RISK AND ADAPTATION BEHAVIOUR TO SEA-LEVEL RISE IN COASTAL RURAL COMMUNITIES IN GHANA

BY

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(PhD/SPS/FT/2019/11124)

WEST AFRICAN SCIENCE SERVICE CENTRE ON CLIMATE CHANGE AND ADAPTED LAND USE (WASCAL)

FEDERAL UNIVERSITY OF TECHNOLOGY MINNA

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THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF DOCTOR OF PHILOSOPHY (PhD) IN CLIMATE CHANGE AND HUMAN HABITAT

JANUARY, 2024

DECLARATION

I hereby declare that this thesis **"Risk and Adaptation Behaviour to Sea-Level Rise in Coastal Rural Communities in Ghana''** is a collection of my original research work and has not been presented for any other qualification anywhere. Information from other sources (published or unpublished has duly been acknowledged.

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CERTIFICATION

The thesis tiled “Risk and Adaptation Behaviour to Sea-Level Rise in Coastal Rural Communities in Ghana” by: ADADE, Richard (PhD/SPS/FT/2019/11124) meets the regulations governing the award of the degree of PhD of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

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ABSTRACT

Most coastal rural communities in Ghana are particularly vulnerable to sea level rise because of poverty, remoteness and isolation from central planning agencies. Understanding future sea-level rise (SLR) risk levels and community adaptation behavior is critical in implementing climate change adaptation strategies. This study assessed the risk level of sea rise and adaptation behavior within three coastal rural communities in Ghana namely, Sawoma, Anlo Beach and Glefe-wiaboman.

The study employed an innovative mixed-methods approach that combines spatial data (UAV and satellite imagery), questionnaire surveys, Focus Group Discussion (FGD) and expert knowledge. Data obtained from both primary and secondary were analysed to generate scores for each component of risk based on the IPPCC AR5 climate risk concept which was then aggregated to obtain risk level scores for each study community. The study utilized a multistage sampling technique to select household respondents and purposive sampling for participants for the Focus Group Discussion (FDG). Descriptive and inferential statistics were used to quantitatively describe and summarize the data collected. The Sea Level Affecting Marshes Model (SLAMM) was employed to simulate the effects of various sea level rise scenarios on rural coastal communities. Multinomial logistic regression was then employed to identify the factors that predict residents' intention to relocate.

Results from the study indicated that cumulative impacts resulting from both erosion/accretion and inundation, on average of about 1.67 ± 0.72 km^2 of rural coastal community land will likely be impacted for up to 1.4 m SLR scenario for Sawoma (0.11 ± 0.03 km^2), Anlo Beach (0.38 ± 0.12 km^2) and Glefe-wiaboman (0.18 ± 0.56 km^2). Socio-ecological vulnerability levels were high in areas where there were human settlements and critical ecosystems. The levels varied between 0.43 and 0.60, with Anlo Beach recording the highest score of 0.60, as anticipated due to its highest ecological vulnerability score. Sawoma and Glefe-wiaboman reported vulnerability scores of 0.43 and 0.49, respectively. In terms of risk to SLR, Glefe-wiaboman community will likely be at high-risk (0.75 – 1) whilst Anlo beach and Sawoma likely be at medium (0.25 – 0.49) and low-risk (0 – 0.24) levels respectively. The high SLR risk level in Glefe-wiaboman is exacerbated by its low-lying topography, high population density and beach sand mining. Also, the study revealed that cognitive and compositional factors (p-value < 0.05) are more important than contextual factors for predicting the relocation intention of coastal rural communities in Ghana. Thus, the study advocated for intensive education on the effects of future sea-level rise impacts on communities and the benefits of relocating vulnerable coastal rural communities.

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LIST OF ABBREVIATIONS

Abbreviation	
AGL	Above Ground Level
CICES	Common International Classification of Ecosystem Services
CoSMos	Coastal Storm Modeling System
DEM	Digital Elevation Model
DRA	Disaster Risk Assessment
DRR	Disaster Risk Reduction
DSAS	Digital Shoreline Analysis Software
DTM	Digital Terrain Model
DSM	Digital Surface Model
EbA	Ecosystem-based Adaptation
EFA	Exploratory Factor Analysis
EPR	End Point Rate
ESA	Europe Space Agency
FGD	Focus Group Discussion
GCP	Ground Control Point
GIA	Glacial Isostatic Adjustment
GIS	Geographic Information Systems
GMSL	Global Mean Sea-level
GPS	Global Positioning System
GSS	Ghana Statistical service
HWL	High Water Line
IPCC	Intergovernmental Panel on Climate Change
LRR	Linear Regression Rate
LULC	Land use/cover
NADMO	National Disaster Management Organization

NAPA	National Adaptation Programmes of Action
NDMI	Normalised Difference Moisture Index
NDVI	Normalized Difference Vegetation Index
NEP	National Environmental Policy
NOAA	National Oceanic and Atmospheric Administration
PMT	Protection Motivation Theory
RCP	Representative Concentration Pathway
RS	Remote Sensing
SFM	Structure from Motion
SLAMM	Sea Level Affecting Marshes Model
SLF	Sustainable Livelihood Framework
SLR	Sea Level Rise
UAV	Unmanned Aerial Vehicle
UNDHA	United Nations Department of Humanitarian Affairs

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the study

The Earth's climate has undergone profound transformations in recent decades, emerging as a pressing global issue characterized by existential threats to humanity. This transformation is epitomized by the escalating global mean sea-level rise driven by thermal expansion caused by ocean warming, as well as the depletion of glaciers and ice sheets. Studies have shown a higher possibility of sea level rise in the 21st century if the Antarctic and Antarctica ice sheets sections were to collapse (Church *et al*., 2013; DeConto and Pollard, 2016; Nerem *et al*., 2018). Analysis of satellite altimetry data from 1993 to 2015, reveals that sea surface height increased nearly three times more than the previous years (Chen *et al*., 2017; Dieng *et al*., 2017). According to the Intergovernmental Panel on Climate Change's fifth assessment report (AR5), the average global sea level will likely rise to between 28-68 cm and 52-98 cm by 2100 (RCP 2.6 and 8.5, respectively) based on process-based model projections (Church *et al*., 2013; Stocker *et al*., 2013). Changes in sea level rise have already impacted coastal communities by increasing the risk of flooding and/or erosion of beaches and infrastructure. The rise of sea level has resulted in detrimental effects on crucial marine environments with significant ecological and economic value, including productive estuaries, coastal wetlands, and coral reefs (Addo *et al*., 2018; Wong *et al*., 2014).

Coastal areas with low elevations face increasing susceptibility to the impacts of rising sea levels and the intensified frequency of extreme events, such as storms linked to climate change. Furthermore, these areas bear the burden of dense populations and rapid urbanization, amplifying their vulnerability to the multifaceted challenges posed by climate change (Neumann *et al*., 2015). About 10 percent of the world's population, along with 13 percent of the world's urban inhabitants, reside in regions situated at an elevation of less than 10 meters above sea level. Remarkably, these areas account for merely 2 percent of the Earth's total land area. (McGranahan *et al*., 2007). The substantial increase in coastal population has resulted in extensive transformation of natural coastal landscapes for agricultural, industrial, and residential purposes, rendering coastal areas as the most economically vibrant regions (Crossland *et al*., 2005).

Increased sea-level are causing recurring and more serious coastal floods leading to forced migration in coastal areas. Sea level rise also contributes to the loss of lives, homes and infrastructure. For instance, between 1995 and 2000, floods and tidal waves in North Korea contributed to the relocation of 300,000-400,000 persons to China's urban centres. Furthermore, the devastation of both human lives and essential infrastructure in the northern Gulf of Mexico as a result of the 2005 Katrina and Rita hurricanes emphasizes the peril posed by rising sea levels to coastal regions. The tragic events of the 1970 Bhola cyclone, which claimed the lives of half a million people in Bangladesh, serve as a stark reminder of the potential for loss of life in vulnerable, low-lying coastal areas (Garrison, 2012).

The relationship between shoreline/beach changes and relative sea levels has been established in many locations. For example, at the Chao-Phraya Delta in Thailand (Uehara *et al*., 2010), the Niger Delta in Nigeria (Musa *et al*., 2014), along the coast of the US (Ding *et al*., 2013; Yin *et al*., 2010) and the beaches of Morocco (Snoussi *et al*., 2008) and in Europe (Yates and Le Cozannet, 2012). The environmental consequences of sea-level rise on coastal areas may not be limited to increased flooding and erosion, but also loss of vital coastal ecosystems such as mangroves. Mangrove ecosystems are resilient to an increase in sea level due to their land migration ability (Di Nitto *et al*., 2014); however, they are among those intertidal that are highly vulnerable to sea level rise associated with climate change.

Using spatial techniques and ground surveys Ellison and Zouh (2012) established that over the past three decades, coastal edges of mangroves in Cameroon witnessed an annual dieback of more than two-thirds of the shoreline and a depletion of up to 89 percent on offshore mangrove island. Similarly, Lovelock *et al*., (2017) also monitored a mangrove forest in northwestern Australia for sixteen years and concluded that fluctuations in sea level have negative effects on some mangrove forests. Studies have shown that a large number of low-lying coastal areas in sub-Saharan African countries are exposed to the impacts of sea-level rise (Jongman *et al*., 2012; Dasgupta *et al*., 2009). Coastal erosion and floods in West Africa pose a significant threat to communities, livelihoods and investments. According to the World Bank report in 2017, at least 55 million Africans live in areas that are less than 10 meters above sea level and an average of 500 000 people who live on the coastline of West Africa are adversely affected by flooding, worsening coastal erosion annually. In some low-lying coastal areas, especially the eastern part of Ghana, the coastline is eroding by 20 metres or more per year (The World Bank, 2017). The vulnerability of West Africa's coast to the impacts of sea-level rise can be due to high economic and industrial growth concentrations, increased population and low adaptability due to chronic poverty, and weak planning (Dasgupta, *et al*., 2009).

Climate risk hazards such as coastal erosion and inundation pose a significant threat to human lives, livelihoods, natural habitats and properties along Ghana’s coastline. While Ghana's coastal region occupies only 7 percent of the nation's total land area, it accommodates roughly a quarter of the country's population and plays a crucial role by hosting approximately 75 percent of its major businesses and industries (Armah *et al*., 1998; Ghana Statistical Service (GSS), 2013). Local sea level estimates suggest an accelerated sea-level rise by 2100. More recently, Evadzi *et al*., (2017) revealed that considering various sea-level rise scenarios (2.6, 4.5, and 8.5 RCPs) and assuming that sea-level rise will account for 31 percent of future shoreline retreat, approximately 6.6, 4.7, and 5.8 meters of coastal terrain in Ghana, characterized by the lowest slope range (0–0.4 percent), is anticipated to become inundated by the year 2025. These increases are expected to grow to 19.8, 20.7 and 24.3 mm in 2050; 36.6, 51.6 and 83.9 mm by 2100 in the case of RCPs of 2, 6, 4.5 and 8.5 in 2050, respectively.

Since early 2000, several studies have been conducted in Ghana to assess rural coastal vulnerability to sea-level rise impacts. For instance, Addo *et al*., (2018) used remote sensing techniques to determine sea-level rise impacts in the Fuveme community in the Volta Region of Ghana. The study revealed that the detrimental effects of rising sea levels had placed rural livelihoods and properties in jeopardy. Additionally, it came to light that over a span of 12 years (from 2005 to 2017), coastal erosion and flooding had obliterated over 77 homes, leaving more than 300 residents without shelter. Also, Osman *et al*. (2016) used ethnography and Geographic Information System (GIS) techniques to assess flood risk within the Ankobra estuary. The finding of the study revealed that the majority of settlements were in the extreme to high-risk areas and recommended that residents in these areas should be relocated to low-risk zones.

Adaptation strategies to curb the risk of increasing sea level requires regulations, plans and measures to reduce risks and create resilience against rising sea level rise. The strategies include the protection of the coast, the accommodation of impacts of sea level rise, retreat from the coast, and Ecosystem-based Adaptation (EbA). Ghana has over the years implemented protective measures such as the construction of groynes and revetment to serve as barriers to sea waves in major cities and towns including Accra, Cape Coast and Takoradi to prevent sea erosion and flooding. These hard engineering measures cost the government of Ghana approximately US$60-90 million for 10-25 km (The World Bank, 2017). Protection adaptation strategy has potential longevity but is costly to build and maintain (Tol *et al*., 2005) and it can have adverse impacts, such as changing sediment dynamics in other areas (Jayson-Quashigah *et al*., 2019). For vulnerable rural communities like Anlo Beach and Sawoma, planned retreat is often proposed; however, relocation costs are often underestimated as losses of future social and cultural value are not always adequately taken into account (The World Bank, 2017).

Rural coastal communities experience double jeopardy of direct risk to human lives and indirect risk to important ecosystem services due to the dire consequences of the sea-level rise (Addo *et al*., 2018; Dasgupta *et al*., 2015; Hino *et al*., 2017; Kankam *et al*., 2016; Osman *et al*., 2016). A report by GSS (2013) established that rural areas in Ghana experience a 13.7 percent higher poverty headcount compared to the national average of 24.2 percent. The main contributors to rural poverty are low wages, limited savings, inadequate education, and a heavy dependence on natural resources. In addition to these, the remoteness and isolation of coastal rural areas from central planning agencies make them more vulnerable to the impacts of sea-level rise (Bhattachan *et al*., 2018).

Knowledge of future sea-level rise impacts provides the framework for risk level assessment, strategies for building resilience, urgent action assessment, reliability and cost-effectiveness evaluation of options, and stakeholder participation and empowerment in adaptive systems (Marshall *et al*., 2013). An effective and sustainable solution to the impacts of sea-level rise requires a detailed mapping and understanding of the local sea-level dynamics as well as its impacts on socio-ecological systems. Hence, this study's main aim is to assess the sea level rise risk levels and adaptation behaviour in three rural coastal communities in Ghana.

1.2 Statement of the Research Problem

The heavy reliance of rural coastal communities on natural resources for their livelihoods, recreation, and settlements makes them highly vulnerable to the serious threat of climate-induced natural disasters (Field *et al*., 2014). Coastal rural communities in Ghana face various risks, including those stemming from rising sea levels, which lead to storm surges, floods, erosion, and flash floods from rivers. For decades, some of these rural communities have been experiencing excessive tidal inundation from both sea-level rise and river flash floods from the river, resulting in the loss of settlements and livelihood assets. Whereas indigenous knowledge had been used to predict the likelihood of floods in the past, climate change has rendered this ineffective as these disasters have become more erratic, thereby making these communities more vulnerable. For instance, the entire settlement in Anlo Beach has been at risk for several years of coastal erosion and sea-level rise. Twice a year, seawater floods the community for several weeks and destroys properties and obstructs economic development. During the flood in July 2009, 78 houses were demolished (Coastal Resources Centre, 2013). Similar incidences have also been noted in Fuveme between 2005 and 2017, where around 77 homes, about 42.0 percent of the total homes, were destroyed due to erosion in the Fuveme community. The destruction of the homes led to the displacement and resettlement of more than 300 residents within the community (Addo *et al*., 2018). In addition to mangrove harvesting for the sustenance of rural livelihoods, the decline of mangrove ecosystems in these areas has been significantly exacerbated by rising sea levels, resulting in the loss of coastal and intertidal habitats. Mangroves provide a multitude of ecological and socioeconomic benefits to both humans and various organisms. They serve as vital breeding habitats for fish, offering a numerous supply of nutrients to support a diverse aquatic ecosystem (Benzeev *et al*., 2017). Additionally, mangroves play a crucial role in safeguarding shorelines from powerful winds, erosion, and currents (Doughty *et al*., 2019) among other essential functions. Moreover, these ecosystems contribute to various sectors, such as fisheries and tourism, generating products, income, and employment opportunities, as well as a diverse array of wood and non-wood forest products (Palacios and Cantera, 2017).

Although, the government's prioritization of adaptation strategies, there is insufficient understanding of individual-level adaptation, especially in the coastal rural areas. According to Amos *et al*., (2015), climate change adaptation strategies will be ineffective unless they are implemented in the context of households' perceptions of climate change risk and self-efficacy in hazard mitigation. Despite the fact that several studies have highlighted the factors that influence climate change adaptation efforts globally (Boyer-Villemaire *et al*., 2014; Fosu-Mensah *et al*., 2012; Gebrehiwot and Van Der Veen, 2013), nonetheless, there are few studies on people's attitudes toward sea-level rise risk and adaptation strategies (Song and Peng, 2017). More importantly, there are few studies linking behavioural aspects to adaptation to sea-level rise in Ghana. This study, therefore, employed an innovative mixed-methods approach that combined Geographic Information Systems (GIS), Unmanned Aerial Vehicles (UAV) technologies, household survey, modelled data and expert knowledge to assess the risk and adaptation behaviour to different scenarios of sea-level rise in Sawoma, Anlo Beach and Glefe-wiaboman rural communities in Ghana. Drawing from the study, a good understanding of sea-level rise risk can provide the basis for policy and adaptation strategy improvement or formulation for rural coastal communities which are mostly neglected in climate change assessments.

1.3 Research Questions

1. How will different sea level rise scenarios impact the study communities?
2. What socio-ecological systems in the study communities will likely be exposed to sea level rise impacts?
3. How vulnerable are the rural coastal socio-ecological systems to the impacts of projected sea-level rise?
4. What are the risk levels of the rural coastal communities to impacts of projected sea-level rise?
5. What factors influence the household intention to relocate in anticipation of sea-level rise?

1.4 Aim and Objectives

The aim of the study is to assess the risk levels and adaptation behaviour of residents of selected coastal rural communities in anticipation of sea-level rise. The specific objectives area to:

i. Model the impacts of different sea-level rise scenarios on study communities.

ii. Map the elements exposed to impacts of projected sea-level rise within the study communities.

iii. Assess the vulnerability of the rural coastal socio-ecological systems to impacts of projected sea-level rise.

iv. Assess the risk levels of the rural coastal communities under study to impacts of projected sea-level rise.

v. Examine the factors influencing household’s relocation intention in response to anticipation of sea-level rise.

1.5 Justification for the Study

(a) **Policy Improvement**: The study will provide vital information to the national data which is essential in achieving the Sustainable Development Goals; Sustainable Cities and Communities (Goal 11) and Climate Action (Goal 13). The study will also identify and generate a risk index for the rural socio-ecological systems in the three communities. This information will aid coastal managers in the district to plan a disaster response. This study will also provide the basis for policy and adaptation strategy improvement or formulation for other vulnerable rural coastal communities.

(b) **Performance Improvement**: It will also provide relevant information for various stakeholders and policymakers such as the District Assemblies and the National Disaster Management Organisation (NADMO) on a comprehensive approach for assessing the potential impacts and responses to sea-level change. It will highlight how to link social and remotely sensed data such as UAV images and high-resolution DTM for assessing sea-level rise impacts and adaptation strategies. The research aims to enhance the understanding of future consequences of sea-level rise within the study areas in terms of its spatial extent and intensity. Encompassing factors like spatial reach and severity. This information is vital and essential for land use mapping and adaptation planning in the locality.

(c) **Body of knowledge**: Although the impacts of sea-level rise and corresponding adaptation may be one of the most costly aspects of climate change (Margulis *et al*., 2010), few studies have assessed this impact on rural socio-ecological systems globally (Bhattachan *et al*., 2018; Genua-Olmedo *et al*., 2016; Smart, 2019). In Ghana, most studies on risk, vulnerability and adaptation strategies of coastal areas to the impacts of sea-level rise generally focused on either the entire country or coastal urban and peri-urban areas where great losses are envisaged, however, the rural coastal areas face unique adaptation challenges because of their dependence on natural resources (Addo, 2013;Addo, 2014, Addo, 2015; Addo *et al*., 2008; Jonah *et al*., 2016a; Yankson *et al*., 2017). The few studies conducted in rural areas mostly considered flood risk to people but without assessment of sea-level rise risk on socio-ecological systems and its associated adaptation (Addo *et al*., 2018; Jayson-Quashigah *et al*., 2019; Osman *et al*., 2016). These studies are also distinct from the socio-ecological datasets and the Digital Elevation Model (DEM) used for modelling SLR impacts. Few studies have explored all these dimensions together. This study will address these gaps by comprehensively assessing the impacts of increased coastal flooding and erosion on the rural population and their livelihood assets as well as adaptation strategies using different socio-economic and sea-level rise scenarios.

(d) **Further Research**: Lastly, the study has the potential to encourage further research on sea-level rise impacts and adaptation options in climate change studies.

1.6 Description of the Study Area

1.6.1 Geographical location and map of study

The study was carried out in three rural coastal communities in the Greater Accra and Western Regions of Ghana (Figure 1.1). The three selected study rural communities, namely Sawoma (latitudes 4° 54' 08.925.3" N; 4° 54' 09.6" N and longitudes 2° 16' 14.1" E44.2" W; 2° 15' 54.4" W), Anlo Beach (latitudes 5° 14' 01' 42.8" N; 5.4" N;° 02' 16.6" N and longitudes 1° 36'37' 12.3" W; 1° 35' 28.9" W) and Glefe-wiboman (latitudes 5° 30' 59.1" N; 5° 31' 3.2" N; 20.2" N and longitudes 0° 17' 21.218' 16.1" W; 0° 16' 57.3" W) have been identified as coastal erosion and flooding hotspots with reports of loss of settlements and livelihood assets. The proximity to some major estuaries and wetlands of these three communities makes them highly susceptible to impacts from sea level rise. (Figure 1.2). These communities were selected based on certain criteria, namely rural areas, estuarine communities, and documented reports of frequent coastal flooding and erosion.

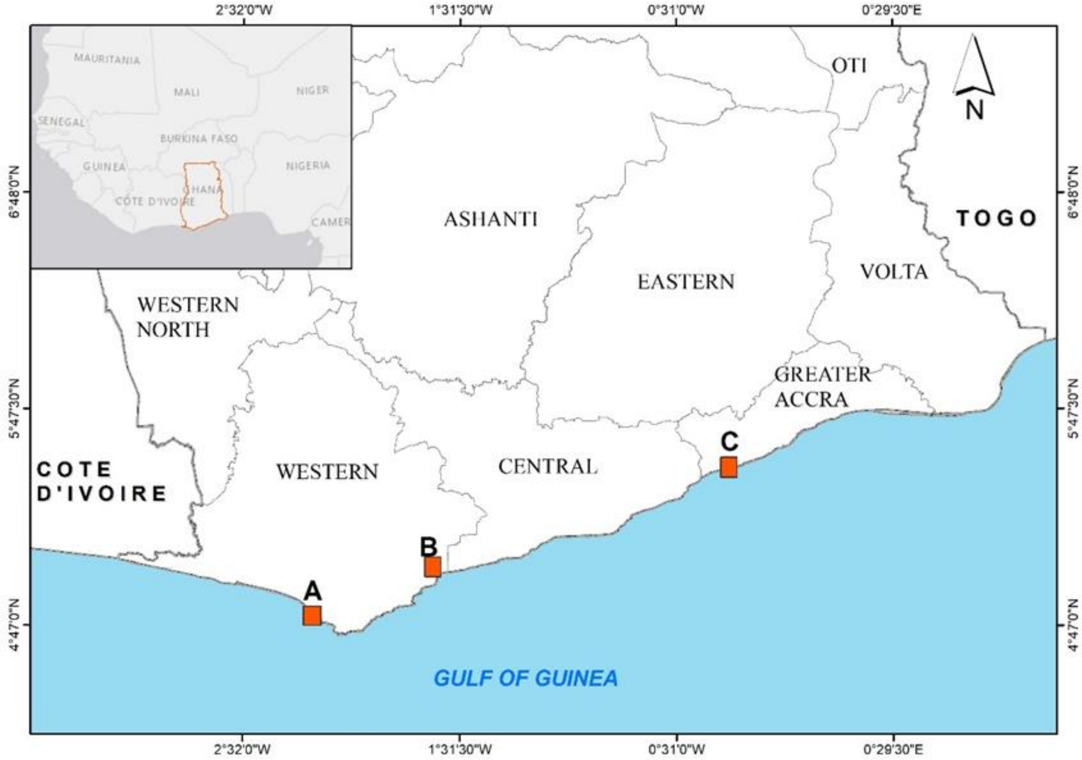

Figure 1.1: Southern Ghana showing the study communities in the regional context. Source: Author, 2023

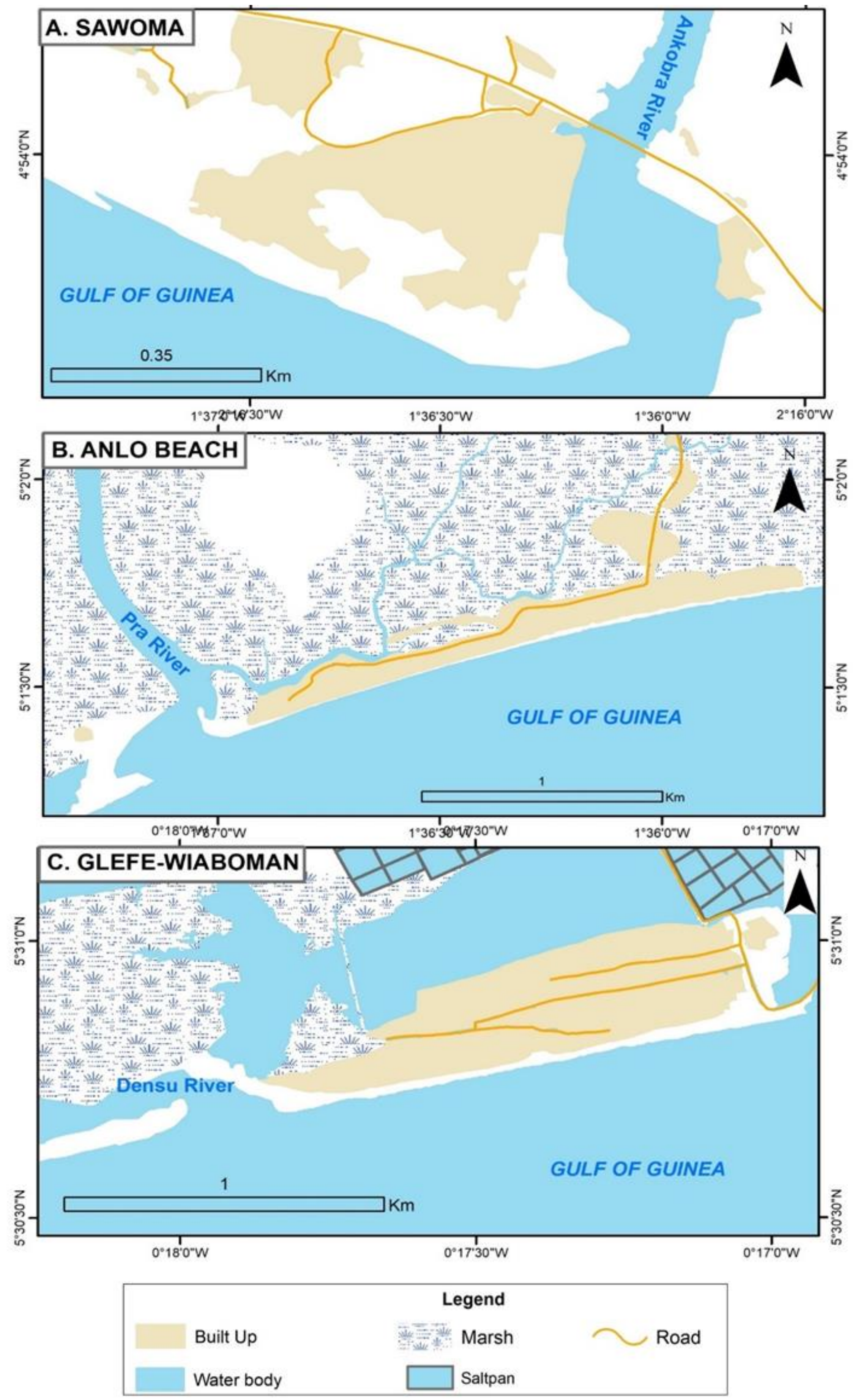

Figure 1.2: Locations of the study communities and their proximity to major rivers.

Source: Author, 2023

1.6.2 Climatic condition of the area

The study communities experience a dry equatorial climate characterized by two distinct peak rainfall periods. The primary rainy season spans from March to June, while the secondary season occurs from September through November. This is followed by a dry period extending from December to March. The coastal savannah region of Ghana maintains consistently high temperatures throughout the year, with an annual mean temperature of 26.5℃. Monthly temperatures range from 24.5℃ in August to 28℃ in March, while daytime temperatures average around 30°C in August. Humidity levels generally range from 65 percent to 95 percent, but they tend to decrease during the warmer months, notably in January when dry northeast harmattan winds prevail (Simmering and Perone, 2013).

1.6.3 Relief and drainage of the area

The study communities lie within the low-lying part of the country with elevation in most parts less than 10 metres above sea level. These low-lying coastal plains, situated at the mouths of the Ankobra, Pra, and Densu rivers, are occasionally prone to flooding and are frequently affected by tidal waves, resulting in the displacement of residents. The study communities do experience periodic flooding due to the interplay of factors including sea level rise, discharge from the adjacent river, rainfall and the storage capacity of the wetland. The topographic settings of the wetlands and drainage characteristics of study areas do not permit the fast evacuation of flood water from the upstream tributaries, this often results in a more muted flood response. Main water sources are pipe-borne water, boreholes and hand-dug wells. However, Sawoma and Anlo beach communities still lag in the supply of potable water. They depend mostly on rainwater, and rivers which are mostly polluted by mining activities upstream. This has rendered these communities highly disadvantaged in terms of access to potable water.

1.6.4 Soil and vegetation of the area

The study communities are characterized by a combination of sandy and clay loamy soils, with a prevalence of alluvial soil. The vegetative landscape consists of coastal strands, mangroves, and freshwater vegetation. Along the estuaries, you can find mangroves from the genera Avicennia, Rhizophora, and Laguncularia lining the banks. In the adjacent marshlands, the predominant vegetation is the saltwater grass Paspalum vaginatum (Poaceae). Unfortunately, the mangrove trees are extensively exploited as the primary source of firewood for cooking and smoking fish in these communities, leading to the degradation of the mangrove forest. These low-lying coastal plains, situated at the mouths of the Ankobra, Pra, and Densu rivers, are occasionally prone to flooding and are frequently affected by tidal waves, resulting in the displacement of residents.

1.6.5 Socio-economic activities of the area

Beach seining fishing and fish mongering serve as the primary sources of livelihood in the study communities, with this occupation being active from mid-July through late April. Typically, fishing is predominantly carried out by men, while women are primarily engaged in fish processing. Following April, subsistence farming becomes the prevailing occupation, lasting for approximately three months during the off-fishing season. The community then reverts to fishing around mid-July or early August for the main fishing season. In certain communities, a minority also partakes in agricultural activities, cultivating crops such as cowpeas, sweet potatoes, maize, okra, tomatoes, peppers, and more. Furthermore, a significant portion of the community's inhabitants are involved in livestock rearing, with cattle, sheep, goats, pigs, and poultry being commonly raised animals within the community.

