	0
		Very High	100
	Response	Very Low	0
		Low	0
		High	100
		Very High	0
Results			
PVI	**Physical**	Very Low	0.98
		Low	19.65
		High	31.04
		Very High	45.47
SVI	**Socio-Economic**	Very Low	1.22
		Low	57.85
		High	26.74
		Very High	14.18
CVI (PVI +SVI/2)	**Coastal Vulnrability Index**	Very Low	3.04
		Low	29.41
		High	50.98
		Very High	16.57
RPIerosion	**Risk perception of coastal erosion**	Very Low	0
		Low	0
		High	0
		Very High	100
ICEVI Akata	**Integrated coastal erosion vulnerability index for Akata community**	Very Low	0
		Low	0
		High	0
		Very High	100
CVI Akata	**Coastal vulnerability index for Akata community**	Very Low	0
		Low	0
		High	22.05
		Very High	77.95

Appendix 5.9A-B**:** Expert AHP weightings for the physical and socio-economic vulnerability index

A: Pairwise Comparison matrix for the physical parameters

Decision matrix for expert 1

	Coastal slope	**Geomorphology**	**Elevation**	**Shoreline change**	**Proximity to the coast**	**Tidal Range**	**Sea Level change**
Coastal slope	1	1/3	2	1/5	1/3	2	2
Geomorphology	3	1	3	1	1/3	2	2
Elevation	1/2	1/3	1	1/2	1/2	2	2
Shoreline Change	5	1	2	1	2	3	3
Proximity	3	3	2	1/2	1	2	2
Tidal range	1/2	1/2	1/2	1/3	1/2	1	1
Sea level Change	1/2	1/2	1/2	1/3	1/2	1	1

Decision matrix for expert 2

	Coastal slope	**Geomorphology**	**Elevation**	**Shoreline change**	**Proximity to the coast**	**Tidal Range**	**Sea Level change**
Coastal slope	1	1/3	1/3	1/3	1/3	3	3
Geomorphology	3	1	5	1/2	1	5	5
Elevation	3	1/5	1	1/3	1/3	5	3
Shoreline Change	3	2	3	1	3	6	5
Proximity	3	1	3	1/3	1	3	3
Tidal range	1/3	1/5	1/5	1/6	1/3	1	1/2
Sea level Change	1/3	1/5	1/3	1/5	1/3	2	1

Decision matrix for expert 3

	Coastal slope	**Geomorphology**	**Elevation**	**Shoreline change**	**Proximity to the coast**	**Tidal Range**	**Sea Level change**
Coastal slope	1	1/2	1/2	1/3	1/2	1	1
Geomorphology	2	1	3	1	1	3	3
Elevation	2	1/3	1	1/3	1/5	2	2
Shoreline Change	3	1	3	1	3	3	3
Proximity	2	1	5	1/3	1	1	1
Tidal range	1	1/3	1/2	1/3	1	1	1/2
Sea level Change	1	1/3	1/2	1/3	1	2	1

B: Pairwise Comparison matrix for the socio-economic parameters

Decision matrix for expert 1

	Land use/ Land cover	Cultural Heritage	Road Network	Coastal Defence	Population
Land use/ Land cover	1	3	3	1/2	1/2
Cultural Heritage	1/3	1	3	1/2	1/3
Road Network	1/3	1/3	1	1/2	1/3
Coastal Defence	2	2	2	1	1
Population	2	3	3	1	1

Decision matrix for expert 2

	Land use/ Land cover	Cultural Heritage	Road Network	Coastal Defence	Population
Land use/ Land cover	1	3	3	1/3	1
Cultural Heritage	1/3	1	3	1/3	1/2
Road Network	1/3	1/3	1	1/3	1/2
Coastal Defence	3	3	3	1	1
Population	1	2	2	1	1

Decision matrix for expert 3

	Land use/ Land cover	Cultural Heritage	Road Network	Coastal Defence	Population
Land use/ Land cover	1	2	3	1/2	1
Cultural Heritage	1/2	1	3	1/2	1/2
Road Network	1/3	1/3	1	1/2	1/4
Coastal Defence	2	2	2	1	1
Population	1	2	4	1	1

Appendix 5.10: Question used to facilitate the focus group discussions and interviews

1) The following questions were used for the FGD, though not limited to these:

- What is your opinion of any changes to the landscape in your community along the coast?
- What is your view on the coastal changes that have occurred here?
- What is opinion on the causes of the changing coastal land?
- Can you give any information on how these changes have affected the community?
- Are there any concerns about the coastal changes?
- Have the activities carried out in the villages contributed to the hazards experienced here?
- What activities has been carried out by the community or government in managing the situation?
- Can you explain why you have chosen to remain here despite the risk of all the coastal hazards.

2) The following question were used during the interviews with the State/environmental agencies:

- Are there any coastal hazards occurring in the State?
- If yes, what are the common reoccurring hazards?
- When last did it occur?
- Are there any documentations of past coastal hazard occurrences?
- Are there any warning systems in place to alert communities of an impending event?
- If yes, briefly explain
- Are there any coastal management measures put in place by the government?
- How effective are these measures?
- If yes, was there any involvement or engagement of the coastal communities in the management plans?
- Are there any challenges in getting the local stakeholders involved in the management plan?
- If yes, what are the challenges faced?
- Is the government open to improving coastal management policies that will engage and involve the local stakeholders from planning to execution processes?

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Christoph.Scheepers@glasgow.ac.uk

Glasgow, August 6, 2018

Ethical approval for:

Application Number: 300170277

Project Title: Vulnerability of the Nigerian coast to climate change induced coastal hazards

Lead Researcher: Dr Brian Barrett

This is to confirm that the above application has been reviewed by the College of Science and Engineering Ethics Committee and **approved.** Please refer to the collated reviews on the system for additional comments and suggestions, if any. Good luck with your research.

Sincerely,

Dr Christoph Scheepers
Ethics Officer
College of Science and Engineering
University of Glasgow

Did you know? For projects requiring the use of an online questionnaire, the University has an Online Surveys account for research. To request access, see the University's application procedure at https://www.gla.ac.uk/research/strategy/ourpolicies/useofonlinesurveystoolforresearch/.

Appendix 5.11: Ethics Approval

AKWA IBOM STATE GOVERNMENT OF NIGERIA

Telegrams:
Telephone:
Our Ref: MEMR/S/137/VOL./478

All replies should be addressed
To the Hon. Commissioner

MINSTRY OF ENVIRONMENT AND MINERAL RESOURCES
Block 3, 1st Floor, Phase 2
Idongesit Nkangas Secretariat Complex
Uyo

Date: 2nd October, 2018

Uduak E. Affiah
Plot 6, Unit B
Ewet Housing Estate
Uyo, Akwa Ibom State

RE: NOTIFICATION AND CONSENT TO UNDERTAKE AN ACADEMIC STUDY ON THE VULNERABILITY OF THE AKWA IBOM COASTALINE TO THE IMPCAT OF COASTAL HAZARDS

Your letter dated 10th September 2018 on the above subject matter refers, please:

A meeting was schedule for Tuesday 25th September 2018 for further discussion regarding the request for your project work, but you did not turn up.

In view of the above, the meeting had been rescheduled for:

Date:	**Thursday 4th October 2018**
Time:	**10am**
Venue:	**Ministry's Conference room**

Thanks.

Comfort Tom Asuquo (Mrs)
Director, Climate Change Awareness

Appendix 5.12: Letter of invitation for a meeting with the Ministry of Environmental Resources, Akwa Ibom State Government

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