1.7 Scope of the Study

The scope of the study was delimited to three rural coastal communities in three coastal regions of Ghana. These communities were selected based on recent and past reports of loss of settlements and livelihood assets resulting from sea-level rise. Also, these communities' proximity to major estuaries and a wetland in Ghana makes them suitable for the study.

The SLR scenarios considered in this study were based on the projections AR5 IPCC RCP 8.5 up to 2090. Sea level rise risk modelling was conducted under four higher sea level scenarios – corresponding to the upper limit of projected levels for years 2030, 2050, 2070, and 2090 outlined in IPCC AR5, Additionally, a baseline scenario (2021) representing present-day conditions. Shoreline positions for the years 1975, 2005 and 2021 UAV imagery were considered due to data availability.

The heads of households were selected as respondents for the survey in the study communities. This is because they are the primary earners of various households in the communities and any impacts on their social and economic well-being will significantly affect the other members of their household.

1.8 Limitation of the Study

One of the major limitations of this study was the respondents' inability to quantify their lost properties to the impacts of sea-level rise level which has an effect on the quality of the damage loss assessment. However, the researcher study relied on literature to estimate these losses. Also, the coastal terrain posed a major challenge to the appropriateness of the Ground Control Points (GCP) for the UAV survey since wetlands and beaches cover most areas in these communities. This was overcome by ensuring that the GCPs were well distributed throughout the study area before the flights. The study employed a “bathtub” modelling which did not include other physical processes such as wave actions, sedimentation and storm surges. However, it provides some guidance and raises awareness that SLR is a threat, and more data will be needed. Also, the adoption of global projection future SLR due to limited studies at a local scale may have the tendency to introduce uncertainties in the model.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Conceptual Framework

Following the uncertainties about climate change factors, the study focuses on the assessment impacts and responses to sea-level rise. In order to provide a good understanding risk of rising sea levels in a coastal rural socio-ecological system, the study adapted the IPCC AR5 risk concept (Field and Barros, 2014), Sustainable Livelihood Framework (SLF) (Ashley & Hussein 2000), The Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin-Young, 2018) and Protection Motivation Theory (Rogers, 1983) as the conceptual framework for the study (Figure 2.1). The model captures all the variables used in the study and, therefore, provides a useful framework within which all the objectives set for the study can be achieved. The four frameworks enabled the investigation of future sea-level risk to inform adaptation strategies that integrate community level, policies, and institutional priorities.

As proposed in its AR5 report by the IPCC, the conceptual framework indicates that climatic risk is a function of hazard, exposure, and vulnerability features (Field and Barros, 2014). The risk of sea level rise and its associated impacts are collectively calculated, in combination with exposure, hazard and vulnerability. The hazard, due to any factor, has a number of biogeophysical implications, for instance, increased coastal erosion, coastal floods and wave inundation. Exposure refers to "relevant elements of the socio-ecological system (e.g., people, livelihoods, infrastructure and coastal ecosystems) that could be adversely affected by hazards" (Field and Barros, 2014). Vulnerability looks at "certain attributes of exposed SES-elements that may increase (or decrease) the possible impacts of sea-level rise. It includes two pertinent elements: sensitivity and adaptive capacity" (Field and Barros, 2014). The socio-economic and ecological systems can be defined by their sensitivity and ability to adapt to the increase in sea levels. Variables such as livelihood assets and transforming agents from the sustainable livelihood framework were used to ascertain the socio-economic system's sensitivity and adaptive capacity components. Under the ecological vulnerability assessment, key indicators from the CICES were used to identify and score ecosystem services derived from the selected coastal ecosystems in the study communities. The conceptual framework shows that rural household behaviour can influence a single adaptation strategy (protect, accommodate and managed retreat) that aims to mitigate the sea level rise risk by reducing vulnerability and, in certain cases, exposure. Factors that influence adaptation behaviour and predictor variables that will lead to the implementation of selected adaptation measures These factors were assessed using the Protection Motivation Theory by Rogers (1983). In addition to the traditional components, the extended version of the PMT used in the study includes three additional components that were identified through the literature review (see Figure 2.1). These include risk perception, compositional and contextual factors. Compositional factors were subdivided into biosocial factors (age, and sex) and socio-cultural factors (education, income, employment status, and years of hazard experience). Contextual factors include biophysical attributes (slope, elevation, distance to hazard-prone areas, etc.)

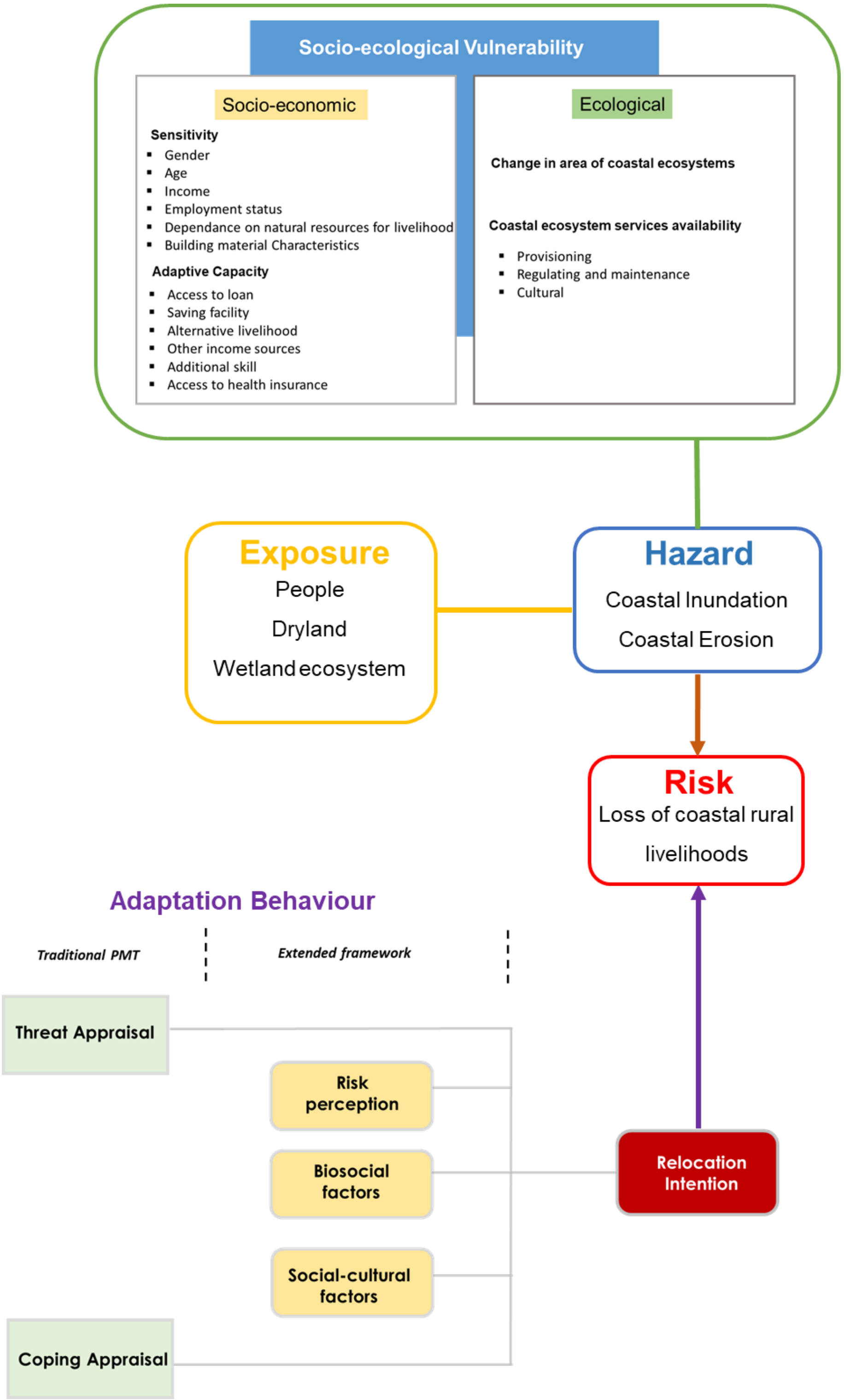

Figure 2.1: Conceptual framework for the study

Source: Adapted from (Field and Barros, (2014); Ashley & Hussein (2000), Haines-Young and Potschin-Young, (2018), Poussin *et al*. (2014) and Rogers 1975).

2.2 Theoretical Framework

The study is based on the IPCC AR5 climate risk assessment concept, Sustainable Livelihood Framework (SLF) and Protection Motivation Theory (PMT). IPCC AR5 climate risk assessment concept explains climate risk as a combination of hazard, exposure and vulnerability. Sustainable Livelihood Framework (SLF) also explains the vulnerability and exposure context of livelihood assets as well as the processes through which capacity is built for sustainable outcomes in response to the hazard. The Common International Classification of Ecosystem Services (CICES) also assesses the consequences of ecosystem change and its implications on human well-being. Protection Motivation Theory (PMT) explains the motivation of individuals to protect themselves from climate hazards. The combination of the three models can help in the understanding of future sea-level rise impacts on rural coastal socio-ecological systems and identify strategies to develop the capacity for building the community's resilience.

2.2.1 IPCC AR5 Climate Risk Assessment Concept

The IPCC AR5 climate risk assessment concept (Figure 2.2) published in 2014, introduced new concepts for identifying and evaluating risks of impacts resulting from climate change. It was adopted from the Disaster Risk Reduction (DRR) community's principles and practices of risk assessment. The concept of climate risk enables the comprehensive incorporation of all components within a socio-ecological system, encompassing climate-related hazards, as well as factors related to social and ecosystem vulnerability and exposure, all of which collectively contribute to the assessment of risks. The framework shows how the interaction between the physical climate systems, exposure and vulnerability produce risk. The risk of impacts from climate change arises from climate-related threats interacting with vulnerability and exposure to humans and natural systems. As Figure 2.2 shows, vulnerability and exposure are primarily the product of social and economic pathways. The main drivers of the components of risk stem from changes in both the climate system and socio-economic processes. Risk is defined as “the potential for consequences where something of value is at stake and where the outcome is uncertain.” (Field and Barros, (2014), p. 40).

Risk in Disaster Risk Assessment (DRA) is considered a probability assessment where risk is represented as the product of the probability of the hazardous event occurring and the impact of the event. However, in the context of climate risk assessment, such a probabilistic approach is always impossible (Zebisch *et al*., 2017). Thus, this study measured sea-level rise risk as a function of hazard, exposure and vulnerability. However, to make the probability and uncertainty clear where possible, particularly in selecting hazard indicators. Hazard is defined as “the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources” (Field and Barros, (2014), p. 40). IPCC also defines exposure as “the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected. Exposure, according to IPCC relates to specific exposed elements (or elements at risk), e.g., people, infrastructure, ecosystems and the degree of exposure can be expressed by absolute numbers, densities or proportions, etc. of the elements at risk (e.g., population density in an area affected by sea-level rise).” (Field and Barros, (2014), p. 40). The concept of vulnerability differs from the way it was used in the IPCC AR4 report. The IPCC AR5 reports define it as the propensity or predisposition to be adversely affected (Field and Barros, (2014), p. 40). It has two important components, namely sensitivity and capacity.

Sensitivity is “determined by those factors that directly affect the consequences of a hazard. It may include physical attributes of a system (e.g., building material of houses, type of soil on agriculture fields), social, economic and cultural attributes (e.g., age structure, income structure)” (Field and Barros, (2014), p. 40). The meaning of sensitivity remains therefore relatively unchanged from the AR4 concept. On the other hand, capacity “refers to societies and communities' ability to prepare for and respond to current and future climate impacts” It comprises of coping capacity (the ability of people, institutions, organizations, and systems, using available skills, values, beliefs, resources, and opportunities, to address, manage, and overcome adverse conditions in the short to medium term) and adaptive capacity (the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences)”.

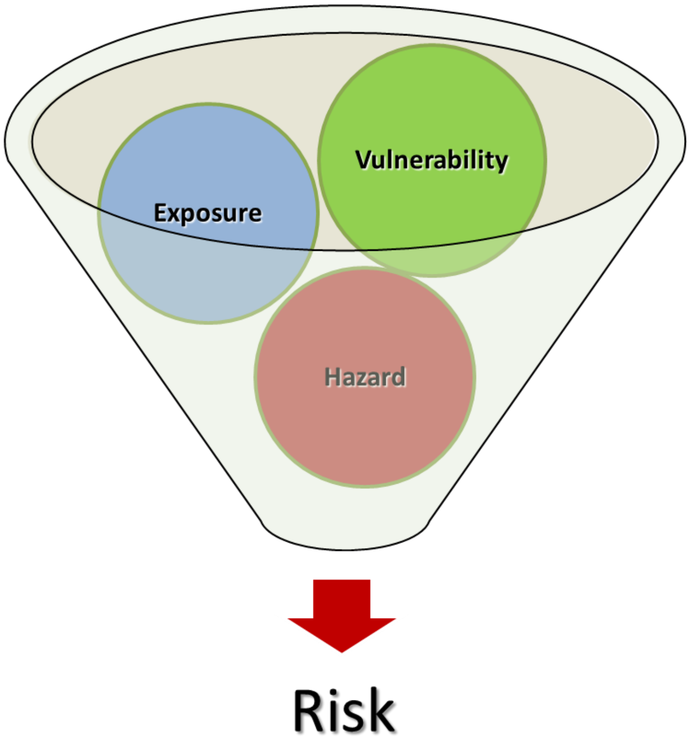

Figure 2.2: Fundamental concept of climate risk
Source: Field and Barros, (2014)

2.2.2 Sustainable livelihood framework

Approaches for sustainable livelihoods are focused on developing thought about reducing poverty, how the poor live their lives and how important systemic and institutional problems are. The Sustainable Livelihood Framework (Figure 2.3) constitutes the basis of different Sustainable Livelihood Approaches and has been adapted by various development agencies such as the Department for International Development (Ashley & Hussein ,2000). The livelihoods framework brings together assets and activities and illustrates the interactions between them. The livelihood framework is an approach that helps us understand human societies' economic strategies. It explores the variety of practices people use to minimize risk, how people collaborate, and how human societies manage investments and resources to ensure well-being in the present and the future (Waddington, 2003).

The framework was used for the study to measure aspects of household socioeconomic vulnerability. From the framework, the coastal rural households' vulnerability context is the shocks, seasonality and trends are changes and occurrences of sea-level rise impacts (Coastal erosion, wave inundation and coastal flooding). These are generally beyond people's control and influence the human, natural, financial, physical, and social capital of the coastal rural households. These changes affecting livelihoods could influence the policies, institutions and processes (adaptation strategies), leading to livelihood strategies by coastal rural households and a livelihood outcome. These outcomes, however, in the long run, influence the assets of the coastal rural households being the human, natural, financial, physical and social capital.

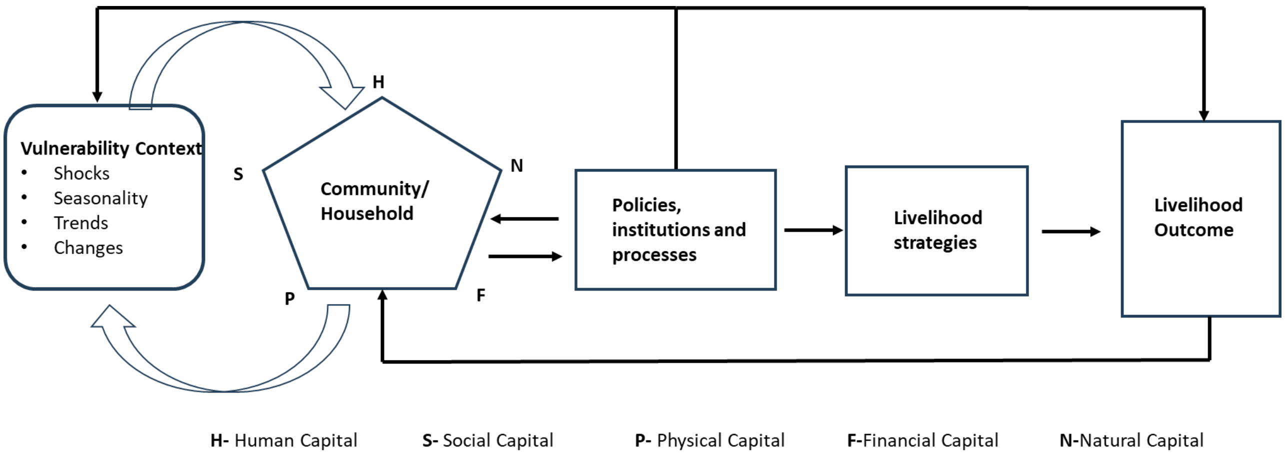

Figure 2.3: Sustainable Livelihood Framework.

Source: Ashley & Hussein (2000)

2.2.3 Common International Classification of Ecosystem Services (CICES)

The Common International Classification of Ecosystem Services (CICES) (Table 2.1) proposed in 2009, provides a classification scheme that facilitates the measurement, accounting for, and assessing ecosystem services. Ecosystem services are contributions that ecosystems make to human well-being mostly through the interactions between biotic and abiotic processes. CICES classification seeks to provide a formal systematic definition of different ecosystem services, proposing a new standard of classification to aid in essay identification, thus creating typologies for describing ecosystem services. Additionally, CICES also help support and analysis any changes in the value of different kinds of goods generated by these identified ecosystem services.

Table 2.1: Description of the Various Categories of Ecosystem Services

Category of Ecosystem Service	Description
Provisioning services	Benefits people can extract from ecosystems, including food, fibre, energy, genetic materials, artificial and natural medicines and fresh water.
Regulating and Maintenance services	This category encompasses all the benefits that moderate the natural environment. It includes pollination, decomposition, water purification, erosion and flood control, and carbon storage.
Cultural services	Cultural ecosystem services encompass the benefits individuals derive from their engagements with various environmental settings, such as forests or recreational areas, as well as the activities, like hiking and biking, they undertake within the spaces

Source: Haines-Young and Potschin, (2018)

2.2.4 Protection motivation theory

The protection motivation theory (PMT) was initially developed to explain how people are motivated to respond to the perceived health threat in a self-protective way. PMT was originally formulated by (Rogers, 1983) based on the work of (Lazarus and Folkman, 1984). It was first used in health threat and safety and later used beyond health-related issues to a more general theory to solve problems like political issues, environmental issues, injury prevention, and other social issues. The PMT suggests that individuals protect themselves based on their perception of the likelihood of an event happening, their perception of how severe the threat is, their belief in the effectiveness of suggested preventive actions, the efficacy of the recommended preventive behaviour, perceived self-efficacy and finally, the response cost (Floyd *et al*., 2000). According to Rogers (1983), individuals weigh various risks and potential benefits, guided by their motivation to protect themselves against hazards like natural disasters, nuclear explosions, and climate change. As a result, PMT assumes that people's decisions to engage in risk-reducing behaviours are based on two cognitive processes; threat appraisal and coping appraisal.

Rogers (1983) stated that threat appraisal and coping appraisal mediate the effects of the components of fear appeals on attitudes by arousing individuals, motivation to protect (Figure 2.4). Threat appraisal is a cognitive process that refers to the perceived expectation of being exposed to a particular threat/risk. It has two key components: assessing the threat's perceived intensity and the likelihood of suffering negative consequences as a result of the threat (vulnerability). Perceived severity of the threat means the referred to the level of gravity of the potential damages that an individual perceives. Perceived vulnerability is the individual’s belief that he is susceptible to an illness that is a potential health threat.

These perceptions of vulnerability, severity, and reward can motivate individuals to perform adaptation actions such as relocation in anticipation of sea-level rise. Coping appraisal evaluates a person's ability to engage in preventive actions against risks and has an impact on their motivation to protect themselves. It consists of two components: self-efficacy, which is a person's belief in their ability to carry out these actions, and response efficacy, which is how effective they perceive these recommended preventive measures to be. Coping strategies also take into account the response cost, which refers to the cost associated with carrying out the suggested behavior (Roger, 1983). The high cost associated with engaging in preventive actions could discourage individuals from participating in recommended behaviours.

Rogers (1983) asserts that coping appraisal arises from the combination of self-efficacy and response efficacy assessment, minus the costs associated with carrying out the suggested preventive action. PMT has been used by many researchers in natural hazards, disasters and pro-environmental behaviours. For instance, Reynaud *et al*., (2013) carried out research in Vietnam using the Protection Motivation Theory as a conceptual framework to explore the factors influencing household flood preparedness measures and their perception of risk, utilizing information gathered from a survey conducted at the household level. Also, in 2013, Koerth *et al*., (2013) conducted a study in Greece that focused on examining how households in coastal areas were adapting to the threat of flooding. They utilized the Protection Motivation Theory (PMT) to investigate current adaptation practices among coastal households, identify factors impacting their precautionary actions, and evaluate their intentions regarding future adaptation.

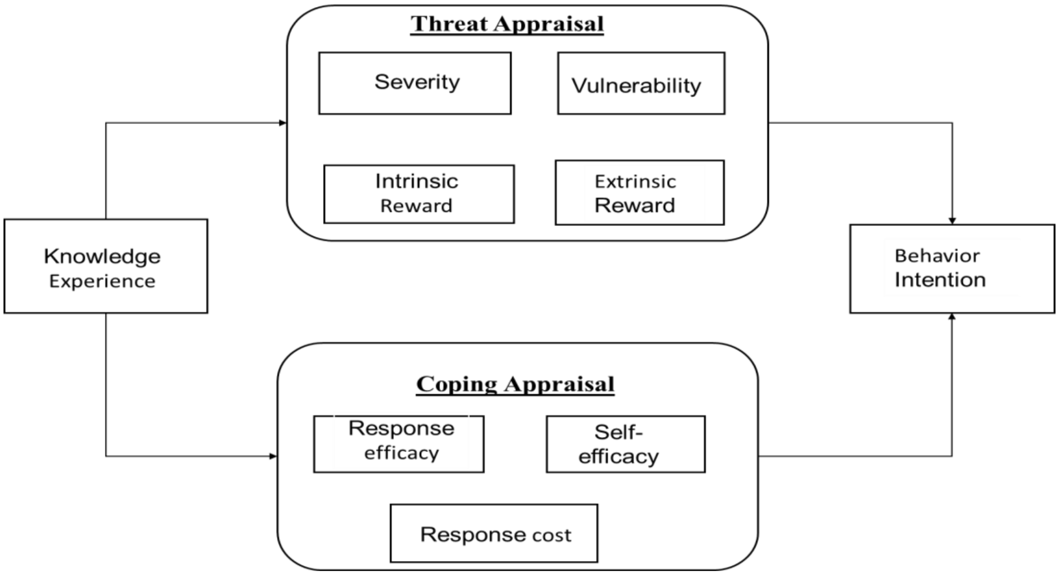

Figure 2.4: Protection Motivation Theory
Source: Rogers, (1983)

2.3 Review of Related Studies

2.3.1 Global overview of sea level rise risk

The general overview of sea-level rise is not uniform across the globe. Rising exposure, risk and impact defer globally (Field and Barros, 2014). The least developed countries and, most importantly, rural areas represent 11 percent of the global population exposed to rising sea levels leading to related flood hazards but account for 53 percent of casualties. On the other hand, developed countries represent 15 percent of human exposure to the impacts of sea level rise but account for only 1.8 percent of all casualties (Jongman *et al*., 2012). The high losses in developing countries and most significantly rural areas are mainly driven by the low capacity of these countries and communities to adapt to the flood hazard resulting from sea-level rise; mainly due to poor or non-existent early warning systems and emergency response measures to these areas (Addo and Lamptey, 2012; The World Bank, 2017). The risk of sea-level rise in rural communities is expected to worsen as the sea level is expected to rise by 1m or more by 2100 and is likely to result in greater exposure to coastal flooding (Neumann *et al*., 2015).

2.3.2 Impacts of sea level rise on socio-ecological systems

Due to numerous complex interacting processes such as population growth and urbanization have caused significant changes in coastal settlement patterns in the 20th century and have further increased the exposure and vulnerability of these settlements to climate change and sea-level rise (Neumann *et al*., 2015). This has contributed to an increased number of people living in the low-lying coastal areas as well as infrastructure and properties. According to UN-Habitat, (2009), there are about 3,351 cities located in low-lying coastal zones and 13 out of 20 megacities worldwide are also located in low-lying coastal areas. Low-lying coastal areas are typically highly populated and developed areas, yet these areas are at risk of the adverse impacts of climate change and sea-level rise. Several studies have projected an increasing exposure of the coastal zone to the impacts of sea-level rise particularly in Africa and Asia. Sea level rise contributes to the intensity and frequency of some coastal hazards. A study by Nicholls and Klein, (2005), based on data from the year 2000, suggested that in the event of a one-meter rise in sea level, 131 million of the world's population will likely be exposed to inundation and 2,463,000 km^2 of land affected.

Sea level rise impacts affect farmers and their links to associated industries. The presence of saltwater in groundwater can have a substantial impact on crop yields and product quality (Moore and Joye, 2021). The impact of a rise in sea level on water resources will likely reduce freshwater suitability and that is salinity intrusion in both water and soil salinity along the coast. SLR can also cause severe damage to productive agricultural land

and crops however, floods, in some local communities see coastal inundation as a positive phenomenon as they distribute fertile silt across the fields. Temperature increases and saline incursion always have an impact on aquaculture. Salinity intrusion might seriously harm the aquatic ecosystems in the area by promoting eutrophication and the establishment of algal blooms, which could be harmful to sensitive species (Nwankwegu *et al*., 2019).

Numerous research have examined the effect of sea level rise on beaches, living organisms (plants and coastal species), and coastal surroundings. Sea level rise impact can be positive or negative. Research by (Griggs and Reguero, 2021), discovered that rising waters reduced the temperature near coral reefs, putting less stress on them and possibly providing them with a lifeline. Also, there has been a decrease in the mangrove ecosystem over the past decades, and other remaining habitats are suffering from these unsustainable practices. Despite the numerous benefits that are derived from mangroves such as coastal safeguard, habitat for wildlife and fishes, carbon sequestration, deposit, and pollution filtering (Ellison, 2015). The ability of organisms to keep up with the vertical rise of the water is largely what determines how sea level affects things like corals and mangroves (Wong *et al*., 2014). Similarly, Wong *et al*., (2014) explain how due to their sensitivity to these changes, plants such as mangroves and coastal wetlands may leak part of their stored chemicals, increasing the number of greenhouse gases in the atmosphere. Mangroves pose an exposure variable that is independent of climate change, whereas the rise in sea level and lower precipitation are exposure mechanisms directly related to climate change, which may result in heightened sensitivity when stress levels rise (Ellison, 2015). Again, with the mangrove ecosystems, in a situation where the net vertical accretion cannot match up with the relative sea level rise then the adaptation measures will be through inland migration, they are dependent on the availability of suitable topography and area. (Ellison, 2015).

Globally, vegetative habitats and coastal wetlands have declined with a rise of rising in sea level. For example, in North America, the coastal vegetation is reacting to the rise in sea level and climate change through variations in composition and structure (Bhattachan, *et al.*, 2018). SLR will likely harm the mangrove ecosystem. It is very important to note how the mangrove ecosystem serves as a habitat for many species. Mangroves provide a serene breeding environment for most of the world's crabs, fishes, shrimp, shellfish, and other organisms. It also serves as a habitat for migratory birds. SLR impacts on mangrove species will harm the ecological activities that the ecosystem provides. Also, it is anticipated that ecological reactions to the rise in sea level and saltwater intrusion will have a substantial influence on the range as well as the abundance of many wildlife species (Bhattachan *et al.*, 2018).

2.3.3 Responses to sea level rise risk

Coping with Sea-Level Rise (SLR) as a result of climate change is one of the biggest societal challenges of this century (Lebbe *et al.*, 2021). Sea-level rise adaptation strategies require regulations, plans, and measures that reduce risks and build resilience. The 5th Assessment Report (AR5) by the International Panel on Climate Change (IPCC) introduced a three-part strategy involving retreat (moving from coastal areas), protect (utilizing both structure and no-structural approaches), and accommodation (adjusting human activities and infrastructure). Abel *et al.*, (2011) stated that among the three basic categories of sea-level rise SLR risk reduction approaches (protection, accommodation, and retreat) reviewed in the literature, managed retreat will likely be the only long-term adaptation approach in many flood-prone areas.

Managed retreat means rethinking coastal life and accepting that certain coastal infrastructures, neighbourhoods, or even cities will have to be completely relocated (Lebbe *et al*., 2021). This adaptation response can be carried out at different scales and with varying degrees of complexity. It may involve the relocation of a few vulnerable homes, a community, or a large city. It can be even more complicated when it involves relocating inhabitants of an island to a new country. An important issue with relocation is the cooperation of the affected population, which is sometimes difficult. Relocation of low-lying areas is anticipated worldwide, especially in areas where sea-level rise causes flooding and coastal erosion, reduces arable land, depletes groundwater supplies, destroys infrastructure, and endangers human lives and well-being (Hino *et al*., 2017; Wong *et al*., 2014). Some countries such as Fiji, Mozambique and the Solomon Islands have developed and included planned relocation strategies as part of National Adaptation Programmes of Action (NAPAs) in their various countries (Mcadam and Ferris, 2015; Warner *et al*., 2014).

Protection (Coastal defence) involves fortifying the shoreline with hard constructions like seawalls, rock revetments, ripraps, or levees in order to safeguard coastal communities, valuable infrastructure, and ecologically significant places (Watson *et al*., 2015). Hard coastal protection measures are used all around the world, yet it is difficult to estimate how many people are affected. Currently, hard structures (including drainage) provide protection for at least 20 million people who reside below typical high tides around the world. In Ghana, for instance, these hard measures cost the government approximately US$60-90 million for 10-25 km of tranches (The World Bank, 2017). Protection adaptation strategy has potential longevity but is costly to build and maintain (Tol *et al*., 2005) and it can have adverse impacts, such as changing sediment dynamics in other areas (Jayson-Quashigah *et al*., 2019). Beach replenishment is one method for rehabilitating beaches that can significantly improve their tourist appeal (Houston, 2008). On the low relief, often barrier island-backed sandy shorelines of the U.S. Atlantic and Gulf coasts, beach nourishment has been practiced for decades. Since 1923, more than 1.35 billion m^3 of sand have been delivered to 475 American communities at a real cost of US$10.8 billion in 2020 (Reguero *et al*., 2021). The Netherlands' Spanjaards Duin is one of the earliest examples of artificial dunes being built to mimic natural dune ecosystems as a means of making up for port expansion. This initiative harnesses organic processes to shape the dunes by ensuring the right grain size for Aeolian dynamics and preserving groundwater levels to support vegetation. The U.S. Gulf Coast's experiences also show that protection in low-energy conditions works well (Bridges, 2018).

Accommodation consists of alterations and modifications in existing structures and human behaviour, which allow land use to be sustained (Koerth *et al*., 2014; Wong *et al*., 2014) As a result, accommodating might be defined as "living with hazards". It refers to both community-based strategies like informal money pooling and collective workforce organization as well as top-down strategies like altering land use and building types. A study by (Bott and Braun, 2019) in the Semarang Bay region in northern Java revealed that communities' ability to self-organize and participate actively in their settings is crucial for surviving in unstable circumstances. One of the most important non-structural community efforts to lower flood hazards is through this response. In various regions of Ghana, local governments and communities have already implemented or are preparing to implement each of these practices. To adapt to a shifting shoreline and lessen the negative effects of sea level rise, however, some of the cases covered by this study are pioneering.

It is crucial to plan for sea level rise if coastal populations and ecosystems are to remain secure. Communities must be prepared throughout time and with a variety of strategies to deal with the effects of rising tides now and in the future. It is also important to have a platform for discussion that incorporates all stakeholders' needs and concerns throughout the planning, implementation, and maintenance stages. This is important because resilient communities are essential to combating the adverse effects of sea level rise. Providing the necessary forum to discuss, plan, and implement the appropriate planning approach is essential to crafting a planning strategy that is based on the community's needs. Additionally, it's critical to establish a forum for conversation that takes into account the demands and worries of each stakeholder during the stages of planning, execution, and upkeep. This is crucial because fighting the negative effects of sea level rise requires resilient communities. In order to develop a planning strategy that is based on the needs of the community, it is crucial to provide the necessary platform for discussing, planning, and implementing the proper planning approach.

2.3.4 Concept of risk, exposure and vulnerability

There are several definitions and frameworks that explain the concept of risk and, as a result, the concept has evolved over time. The multiple definitions of the concept of risk are due to its application to specific decision-maker needs. Wisner *et al*., (2014) argued that risk has shifted from an early stage of matching it to hazards to a period where risk is described as hazard and vulnerability and then finally to hazard, vulnerability and coping capacity. Morgan *et al*. (1990) as cited in Brooks, (2003) defined risk as an "exposure to a chance injury or loss. In 1992, the United Nations Department of Humanitarian Affairs (UNDHA) provided a definition for the term "risk" as the anticipated consequences, including loss of life, injuries, property damage, and disruptions to economic activity, resulting from a specific hazard within a specified area and timeframe.

Mathematically, risk is calculated as the product of hazard and vulnerability (United Nations Department of Humanitarian Affairs, 1992). According to Thywissen, (2006), risk is defined as “a function of the probability of the hazard of exposure to the hazard, and the vulnerability of receptors to the hazard.” The United Nations International Strategy for Disaster Reduction (UNISDR) characterizes disaster risk as the prospective losses resulting from disasters, encompassing factors like human lives, well-being, economic stability, possessions, and essential services, which may transpire within a specified timeframe for a specific community or society (UNISDR, 2009). As defined by several scholars and organizations, risk is considered a probability assessment where risk is represented as the product of the probability of the hazardous event occurring and its impact. However, in the context of climate risk assessment, such a probabilistic approach is always impossible (Zebisch *et al.*, 2017). Recent literature emphasized that risk arising from climate change is externally induced or a change in the climate system, resulting from complex interactions between communities, ecosystems, and hazards (Birkmann and Birkmann, 2011; Field, 2012). Therefore, the latest IPCC assessment report (AR5), published in 2014, and introduced the concept of climate risk that replaced the AR4 approach to vulnerability to climate change. The IPCC AR5 assessment report defines risk as “the potential for consequences where something of value is at stake and where the outcome is uncertain” (IPCC 2014, p. 40). From the report, risk results from the interaction of vulnerability, exposure, and hazard but emphasizes the significant contribution of the system on these components. Climate change is not a risk per se; instead, climate change and associated hazards interact with changing vulnerability and the system's exposure, thereby determining the change in risk levels. The identification of key vulnerabilities enables the assessment of key risks in conjunction with climate change risk information. Thus, the IPCC AR5 approach to risk was used as the basis for measuring sea level rise risk in the selected coastal rural areas.

Although the term 'vulnerability' has gained popularity in the past few years, research into its various aspects has largely focused on understanding theories and descriptions (Adger, 2006; Alwang *et al*., 2001; Bohle, 2001; Gallopin, 2007). The concept of vulnerability evolved as people became more conscious of the relevance of society's structure and people's skills to tolerate and cope with the effects of disasters. Vulnerability has typically been defined in two ways: geographically, as being positioned in a location that exposes one to environmental risks, and by context, as "a state of increased exposure or sensitivity to environmental hazards as a result of socio-political limitation" according to O'Brien *et al*., (2004). According to Eisenhauer, (2014), vulnerability can be described as "a condition of health and stability," but it varies among diverse communities living in distinct environmental circumstances and dealing with intricate interplays of social norms, political structures, resource availability, technological advancements, and disparities. Cutter, (1996) recognized three themes in vulnerability research. The first is vulnerability as risk/hazard exposure and determines the spatial parameters of biological and physical or technical threats, the population affected, and the intensity of possible loss. The second is a social constructionist perspective, which emphasizes resilience as well as the historic, cultural, and economic processes that shape an individual’s capacity to deal with disasters. The third focus is place vulnerability- defined as a biophysical danger as well as a social response that is rooted in a specific location. Class, ethnicity, and immigration status have all been demonstrated to have an impact on people's capacity to deal with environmental risks (Peacock *et al*., 2012). After Hurricane Katrina in 2005, it was discovered that socio-economic conditions including age, income and race determined which individuals resided in high-risk locations and which individuals had the ability to evacuate, resulting in varied levels of vulnerability and outcomes (survival and recovery) (Finch *et al*., 2010). Thus, researching societies experiencing the immediate effects of sea level rise can reveal the characteristics of vulnerability, as well as the shortcomings, reactions, and implications of climate change adaptation.

In essence, vulnerability considers the intricacy of systems under evaluation, created by a large number of driving elements as well as multiple interconnections and responses among the various sections of the system. As a result, vulnerability assessments in recent years do not focus on individual aspects, but instead on the entire coupled socio-ecological system, including all of its interconnections and responses (Adger, 2006; Gallopin, 2007). Thus, there is a widespread inclination to divide vulnerability into two components. Bohle, (2001) combined these two elements into a framework, defining "exposure" as the external face of vulnerability and "coping" as the interior face. Unlike socio-economic fragility, Cardona, (2003) refers to it as "physical fragility" (exposure) and Adger *et al*. (2004) use the terms “biophysical” and “social vulnerability”. Another widely acknowledged feature of vulnerability is its complexity, which stems from its multidimensionality, changing nature, and effects from many scales (Vogel and Karen O’Brien, 2004). The idea of vulnerability expanded on the traditional impact-focused approach by shifting the attention to the individual. Putting the human at the heart of the research. Hence, different sorts of socio-economic, political, cultural, institutional, and ecological elements, and the interconnections and feedback between them, must be considered in any analysis to include all components that affect the susceptibility of coupled systems (Few, 2003; Thywissen, 2006).

On the other hand, simple approaches that concentrate on a single area of vulnerability have their own strengths, as they keep the study uncomplicated and could deliver speedy results with relatively little effort. Yet, because these methods do not take into account all relevant interconnections and feedback, they are unable to give a thorough vulnerability evaluation of coupled systems. A suitable technique to recognize the complexity of vulnerability and find underlying weaknesses that go beyond the hazard's immediate effects has been identified as analyzing signs quantitatively using the categories provided by an integrated vulnerability framework. Vulnerability assessments are a forward-looking approach that measures the possible implications of hazards that may harm the system in the future. Attempts to build "integrative" techniques that integrate the biophysical and social elements of disaster vulnerability have been made during the last two decades, and in spite of criticisms, this method remains very prominent (Rothman *et al*., 1997). The integrative technique has been employed in particular in analyzing vulnerability, assisted by advancements in the potential to map massive datasets. Cutter, (1996) created a hazards of place model that integrates biophysical and social characteristics to determine a community's vulnerability. The model involved indicators of physical hazard risk, which includes the probability of disaster and demography. These indicators were used to produce an index of "overall hazard vulnerability" that changed over a local area, using GIS. A version of the model was released for Social Vulnerability Index for sea level rise.

However, the two-dimensional conceptual model has been criticized for being simplistic and failing to consider the root causes of antecedent social vulnerability, larger contexts, and post-disaster impact and recovery all of which are important factors to consider when the model is designed for measuring and eventually lowering emissions and reducing vulnerability (Eisenhauer, 2014). The integrated approach is often accompanied by the multi-scale characteristics of potential stressors and how they affect the system (Gallopin, 2007). In recent decades, efforts to study the impacts of hazards and related vulnerabilities have increased in response to observed and expected increases in risks and negative impacts. Natural risks have been acknowledged as not disasters in and of themselves, but only become such when they are combined with other factors (Kaplan, 2011). This has resulted in a shift in emphasis from the hazard itself and practical solutions to mitigate the effects of hazards to the interaction between the damaging event and a community’s infrastructure, economy, and environment (Birkmann, 2006). Various disciplines and sectors address the notion of vulnerability differently, including academics, disaster management organizations, the community fighting climate change, and development organizations. Depending on the approach taken, this results in a variety of definitions for vulnerability and associated concepts such as exposure, and risk.

Aside from this wide viewpoint on vulnerability, the inclusion of many scales, and the coupled system as an element of analysis, the Turner framework (which is regularly adapted by researchers) has a number of other features that are particularly important. It is acknowledged that within a linked system, there is not just one vulnerability, but that different vulnerabilities exist in different elements and subsystems that link the coupled system Connections between hazards demonstrate that hazards are a collection of varied disruptions and pressures that arise from several levels of influence, is another facet of relevance. They could also be influenced by the system, which is why they are classified as a hazard. The concept highlights the risks' complexity and nonlinearity, which arise from various interactions of interconnected factors at different scales. However, criticisms of the integrated models mentioned its failure to pinpoint the core reasons for vulnerability. O'Brien *et al.*, (2004), identified two perspectives on vulnerability that are diametrically opposed: a "scientific framework" in which vulnerability is viewed as a result or endpoint of adaptation, as well as a "human" vulnerability as an existing incapacity to cope with exterior forces or changes, as defined by security framework. The contextual approach indicates a concern for individual and group vulnerability, more than a standpoint of systems theory (Berkes, 2007), which ignores the varying impacts of disasters on individuals and communities in different parts of the system.

2.3.5 Risk experience, perception, and adaptive behaviour nexus

Literature has shown that several factors influence climate change adaptation and mitigation strategies. These include risk perception, hazard experience, distance to hazards, type of settlement and socio-demographic factors. An increasing body of literature examines individual responses to sea-level rise impacts such as flooding, storm surge, erosion and other related risks, with the majority focusing on determining the relationship between these factors and adaptation efforts. For example, several studies have shown that risk perception positively influences individual adaptation behaviour. A person with a high-risk perception is more likely to undertake adaptation measures (Poussin *et al.*, 2014;

Song and Peng, 2017; Wouter Botzen and Van Den Bergh, 2012; Zaalberg *et al*., 2009). However, Zheng and Dallimer, (2016), in their study on the factors that motivate rural households to adapt to climate change, established that adaptation appraisal rather than risk perception is a better predictor of climate change adaptation. In comparison to risk perception, the relationship between socio-demographic variables and protective behaviour adoption is significantly less clear. Notwithstanding, several studies have identified various socio-demographic factors related to climate change adaptation efforts such as educational level (Bryan *et al*., 2009), income (Poussin *et al*., 2014), age (Bryan *et al*., 2009; Song and Peng, 2017), gender (Silva *et al*., 2014) and location in terms of rural or urban setting (Mwinkom *et al*., 2021). Hazard experience is also considered to have a significant influence on risk recognition and appears to be a significant component in individual adaptation behaviour (Weinstein, 1989). For instance, Individual views of flooding resilience were explored in four communities in Birmingham and London by Soetanto *et al*., (2017), who found that people's social responsibility for adaptation measures was influenced by their experience with floods as well as other demographic factors. Ling *et al*., (2015) and Frondel *et al*., (2017) confirmed that hazard experience was positively associated with adaptation efforts in their respective studies. On the other hand, Lawrence *et al*. (2014) maintain that experiencing flood hazards did not motivate citizens to take more proactive adaptation measures. The capacity of human systems to adapt to a changing climate is linked to characteristics of the physical environment. Physical factors such as a lack of high elevation to relocate, for example, can limit relocation (Clark *et al*., 2011). Also, proximity to hazards can also limit adaptation efforts. Studies have been conducted to assess the relationship between proximity to hazards and adaptation efforts. However, their findings have been inconsistent; although some researchers have discovered a positive link, others have not. Bubeck *et al*., (2013) discovered in their study about analysing risk perception and precautionary behaviour, that the distance to a river or waterbody had only a minor impact on people's current mitigation efforts whiles Kellens *et al*., (2011) came out with contradictory findings.

2.3.6 Sea level rise modelling approaches

Various models have been developed to address the coastal impacts caused by Sea Level Rise (SLR). These models have the capability to predict changes in environmental processes due to sea level fluctuations, as well as evaluate the outcomes of different strategies for managing long-term ecosystem behavior (Costanza, 1997; FitzGerald *et al*., 2008). They can be applied at local, regional, or global levels. Examples of such models include the CoastCLIM Sea-Level Simulator, the Coastal Storm Modeling System (CoSMos), the Inundation Frequency Analysis Program by the National Oceanic and Atmospheric Administration (NOAA), and the Sea Level Affecting Marshes Model (SLAMM).

2.3.6.1 CoastCLIM sea-level simulator

According to Doyle *et al*., (2015), CoastCLIM is a database tool designed to forecast sea-level curvatures in coastal areas across the globe. It employs a comprehensive global database of regional cell grids to generate localized rates of sea-level change. These estimates are derived from downscaled projections of future sea-level rise and Carbon dioxide emissions, utilizing Global Climate Model data and various climate change scenarios. The tool encompasses six emission scenarios, enabling analysis of temperature fluctuations, impacts of ice melt, and CO2 concentrations, all based on predictions provided by the IPCC. CoastCLIM offers a user-friendly interface that allows users to select their area of interest within a global context.

2.3.6.2 The national oceanic and atmospheric administration (NOAA) inundation frequency analysis program

The NOAA Inundation Frequency Analysis Program proves to be an invaluable resource for coastal planners. By utilizing observed 6-minute water-level recordings from tidal gauges as input data, this application establishes connections between recorded high-water tide periods and their corresponding heights within a specified timeframe (Doyle *et al*., 2015). Through this process, the application generates an Excel spreadsheet that computes the elevations and durations of inundation for each listed high tide, relative to the user-provided reference datum or maximum altitude above it, as well as any threshold elevations. Additionally, the program produces graphs, histograms, and statistical summaries, providing insights into the impact of various sea level rise scenarios.

2.3.6.3 Coastal Storm Modeling System (CoSMos)

The United States Geological Survey developed the Coastal Storm Modeling System (CoSMoS) to forecast coastal flooding, shoreline alteration, and the effects of rising sea levels and climate change-induced coastal storms. CoSMoS aids federal and state climate change advisories, local planning, and disaster response teams in understanding the vulnerability of coastal areas. According to Doyle *et al*., (2015), the software generates comprehensive forecasts of storm-induced coastal floods, erosion, and cliff failures over large geographic scales. CoSMoS provides hindcast studies, operational applications, and future climate scenarios to emergency responders and coastal planners, enabling them to improve public safety, mitigate physical damage, and effectively allocate resources in complex coastal settings. For example, the California Department of Transportation (Caltrans) District 4 utilized CoSMoS/OCOF data on flood extent, water surface elevation, and maximum wave height to assess the vulnerability of the road network in the San Francisco Bay Zone.

2.3.6.4 Sea Level Affecting Marshes Model (SLAMM)

The Sea Level Affecting Marshes Model (SLAMM) simulates the conversion of coastal land use and the alteration of shorelines over long-term scenarios of sea level rise (SLR). This map-based simulation software employs discrete time steps ranging from five to twenty-five years to assess the impact of various SLR scenarios on the coastal landscape. The different versions of the model primarily involve updates in data sources, software, and spatial resolution for specific site applications, rather than significant changes in design or functionality. The spatial resolution of input and output data ranges from 10m to 500m, while SLR is modeled as a static increase in predicted eustatic rise in sea level corresponding to the model's time step duration (Clough, 2010). For each time step (year), the model modifies the elevation of the study area cell by cell using inputs such as the Digital Elevation Model, land cover data, site environmental parameters (erosion and accretion rates, subsidence, and tidal range), and predicted sea level rise based on future climate change scenarios. The model simplifies the classification of cell conditions (eroded or inundated) based on the cell's context and highest fetch. Clough, *et al*., (2016) explained that the software employs a decision tree approach to determine wetland and other land cover types by adjusting the elevation of each cell based on the correlation between minimum elevation and various land cover types within the cell.

In this study, the Digital Elevation Model for the modeling communities was obtained from an Unmanned Aerial Vehicle Digital Terrain Model generated through Structure-from-Motion techniques. Furthermore, land cover data for each study community were acquired from remote sensing Sentinel-2 satellites in 2021. These data were classified and transformed into SLAMM wetland categories. The modeling procedure did not include dikes since there were none present in the study communities. Additionally, the projected sea level rise under the climate change scenario from the Intergovernmental Panel on Climate Change was utilized as the reference for sea level rise in this model.

SLAMM is an open-source software that offers user-friendly features in comparison to other models reviewed in this study. It provides detailed information on a local scale, making it particularly suitable for coastal rural communities. However, due to the datasets it employs, SLAMM is not well-suited for global-scale analysis or supporting international negotiations. Instead, it is more applicable for national governments in their efforts related to adaptation, mitigation, and policy development.

2.4 Examples from Other Regions/Countries

Since early 2000, several studies have been conducted globally to assess rural coastal vulnerability to sea-level rise impacts. For instance, Appeaning-Addo *et al*., (2020) used remote sensing techniques to determine sea-level rise impacts in the Fuveme community in Ghana. The study revealed that rural livelihoods and properties had been endangered by the detrimental effects of rising sea levels. Furthermore, it was discovered that over a span of 12 years (2005-2017), more than 77 structures were destroyed by coastal erosion and flooding, leading to the displacement of over 300 residents. Using a socio-ecological system framework, Bhattachan *et al*., (2018) conducted an investigation into the impacts of sea level rise on the Albemarle-Pamlico Peninsula, a coastal region in eastern North Carolina known for its rural and low-lying characteristics. The findings of the study indicated that approximately 42 percent of the study area is vulnerable to flooding, and if the sea level were to rise by 100 cm, property losses could amount to a staggering 14 billion dollars. Using both qualitative and quantitative data, Shameem *et al*., (2014) explored the mechanism by which significant stresses and hazards shape the vulnerability of rural livelihoods in complex social/ecological environments in the southwest coastal area of Bangladesh. The study concluded that increasing sea level rise impacts (salinity intrusion, storm surge and land-use change) directly or indirectly affect access to livelihood assets at the household level, which undermines social well-being by seriously impacting food and water security. Drawing from these studies, an adequate comprehension of the risk posed by sea-level rise can serve as a foundation for enhancing or developing policies and adaptation strategies specifically tailored to rural coastal communities, which have largely been overlooked in climate change assessments. However, most of these studies focused on a single sea-level rise impact and did not assess its associated adaptation strategy to help improve policy in the area of study. Also, most of the studies used medium-resolution satellite imagery to detect changes in the rural coastal regions (Dereli and Tercan, 2020; Konko *et al*., 2018; Yasir *et al*., 2020). However, these images are affected by cloud cover, revisit time, pixel resolution and operation cost. Additionally, the acquisition of very high-resolution satellite images capable of detecting subtle changes is a costly process that requires pre-ordering and programming, which is also similar to airborne photogrammetry (Díaz-Delgado *et al*., 2018).

2.5 Overview and Key Issues of the Study

2.5.1 Overview of global and regional sea level measurements

Over the last century, sea-level changes have been obtained from tide gauge measurements located at various coastlines worldwide. According to Cazenave and Cozannet, (2014), about ten (10) percent of tide gauge measurements can be used due to data gaps and the small number of available tide gauges. Vertical land movements also impact tide gauge data as they measure sea-level relative to the ground. Thus, in studying the climate-related component of sea-level rise, especially in areas where there are strong ground movements resulting from a natural cause or human activities, vertical land movements must be deleted from the measurements. Various analytical methods have been developed to give accurate historical time series based on measurements of the tide. For instance, Jevrejeva *et al*., (2010) used over sixty (60) years of tidal gauge measurement from areas with stable tectonic activities and corrected the data for Glacial Isostatic Adjustment (GIA). The study predicted a 0.6-1.6m increase in Global Mean Sea-level (GMSL) based on a mathematical model driven by expected natural and anthropogenic forcing.

On the other hand, Church *et al*., (2004) used reconstruction methods to fix over 50-year tide gauge records across several regions. The reconstruction was an effort to restrict existing large-scale estimates of sea-level rise, recognize any patterns of sea-level rise trends, and assess any sea-level variation over the period. The study estimated that the global average sea level rise is 1.8 to 0.3 mm per year. Dangendorf *et al*., (2017) argued that tide gauge measurements give a poor representation of the global ocean and they are based in the northern hemisphere, particularly at the beginning of the 20th century. As a result, their study presented a reconstruction method that uses an area-weighting technique that also that into account vertical land motion, ice melting and terrestrial, freshwater storage. The technique estimated 1.1 ± 0.3 mm per year before 1990 falls below previous estimates, and an estimate of 3.1 ± 1.4 mm per year from 1993 to 2012 was inconsistent with other 20th-century estimates.

Besides tide gauge measurements, sea level is also measured accurately by altimeter satellites. Examples of such satellite instruments include Topex/Poseidon (1992–2006), Jason-1 (2001–2013) and Jason-2 (2008– date) developed jointly by the United States and France. Others developed by the Europe Space Agency (ESA) also include Envisat (2002-2011) and Cryosat (2010-date). Satellite altimetry measures absolute fluctuations in sea levels in a geocentric reference system compared with tide gauges that provide sea-level measurements relative to the earth. Satellite altimetry measures sea level by basically measuring the distance from the satellite to the sea surface and the satellite-to-surface round-trip time of transmitted microwave radiation. However, these measurements sometimes interfere with electromagnetic scattering and atmosphere elements such as dust and water vapour. Church and White (2011) reported an increase in global mean sea level from satellite altimetry (1993-2009) and tidal gauge measurements (1880-200).

The approximate rate of increase after correction of glacial isostatic adjustment was 2 ± 0.4 mm per year from the satellite data and 2.8 ± 0.8 mm per year from the tidal gauge measurements. Watson *et al.*, (2015) also combined reprocessed ERS-2/Envisat altimetry data with a network of tidal gauges with GPS-based vertical land motion installed to estimate global mean rate sea-level. The results indicate an acceleration in sea-level rise compared to recent projections by Church *et al.*, (2013) and Stocker *et al.*, (2013). Dieng *et al.*, (2017) revisited the GMSL budget using six different altimetry-based GMSL data

(TOPEX/Poseidon, Jason-1 and Jason-2, and Envisat 1/2) CSIRO from January 1993 to December 2015. The study estimated a new GMSL rate of approximately 3.0 mm per year with an increase of 0.8 mm per year between 2004 and 2015.

2.5.2 Key issues of the study

The 1992 constitution of Ghana has made the government responsible to the people of Ghana. In chapter six, Article 36 (9), the constitution clearly, stipulates that “the State shall take appropriate measures needed to protect and safeguard the national environment for posterity; and shall seek cooperation with other states and bodies for purposes of protecting the wider international environment for mankind”. Thus, protecting the people of Ghana from the adverse effects of sea-level rise is a constitutional right. In view of this, the country has also enacted several national policies and legislation to safeguard its environment and citizens from any adverse effects. These policies and legislation are spread all over old statutory books and policy documents. Though they are unable to address the problems related to climate change adequately, they offer a basis for the formulation of relevant legislation. Such policies and laws include the Environmental Protection Agency Act (1994), Management of Ozone Depleting Substances and Products Regulations (2005), Renewable Energy Act (2011), etc.

In addition, Ghana is also a signatory to several international agreements on climate change, such as the Kyoto Protocol and the Paris Agreement. Though Coastal zone Management originated from the Earth Summit at Rio Janeiro in 1992 as a management tool for managing and protecting coastal resources, Ghana has no specific policy regarding integrated coastal zone management. According to Boateng (2006), there is no holistic or integrated coastal erosion and flood management strategy or plan in Ghana that focuses on how individuals, communities, and government respond to coastal erosion and flooding and other sea-level rise-related impacts. The present 2014 National Environmental Policy (NEP) does not provide specific plans of action but only considers the need to manage the coastal and marine resources. As a result, management of sea level-related impacts has remained conventional, site-specific and often dominated by hard engineering methods.

Several national and private institutions and organizations have different mandates and activities that address climate and climate change issues. Almost every branch of government is directly or indirectly affected by climate change, which influences the way the government response to climate change. In the area of sea-level rise risk, several ministries and their associated department and agencies are responsible for ensuring its mitigation. Some of these institutions include the Ministry of Environment, Ministry of Works and Housing, Coastal Development Authority, National Disaster Management Organization (NADMO), traditional chiefs, etc. However, these institutions face significant challenges in climate change information and data flow, including data quality, access to data and data collection, sharing, and translation.

Also, to meet national and international commitments, there is a need to build human and institution capacities to respond to the adverse effects of climate change. The government of Ghana and several civil society organizations have taken several actions to address national capacity gaps but still face institutional capability, strengths and interaction challenges. According to the National Climate Change Policy (2013), current institutional gaps include the challenge of translating complex science into simple messages that the general public will understand. The government has taken initial steps to build district capacity but needs support for capacity building in local communities' policy is implemented. Again, Ghana can build on rich traditional knowledge that can be an effective asset in the face of climate change. However, many traditional reactions may increase vulnerability unintentionally. For instance, for decades, indigenous knowledge had been used to predict the likelihood of floods in the past, but climate change has rendered this ineffective as these disasters have become more erratic, thereby making this community much more vulnerable. Lastly, in order to preserve institutional memory and continuity, robust internal systems and incentives are required to ensure that Ghana does not lose its best in the so-called brain drain.

Coastal erosion and flooding are, however, not solely a result of sea-level rise. Anthropogenic activities (planned and ongoing activities both inland and along the coast) significantly impact the coastal morphology. For instance, Ly, (1980) argued that a significant increase in the coastal recession had taken place along the central to eastern shores of Ghana, following the construction of the Akosombo Dam, which had previously been replenished with sand from the Volta River. This was confirmed by (Collins and Evans, 1986), who also argued that the sand input in the coastal systems was reducing due to inland dam construction and irrigation. Several researchers have also argued that the cause of coastal erosion in Ghana is that coastal management strategies, both past and present, have primarily focused on hard protection measures at a specific location. These hard measures cost the government approximately US$60-90 million for 10-25 km of tranches (The World Bank, 2017). Protection adaptation strategy has potential longevity but is costly to build and maintain (Tol *et al*., 2005) and it can have adverse impacts, such as changing sediment dynamics in other areas Jayson-Quashigah *et al*., (2019). For instance, Angnuureng, Addo, and Wiafe (2013) reported an increase in coastal erosion in nearby coastal communities after the construction of the Keta Sea Defense. Similarly, using high-resolution satellite images, (Jayson-Quashigah *et al*., 2013) also report that some sites near the Volta estuary and to the east of the Keta Sea defense project receded at a rate as high as 16 meters per year. Thus, there is a need for the government of Ghana to consider other solutions such as accommodating the impacts of sea-level rise, retreating from the coast, and ecosystem-based adaptation strategies.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of Materials

The study employed an innovative mixed-methods approach which combined both spatial and non-spatial data that were obtained from primary and secondary sources. The data comprises remote sensing, ethnography, ecological data and expert knowledge.

3.1.1 Spatial data

The spatial data were categorized into secondary and primary. Primary data collection primarily involved methods such as Unmanned Aerial Vehicle (UAV), Global Positioning System (GPS) surveys participatory mapping and on-screen digitising. A DJI Phantom 4 Pro V2 multirotor quadcopter was employed to capture high-resolution aerial photographs within the three research areas. This helped to construct Digital Terrain Model (DTM) for the sea-level rise modelling. The UAV imagery was also employed in constructing rules for the classification of the satellite imagery and collecting true world points for validation of land use/cover classification results since most of the area was waterlogged. Also, a GPS survey was conducted using dual-frequency GPS with an accuracy of 2cm. Some of the GPS coordinates were used to map the Ground Control Points (GCP) during the UAV flights. Critical infrastructure such as hospitals, markets and schools within communities were also mapped. Through community participatory mapping, residents of the community were asked to identify the position of the shorelines in 10- and 20 years’ time using different colour threads and stickers. This helped validate the risk map stimulated by the

SLAMM model. Lastly, onscreen digitizing was carried out to map the building footprint and grid from an orthophoto,

In addition, secondary spatial data collected by individuals, government bodies, and various organizations. were also used in the study. The predominant method employed for acquiring this secondary data primarily involved downloading it from the internet. Sentinel-2 satellite images with a resolution of 10m were downloaded from the Copernicus datahub for each of the study communities. Historical orthophotos as well as topographic maps of the study communities were also obtained from the Centre for Coastal Management, University of Cape Coast (Table 3.1).

In addition, secondary spatial data collected by individuals, government bodies, and various organizations. The predominant method employed for acquiring this secondary data primarily involved downloading it from the internet. Sentinel-2 satellite images with a resolution of 10m were downloaded from the Copernicus datahub for each of the study communities. Historical orthophotos as well as topographic maps of the study communities were also obtained from the Centre for Coastal Management, University of Cape Coast (Table 3.1).

3.1.2 Non-spatial data

Non-spatial data were collected through Focus Group Discussion (FGD), interviews and observation. Questionnaires. Two questionnaires were used to solicit information from household heads and experts (Appendix A & B). Data collected using the first questionnaire included socio-demographic characteristics of the respondents, perception/experience of sea-level rise impacts and preferred adaptation options. The household survey was supplemented by information from focus group discussions as well as key informant interviews. By means of Focus Group Discussion (FGD) (Appendix C). The second was a close-ended questionnaire, data which was used to solicit information on ecosystem availability for estimating the ecosystem and vulnerability of the selected coastal ecosystems in the rural coastal communities. The CICES system, known as the Common International Classification of Ecosystem Services, was employed to categorize services, facilitating a more straightforward and transparent assessment. Additionally, experts specializing in marine and wetland ecology, environmental chemistry, environmental sciences, and fisheries science were selected to participate in this assessment.

Table 3.1: Summary of data types and sources for the study

Category	Data Type	Data source	Use
Spatial data	UAV-based orthophoto (2021)	Fieldwork	Digital Terrain Model (DTM), LULC mapping
	GPS Survey	Fieldwork	Ground Control Points Land use mapping
	Aerial orthophoto (1975 and 2005)	Centre for Coastal Mgt., UCC	Shoreline analysis
	Sentinel satellite images (2021)	Copernicus Hub	LULC mapping
Non-spatial data	Social survey (FGD, household survey, expert survey and Interviews)	Fieldwork	Risk assessment adaptation behaviour assessment

Source: Author (2023)

3.2 Methods of Data Collection

3.2.1 Unmanned aerial vehicle (UAV) survey

A multirotor quadcopter DJI Phantom 4 Pro V2 (Plate 3.1), was used to collect high-resolution aerials in the three-study area. The UAV was equipped with a 1-inch 20-megapixel RGB 1" CMOS camera mounted with a mechanical shutter. Rotary-wing UAVs have been largely used for DTM generation because of their low speed, point cloud improvement and cost-effectiveness (Adade et al., 2021; Ruggles et al., 2016). The monitoring of the UAV and establishment of flight paths were facilitated by the employment of Pix4D capture software. Images were taken from directly above the ground every 3.5 seconds while the UAV was flying at a height of 120 meters Above Ground Level (AGL). These images were captured with an 80 percent overlap in the frontal direction and a 70 percent overlap in the side direction. These parameters were chosen based on studies demonstrating their effectiveness in generating high-quality UAV DTMs (Adade et al., 2021; Ruggles et al., 2016). Also, as required by the Ghana Civil Aviation Authority all drone flights are limited to a maximum height of 122 metres above ground level. Prior to the flights, black and white Ground Control Points (GCP) targets were placed at targeted points within the study area and their geographical locations were measured using Dual Frequency GPS with an accuracy of 2cm (Plate 3.2). The GCPs were used in geo-referencing and mosaicking of imagery in order to ensure accuracy by geo-rectifying the orthophoto and digital surface models.

Plate 3.1: Micasense camera-equipped UAV used for aerial photography.
Source: Author (2023)

Plate 3.2: Measuring the geographic location of Ground Control Point (GCP)
Source: Author (2023)

3.2.1 Social survey

The social survey consists of questionnaire surveys and Focus Group Discussions (FDG) and observation. Community entry was undertaken in each community to brief the traditional authorities on the purpose of the study and also seek permission to collect data from the residents. An initial draft of the instrument was designed and pretested to see the practicalities of administering the instrument and identify possible challenges that could be faced. The structured questionnaire was administered using KoBoTool box mobile application. The instrument was mainly designed based on the work of Song & Peng, (2017) and also information from the three Focus Group Discussions (FDG) conducted in the study communities. The first section of the questionnaire addressed respondents' background characteristics. This information was relevant because it has been noted that it is a factor which influences residents' perceptions. The second section assessed the sensitivity and adaptive capacity of the residents to SLR risk whilst the third section investigated the respondents' behaviour towards relocation. Research. Four research assistants were employed to aid in the data collection exercise. They were also taken through the questions for uniform understanding and interpretation.

Out of a total population of 1,468 household heads, 359 respondents were chosen at random using the sampling method outlined in Dusick's 2014 work. The survey targeted heads of households in various communities. Out of a total population of 1,468 household heads, 359 respondents were chosen at random using the sampling method outlined in Dusick, (2014) sampling calculation. The study utilized a multistage sampling technique to select participants. In the initial phase, a cluster sampling method was employed, wherein the study areas were categorized into clusters using a georeferenced hexagonal grid, each covering an area of 2000 square meters (Figure 3.1). The unit for allocating respondents in the hexagon grid was determined based on the number of buildings identified in the 2021 UAV image, which were digitized on-screen. Grids with only one building were not included in the sample. In the third stage, a specific building within each grid was selected using a simple random sampling method. To identify and locate these selected buildings, the spatial extent was converted to a shapefile and loaded onto the SW Map App on a mobile phone, allowing the researcher to pinpoint their exact location within the group. Subsequently, a convenience sampling approach was employed to select the household head for interviews in the selected buildings. However, buildings without occupants during the interview or lacking an adult in charge of the household in the absence of the household head were excluded from the study. In such cases, the next building with a household head was selected as a replacement. Figure 3.2 provides an overview of all the stages involved in the sampling of household heads.

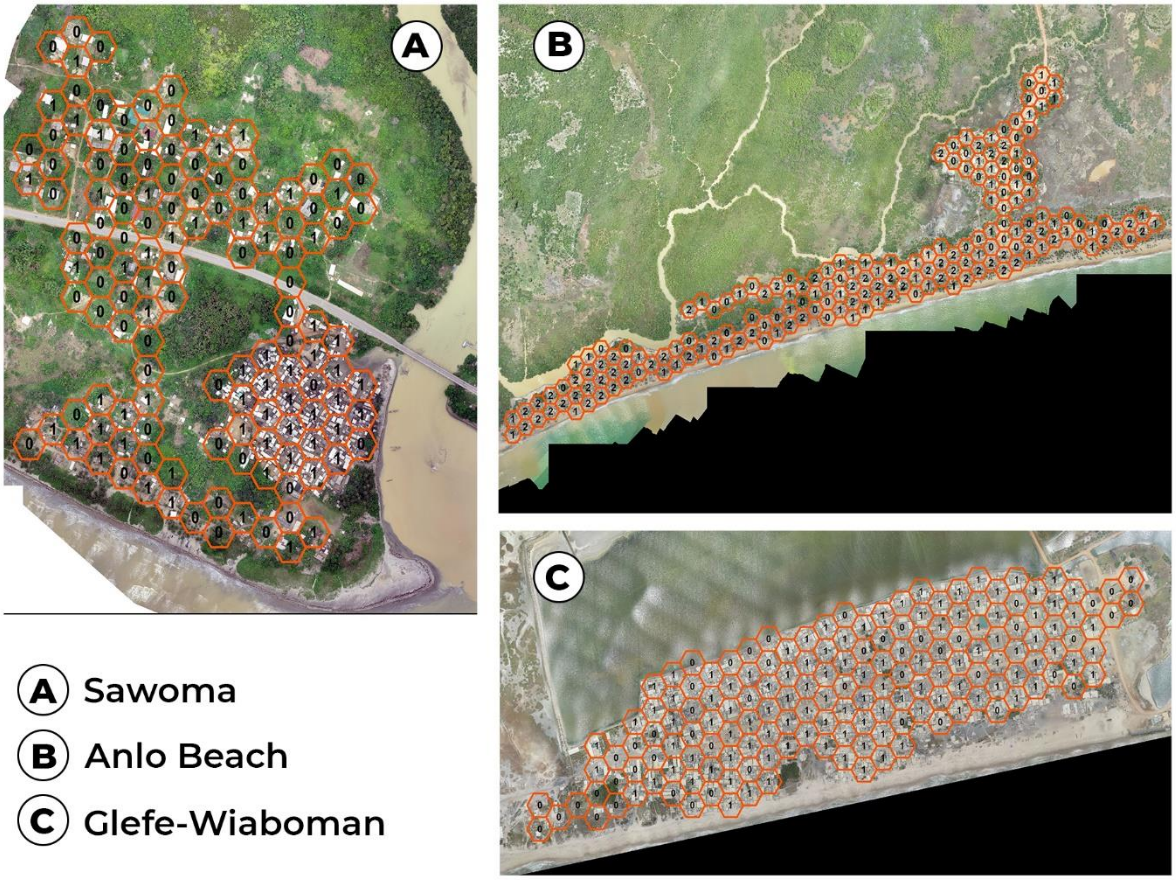

Figure 3.1: Sample grids for the three study communities.

(NB: Numbers in the diagrams represent the respondents selected.)
Source: Author (2023)

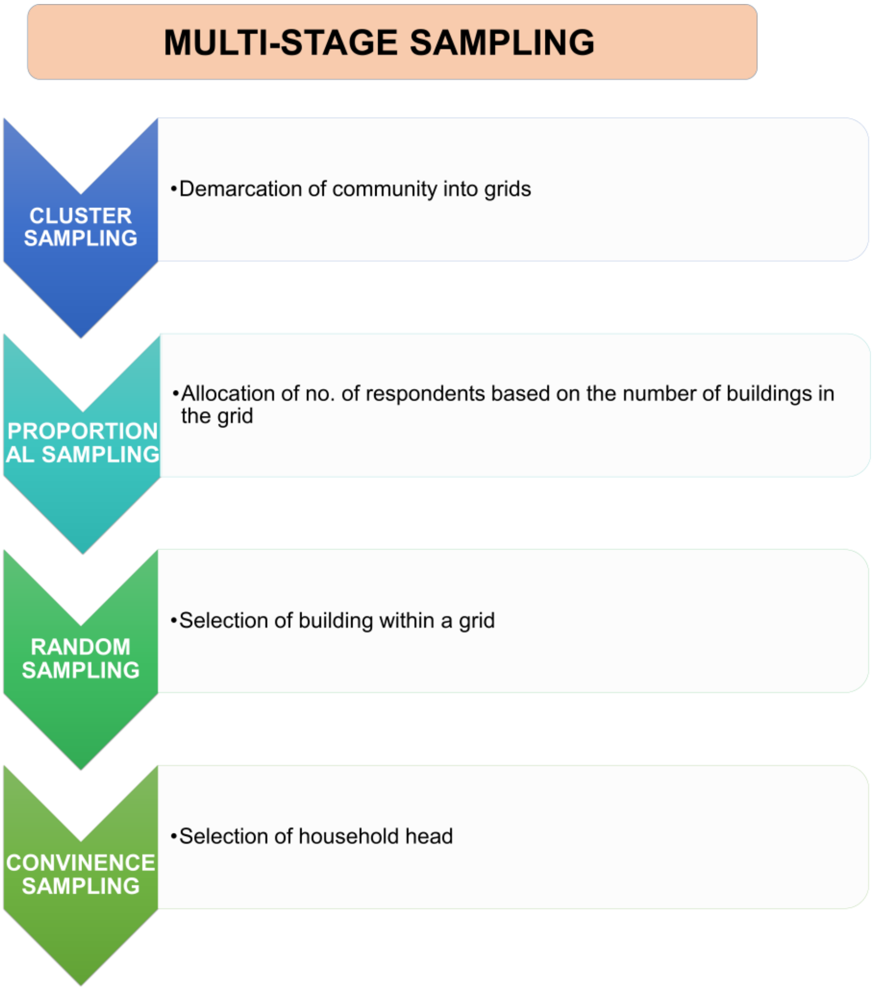

Figure 3.2: Summary of the sampling procedure for the selection of respondents for the study.
Source: Author (2023)

One focus group discussion was conducted in every study community, involving purposefully selected individuals, including community chiefs and opinion leaders. Prior to gathering any information, consent was secured from all participants in the social data collection, and their confidentiality throughout the study was guaranteed. The discussion centred on the impacts of Sea Level Rise (SLR) within local communities and the corresponding plans for the adaptation. Participants were chosen through purposive sampling, specifically targeting community members with a minimum residency of five years who expressed interest in joining the study. In each community, one focused group discussion (FGD) was held, comprising 8 to 12 individuals. To ensure diverse perspectives on the nuances of sea level rise and adaptation strategies, considerations were made regarding the age and gender of the respondents (Plate 3.3).

Plate 3.3: Researcher facilitating focus group discussion session at Sawoma
Source: Author (2023)

3.3 Data Analysis

Data analysis involves the analysis of the historical shorelines for the communities, the generating of the Digital Terrain Model, and analysis of the Land use/cover map. All these products were required as inputs in the SLAMM model to estimate the impact of different sea level scenarios on the communities under study. Non-spatial social data were also analysed in order to perform the risk assessment and assess the factors that influence the respondent relocation intention.

3.3.1 Analysis of shoreline data

The erosion and accretion rates in the study communities were determined by analyzing the shorelines obtained from a topographic map from 1974, an orthophoto from 2005, and UAV images from 2021. Shoreline positions in the study communities were determined using both automated extraction and manual digitization techniques. The manual method involved the digitization of shorelines from images using the High Water Line (HWL) proxy, a widely acknowledged and reliable predictor of shoreline location as indicated by Gorman *et al*. (1998), and sometimes the only available indicator. Prior to digitizing the shorelines, the images were georeferenced and projected into the same coordinate system using the Ghana Metre Grid. To analyze shoreline changes in the study area, the Digital Shoreline Analysis Software (DSAS) was employed to calculate the Linear Regression Rate (LRR) and Endpoint Rate (EPR) statistics. Thieler *et al*. (2009) provided a comprehensive guide on how to use DSAS for shoreline change analysis.

3.3.2 Generation of mosaicked orthophoto and digital terrain model

The Pix4D Mapper software version 4.1 was utilized to process all acquired images and generate the Digital Terrain Model (DTM) and Ortho mosaicked images. These products were created using the Structure from Motion (SfM) photogrammetric processing workflow, which involves aligning and matching key points from individual images, georeferencing images using Ground Control Points (GCPs) to optimize camera position and orientation and densifying the point cloud while filtering the ground to facilitate product generation. Ground filtering is a crucial step in DTM generation, classifying point clouds into ground points and above-ground objects like vegetation and buildings. In this study, noise points were manually eliminated following dense point cloud classification. Subsequently, the DTM was produced by interpolating the ground points representing the bare earth surface. Lastly, the Digital Surface Model (DSM) was utilized to generate the mosaicked orthophoto.

3.3.3 Land use/cover mapping

The primary purpose of land use/cover mapping in this study was to provide input data for the SLAMM model. To achieve this, we initially processed the downloaded Sentinel satellite images using ERDAS Imagine 2015 software. This involved stacking bands 2, 3, 4, and 5 to create a multispectral image and then cropping the image to match the specific communities covered by the UAV flight, as the original satellite image extended beyond this area. Additionally, we conducted radiometric correction to eliminate atmospheric and lighting effects, enhancing the accuracy of image classification. This correction process addressed issues like haze and noise for each band of the Sentinel-2 datasets.

Furthermore, we performed geometric correction to enable integration with other spatial data. This step involved geo-referencing the image since the original Sentinel-2 images were in a global coordinate system (UTM zone 30/WGS 84) and needed transformation to a local projected coordinate system known as the Ghana Metre Grid. For image classification, we used bands 2, 3, 4, and 5 with a 10-meter resolution. Both unsupervised and supervised classification methods were applied, with the Support Vector Machine (SVM) classifier serving as the decision rule for supervised classification. The categorization of land use/cover types was based on SLAMM's predefined categories, which include mangrove, regularly flooded marsh, open beach, and open ocean, as outlined in the SLAMM manual (Clough, 2010). The Normalized Vegetation Index (NDVI) and the Normalized Difference Moisture Index (NDMI) generated from the satellite images to aid in distinguishing mangrove and wetland areas.

3.3.4 Sea-level rise risk assessment

Sea level rise risk assessment was performed using the IPCC, the conceptual framework that indicates that climatic risks are a function of hazard, exposure and vulnerability features (IPCC 2014). Data obtained from both primary and secondary were analysed to generate scores for each component of risk which were then aggregated to obtain risk level scores for each study community.

3.3.4.1 Sea-level rise hazard modelling

The Sea Level Affecting Marshes Model (SLAMM) was employed to simulate the effects of various sea level rise scenarios on rural coastal communities. The model reveals the processes in the conversion of coastal land use/cover and modification of shorelines over long SLR scenarios. SLR impact analysis was done based on the AR5 IPCC RCP 8.5 projections up to 2090 to assess SLR scenarios. Sea level rise risk modelling was conducted for four different high sea level scenarios, corresponding to the upper limit of expected levels in 2030, 2050, 2070, and 2090, as defined by IPCC AR5. Additionally, a baseline scenario representing conditions in 2021 was used. The UAV survey produced a Digital Terrain Model (DTM), which we used to calculate slope angles in degrees using the spatial analyst extension in ArcGIS Pro. The land use/cover, DTM, and slope files were then converted from raster data format to ASCII Text format. The converted files, including a site environment parameter (erosion and accretion rates) for the study communities were used in the SLAMM Model software version 6.7 to develop the SLR impacts maps. A change detection technique was conducted to identify the changes in the extent, locations, and trajectory of change within the LULC categories. Scores for coastal hazards (erosion and inundation) as stimulated by the SLAMM model were derived from the SLR impacts maps (0.2m, 0.5m, 0.9 m, and 1.4m) for each of the study communities. Figure 3.3 shows a summary of the methodological workflow for Sea-level rise impact modelling.

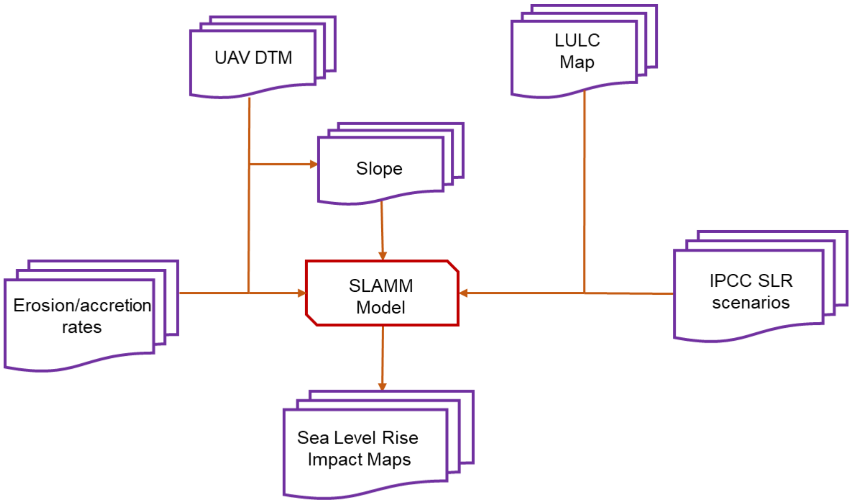

Figure 3.3: Methodological workflow for Sea-level rise impact modelling
Source: Author (2023)

3.3.4.2 Mapping elements exposed to sea level rise

Three main indicators were used to estimate the community's exposure to SLR impacts namely land use/cover (LULC), people and residents who have had experience with SLR impacts. The Land use/covers (LULC) in study communities exposed to different SLR scenarios was determined through the post-classification change detection method. This method involved overlaying independently classified images. The SLR impact maps (0.2m, 0.5m, 0.9 m, and 1.4m) simulated in the SLAMM model and 2021 LULC map of the study communities were loaded in combinatorial and spatial analyst tool in ArcGIS Pro 2.7 to indicate LULC that will be likely exposed to SLR impacts. This analysis produces two results, comprising maps and change matrix tables, which were subsequently employed for further analysis. In order to determine the population likely to be exposed to projected SLR impacts, an overlay analysis was performed which involved overlaying the SLR impact maps (generated from the SLAMM model) and buildings (digitized from the 2021 UAV image) in ArcGIS Pro software 2.7 software. Next, a spatial inquiry was carried out to visually choose the structures within the affect impact area. The number of buildings impacted was then multiplied by the average house size for each community obtained through the questionnaire survey to arrive at the number of people likely to be exposed to SLR impacts. Number of people in the study community who have experienced coastal hazards was obtained from the questionnaire survey.

3.3.4.3 Socio-ecological vulnerability assessment

The assessment of socio-ecological vulnerability focused on two primary elements: socio-economic vulnerability and ecological vulnerability. In terms of the socio-economic vulnerability to the impacts of SLR, six key indicators were selected for both sensitivity and adaptive capacity based on literature and verification from focus group discussions that were conducted in the community communities. The values for the indicators were obtained from the analysis of the questionnaire data. In analysing socio-economic vulnerability within the study communities, the communities were divided into clusters using a georeferenced hexagon with a side of a 2000 square meter grid. Since socio-economic vulnerability levels vary within a community, the delineation was to assist in identifying which grids were more vulnerable. The advantage of using the spatial hexagonal pattern model in territorial analysis is the ability to perform complex calculations quickly and automatically and also improves the visualization of the results (Birch *et al*., 2007). The indicators were normalized to come up with standard values between 0 and 1 using Eq. (1) in Table 3.2. Cumulative indicators Eq. (2) (Table 3.2) were also used to calculate the sensitivity and the adaptive capacity index.

SLR Impacts on the coastal ecosystems as stimulated by the SLAMM model and the expert scores on the ecosystem services of the selected ecosystem were used to measure ecological vulnerability. The study adopted the workflow proposed by Cabral et al., (2015) ecological vulnerability assessment, but introduced some modifications in the calculations. Unlike the workflow from Cabral et al., (2015), the ecological vulnerability in this study was assessed using the potential impact of SLR on the coastal ecosystem (cumulative risk) and the ecosystem service provided by the coastal habitat as indicators. Based on land cover map generated for the study communities, ecosystem services provided by the selected ecosystems that support livelihood in the communities were identified and listed. They included mangroves, regularly flooded marsh and open beaches. The CICES scheme was employed to classify 10 ecosystem services to enhance the assessment (refer to Table 2.1). This concept also categorised support and regulatory services under the heading regulating and maintenance. The assessment of the coastal ecosystem involved expert judgment and the determination of the availability of ecosystem services was based on a four-point scale:

i. A score of 0 indicated that the ecosystem's contribution to providing the service was unknown to the expert group.
ii. A score of 1 indicated that the contribution to this ecosystem service was minimal, irrelevant, or low.
iii. A score of 2 indicated a moderate contribution, which was important but substantially less than other habitats.
iv. A score of 3 indicated a high contribution, considerably above the average.

The assessments of ecosystem availability were based on the average of expert scores. Average scores were computed for the categories of Provisioning, Maintenance, Regulating, and Cultural ecosystem services, and all scores were standardized to a range of 0 to 1. Lastly, the information on selected coastal ecosystem changes and ecosystem service availability were standardized and aggregated using a modified vulnerability quadrant matrix from Ha-Mim *et al*. (2020) to quantify ecosystem vulnerability to sea-level rise impacts (Figure 3.4). Thus, coastal ecosystems with high exposure to SLR and high ecosystem available have a high ecological vulnerability and vice versa. Figure 3.5 shows a summary of the methodological workflow for the vulnerability assessment.

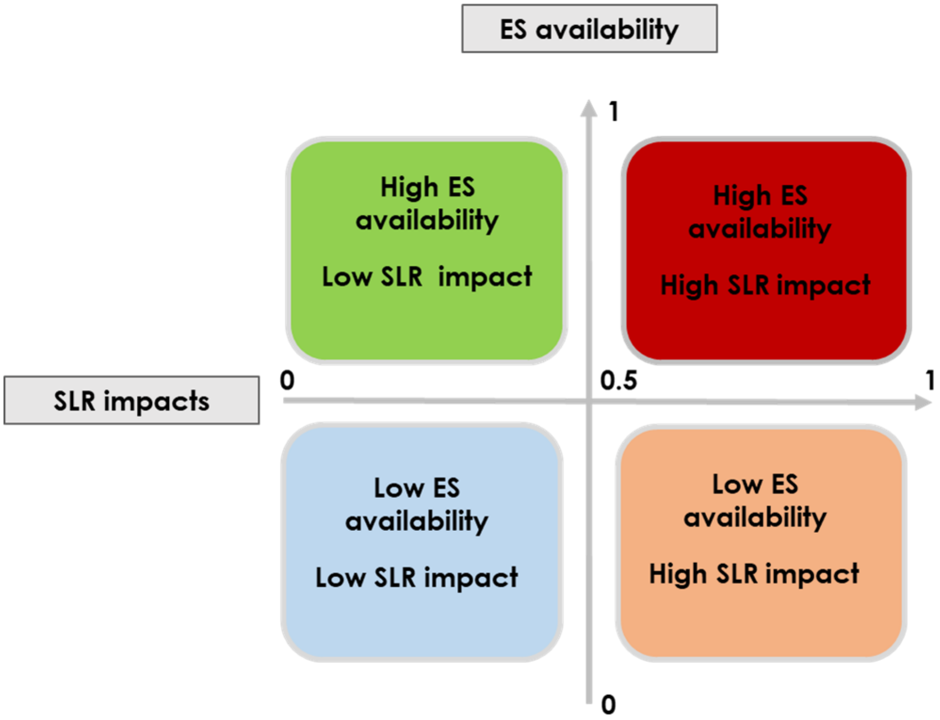

Figure 3.4: Quadrant framework for ecological vulnerability assessment
Source: Adapted from Ha-Mim *et al.*, (2020)

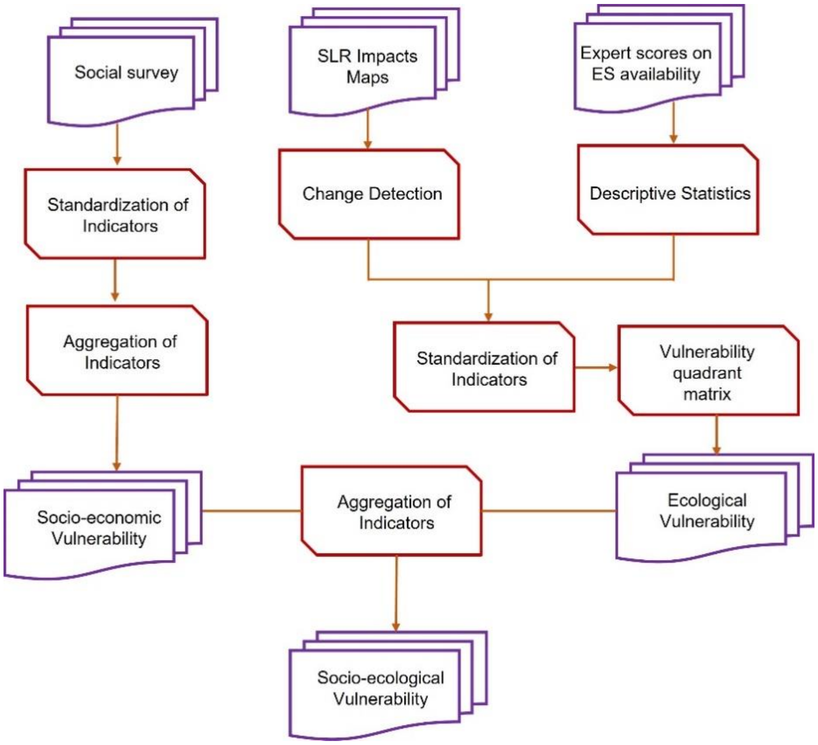

Figure 3.5: Methodological workflow for socio-ecological vulnerability assessment
Source: Author (2023)

3.3.4.4 Sea- level rise risk level assessment

Weighted arithmetic mean (Eq. (3) (Table 3.2) was used to aggregate the three risk components hazard, vulnerability and exposure into a single composite risk indicator and categorized using Zebisch *et al*. (2017) risk level classification, the output was divided into five categories very low (0-0.2), Low (>0.2-0.4), medium (>0.4-0.6), high (>0.6-0.8) and very high (>0.8-1).

Table 3.2: Equation for calculating risk components

Equations	Variable definition	Purpose
Equation (1)		
$I_i = (x_i - Min_i)/(Max_i - Min_i)$	I_i=Normalized value of indicator Max_i= Maximum value of threshold Min_i= Minimum value of threshold x_i= value of an indicator	Standardization of indicators
Equation (2)		
$\mathbf{CI} = \frac{\mathbf{(I_1 * w_1 + I_2 * w_2 + \ldots I_n * w_n)}}{\sum_i^n w}$	CI= Cumulative indicator I_i=Normalized value of indicator W_i=Weight for indicator	Aggregating single indicators to sub component
Equation (3)		
$\mathbf{CI} = \frac{\mathbf{(H * W_H + V * W_V + E * W_E)}}{\mathbf{W_H + W_v + W_E}}$	H = Cumulative indicator for hazard V = Cumulative indicator for vulnerability E = Cumulative indicator for exposure W_H=Weight for hazard indicator W_V=Weight for vulnerability indicator W_E=Weight for exposure indicator	Aggregation of risk components

Source: Author (2023)

3.3.5 Assessment of respondent’s relocation intention

Descriptive and inferential statistics were used to quantitatively describe and summarize the characteristics of the components (factors). Secondly, the cognitive factors (risk perception, threat appraisal and coping appraisal) were subjected to Exploratory Factor Analysis (EFA) to examine the strength and relationship between measured variables before including them in the model. The KMO value (Kaiser–Meyer–Olkin) was 0.782, which was higher than the accepted limit of 0.7 (Hair and Black, 2010). The KMO test measures sampling adequacy for each variable in the model and for the complete model. The Barlett sphericity test yielded a significant value of p = 0.000, rejecting the null hypothesis that the correlation matrix is an identity matrix. The Barlett sphericity checks to see if there is a certain redundancy between the variables that can summarize with a few factors that the original dataset was suitable for factor analysis.

In the EFA process, constructs were extracted from all original items using principal component analysis with varimax rotation and factor loadings greater than 0.6. As shown in Table 3.3, three factors, items TA3, TA5 and CA1, which had a factor loading lower than 0.6, were deleted. Cronbach's values for internal validity were determined to test the revised scale's reliability. The values of all derived constructs were greater than 0.7, ranging from 0.801 to 0.901 (See Table 3.3). Cronbach's Alpha value should be higher than 0.7, according to Hair and Black (2010). Thus, it can be inferred that all the cognitive variables in the modified scale were internally consistent and reliable enough to be included in the model. Analysis of variance (ANOVA) was carried out to examine the factors that have an influence on the scores of the three cognitive factors. Binary logistic regression was then employed to identify the factors that predict residents' intention to relocate. All statistical analyses were carried out under a significance test value of 0.05. All the data analyses were done using IBM SPSS version 24.

Table 3.3: Varimax-rotated component analysis factor matrix and Cronbach's α values for the cognitive variables

Constructs	Items	Main factors			Cronbach Alpha
		1	2	3	
Risk perception	RP1	0.907			0.901
	RP2	0.906			
	RP3	0.915			
Threat appraisal	TA1		0.893		0.861
	TA2		0.922		
	TA4		0.847		
Coping appraisal	CA2			0.835	0.801
	CA3			0.817	
	CA4			0.765	

Kaiser-Meyer-Olkin Measure of Sampling Adequacy= 0.782 and Bartlett's Test of Sphericity p= 0.000

Source: Author (2023)

3.4 Method of Data Presentation

The analyzed data were presented using maps, tables, graphs, pictures and narrations. The usefulness of these formats is they are easy to read and understand. Spatial data such as SLR impacts, and social-economic vulnerability were presented using maps. Other qualitative data were presented using tables and graphs. Qualitative data which included the results from the interviews and focus group discussion, which were put into themes were presented using narrations.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Results

4.1.1 Impacts of coastal hazards on rural coastal communities in Ghana

Sea level rise has several impacts on coastal communities such as erosion of beaches, inundation, saltwater intrusion and storm surges. However, in this study, the Digital Shoreline Analysis Software (DSAS) and Sea Level Affecting Marshes Model (SLAMM) were used to model the impacts of erosion and inundation on the coastal communities. Section 4.1.1 looks at the historical erosion and accretion rates in the various study communities which also served as an input in the SLAMM model. Section 4.1.2 also focuses on the impact of different sea level rise scenarios on study communities.

4.1.1.1 Shoreline changes between 1974 and 2021

Quantification of shoreline changes rate in the study communities was accomplished using End point rate (EPR) and Linear Regression Rates (LRR) statistics to describe the shoreline changes in the study communities. Figures 4.1, 4.2, and 4.3, show the shoreline changes in the various communities from 1974 and 2021. The results show that, from 1974 to 2021, Anlo Beach Community experienced the most consistent shoreline changes, while Sawoma and Glefe-Wiaboman Communities recorded more unpredictable changes. Sawoma experienced changes in shoreline with average EPR ranging from a high of -2.4 m to a low of 0.36 m. The average LRR over the years 1974 to 2021 was 0.86 m/yr ± 0.12 m (Figure 4.1). Trends in the results indicated that shoreline changes were highest around the built-up area. Within the Anlo Beach community, the area close to the Pra River estuary experienced the highest change in coastline extent, with the loss of approximately 100 m of land. This can be attributed to the interaction between the Pra River and sea. The area east of the estuary recorded the lowest changes over the 47-year period. Averagely, the community recorded EPR ranging from a high of -3.95 m to a low of -0.56 m and LRR of 1.21 m/yr ± 0.10 m (Figure 4.2). Glefe-wiaboman generally, also recorded general land loss trends during the period 1974-2021. The greatest shoreline changes were recorded at the westernmost part towards the Densu River estuary and a few areas in the middle portion of the beach. The community recorded an average EPR ranging from a high of -1.75 m to a low of -0.52 m and an LRR of 0.7 m/yr ± 0.04 m over the 47-year period (Figure 4.3).

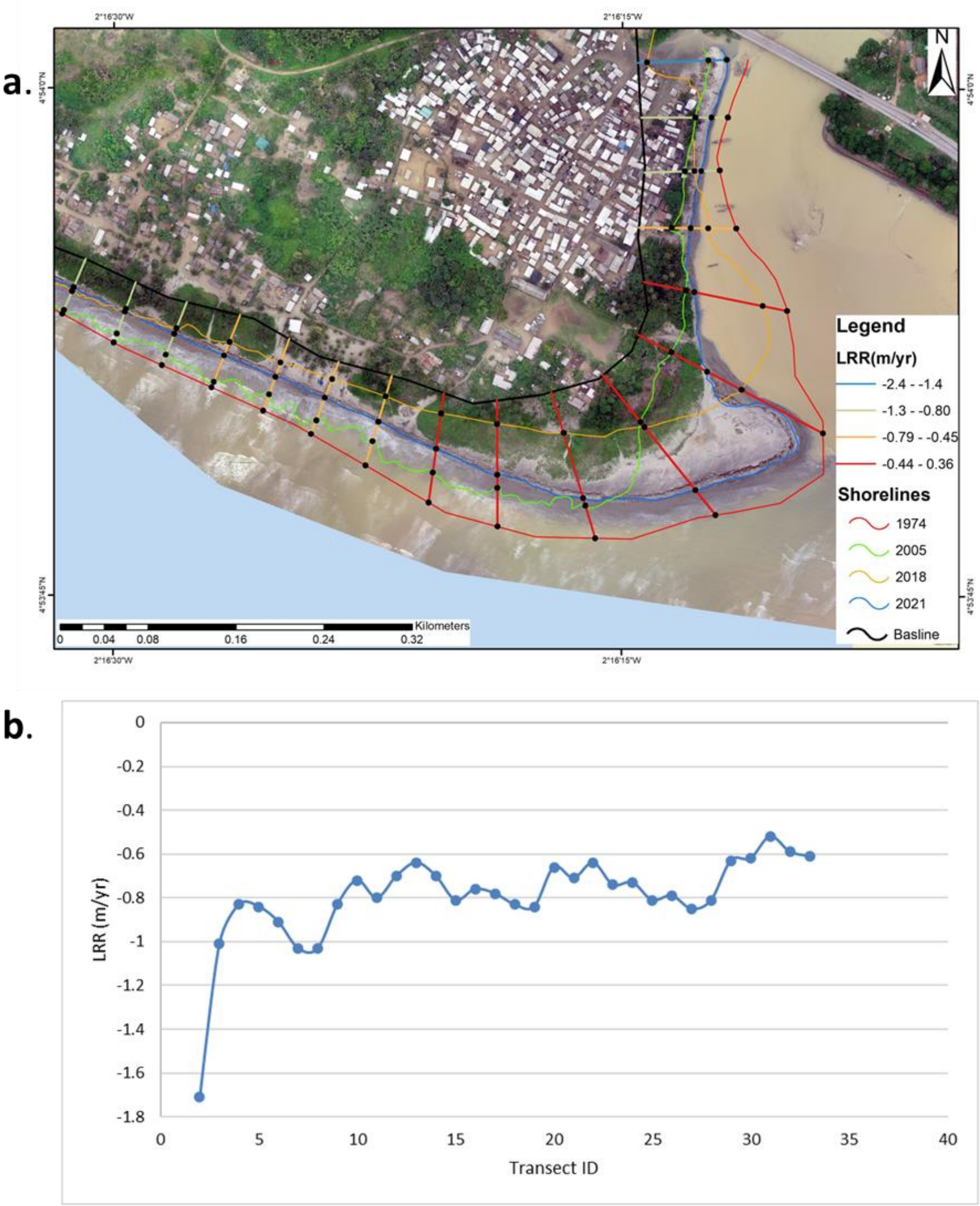

Figure 4.1: Shoreline change and trends in the Sawoma community for the period 1974-2021

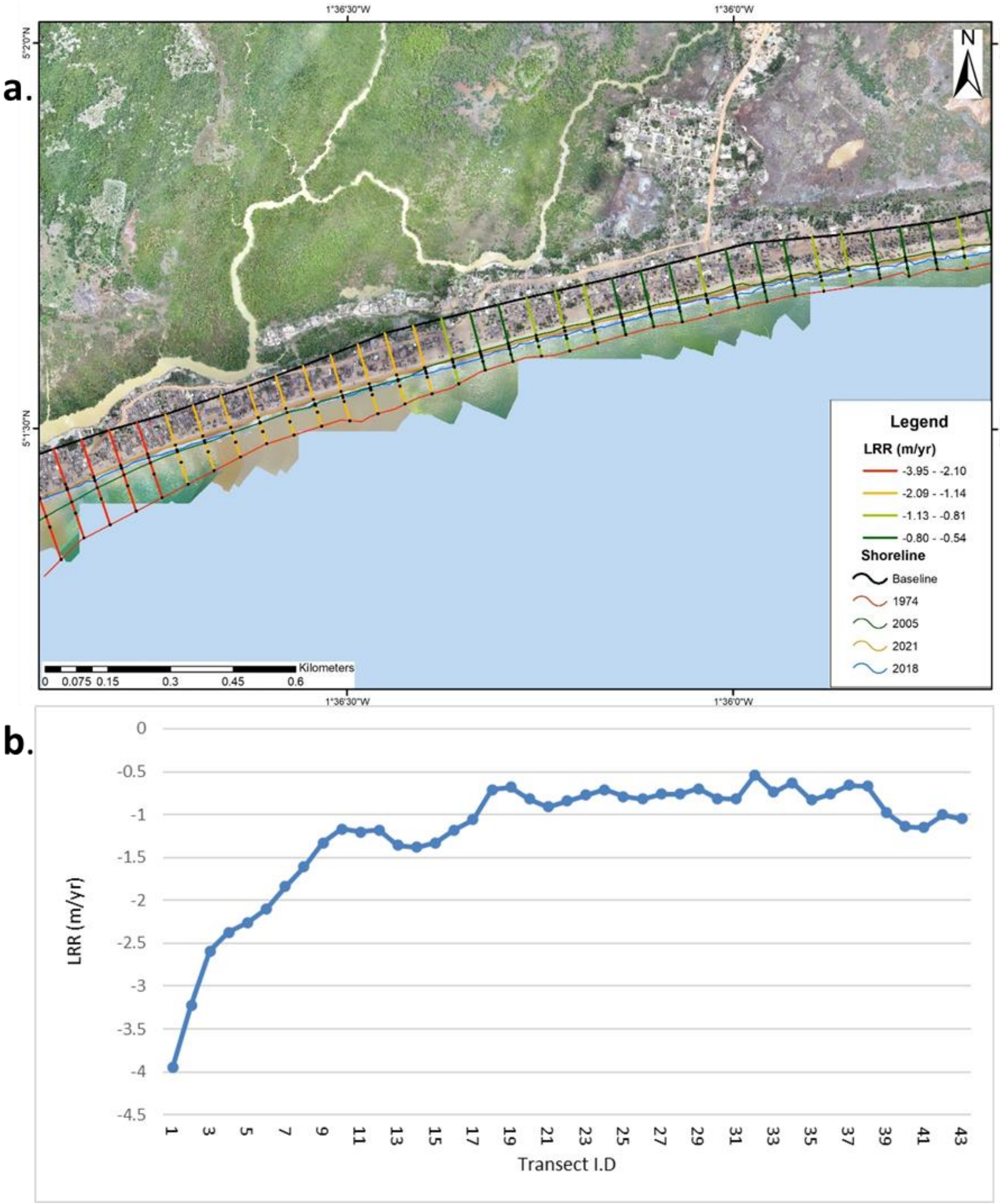

Figure 4.2: Shoreline change and trends in the Anlo Beach community for the period 1974-2021

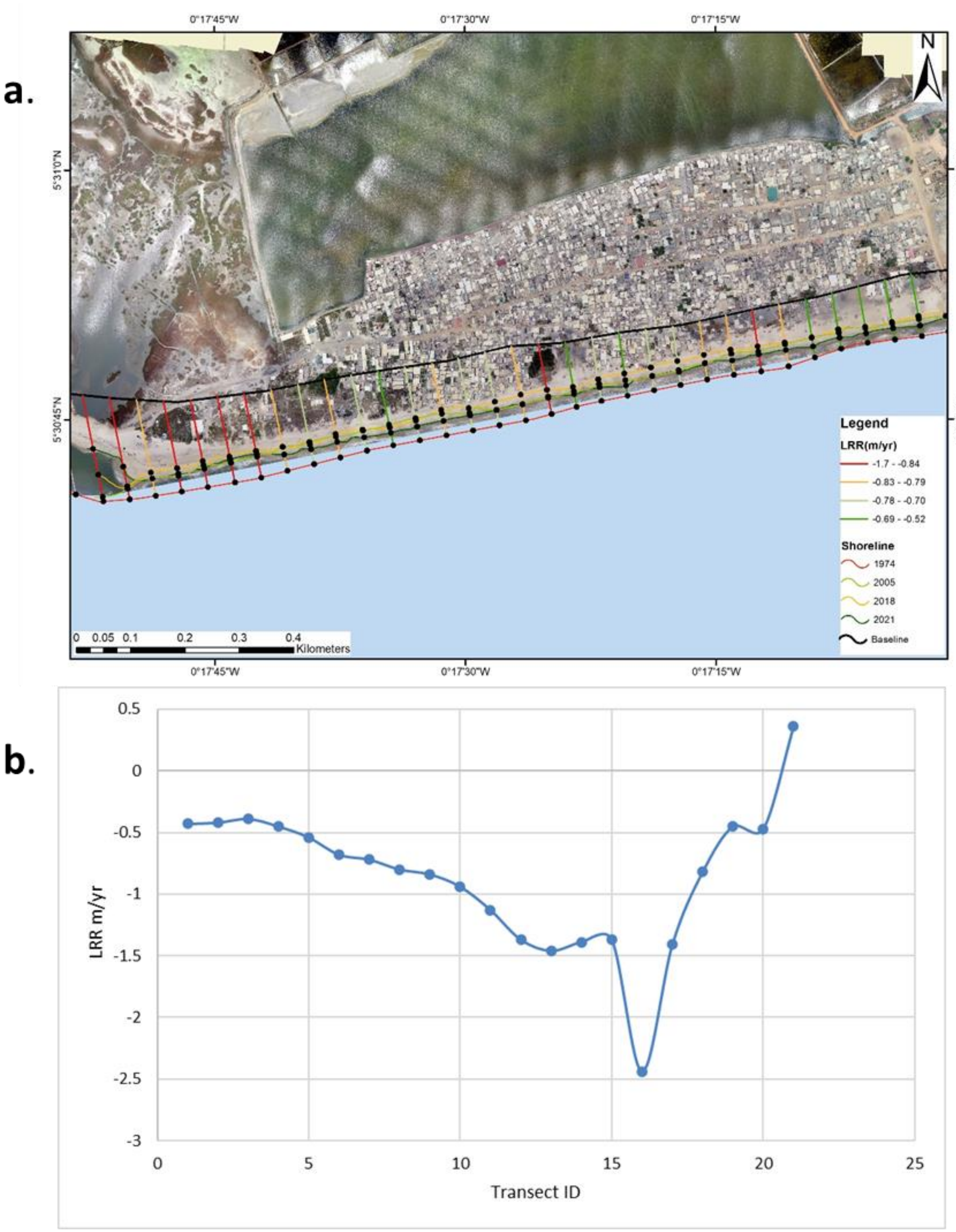

Figure 4.3: Shoreline change and trends in the Glefe-wiaboman community for the period 1974-2021

4.1.1.2 Impact of different sea level rise scenarios on the study communities

The calculation of the combined land area impacted by various hazards such as erosion/accretion and inundation for each sea-level rise scenario, as well as the cumulative impact over time in each community, are depicted in Figures 4.4, 4.5, 4.6 and 4.7. This provided a better understanding of how sea level-related phenomena affect rural coastal communities in terms of their geographical reach. As shown in Figure 4.4a and Figure 4.5, the land area impacted by erosion/accretion resulting from SLR indicates that Glefe-wiaboman will likely experience the largest impact of erosion/accretion, at a growth rate that substantially exceeds the other communities. A rise in SLR from 0.2 m to 1.4 m will likely lead to an additional 0.8 ± 5.9 km^2 of land impacted by erosion/accretion on Sawoma (0.11 ± 0.02 km^2), Anlo Beach (0.18 ± 0.03 km^2) and Glefe-wiaboman (0.53 ± 0.12 km^2) combined (± values are standard errors). It is anticipated that each community's land area that will likely be inundated will likely increase by roughly the same amount over time except for an exacerbated increase in Glefe-wiaboman by 2090 (Figure. 4.4b). With SLR up 1.4m, approximately 0.86 ± 0.42 km^2 of land will be impacted by inundation in the rural communities of Sawoma (0.01 ± 0.01 km^2), Anlo Beach (0.19 ± 0.09 km^2) and Glefe-wiaboman (0.6 ± 0.42 km^2) combined. Cumulative impacts resulting from both erosion/accretion and inundation (Figure. 4.4c) indicate that on average of about 1.67 ± 0.72 km^2 of rural coastal community land will likely be impacted for up to 1.4 m SLR scenario for Sawoma (0.11 ± 0.03 km^2), Anlo Beach (0.38 ± 0.12 km^2) and Glefe-wiaboman (0.18 ± 0.56 km^2). Although further research is needed to fully understand the specific mechanisms behind the variations among communities, it is possible that the low-lying topography of Glefe-wiaboman resulted in the increase SLR impacts in this community.

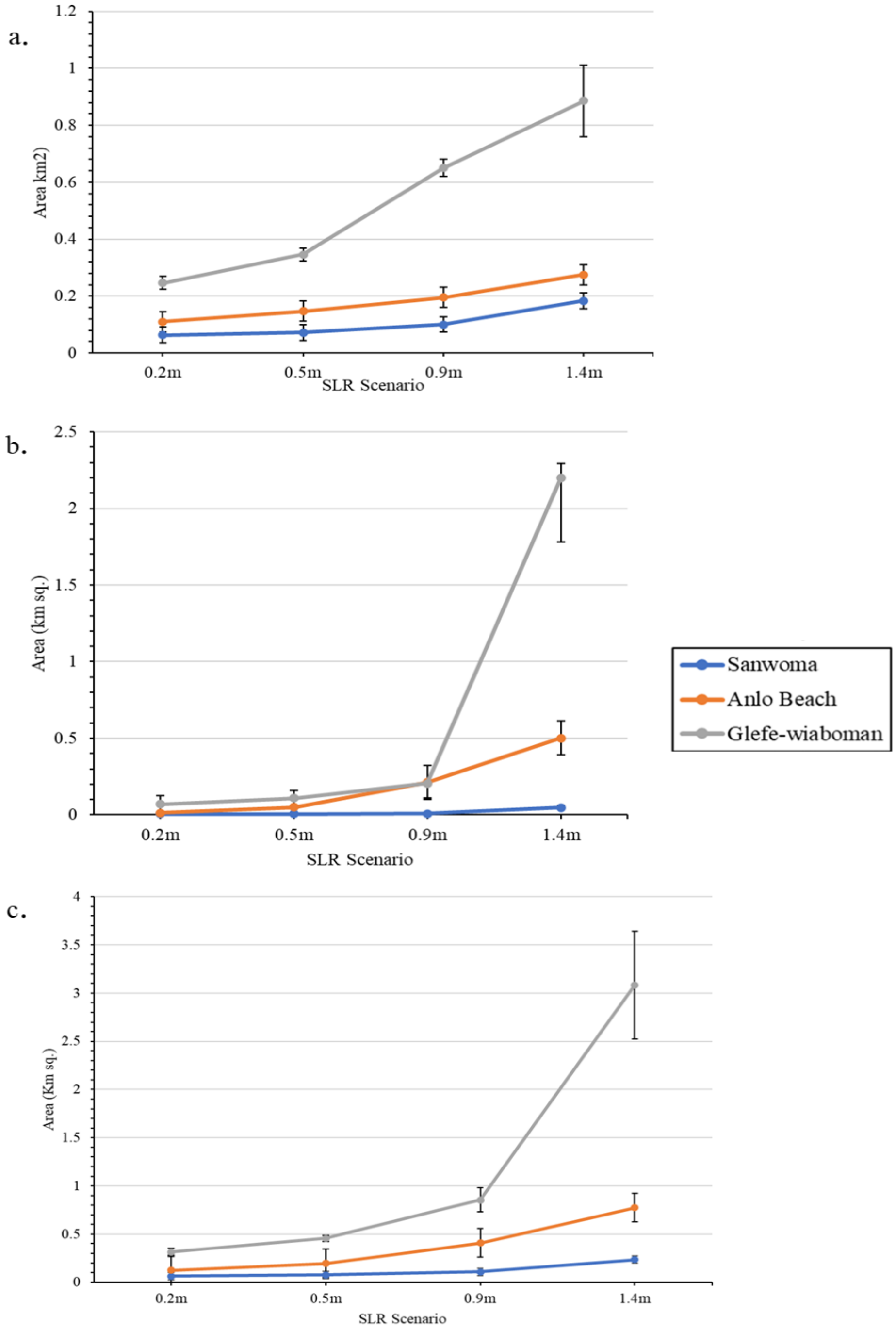

Figure 4.4: Quantification of the land area impacted by (a) Erosion (b) Inundation and (c) Cumulative hazard

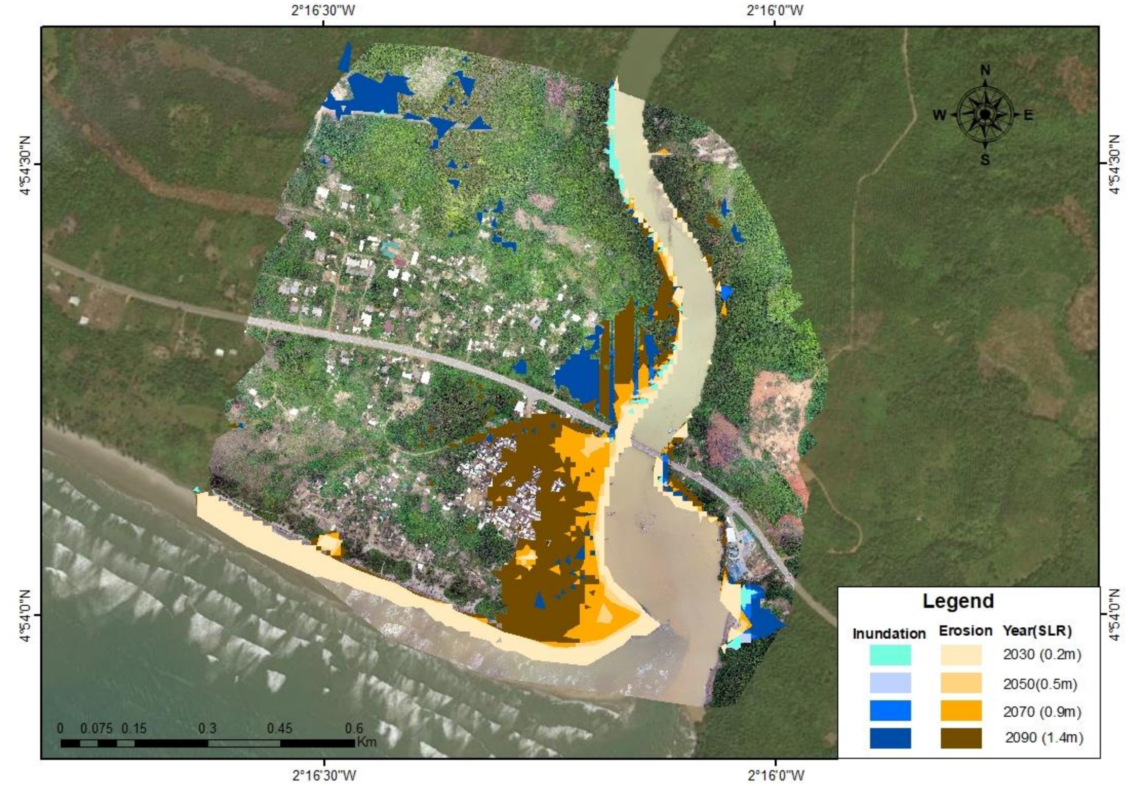

Figure 4.5: Land area impacted by coastal erosion/inundation due to increased SLR in Sawoma

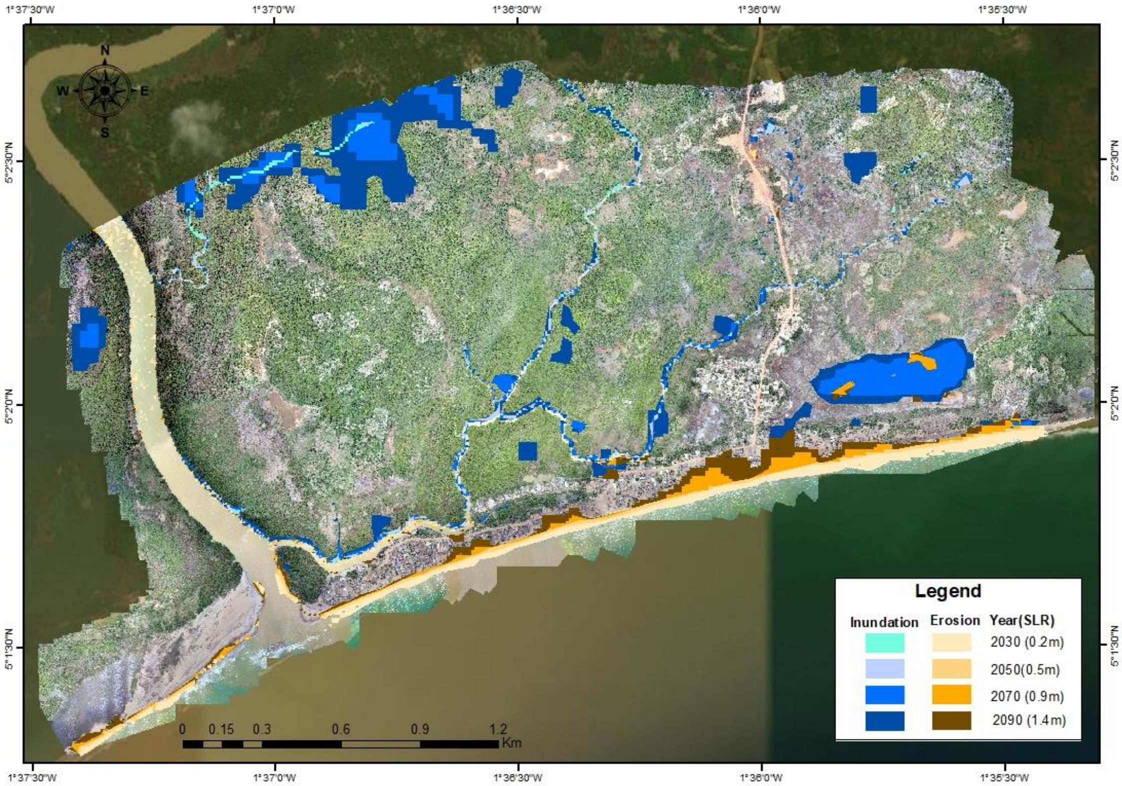

Figure 4.6: Land area impacted by coastal erosion/inundation due to increased SLR in Anlo Beach

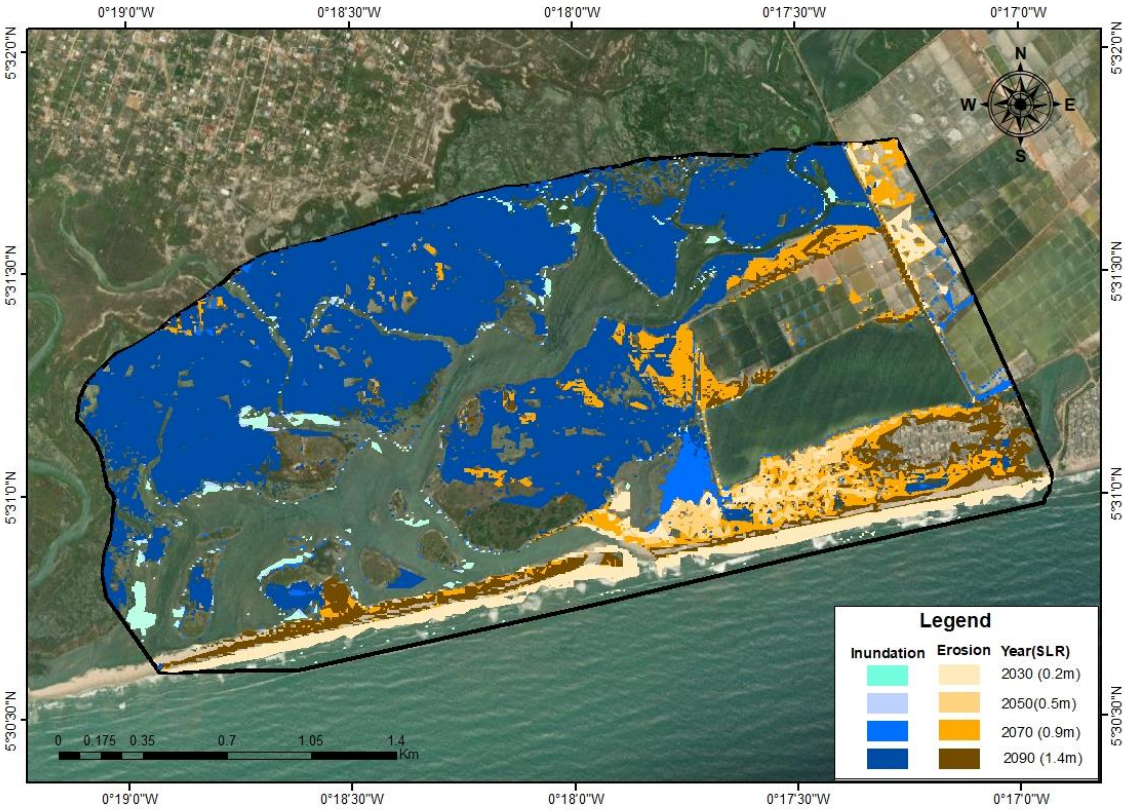

Figure 4.7: Land area impacted by coastal erosion/inundation due to increased SLR in Glefe-wiaboman

4.1.2 Mapping elements exposure to sea level rise impacts

Elements exposed to climate hazards as explained by IPCC (2014) are the people, livelihood, ecosystem, etc. that could be adversely affected by the hazards. In order to know and quantify these exposed elements in the study communities, it was necessary to model the land use/ cover within the rural coastal community's landscape, map the buildings within the study communities and estimate the population exposed to SLR impacts.

4.1.2.1 Land use/cover (LULC) in study communities exposed to different SLR scenarios

The Land use/covers (LULC) in study communities exposed to different SLR scenarios was generated through the post-classification change detection technique. The analysis involved overlay of the SLR impact maps (0.2m, 0.5m, 0.9 m, and 1.4m) simulated in the SLAMM model and 2021 LULC map of the study communities. Table 1-3 in Appendix D contains details results for the analysis.

(a) Proportion of land use/covers in study communities in 2021

In the context of this study, the 2021 land use/cover maps for the study communities, served as the baseline for sea level rise modelling. As shown in Table 4.1, in 2021 the most predominant LULC in Sawoma was the developed/undeveloped which occupied 0.963 km^2 (70.3 percent) of the study community. Open ocean including the river estuary occupied 0.186 km^2 (13.6 percent) of the area. Regularly flooded marshes occupied approximately 0.148 km^2 representing 10.8 percent of the total study area. The rest of the study area was occupied by open beach which represented 0.073 km^2 (5.3 percent) of the total wetland area. It is worth mentioning that the mangrove strand located about a kilometre from the Sawoma community was not captured as part of the study area.

In Anlo Beach, Results from the LULC classification shown in Table 4.1 reveals that the land area under study is covered in descending order by regularly flooded marsh 2.527 km^2 (38.7 percent), mangrove 2.152 km^2 (32.9 percent), developed/undeveloped land 0.811 (12.4 percent), open ocean (including the river estuary) 0.772 km^2 (11.8 percent), and ocean beach 0.274 (4.2 percent). It was found that regularly flooded marsh was the major land cover whereas the least was ocean beach in 2021.

Open ocean was the most prevalent land cover class in Glefe-wiaboman in 2021 as a result of the dendritic nature of the Densu River estuary taking up about 1.877 km^2 (38.3 percent). The rest of the study area was covered in descending order by regularly flooded marsh 2.527 km^2 (30.5 percent), mangrove 0.838 km^2 (13.6 percent), developed/undeveloped land 0.676 km^2 (11.0 percent), and ocean beach 0.411 km^2 (6.7 percent) (Table 4.1).

Table 4.1: Proportion of land use/covers in study communities in 2021

	Sawoma		Anlo Beach		Glefe-wiaboman	
LULC class	Area (km^2)	percent	Area (km^2)	percent	Area (km^2)	percent
Developed/undeveloped land	0.963	70.3	0.811	12.4	0.676	11.0
Regularly flooded marsh	0.148	10.8	2.527	38.7	1.877	30.5
Mangrove	-	-	2.152	32.9	0.838	13.6
Ocean beach	0.073	5.3	0.274	4.2	0.411	6.7
Open ocean	0.186	13.6	0.772	11.8	2.356	38.3
Total	**1.371**	**100**	**6.5366**	**100**	**6.157**	**100**

Source: Author (2023)

(b) Proportion of LULC likely to be exposed to different SLR scenarios (2030-2090)

Figures 4.8a-c indicate the land use/cover types that will likely be exposed to different SLR scenarios simulated by the SLAMM Model. With the assumption of no protection in the model procedure, the areas of developed dry land and undeveloped will change significantly in all the communities. Figure 4.8a shows that with an increase in the SLR to 0.9 m, about 17.0 percent of the developed/undeveloped lands and ocean beach areas in Sawoma are likely to be exposed to SLR impacts. If the sea level rises up to 1.4 m in the study area, 10.8 percent of only developed/undeveloped land areas are likely to be exposed to SLR impacts.

With an increase of 0.5m rise in sea level in 2050, 4.1 percent of developed/undeveloped land, mangrove and ocean beach areas will likely be exposed to coastal erosion/inundation in Anlo Beach. Also, about 3.0 percent of regularly flooded marsh, developed/undeveloped land and ocean beach areas are likely to be exposed to SLR impacts at a rise of 1.4m. Approximately 2.3 percent and 0.9 percent of developed/undeveloped land and ocean beach area in Anlo beach will likely be exposed with a SLR of 1.4m (Figure 4.8b).

As indicated in Figure 4.8c, ocean beach, developed/undeveloped land, and regularly flooded marsh areas in Glefe-wiaboman covering 1.6 percent, 1.4 percent and 0.8 percent respectively will likely be exposed to an SLR of 0.2m. When the sea level rises between 0.5-1.4 m above the present Mean Sea Level (MSL), about 35.7 percent of developed/undeveloped land, and regularly flooded marsh in Glefe-wiaboman will likely be exposed to sea level rise impacts.

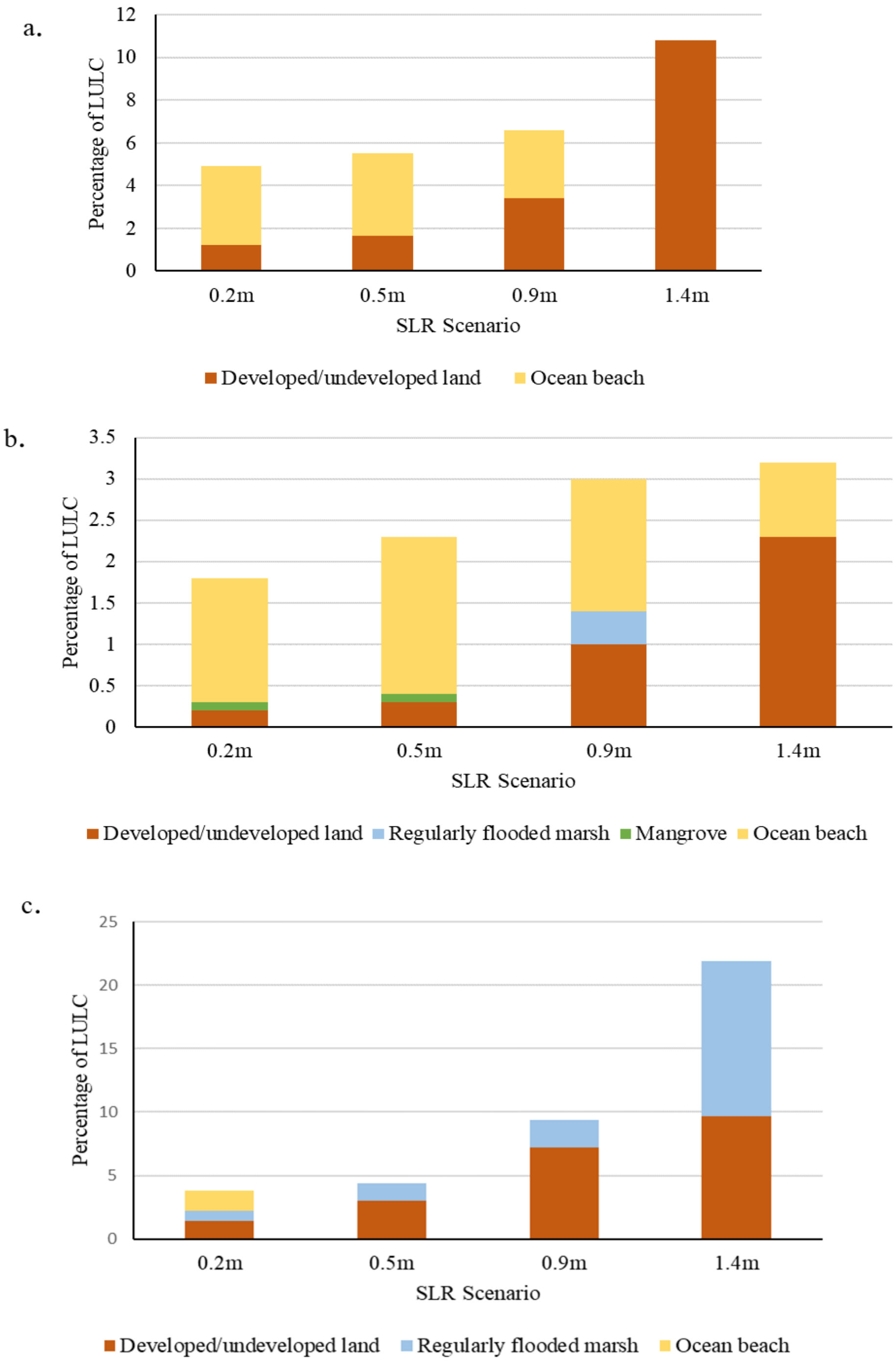

Figure 4.8: Percentage of Land use/cover likely to be exposed to SLR impacts in (a) Sawoma (b) Anlo Beach and (c) Glefe-wiaboman

4.1.2.2 People likely to be exposed to different SLR scenarios

The results of the SLR scenarios indicated that the number of buildings likely to be exposed are 129, 368 and 1610 for Sawoma, Anlo Beach and Glefe-Wiaboman respectively (Figure 9). These values were then multiplied by the average household size (obtained through the questionnaire survey) in each community. Figure 4.9 shows that with an increase in SLR between 0.2-1.4m about 761, 2024 and 8211 people in Sawoma, Anlo Beach and Glefe-wiaboman respectively are likely to be exposed to SLR impacts.

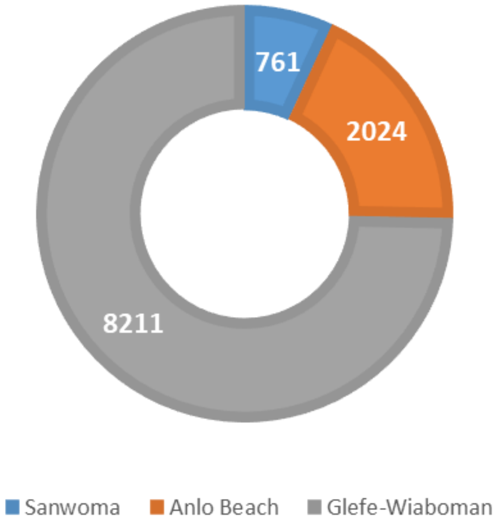

Figure 4.9: Number of people likely to be exposed to SLR impacts

4.1.2.3 People with experience of sea-level impacts

People with experience in dealing with hazards could potentially increase the area's readiness or preparedness for the impacts of sea level rise. They might have insights into how to manage or mitigate the effects of SLR due to their prior experiences with other hazards. As a result, areas that are more likely to be exposed to SLR may be better equipped to handle the consequences. Of the 359 people surveyed, 293 indicated that they have experienced hazards resulting from sea-level rise (Figure 4.10). Of these, 185 (63.1 percent) were reported in Anlo Beach while 57 (19.5 percent) and 51 (17.4 percent) were in Sawoma and Glefe-Wiaboman, respectively.

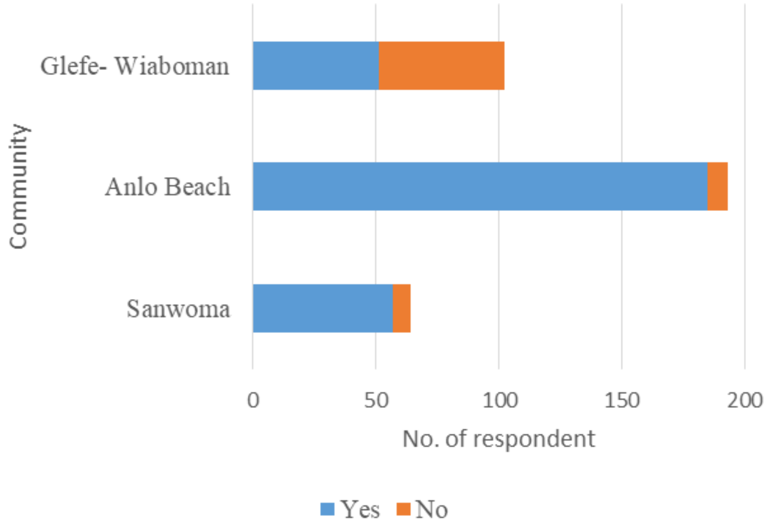

Figure 4.10: Respondents' experience of sea-level impacts (Coastal erosion/flooding) in the study communities

4.1.3. Assessment of the vulnerability of the rural coastal socio-ecological systems to Sea-Level Rise (SLR) impacts

Socio-ecological vulnerability (SEV) assessment is essential to better inform management interventions for community resilience in SLR. Socio-ecological vulnerability takes into account both social factors (access to resources, livelihoods) and ecological factors (such as ecosystem degradation and ecosystem service availability). These factors can interact and exacerbate each other, leading to increased vulnerability. The analysis in this study was based on two main components socio-economic (sensitivity and adaptive capacity) and ecological vulnerability (Change in area and ecosystem service availability).

4.1.3.1 Socio-economic vulnerability components

Socio-economic vulnerability takes into account the interplay between social factors, such as gender, age, ethnicity, and education, and economic factors, including income, employment, and access to basic services. It recognizes that communities facing multiple disadvantages are more likely to be vulnerable. In analysing socio-economic vulnerability, six (6) sensitivity and adaptive capacity, key indicators were used to quantify socio-economic vulnerability.

(a) Community sensitivity components

According to IPCC (2014), sensitivity refers to attributes of the system that directly affect the consequences of a hazard. It may include physical attributes of a system or social, economic and cultural attributes. In this study, six attributes that were used to assess the sensitivity level of the communities included gender, age structure, income structure, employment status, dependence on natural resources and quality of building material (Table 4.2).

Table 4.2: Characteristics of community sensitivity level

Indicator		Community		
		Sawoma (N=64)	Anlo Beach (N=193)	Glefe-wiaboman (N=102)
Gender	Percentage			
	Male	36.5	50.3	55.3
	Female	63.5	49.7	44.7
Age	Years			
	Minimum	18	18	18
	Maximum	67	73	74
	Mean	40.5	42.9	35.5
Income (Monthly)	Ghc			
	Minimum	0	0	0
	Maximum	1200	2500	3000
	Mean	378.1	556.0	681.7
Employment status	Percentage			
	Yes	93.7	98.4	91.3
	No	6.3	1.6	8.7
Dependence on natural resource	Percentage			
	Yes	71.4	89.1	24.3
	No	28.6	10.9	75.7
Building quality				
Foundation material				
	Concrete	27.0	23.8	34.0
	Block	60.3	57.5	66.0
	Clay	-	11.9	-
	Rafia	12.7	6.7	-
Wall material	Percentage			
	Block	31.7	69.9	99.0
	Clay	1.6	17.6	1.0
	Rafia	66.7	12.4	

As indicated in Table 4.2 out of the 359 respondents from the three coastal rural communities, 64 (17.8 percent) were from Sawoma, 193 (53.8 percent) from Anlo Beach and 102 (28.4 percent) from Glefe-Wiaboman. The percentages of male and female respondents were nearly equal among communities except Sawoma which had more females (63.5 percent) than males (36.5 percent). The average age of the household heads was between 35.5 and 40.5 years. In analysing the income levels, the mean income for respondents was between 378.1 and 681.7 Ghana cedis with Sawoma having the lowest maximum income of 1200 Ghana cedis. The income disparity can be attributed to the fact that most respondents were engaged in fishing and subsistence agriculture. Household heads who are unemployed were categorized as having high sensitivity to SLR impacts compared to household heads employed and most of the respondents in the study community were employed. Most of the respondents in Sawoma (71.4 percent) and Anlo Beach (89.1 percent) depended solely on natural resources for their livelihoods compared to the respondents in Glefe-wiaboman community which is close to the capital city Accra.

Vulnerability to the impacts of SLR also depends on the quality of the materials used to build the houses. Compared to buildings with mud foundations, buildings with block or concrete foundations are likely to be more resistant to the impacts of SLR. As depicted in Table 1, about 50 percent of the respondents in each of the study communities had buildings with block foundations. Building with a block foundation is common since is more affordable compared to the concrete foundation. Understanding the physical fragility of buildings and structures to SLR impacts requires knowledge of their wall materials (Tiepolo, 2014). Table 4.2 shows that the main wall material for most of the buildings in

Sawoma was raffia (66.7) as compared to Anlo Beach and Glefe-wiaboman with 69.9 percent and 99.0 percent of buildings with block as wall material.

Indicators such as gender, age, income structure, employment status, dependence on natural resources for livelihood and quality of building materials were combined to generate the sensitivity map for the study communities (Figure 11). The grids were categorized into low ($0 < VI < 0.45$), medium ($0.45 < VI < 0.70$), and high ($0.70 < VI < 1.00$) sensitivity by their sensitivity index. Sawoma community had approximately 71.4 percent, 20.6 percent and 7.9 percent of the respondents in the medium, high, and low sensitivity levels respectively. Most of the respondents who scored medium sensitivity levels were located within the Sawoma old close to the Ankobra River estuary. Similar trends were recorded in Anlo Beach with about 81.3 percent, 11.9 percent and 6.2 percent in the medium, high and low sensitivity levels respectively. Glefe-wiaboman on the other hand about 50.5 percent of the respondents scored low sensitivity, followed by 48.5 percent and 1 percent in medium and high sensitivity levels respectively.

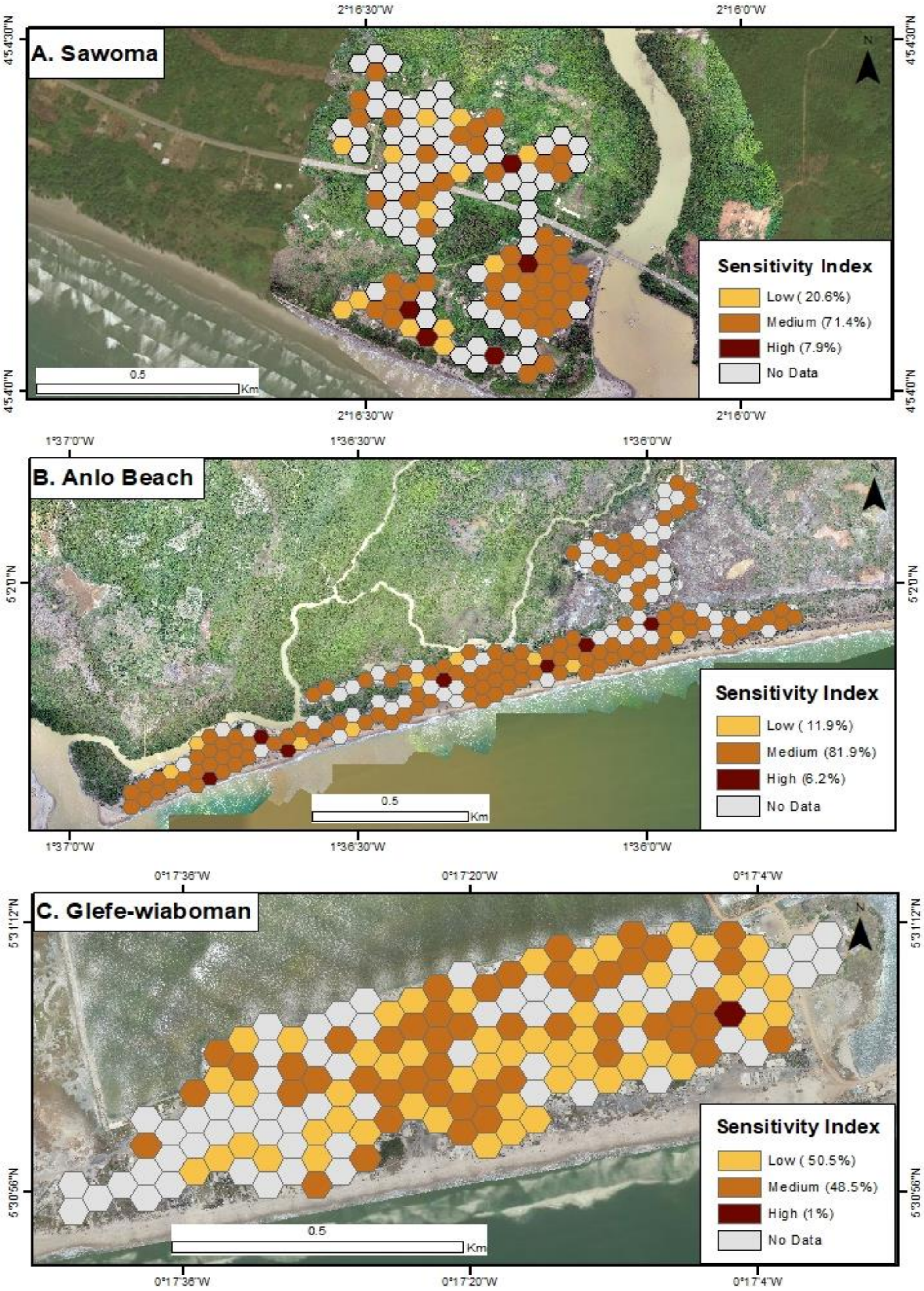

Figure 4.11: Sensitivity levels of the study communities

(b) Community adaptative capacity level

Adaptive capacity refers to the capability of systems, institutions, individuals, and other living entities to adapt in the face of potential harm, seize opportunities, or react to outcomes (IPCC, 2014). Six indicators obtained from the questionnaire survey were used the measure the capacity level of the communities. They included access to loans, availability of saving facilities, alternative livelihood, other income sources available to the respondent, membership in the health insurance scheme and respondent's involvement in social groups (Figure 4.12 a, b and c).

With regard to access to loans, more than half of the respondents in Anlo Beach responded in the affirmative. Sawoma and Glefe-wiaboman communities were almost at pal with 19 percent and 19.4 percent of the total respondents having access to loans. About 68.4 percent of respondents in Anlo Beach community have access to saving facilities followed by Sawoma community with 36.5 percent and Glefe-wiaboman community with 25.2 percent. percent. Furthermore, the majority of respondents in Anlo Beach (63.2 percent) had alternative livelihoods compared to Sawoma (38.1 percent) and Glefe-wiboman (19.4 percent). Among all the three communities, there was generally a low number of respondents who had other sources of income. The percentage of respondents who had access to health insurance was in the same range of 78.2 percent, 71.7 percent and 61.9 percent for Anlo Beach, Glefe-wiaboman and Sawoma respectively. In terms of affiliation to social groups, the majority of the respondents in Anlo Beach (78.2 percent) responded in the affirmative. This is followed by Sawoma (28.6 percent) and Glefe-wiaboman (17.5 percent) of respondents that belong to the social group.

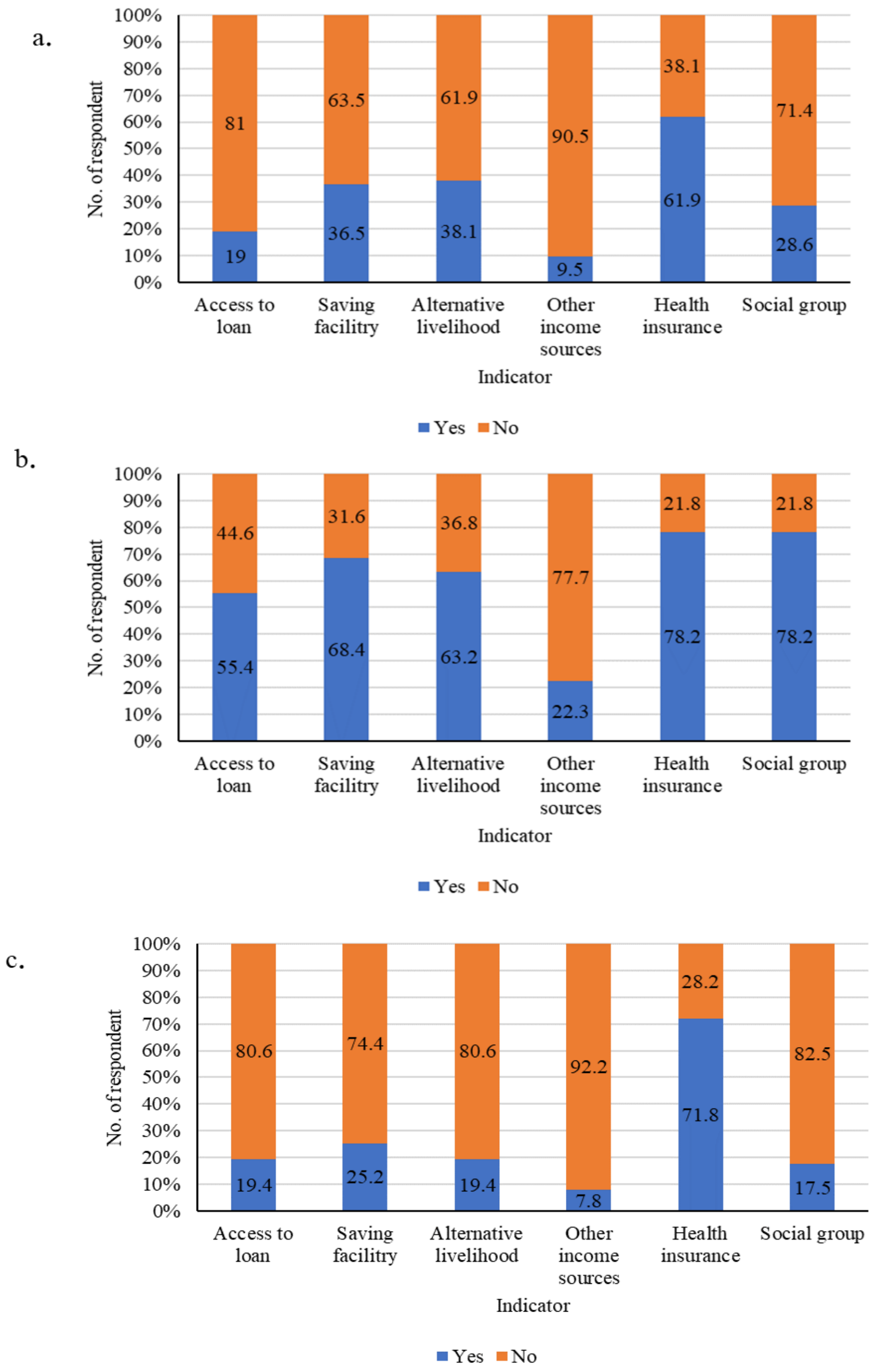

Figure 4.12: Percentage of response for the adaptive capacity indicator in (a) Sawoma (b) Anlo Beach and (c) Glefe-wiaboman

The indicators were aggregated to measure the adaptive capacity of the communities, a spatial map was created as shown in Figure 4.13. Sawoma community had approximately 79.4 percent, 19.0 percent and 1.6 percent of the respondents were in the low, medium, and high adaptive capacity levels respectively. Unlike Sawoma community, Anlo Beach had about 48.2 percent 32.6 percent and 19.2 percent in the low and high adaptive capacity levels. In Glefe-wiaboman, a similar trend as in the Sawoma community was observed: 80.6 percent of the respondents had adaptive capacity, followed by 16.5 percent and 2.9 percent with medium and high adaptive capacity levels respectively.

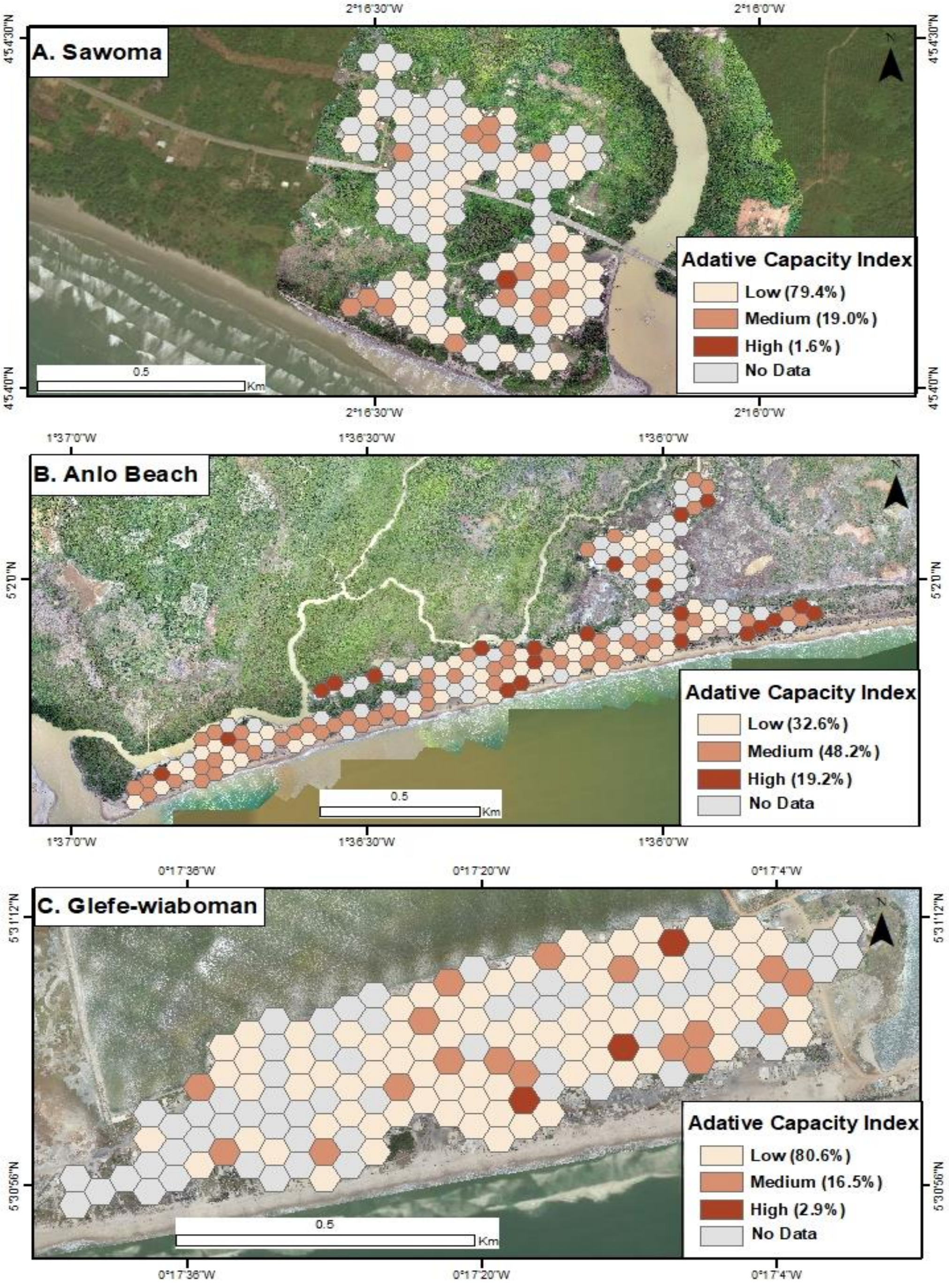

Figure 4.13: Adaptive capacity levels of the study communities

(c) Socio-economic vulnerability

Socio-economic vulnerability maps were generated by combining the sensitivity and adaptive capacity maps of the study communities. The maps were categorized into low (0 < VI > 0.45), medium (0.45 < VI > 0.70), and high (0.70 < VI >1.00) socio-economic vulnerability. Figure 4.14a-4.14c depicts the socio-economic vulnerability levels in Sawoma, Anlo Beach and Glefe-wiaboman respectively. Sawoma community had approximately 50.8 percent, 47.6 percent and 1.6 percent of the respondents were in medium, high and low socio-economic vulnerability respectively. Anlo Beach also had about 75.6 percent, 12.4 percent and 11.9 percent in the medium, high and low socioeconomic vulnerability levels. Glefe-wiaboman had a similar trend compared to the other two communities with about 76.7 percent, 19.4 percent and 3.9 percent of the respondents in medium, high and low socio-economic vulnerability.

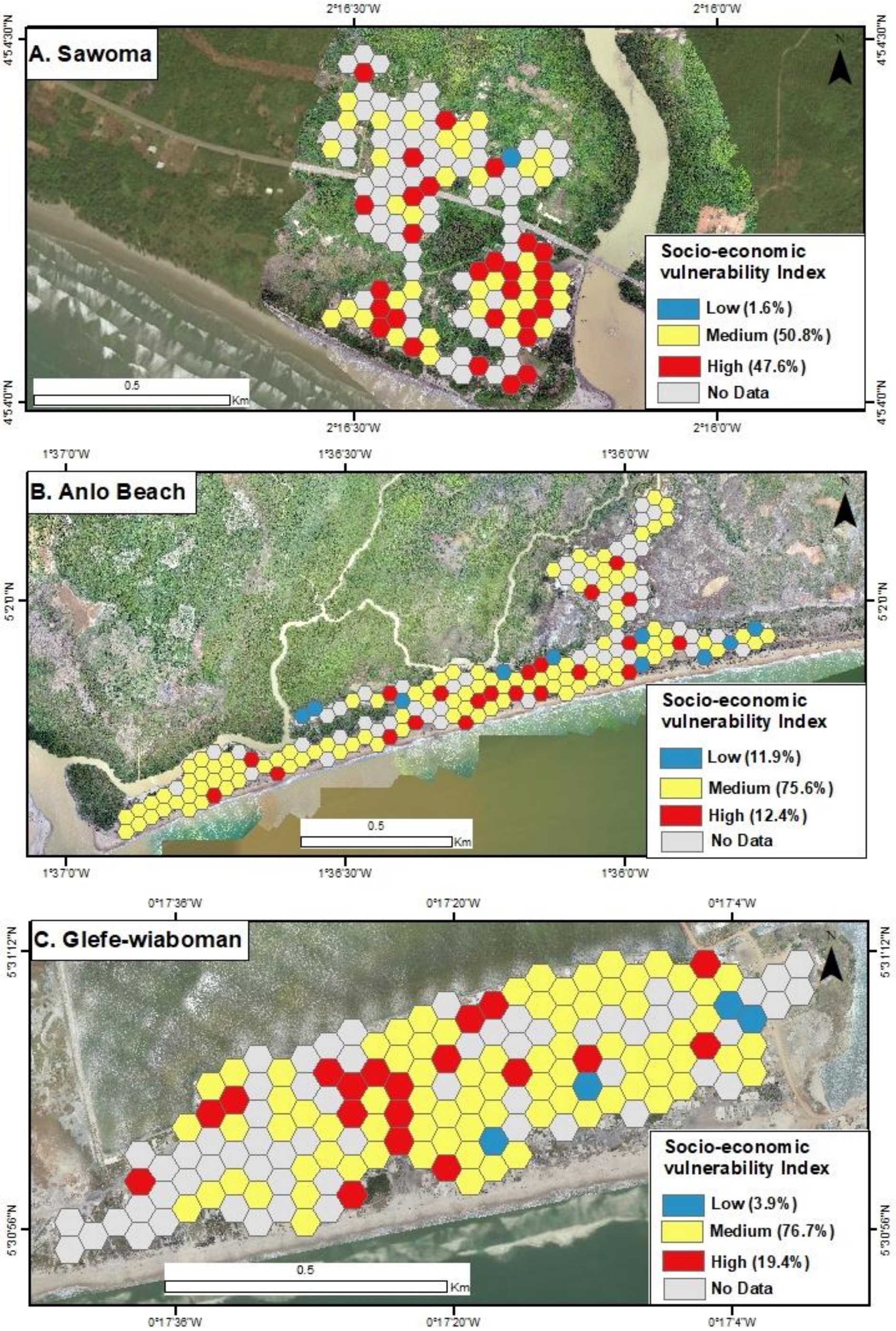

Figure 4.12: Socio-economic vulnerability levels of the study communities

4.1.3.2 Ecological vulnerability

Several studies have been conducted on ecological vulnerability from the perspectives of exposure, sensitivity, and adaptability of ecosystems to climate change (Kling *et al*., 2020; Metcalf *et al*., 2015). In this study, ecological vulnerability was assessed using the potential impact of SLR on the coastal ecosystem and the ecosystem service provided by the coastal habitat. The area changes stimulated by the SLAMM model and the expert assessments of the ecosystem services of the selected ecosystems were used as a proxy for measuring the vulnerability of the ecosystem to the impacts of sea level rise.

(a) Changes in coastal ecosystems induced by SLR

Table 4.3 indicates the coastal ecosystems in the study communities that are likely to be impacted by different SLR scenarios. With the assumption of no protection in the model procedure, the proportion of different coastal ecosystems changed significantly compared to the present day. The modelling results show that with an increase in SLR of 0.2m open beach areas are likely to be reduced in all the study communities with Glefe-wiaboman having the highest reduction of 1.601km^2. Regularly flooded marsh will likely increase in Anlo beach and Sawoma but reduce substantially in Glefe-wiaboman. Mangrove area will likely reduce slightly in Anlo beach but increase in Glefe-wiaboman.

Open beach area will likely decrease significantly in all the study communities with a 0.5m SLR. Regularly flooded marsh will likely increase slightly in Anlo Beach and Sawoma but will likely reduce Glefe-wiaboman. Mangrove areas will likely increase significantly in Glefe-wiaboman, it will, however, remain unchanged in Anlo beach. With an increase of 0.9m rise in sea level, open beach will likely be reduced in Sawoma and Anlo Beach but will likely increase significantly in GLefe-wiaboman. Both Anlo Beach and Glefe-

Wiaboman will likely see a decrease in regularly flooded marsh. In Glefe-wiaboman, mangrove areas will likely increase, whereas, in Anlo Beach, they will likely decline. The open beach area will likely increase to occupy about 2.683 km^2 and 1.919 km^2 in Glefe-wiaboman and Sawoma as accretion will likely occur with a SLR of 1.4m. However, open beach area in Anlo Beach will likely decrease. Regularly flooded marsh will increase in Anlo beach and Sawoma but will likely reduce considerably in Glefe-wiaboman. The braided deltaic nature of the Densu estuary, which allows for a large portion of the land to be covered by seawater, maybe attributed to the decline in regularly flooded marsh in Glefe-wiaboman. As a result of increasing soil salinity caused by SLR flooding, and favouring mangroves, mangrove areas in Anlo Beach and Glefe-wiaboman are likely to increase.

Table 4.3: Change in area (Km^2) coastal ecosystems induced by different SLR scenarios

	0.2m	0.5m	0.9m	1.4m
Coastal ecosystems		**Sawoma**		
Regularly flooded marsh	+0.277	+0.350	+0.562	+2.197
Open beach	-3.715	-3.883	-3.197	+1.919
		Anlo Beach		
Regularly flooded marsh	+0.138	+0.173	-0.370	+0.115
Mangrove	-0.101	-0.115	+ 0.586	+0.439
Open beach	-1.495	-1.854	-1.632	-0.907
		Glefe-wiaboman		
Regularly flooded marsh	-0.737	-1.369	-2.212	-12.186
Mangrove	+0.750	+1.384	+2.451	+12.974
Open beach	-1.601	-0.174	+2.599	+2.683

+ = Increase, - = Decrease

Source: Author (2022)

(b) Coastal ecosystems service availability

Table 4.4 shows the correspondence matrix between the most relevant coastal ecosystems in the study communities and the expert assessment of the selected coastal ecosystem services availability. Mangroves and regularly flooded marshes are the ecosystems that provide the highest availability of provisioning, regulating and maintenance services. Cultural services are mostly provided by the open beach ecosystem.

Table 4.4: Ecosystem service availability by habitat

Coastal ecosystems	Provisioning	Regulating and maintenance	Cultural
Mangrove	0.6	0.9	0.4
Regularly flooded marsh	0.5	0.7	0.3
Open beach	0.2	0.3	0.6

Source: Author (2023)

(c) Cumulative ecological vulnerability

A modified vulnerability quadrant matrix from Ha-Mim *et al*., (2020) was used to aggregate the scores obtained for SLR impact on the coastal ecosystem and its resultant ecosystem service availability in the study communities (See Figure 3.4). As depicted in Table 4.5, coastal ecosystems in Anlo beach and Sawoma will likely be moderately vulnerable to sea level rise impacts whilst that of Glefe-wiaboman will likely be highly vulnerable to an increase in sea level rise.

Table 4.5: Cumulative ecological vulnerability index for the study communities

Community	Ecological vulnerability
Sawoma	0.5
Anlo beach	0.6
Glefe-wiaboman	0.3

Source: Author (2023)

4.1.4 Assessment of risk levels of the rural coastal communities to sea-level rise (SLR) impacts

In order to generate the SLR risk levels for the communities, the conceptual framework for climate risk which was adapted from IPCC (2014) was used. This framework outlines risk as being dependent on factors such as hazards (impacts), exposure, and vulnerability. Table 4.6 shows the index for the risk component. Each component of risk as discussed below is categorized using Zebisch *et al*., (2017) classification of risk level using the relative scores for each component. Also, see Sections 4.1, 4.2 and 4.3 for the descriptive statistics on hazard, exposure, and vulnerability scores.

Table 4.6: Indices for hazard, exposure, vulnerability, and risk for the study communities

Community	Hazard	Exposure	Vulnerability	Risk
Sawoma	0.01	0.31	0.49	0.27
Anlo Beach	0.25	0.48	0.60	0.44
Glefe-wiaboman	1	0.7	0.43	0.71

Source: Author (2023)

4.1.4.1 Impacts of coastal hazards on study communities

The coastal hazards modelled in this study included erosion and inundation and helped to understand how different SLR scenarios can influence community risk. The hazard index ranges from 0.01 to 1 with Glefe-wiaboman recording the highest hazard score of 1 and can be attributed to the low-lying topography of Glefe-wiaboman. Anlo Beach recorded 0.25 whilst Sawoma recorded the least of 0.01 (Table 4.6). The scores show how the three rural communities are exposed to different levels of coastal hazards.

4.1.4.2 Community exposure to SLR

In general, the exposure of the rural coastal communities to the impacts of SLR ranged from high to medium, as the characteristics of the communities were not the same. Information derived from people’s experiences of SLR impacts also accounts for the differences in exposure levels. As shown in Table 4.6, Glefe-wiaboman scored the high (0.7) whilst Anlo Beach and Sawoma recorded 0.48 and 0.31 respectively.

4.1.4.3 Socio-ecological vulnerability of the study communities

Table 4.6 shows the socio-ecological profiles of all the study communities. The socio-ecological vulnerability ranged from 0.43 to 0.60 with Anlo Beach recording the highest score of 0.60. This was expected as Anlo beach community recorded the highest ecological vulnerability score (Section 4.3.2). Sawoma and Glefe-wiaboman recorded 0.43 and 0.49 respectively. With majority of the respondents scoring medium sensitivity level and low adaptive capacity level significantly contributed to low to medium Socio-ecological vulnerability levels.

4.1.4.4 SLR risk levels in the study communities

To determine the SLR risk for the study communities, the weighted arithmetic mean was used which involved aggregating the three risk components of hazard, exposure and vulnerability into a single risk indicator. Using Zebisch *et al*., (2017) classification, the risk levels of the study communities ranged from low to high risk, with Glefe-wiaboman having a high risk of 0.71 while Anlo beach and Sawoma had medium and low-risk levels of 0.27 and 0.44 respectively (Table 4.6). The case of Glefe-wiaboman was not surprising as it recorded the highest hazard and exposure score. Although it recorded the lowest vulnerability level it was not enough to offset these scores.

4.1.5. Factors influencing household's relocation intention in response to anticipation of sea-level rise

Understanding individual adaptation and community behaviour is critical in implementing climate change adaptation strategies. This section draws on the Protection Motivation Theory (PMT) to assess the factors influencing the relocation intention of study communities. It employs both descriptive and inferential statistics to assess key factors that influence residents' readiness to relocate in anticipation of sea level rise.

4.1.5.1 Descriptive statistics of variables used in the study

Table 4.7 summarizes the respondent's socio-demographic characteristics. The communities studied are not homogeneous, it is, therefore, important to understand their socio-economic composition in order to assess their behaviour towards climate adaptation measures. Other variables considered in the study are also summarized using figures.

(a) Socio-Demographic Characteristics of Respondents

Of the 359 respondents from the three coastal rural communities, 64 (17.8 percent) were from Sawoma, 193 (53.8 percent) from Anlo Beach and 102 (28.4 percent) from Glefe-wiaboman (Table 3). The percentages of male and female respondents were 46.0 percent and 54 percent, respectively. The majority of respondents (49.0 percent) were between the ages of 35 and 55. In terms of educational level, the majority of the respondents had completed middle school/junior high school (42.9 percent). Most of the respondents (53.2 percent) earned GHC101-500 every month. Only 10 percent of the respondents earned less than GHC 100 per month.

Table 4.7: Socio-demographic characteristics of respondents

Background characteristics	**Community**							
	Sawoma		Anlo Beach		Glefe-Wiaboman		Total	
	N	%	N	%	N	%	N	%
Community	64	17.8	193	53.8	102	28.4	359	100
Sex								
Male	23	13.9	96	58.2	48	27.9	165	46.0
Female	41	21.1	97	50.0	58	28.9	194	54.0
Age (years)								
<35 (Young adult)	22	17.2	55	43.0	51	39.8	128	35.7
35-55 (middle aged adult)	33	18.8	98	55.7	45	25.6	176	49.0
>55 (older adult)	9	16.4	40	72.7	6	10.9	55	15.3
Educational level								
No formal education	13	20.0	46	70.8	6	9.2	65	18.1
Primary	19	19.4	67	68.4	12	12.2	98	27.3
JHS/Middle	25	16.2	66	42.9	63	40.9	154	42.9
SHS/Voc/Tech	7	16.7	14	33.3	21	50.0	42	11.7
Average monthly income								
> GHC 100	8	22.2	17	47.2	11	30.6	36	10
GHC101-500	44	23.0	104	54.5	43	22.5	191	53.2
GHC 501-999	8	10.3	48	61.5	22	28.2	78	21.7
<GHC 1000	4	7.4	24	44.4	26	48.1	54	15.0

Source: Author (2022)

(b) Risk perception, Threat and Coping Appraisal

As shown in Figure 4.15, the communities had some differences in terms of cognitive factors. Anlo Beach and Sawoma had a score greater than 4.0 for all factors of threat appraisal except for TA3 (Neighborhood, friends, and/or family decide to leave the area) which Sawoma scored less than 4.0. Glefe-Wiaboman, on the other, had a score of less than 4.0 for all the threat appraisal factors (Figure 4.14a). For coping appraisal factors, Anlo Beach had a score greater than 4.0 for all the factors. Sawoma had a score of less than 4.0 except for CA1 (Relocation cost), with a score of 4 (Figure 4.14b). Anlo Beach and Sawoma scored the highest mean score greater than 3 in all the risk perception factors whilst Glefe had a mean score less than 3 (Figure 4.14c).

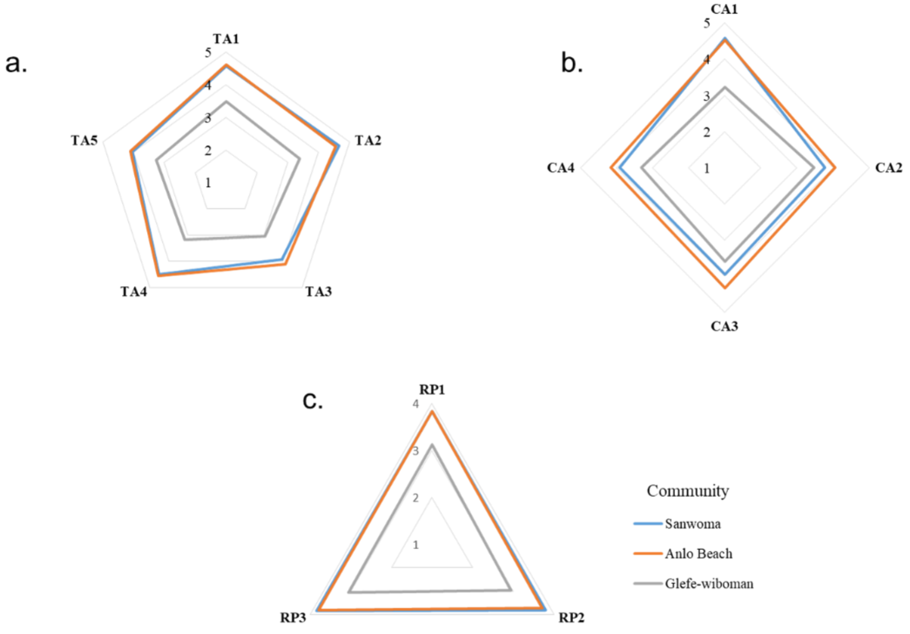

Figure 4.15: Scored values of factors associated with (a) Threat Appraisal (TA) (b) Coping Appraisal (CA) and (c) Risk Perception (RP)

(c) Hazard experience

Out of 359 respondents interviewed, 293 indicated that they have experience hazards resulting from sea-level rise (Figure 4.16). Of these, 185 (63.1 percent) were reported in Anlo beach whilst 57 (19.5 percent) and 51 (17.4 percent) were in Sawoma and Glefe-Wiaboman, respectively.

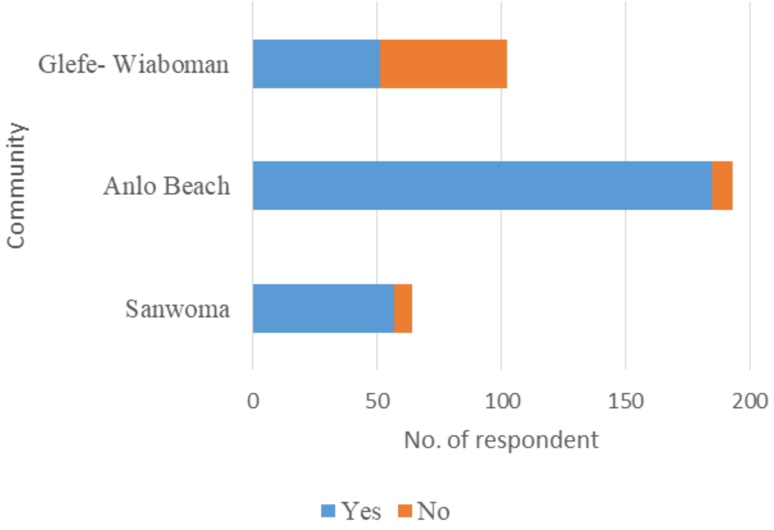

Figure 4.16: Respondents' experience of sea-level impacts (Coastal erosion/flooding) in the study communities

(d) Proximity to hazard areas.

Studies have revealed that proximity to hazard can influence risk perception and people living close to hazard areas will likely adopt coping strategies to mitigate the risk (Arias *et al*., 2017; Zhang *et al*., 2010). Most of the respondents in study communities were affected by the flood and/or erosion depending on their proximity to these hazards. The results presented in Figure 4.17 indicated that, in terms of erosion, 40 percent of the respondents in Sawoma were located 101- 400 m to the erosion risk areas and 5 percent were located 700 m and beyond away from the erosion risk areas. In the Anlo beach community, 88 percent of the respondents were less than 100 m from the erosion risk areas and 5 percent were within 401-700 m of the erosion risk areas. A vast difference was noted in Glefe-wiaboman community, half of the respondents (51 percent) were located less than 100 m from the erosion risk areas. With regards to proximity to flood risk areas, as shown in Figure 4.17, the majority of the respondents in Sawoma (39 percent) were within 401-700 m close to the flood risk areas. All the respondents in Anlo beach were located less than 100 m to the flood risk areas. In Glefe-wiaboman, the majority of the respondents (73 percent) were within less than 100m of the flood risk areas.

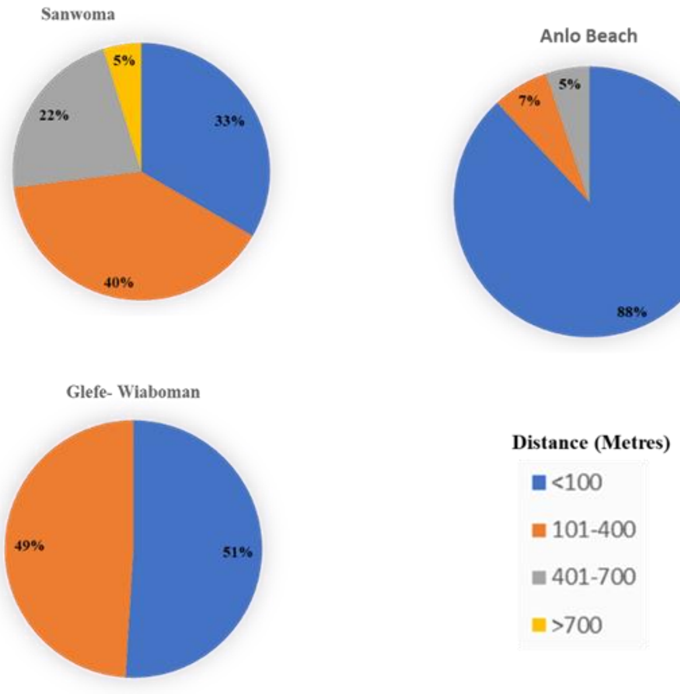

Figure 4.15: Respondents proximity to shoreline in the study communities

4.1.5.2 Measures of association between factors considered in the study

Post Hoc Tests were conducted to find the difference between the compositional/contextual factors and the cognitive factors (Table 4 in Appendix E). The results indicated that the age group middle-aged adults and older adults were statistically associated with risk perception ($P< 0.008$ and $P< 0.005$ respectively) compared to young adults. In terms of the level of education of the respondents with primary education had a statistically significant influence on coping appraisal ($P < 0.027$) compared to respondents with no formal education. Respondents within the income category GHC 101-500 and GHC 501-999 had a statistically significant influence on both threat appraisal and coping appraisal. Hazard experience of the respondents had a statistically significant influence on risk perception ($P < 0.000$) and threat appraisal ($P < 0.019$). Respondents living at a distance between 100 and 300 metres from showed a statistically significant association with risk perception ($P < 0.000$), threat appraisal ($P < 0.009$), and coping appraisal ($P < 0.015$). Distance to flood risk areas of the respondents had a statistically significant influence on both threat appraisal ($P < 0.002$) and coping appraisal ($P < 0.036$). ANOVA was conducted to examine the association between the cognitive factors and relocation intention whilst Pearson chi-square and Cramer's V statistics were employed to assess the relationship between compositional/ contextual factors and relocation intention.

The results of the one-way ANOVA (Table 4.8) show that among the three cognitive factors, risk perception had a statistically significant relationship with relocation intention. Additionally, the Pearson chi-square and Cramer's V statistics results (Table 4.9) indicated there is no association between relocation intention and the compositional and contextual factors.

Table 4.8: Analysis of variance (ANOVA) results of Cognitive factors and relocation intention

Variable	**P-value**
Risk perception	0.000*
Threat Appraisal	0.084
Coping Appraisal	0.040*

Source: Author (2022)

Table 4.9: Distribution of compositional and contextual variables by predictor variables.

Variable	**Relocation Intention**		
	Will relocate	**Will not relocate**	**Inferential statistics**
Sex of respondent			
Male	147	18	χ^2=0.79, p-value =0.456; Cramér's V = 0.15
Female	171	23	
Age of respondent			
Young adult	117	11	χ^2=1.879, p-value =0.391; Cramér's V = 0.72
Middle-aged adult	152	24	
Older Adult	49	6	
Educational level			
No formal education	55	10	χ^2=2.700, p-value =0.440; Cramér's V = 0.087
Primary	85	13	
JHS/Middle	141	13	
SHS/Voc/Tech and above	37	5	
Average monthly income			
> GHC 100	33	3	χ^2= 3.524, p-value = 0.318; Cramér's V = 0.099
GHC101-500	170	21	
GHC 501-999	71	7	
<GHC 1000	44	10	
Elevation			
>4m	233	30	χ^2=1.780, p-value =0.411; Cramér's V = 0.070
4-9m	73	11	
<9m	12	0	
Distance to shoreline			
>100m	134	12	χ^2=3.671, p-value =0.160; Cramér's V = 0.101
100-400m	159	27	
<400	25	2	
Hazard experience			χ^2= 3.654, p-value =0.440; Cramér's V = 0.101
Yes	264	29	
No	54	12	

Source: Author (2022)

4.1.5.3 Factors affecting relocation decision

The relationship between relocation intention and the key predictors (cognitive factors), compositional and contextual were examined using four different models in the multivariate analysis. The models employed were cognitive factors (model 1), biosocial factors (model 2), sociocultural factors (model 3), and contextual factors (model 4). Table 4.10 presents the proportional odds ratios, robust standard errors, probability values, and confidence intervals for the cognitive factors, compositional, and contextual components.

Table 4.10: Ordered logistic regression model showing the relation between relocation intention and household characteristics.

Variables	Odds ratio	Robust SE	P-value	Conf. Interval	
Model 1: Cognitive Factors					
Risk perception	1.495	0.179	0.001	1.182	1.890
Threat Appraisal	1.334	0.160	0.017	1.054	1.688
Coping Appraisal	1.304	0.190	0.068	0.980	1.734
Model 2: Model 1 + Biosocial factors					
Risk perception	1.572	0.200	0.000	1.225	2.018
Threat Appraisal	1.327	0.165	0.023	1.040	1.692
Coping Appraisal	1.290	0.182	0.071	0.979	1.700
Sex (ref: Female)					
Male	1.202	0.350	0.527	0.679	2.128
Age (ref: Young adult)					
Middle-aged adult	0.440	0.155	0.020	0.221	0.876
Older adult	0.919	0.490	0.875	0.323	2.614
Model 3: Model 2 + Socio-cultural factors					
Risk perception	1.633	0.215	0.000	1.261	2.115
Threat Appraisal	1.359	0.177	0.019	1.052	1.754
Coping Appraisal	1.208	0.178	0.198	0.906	1.611
Sex (ref: Female)					
Male	1.141	0.346	0.664	0.629	2.068
Age (ref: Young adult)					
Middle-aged adult	0.397	0.154	0.017	0.185	0.850
Older adult	0.725	0.402	0.562	0.245	2.148
Education (ref: No formal education)					
Primary	1.370	0.608	0.478	0.574	3.270
Middle School/JHS	1.383	0.615	0.467	0.578	3.308
Secondary School and above	1.290	0.717	0.646	0.434	3.832
Household monthly income (GHC) (ref: below 100)					
101-500	0.394	0.218	0.093	0.133	1.167
501-999	1.014	0.692	0.984	0.266	3.862
1000 and above	0.303	0.189	0.056	0.089	1.030
Model 4: Model 3+ Contextual factors					
Risk perception	1.421	0.223	0.025	1.045	1.933
Threat Appraisal	1.316	0.175	0.039	1.014	1.707
Coping Appraisal	1.178	0.171	0.260	0.886	1.565
Sex (ref: Female)					
Male	1.141	0.352	0.668	0.623	2.090
Age (ref: Young adult)					
Middle-aged adult	0.403	0.155	0.018	0.190	0.857
Older adult	0.693	0.380	0.504	0.237	2.030
Education (ref: No formal education)					
Primary	1.473	0.676	0.398	0.599	3.620
Middle School/JHS	1.547	0.702	0.336	0.636	3.765
Secondary School and above	1.519	0.908	0.485	0.471	4.900
Household monthly income (GHC) (ref: below 100)					
101-500	0.375	0.200	0.067	0.132	1.069
501-999	0.995	0.661	0.994	0.271	3.657
1000 and above	0.302	0.184	0.049	0.092	0.995
Hazard Experience (ref: No)					
Yes	1.704	0.683	0.184	0.777	3.739
Elevation	1.010	0.100	0.918	0.832	1.226
Distance of house from Shoreline (ref: below 100m)					
100-300m	0.655	0.238	0.244	0.321	1.335
Above 300m	0.862	0.469	0.785	0.297	2.502

The results of model 1 indicate that risk perception (p-value < 0.005) and threat appraisal (p-value < 0.05) among the cognitive factors have a positive significant relationship with relocation intention. This suggests that households who believe that sea-level rise is taking place and poses a danger to both natural and built environments are more likely to consider relocating. In Model 2, where we controlled for biosocial factors, found that risk perception and threat appraisal continued to have a positive significant relationship with relocation intention. Furthermore, households headed by middle-aged adults were found to be 56 percent (p-value < 0.05) less likely to relocate compared to households with young adult heads. However, there was no significant relationship between sex and relocation intention. The results of Model 3 (sociocultural) showed no substantial differences from Model 2 concerning risk perception, threat appraisal, sex, and age, except for minor variations in the proportional odds ratios. Moreover, the sociocultural factors, including education and household income, had no significant relationship with relocation intention. In the final model, where contextual factors including hazard experience and distance of house from shoreline were controlled for, there were slight changes in the proportional odds ratios for the variables, including risk perception, threat appraisal, and age, that had a significant relationship with relocation intention in Model 3. Besides, the study found that household monthly income, which was not significant in Model 3, became a significant predictor in the contextual model. Households with a monthly income of 1000 cedis and above were 70 percent less likely to relocate (p-value < 0.05) compared to those with a monthly income below 100 cedis. However, neither of the two contextual factors exhibited any significant association with relocation intention.

4.2. Discussion of Results

Sea Level Rise (SLR) impacts have been a major issue in Ghana in recent years and it has triggered a lot of studies and management interventions. Evidence from this study as well as other recent studies, (Amoani *et al*., 2012; Addo, 2009, Addo, 2015; Jayson-Quashigah *et al*., 2013; Jonah *et al*., 2016b) have shown the physical, social, economic and ecological consequences of the impacts of SLR of coastal communities in Ghana. Low-lying coastal areas, including urban centers like Accra and Sekondi-Takoradi, are susceptible to being submerged or flooded with rising sea levels. This would result in the loss of valuable land, infrastructure, and property, displacing communities and disrupting economic activities. Most of the studies, as well as adaptation interventions, largely focused on coastal cities and towns (The World Bank, 2017), where the greatest losses occur, however, rural coastal communities are confronted with unique adaptation challenges to sea level rise which are far more than that of the urban areas (Dasgupta *et al*., 2015). For instance, the average erosion rate in Anlo Beach community over the years 1974 to 2021 was 1.21 m/yr ± 0.10 m (Figure 4.2) which is slightly greater than that of Accra and Elimina-Cape Coast as reported by Addo, (2015) and Jonah *et al*., (2016) respectively. The area close to the Pra River estuary experienced the highest change in coastline extent, with the loss of approximately 100 m^2 of land. This can be attributed to the interaction between the Pra River and the sea. Coastal areas are dynamic in nature and the wave actions in response to ocean tides and climate change will continue to threaten life and properties in those vulnerable communities, hence the need for urgent proactive mitigation actions by both local and national governments.

According to Jonah *et al*. (2016), open ocean sandy beaches are more prone to erosion than other coastal landforms. In this study, for instance, all the study communities have a continuous stretch of sandy open ocean beaches and which accounts for the high erosion rates. This explains why coastal rural settlements are increasingly being destroyed and the inhabitants displaced (CRC, 2013; Addo *et al*., 2018). Also, the erosion of beaches, which act as the fish landing sites for the rural coastal communities are crumbling the local fishing sector and has worsened the unemployment and the related issues in these communities. Since the vulnerability of those communities is a function of their livelihood and the instability of the coastal ecological services is not sustainable, there is, therefore, a need for rural empowerment programmes that meet the needs of the local condition in that region. Mitigation activities that harness indigenous knowledge will be a major strategy for these communities. Inclusive planning approaches as indicated in the SDGs target 'leave no one behind' will be very apt in policy formation in this region and for the entire country.

SLR scenarios as stimulated by the SLAMM model, reveal the spatial extent to which sea level-related processes will likely affect coastal rural communities. As shown in Figure 4.3c, the coastal land area impacted by erosion/accretion and inundation resulting from a rise in sea-level from 0.2 m to 1.4 m, indicates that Glefe-wiaboman will likely experience the loss of land area at a rate that substantially exceeds the other communities. The observed trend is consistent with the study by Amoani *et al*., 2012) which established that continuous increase in sea level, will likely have a significant impact on the Densu wetlands, a wetland of international importance and serves as the habitat for waterfowl and some important migratory birds. The study pointed out that the existing unemployment issue in the Glefe-wiaboman will worsen if the saltpans for the salt industry nearby are flooded. Besides, human activities such as physical development and deforestation have also interfered with the natural coastal processes will likely aggravate the impact of SLR. For example, the widespread sand mining activities in Glefe-wiaboman will likely reduce the beach elevation and allow more water into the beach. Rising sea levels combined with sand mining made communities more susceptible to erosion and inundation leading to the destruction of settlements and properties. Sand mining as an anthropogenic activity in the coastal areas of Ghana should receive major planning attention in the country. Although, sand mining is a major source of construction material in the building industry, the Ministry of Environmental agencies and other related MDAs must carry out action and subject plan mappings to delineate marginal coastal lands for conservation and preservation activities.

Also, a detailed vulnerability assessment of the salt factory and its Environmental Impact Audit should be carried out on a specified regular time frame. A loss of the industry to SLR without adequate preparation will have a ripple effect on the region and the nation in the form of rural-urban migration that is already a challenge to urban managers. More so, unemployment and poverty have been adjudged as the incubators of conflict in its entire ramification, hence the need for all hands to be on deck.

According to Kuenzer and Renaud, (2012), deltaic areas are dynamic, low-lying zones formed by the interplay of rivers and the ocean. These areas are frequently hubs of biodiversity, as well as centres of intensive agricultural activity and high population due to their abundant natural resources like water and fertile soils. However, they are also highly susceptible to environmental threats such as rising sea levels. (Wong *et al*., 2014). As shown in Figure 4.8 with an increase in the SLR up to 1.4 m, more than 10 percent of the land use/cover in study communities will likely be exposed to SLR impacts and may significantly affect the livelihoods as the economies of coastal rural communities are heavily dependent on local natural resources, which sea level rise may have the potential to deplete. The presence of saltwater in groundwater can have a substantial impact on crop yields and product quality (Xiao *et al*., 2021). Despite the numerous benefits that are derived from mangroves such as coastal safeguard, habitat for wildlife and fishes, carbon sequestration, and pollution filtering (Ellison, 2015), mangrove ecosystems in the Anlo Beach and Glefe-wiaboman will likely reduce with a rise of 0.9m in Sea level (Figure 4.8b, Figure 4.6c and Table 4.3). Some studies have shown that the relationship between the growth of coastal wetland vegetation and hydro-geomorphology will assist coastal wetlands survive despite the devastating impacts of SLR (Kirwan and Megonigal, 2013 and Ellison, 2015). As shown in Figure 4.6c and Table 4.3 mangrove ecosystem in Glefe-wiaboman will likely increase in extent with the continuous increase in SLR. This may be attributed to the availability of suitable topography and area which allow the net vertical marsh movement to match with the relative SLR. A typical example can be found in North America, where several coastal vegetations are reacting to the rise in sea level and climate change through variations in composition and structure (Bhattachan *et al*., 2018).

With the socio-ecological security being threatened by climate change extreme events. Most rural households in Ghana are below the poverty line and have extremely limited access to resources and infrastructure, making it difficult for them to deal with any kind of climate change extreme events (GSS, 2013). Over the years, there have been significant economic and social changes in the three study communities. The decline in fish productivity has left many families unemployed. About three hundred residents in the three communities have been displaced due to coastal erosion and inundation (Figure 4.10). This has resulted in residents migrating from the communities, especially in Anlo beach and Sawoma communities (CRC, 2013; Osman *et al*., 2016). With the anticipation of sea level rise significant number of residents in the study communities will likely be exposed to the impact of SLR as indicated in Figure 4.7. The socio-economic situation is an important factor in the vulnerability of rural coastal communities to the impacts of sea level rise. The socioeconomic situation is a major factor in the coastal rural communities' susceptibility to the impacts of sea level rise. The findings of the study have shown that the communities have high to medium sensitivity and low adaptation to the impacts of SLR. These account for the medium socio-economic vulnerability recorded (see Figures 4.11. 4.12 and 4.13). This finding is consistent with a study by Tessler *et al*. (2015) who conducted a study on 48 major deltaic areas and found that low GDP is the primary cause of the high vulnerability in the deltaic areas in developing countries.

The assessment of climate risk is urgently needed to enhance knowledge of the risk of climate change and develop effective adaptation strategies. In this study, SLR risk assessment was conducted for coastal rural communities by combining three categories of hazard, exposure and vulnerability. According to Nguyen *et al*., (2019), it is very important to combine the three categories of climate risk assessment in order to have a good understanding of the situation. The results of this study indicate that the coastal rural communities face different levels of SLR risk and the impact on these communities with higher risk levels is likely to be exacerbated in the future considering different SLR scenarios. For instance, Glefe-wiaboman with a high population density and comparatively good economy was identified as a high-risk community whilst Anlo beach and Sawoma recorded medium and low risk levels of 0.27 and 0.44 respectively (Table 4.6). Apart from sea level rise, which is a proven contributor to coastal erosion and inundation along the majority of Ghana's beaches, sand mining is a common activity along most Ghanaian coastlines (Amoani *et al*., 2012; Addo, 2009; Boateng *et al*., 2017; Jonah, *et al*., 2016) and is also true for the Glefe-wiaboman and its surrounding beaches. There are many construction-related factors that contribute to excessive sand mining, including the development of new buildings to meet the growing population. Beach sand mining operations are prohibited by law, and strong restrictions have been put in place to ensure local-level compliance, (Wiafe, 2010). Nevertheless, the lack of enforcement tempts people to continue to engage in this illegal activity along the beaches of Ghana. Also, the low-lying topography of Glefe-wiaboman compared to other study communities also makes the areas susceptible to SLR impacts as stipulated by (Wong *et al*., 2014). They found that communities with low-lying topography are more vulnerable to the impacts of SLR. Proper coastal zone management, provision of infrastructural development, and sufficient institutional arrangement are effective management strategies for reducing community’s SLR risk levels (Dasgupta *et al*., 2015; Wong *et al*., 2014)

The study reveals some new trends in how different types of coastal rural communities react to long-term threats arising from the impacts of climate change. This provides insights into the behavioural aspect of implementing managed retreat as an adaptation strategy to curb the impacts of sea-level rise. According to protection Motivation Theory (Rogers, 1975, Rogers, 1983) and other previous studies (e.g., Koerth *et al*., 2013), adaptation behaviour is linked to cognitive variables such as risk perception, threat and coping appraisal. In this study, risk perception appears to be a significant factor in explaining relocation intention. The prominent role of perceived sea level rise risk in promoting adaptation has been found by Koerth *et al*., (2013) and Song and Peng (2017). Since risk perception increases the intensity of adaptation, it is important to emphasize this to encourage the coastal rural households to take protective measures and one way to improve risk assessment would be to educate them on the impending sea level rise impacts. Contrary to the study by Zheng *et al*., (2016) risk perception as shown in this study is a better predictor of climate change adaptation compared to adaptation appraisal. In addition, the study also established that threat appraisal is a better predictor for relocation intention than coping appraisal. This echoes the findings of (Song and Peng, 2017).

As shown in Table 4.10, model 1 shows that the perceived risk and the perceived expectation of being exposed to the risk in the study communities positively influence respondents' intentions to relocate, but the capacity to perform risk preventive behaviours does not significantly influence these intentions. The study also confirms the conclusion drawn by researchers such as Kellens *et al*., (2011) and Song and Peng, (2017) that the influence of biosocial factors on climate change adaptation action is mixed and varies between contexts. In this study, age appears not to be a significant factor in explaining adaptation behaviour. Age, on the other hand, was found to have a strong positive association with risk perception (Table 4 Appendix E). In general, the older the respondents, the higher the sea level rise risk perception level they have. This may be because older respondents have experienced many historical sea-level rise impacts and they are accountable for the safety of their families. Song and Peng (2017) further argued that in the event of a sea-level rise disaster, young people are more likely to stay since they have stable income sources and strong social ties. As a result, letting go of these areas of one's life and relocating to a new location might be difficult.

People with higher education should be more likely to pursue individual-level adaptation strategies in theory, however, the results in Table 4.10 indicated no association between relocation intention and education in the three rural coastal communities. However, studies have also reported a strong association between education and mitigation behaviour (Qasim *et al*., 2015; Song and Peng, 2017) and climate change action (Bryan *et al*., 2009; González-Hernández *et al*., 2019). According to these studies, higher-educated persons were less likely to adapt to climate change because they were more likely to understand issues of climate change and they also believe it is the government obligation to undertake high-cost adaptation strategies and while they are able to implement low-cost and low-effort preventative steps. In terms of the respondents' monthly income, there was a significant relationship between income and relocation intention. This study revealed that high-income households were more likely to relocate compared to lower-income households as they can afford the cost of relocation and also take other adaptation measures since they have more assets to protect themselves from sea-level rise disasters. Similar conclusions were also drawn by (González-Hernández *et al*., 2019).

As seen in Figures 4.14 and 4.15 majority of the respondents have experienced hazards in their lifetime and also live within erosion and flood risk areas. This was not surprising as these communities were situated along major estuaries and wetlands, making them highly susceptible to impacts from sea level rise. In Anlo Beach, for example, the community is flooded for several weeks by seawater twice every year, destroying properties and obstructing economic activities. In July 2009 alone, 78 houses were destroyed, rendering several inhabitants homeless (CRC, 2013). Despite these events, these hazard experiences and proximity to risk areas do not seem to influence their intention to relocate to a new area. However, these factors significantly influence the cognitive factors, as indicated in Table 4 in Appendix E.

4.3. Summary of Findings

The following are summaries of the findings of the study;

The study reveals that not all the study communities are equally susceptible to the impacts of SLR. With an increase of SLR up to 1.4m, about 3.8 km^2 area will likely be affected by erosion and inundation induced by SLR. Glefe-wiaboman community will likely experience a high cumulative impact resulting from both erosion and inundation due to its low topography. Anlo beach with open sandy beaches will also experience higher coastal erosion compared to urban areas.

Secondly, a significant number of people and coastal ecosystems will be exposed to SLR impacts especially in Glefe-wiaboman community. With a sea level rise of 0.5-1.4 meters above the current Mean Sea Level (MSL), approximately 35.7 percent of the total land area and 8211 residents in Glefe-wiaboman will likely be exposed to sea level rise impacts. This area also inhabits the Densu wetland, which is a wetland of international importance which provides numerous supports for biological diversity including migratory birds.

Socio-ecological vulnerability levels were high in areas where there were human settlements and critical ecosystems. The levels varied between 0.43 and 0.60, with Anlo Beach recording the highest score of 0.60, as anticipated due to its highest ecological vulnerability score. Sawoma and Glefe-wiaboman reported vulnerability scores of 0.43 and 0.49, respectively. The prevalence of respondents scoring at the medium sensitivity level and low adaptive capacity level significantly contributed to the overall low to medium levels of socio-ecological vulnerability.

Glefe-wiaboman community was identified as a high-risk to SLR impacts, despite its high socioeconomic structure and population density. Glefe-wiaboman having a high risk of 0.71 while Anlo beach and Sawoma had medium and low-risk levels of 0.27 and 0.44 respectively.

The study reveals that apart from the cognitive factors, compositional factors such as household age and income were more important for predicting the relocation intention of coastal rural communities in Ghana. Contextual factors such as hazard experience and proximity to shoreline did not appear to be significant in influencing residents' relocation intention, which was explained by the fact that most of the households were already used to sea-level rise impacts such as erosion and flooding.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The study involved the assessment of risk levels and adaptation behaviour within three coastal rural communities in Ghana. Understanding future sea-level rise risk levels and community adaptation behaviour is critical in implementing climate change adaptation strategies. This study was premised on the concept of climate risk that explained climate risk as a function of impacts, exposure and vulnerability. While prior studies have mostly concentrated on the impacts of sea level rise on urban coastal regions, coastal rural areas confront a unique set of risks given their socioeconomic structure, particularly in regard to their dependence on natural resources. The finding of the study indicated that about 3.8 km^2 area will likely be affected by erosion and inundation induced by SLR. As a result, a significant number of people and coastal ecosystems will likely be exposed to these impacts and will have a significant negative effect on the livelihood of the communities. With the socio-ecological integrity being threatened by climate change extreme events, the livelihood of the coastal community will likely worsen with the increase in SLR. The socioeconomic situation is a major factor contributing to the vulnerability of the coastal rural communities. The study examined risk levels of the rural coastal communities under study to impacts of projected sea-level rise by aggregating indices from the risk component.

Although Glefe-wiaboman had a high socioeconomic structure and population density than the other communities, it was identified as a high-risk community due to its location as a low-lying area.

The study further provided insights into the behavioural aspect of implementing managed retreat as an adaptation strategy to curb the impacts of sea-level rise. The results of this study showed that apart from the cognitive factors, compositional factors such as household age and income were found to be more important for predicting the relocation intention of coastal rural communities in Ghana. Contextual factors such as hazard experience and proximity to shoreline did not appear to be significant in influencing resident relocation intention, which was explained by the fact that most of the households were already used to sea level rise impacts such as erosion and flooding.

5.2 Recommendations

The following recommendations are based on the conclusions and major findings of the study.

5.2.1 Recommendations on policy improvement

The findings of this study have significant implications for current policy processes, specifically regarding the development of locally based strategies and plans for adapting to sea level rise. Although the individual indicators of different components show different trends for different communities understudy the overall risk indexes indicated that residents of Glefe-wiaboman are at high risk of increasing sea level. Therefore, this study calls for stakeholders such as the Land Use and Spatial Planning Authority (LUSPA) and National Disaster Management Organization (NADMO) to prepare a disaster risk management plan which involves strict zoning regulations that prohibit or restrict construction within a 30m from the coastline as stipulated in The Environmental Assessment Regulations, LI 1652. This can help maintain a buffer zone and prevent encroachment into hazardous areas prone to erosion, storm surge, or sea-level rise.

Assessing the level of risk due to SLR is an important study for policy design and national sustainable development more especially Sustainable Cities and Communities (Goal 11) and Climate Action (Goal 13). The findings from the study have provided important information for community-level SLR risk assessment along the coast of Ghana. As a matter of national interest, relevant government institutions can replicate the methodology used in this study, to identify high-risk and vulnerable coastal communities within the country and such information can also be integrated and used in the policy formulation.

Strategies to relocate these rural communities should target cognitive characteristics and, in particular, promote household-level adaptation as a viable and cost-effective approach to responding to sea-level rise impacts. Increased information dissemination by the government and civil society organizations could motivate households to prepare for floods even more. The campaigns should emphasize the effects of future sea-level rise impacts on communities, increasing household self-confidence in adaption strategies and educating people about the benefits of relocation at the community level.

5.2.2 Recommendations on performance improvement

This study found that a significant number of socio-ecological systems in the study area will likely be exposed to sea-level impacts. It is expected that risk/vulnerability maps as well as the inundation maps will be useful for the district assemblies to develop sustainable land use planning and zoning for the communities. This will restrict development in high-risk areas, such as floodplains and low-lying areas. The assemblies should encourage the relocation of infrastructure and new settlements to safer locations. Reducing the price of land in these areas by the chiefs in communities could prove successful in enticing people to relocate to low-risk zones.

Structural and non-structural measures are required to improve the physical and socio-economic resilience capacity of coastal rural communities in order to cope with rising sea levels. For instance, rural communities should be encouraged to diversify their economic activities beyond sectors vulnerable to sea level rise, such as agriculture or tourism. The Ministry of Trade and Industry should promote the development of sustainable industries and provide support for business transitions.

Also, the communities should be encouraged to adopt nature-based solutions to the SLR impacts which involve educating the communities on protecting and restoring natural barriers, such as mangrove forests, salt marshes, and dune systems. These ecosystems provide valuable protection against erosion, storm surges, and flooding.

5.2.3. Suggestions for further research

This study focused on sea rise level risk due to erosion and inundation. Other impacts of SLR that were not considered in the study but are relevant to the understanding of dynamics along the coast of Ghana include storm surges as well as saltwater intrusion of estuaries and groundwater. Additional measurements on the phenomena should be carried out to gain a deeper understanding of SLR risk and adaptation measures for the entire coast of Ghana.

5.3 Contributions to the Body of Knowledge

1. The study advances the coastal resilience literature by illuminating the impacts of different SLR scenarios on coastal rural communities.
2. It contributes to the climate adaptation literature through the application of the Protection Motivation Theory (PMT).
3. The methodology employed in the study demonstrates how remote sensing can be linked to social science to understand human-environment interactions.
4. The study shed light on how UAV technology can used in flood risk assessments.
5. Lastly, it intervenes in ongoing debates on climate change adaptation planning. The analysis indicates that a mix of infrastructure and behavioural change is required to adapt to the impacts of climate change.

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APPENDICES

Appendix A – Questionnaire for household respondents in the study communities

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA.
GRADUATE RESEARCH IN CLIMATE CHANGE AND HUMAN HABITAT
SCHOOL OF PHYSICAL SCIENCE

SEA-LEVEL RISE: RISK AND ADAPTATION STRATEGIES IN RURAL COASTAL COMMUNITIES IN GHANA

QUESTIONNAIRE FOR HOUSEHOLD HEAD

The main objective of this study is to assess the risk levels of some selected rural coastal communities in Ghana under different sea-level rise scenarios. The information you provide is purely for academic purposes. You are assured of full confidentiality, privacy and anonymity of all the information that will be given by you. Kindly express your candid opinion which would serve as a source of vital information for this study. Thank you.

Please, tick here if you have been provided with all the information you need and agree to participate [ ]

Community:…………………………… Grid no. ……………..

GPS coordinate: Longitude…………………….. Latitude……………………….

Interviewer ID………………

Please tick [√] **where applicable.**

1. Sex a. Male [ ] b. Female [ ]
2. Age at last birthday (Please specify) ……………………
3. Education: Primary [ ] Middle School/JHS [ ] Secondary/SHS [ ]

   Post-secondary/Tertiary [ ] No formal education [ ] Other, please specify…………..
4. For how long have you been living in the area?

Below 5years [ ] 5-10 years [ ] 10-15 years [ ] 15-20 years [ ] more than 20 years [ ]

5. Household size………………………………………………….
6. Primary occupation……………………………………………….
7. Secondary occupation…………………………………………….
8. Household monthly income (GHS)…………………………………………
9. Household monthly expenditure…………………………………………….
10. Other source of income aside from the primary/secondary occupation?

    None [ ] Pension allowances [ ] Remittances [ ] Other, please specify ……………

11. Do you have saving? Yes [ ] No [ ]

12. If Yes, where

    Bank [ ] Community group [ ] House [ ] Other, please specify ………

13. If no, why………………………………………………………………..

14. Do you have access to any loan groups, organizations, or companies?

    Yes [ ] No [ ]

15. Do you belong to any social group/association?

    Yes [ ] No [ ]

16. Do you have any specialized skill?

    Yes [ ] No [ ]

17. If Yes, please specify the kind of skill

…………………………………………………………………………………………………

18. Are you registered member of National Health Insurance Scheme (NHIS)?

Yes [ ]   No [ ]

19. Which of these natural assets do you depend on for your livelihood?

Arable land [ ]   Sea [ ]   River [ ]   Mangrove forest [ ]   Fishing grounds [ ]
Other, please specify………………………………………………………………………..

20. Do you have unrestricted access to these natural assets?

Yes [ ]   No [ ]

21. If No, please explain how……………………………………………………….............

22. Physical characteristics of building

Foundation Material	Blocks	Concrete	Rafia	Other ……………..
Floor Material	Sand	Cement	Rafia	Other ……………..
Wall Material	Block	Clay	Rafia	Other ……………..

Roof Material	Zinc	Thatch	Asbestos	Other ……………..

23. To what extent do you agree with the following hypothesis

Hypothesis	**Strongly agree**	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**
Sea-level rise is taking place					
Sea level rise pose a danger to the natural environment					
sea level rise pose a danger to the built environment					

Please Skip to Question 26 if you disagree with each of the hypothesis in Question 23.

24. In your opinion, what is the cause of sea level rise?

……

25. Which kind of damage have you experienced as a result of sea-level rise?

…………………………………………………………………………………
…………………………………………………………………………………
………………

26. If your house is locate in or close to areas that are likely to be inundated or eroded owing to sea level rise, how likely would you move to a new location?

Very likely [ ] Likely [ ] Neutral [ ] Unlikely [ ] Very unlikely [ ]

27. In your opinion, which of these options would be the best to prevent future impacts from sea-level rise in your community? **(Please tick only one)**

a. Artificial protective barriers (sea defense and levees) [ ]
b. Artificial protective barriers (Sand nourishment and wetland) [ ]
c. Relocation [ ]
d. Increased housing elevation [ ]
e. Do nothing [ ]
f. Other measures…………………………………………………

28. How important are the following factors in your decision to prompt you to move to a new safer location?

Factors	**Very Unimportant**	**Not important**	**No opinion**	**Important**	**Very Important**
	1	**2**	**3**	**4**	**5**
Sea level rise impacts become too frequent and destructive					
Safety of myself and/or my family					
Neighborhood, friends, and/or family decide to leave the area					
Property is severely damaged					
No provision of adaptation measures (eg. shoreline protection)					
Other, please specify:					

29. How important are the following factors in your decision to move to a new safer location?

Factors	**very unimportant**	**Not important**	**No opinion**	**Important**	**Very Important**
	1	**2**	**3**	**4**	**5**
Relocation cost					
Distance to current workplace					
Job opportunities at the new location					
Availability of social amenities at the new location					
Social and family ties					
Other, please specify:					

30. What type of assistance should government offer to support relocation?

………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE!

Appendix *B* – Questionnaire for experts in coastal ecosystems

Coastal Ecosystem Service Supply Assessment.

This assessment is part of a PhD which seeks to assess sea-level rise risk in three coastal rural communities in Ghana. We would be grateful if you could rate the supply of Ecosystem Services (ES) for the selected coastal habitats using four evaluation classes:
0- Unknown, when the contribution of the habitat to provide the ES is unknown to you,
1-low, when the contribution to this ES is low or irrelevant,
2- Moderate, when the contribution is considered important but in a substantially lower magnitude than other habitats,
3- High, when the contribution is elevate and considerably higher than the average.
Your expert opinion which would serve as a source of vital information for this study.
Thank you.

S/N	**Mangrove forest**	**Unknown**	**Low**	**Moderate**	**High**
1.	Food				
2.	Material eg. fuel				
3.	Flood regulation				
4.	Water purification				
5.	Climate regulation				
6.	Nutrient recycling				
7.	Soil formation				
8.	Spiritual/religious experience				
9.	Education/Research				
10.	Recreation/Tourism				
S/N	**Regularly flooded marsh (Intertidal)**	**Unknown**	**Low**	**Moderate**	**High**
1.	Food				
2.	Material eg. fuel				
3.	Flood regulation				

4.	Water purification				
5.	Climate regulation				
6.	Nutrient recycling				
7.	Soil formation				
8.	Spiritual/religious experience				
9.	Education/Research				
10.	Recreation/Tourism				
S/N	**Coastal dunes/sandy beaches**	**Unknown**	**Low**	**Moderate**	**High**
1.	Food				
2.	Material eg. fuel				
3.	Flood regulation				
4.	Water purification				
5.	Climate regulation				
6.	Nutrient recycling				
7.	Soil formation				
8.	Spiritual/religious experience				
9.	Education/Research				
10.	Recreation/Tourism				

Appendix *C* – Focus Group Discussion Guide

Sea level rise impacts

How has the sea level and other climatic variables changed over the past 10 year, 20 years and 30 years?

How will the sea-level change in the future?

What are the current and potential sea-level rise impacts in the community?

What is the frequency/rate of these impacts?

Do you see the sea-level rise as a threat to the community?

What are livelihood resources affected by the hazards?

Adaptation

How do you cope or adapt to the impacts of sea-level rise?

How effective are these strategies?

Are these strategies sustainable?

What are the constraints when undertaking adaptation strategies?

Is the community prepared to relocate to a different site?

If no, what are the reasons for staying in the hazard zone?

If yes, what plans are put in place?

Appendix *D* – LULC matrix in km^2 for different sea level scenarios in the study area

Table 1: Land use/cover change matrix in km^2 for different sea level scenarios in Sawoma

			2030				
	Wetland Class	D/UL	RFM	OB	OO	Total	percent
2021	D/UL	0.9465	0.0038	0.0000	0.0129	0.9632	**70.29631**
	RFM	0.0000	0.1482	0.0000	0.0000	0.1482	**10.81594**
	OB	0.0000	0.0000	0.022	0.0509	0.0729	**5.320391**
	OO	0.0000	0.0000	0.0000	0.1859	0.1859	**13.56736**
	Total	**0.9465**	**0.1520**	**0.022**	**0.2497**	**1.3702**	**100**
	percent	**69.0775**	**11.0932**	**1.6056**	**18.2236**	**100**	

			2050				
2021	D/UL	0.9407	0.0048	0.0009	0.0168	0.9632	**70.29631**
	RFM	0.0000	0.1482	0.0000	0.0000	0.1482	**10.81594**
	OB	0.0000	0.0000	0.0188	0.0541	0.0729	**5.320391**
	OO	0.0000	0.0000	0.0000	0.1859	0.1859	**13.56736**
	Total	**0.9407**	**0.1530**	**0.0197**	**0.2568**	**1.3702**	**100**
	percent	**68.65421**	**11.1662**	**1.437746**	**18.74179**	**100**	

			2070				
2021	D/UL	0.9164	0.0077	0.0177	0.0214	0.9632	**70.29631**
	RFM	0.0000	0.1482	0.0000	0.0000	0.1482	**10.81594**
	OB	0.0000	0.0000	0.0114	0.0615	0.0729	**5.320391**
	OO	0.0000	0.0000	0.0000	0.1859	0.1859	**13.56736**
	Total	**0.9164**	**0.1559**	**0.0291**	**0.2688**	**1.3702**	**100**
	percent	**66.88075**	**11.3779**	**2.123778**	**19.61757**	**100**	

			2090				
2021	D/UL	0.8158	0.0301	0.0931	0.0242	0.9632	**70.29631**
	RFM	0.0000	0.1482	0.0000	0.0000	0.1482	**10.81594**
	OB	0.0000	0.0000	0.0061	0.0668	0.0729	**5.320391**
	OO	0.0000	0.0000	0.0000	0.1859	0.1859	**13.56736**
	Total	**0.8158**	**0.1783**	**0.0992**	**0.2769**	**1.3702**	**100**
	percent	**59.53875**	**13.0127**	**7.239819**	**20.20873**	**100**	

Table 2: Land use/cover change matrix in km^2 for different sea level scenarios in Anlo Beach

				2030				
	Wetland Class	D/UL	RFM	M	OB	OO	Total	percent
2021	D/UL	0.8004	0.0017	0.0007	0.0036	0.0054	0.8118	**12.4193**
	RFM	0.0000	2.5253	0.0019	0.0000	0.0000	2.5272	**38.6623**
	M	0.0000	0.0092	2.1424	0.0000	0.0000	2.1516	**32.9162**
	OB	0.0000	0.0000	0.0000	0.1724	0.1013	0.2737	**4.1871**
	OO	0.0000	0.0000	0.0000	0.0000	0.7723	0.7723	**11.8150**
	Total	**0.8004**	**2.5362**	**2.1450**	**0.1760**	**0.8790**	**6.5366**	**100**
	percent	**12.2449**	**38.7999**	**32.8152**	**2.6925**	**13.4473**	**100**	

				2050				
2021	D/UL	0.7904	0.0023	0.0015	0.0078	0.0098	0.8118	**12.4193**
	RFM	0.0000	2.5082	0.0190	0.0000	0.0000	2.5272	**38.6623**
	M	0.0000	0.0280	2.1236	0.0000	0.0000	2.1516	**32.9162**
	OB	0.0000	0.0000	0.0000	0.1447	0.1290	0.2737	**4.1872**
	OO	0.0000	0.0000	0.0000	0.0000	0.7723	0.7723	**11.8150**
	Total	**0.7904**	**2.5385**	**2.1441**	**0.1525**	**0.9111**	**6.5366**	**100.0**
	percent	**12.0919**	**38.8352**	**32.8015**	**2.3330**	**13.9384**	**100.00**	

				2070				
2021	D/UL	0.7468	0.0028	0.0113	0.0379	0.0130	0.8118	**12.4193**
	RFM	0.0000	2.4138	0.1134	0.0000	0.0000	2.5272	**38.6623**
	M	0.0000	0.0864	2.0652	0.0000	0.0000	2.1516	**32.9162**
	OB	0.0000	0.0000	0.0000	0.1291	0.1446	0.2737	**4.1872**
	OO	0.0000	0.0000	0.0000	0.0000	0.7723	0.7723	**11.8150**
	Total	**0.7468**	**2.5030**	**2.1899**	**0.1670**	**0.9299**	**6.5366**	**100**
	percent	**11.4249**	**38.2921**	**33.5021**	**2.5548**	**14.2261**	**100**	

				2090				
2021	D/UL	0.6592	0.0032	0.0330	0.0991	0.0173	0.8118	**12.4193**
	RFM	0.0000	2.2974	0.2298	0.0000	0.0000	2.5272	**38.6623**
	M	0.0000	0.2341	1.9175	0.0000	0.0000	2.1516	**32.9162**
	OB	0.0000	0.0000	0.0000	0.1153	0.1584	0.2737	**4.1872**
	OO	0.0000	0.0000	0.0000	0.0000	0.7723	0.7723	**11.8150**
	Total	**0.6592**	**2.5347**	**2.1803**	**0.2144**	**0.9480**	**6.5366**	**100**
	percent	**10.0848**	**38.7770**	**33.3553**	**3.2800**	**14.5030**	**100**	

Table 3: Land use/cover change matrix in km^2 for different sea level scenarios in Glefe-wiaboman

				2030				
	Wetland Class	D/UL	RFM	M	OB	OO	Total	percent
2021	D/UL	0.5909	0.0006	0.0002	0.0638	0.0201	**0.6756**	**10.9727**
	RFM	0.0000	1.8198	0.0570	0.0000	0.0000	**1.8768**	**30.4819**
	M	0.0000	0.0110	0.8267	0.0000	0.0000	**0.8377**	**13.6054**
	OB	0.0000	0.0000	0.0000	0.2488	0.1624	**0.4112**	**6.6785**
	OO	0.0000	0.0000	0.0000	0.0000	2.3558	**2.3558**	**38.2615**
	Total	**0.5909**	**1.8314**	**0.8839**	**0.3126**	**2.5383**	**6.1571**	**100**
	percent	**9.5971**	**29.7445**	**14.3558**	**5.0771**	**41.2256**	**100**	
				2050				
2021	D/UL	0.4949	0.0006	0.0003	0.1562	0.0236	0.6756	**10.9727**
	RFM	0.0000	1.7802	0.0966	0.0000	0.0000	1.8768	**30.4819**
	M	0.0000	0.0117	0.8260	0.0000	0.0000	0.8377	**13.6054**
	OB	0.0000	0.0000	0.0000	0.2443	0.1669	0.4112	**6.6785**
	OO	0.0000	0.0000	0.0000	0.0000	2.3558	2.3558	**38.2615**
	Total	**0.4949**	**1.7925**	**0.9229**	**0.4005**	**2.5463**	**6.1571**	**100**
	percent	**8.0379**	**29.1127**	**14.9892**	**6.5047**	**41.3555**	**100**	
				2070				
2021	D/UL	0.2326	0.0008	0.0139	0.3821	0.0462	0.6756	**10.9727**
	RFM	0.0000	1.7134	0.1634	0.0000	0.0000	1.8768	**30.4819**
	M	0.0000	0.0264	0.8113	0.0000	0.0000	0.8377	**13.6054**
	OB	0.0000	0.0000	0.0000	0.1891	0.2221	0.4112	**6.6785**
	OO	0.0000	0.0000	0.0000	0.0000	2.3558	2.3558	**38.2615**
	Total	**0.2326**	**1.7406**	**0.9886**	**0.5712**	**2.6241**	**6.1571**	**100**
	percent	**3.7778**	**28.2698**	**16.0563**	**9.2771**	**42.6191**	**100**	
				2090				
2021	D/UL	0.0788	0.0008	0.0477	0.5027	0.0456	0.6756	**10.9727**
	RFM	0.0000	0.4266	1.4502	0.0000	0.0000	1.8768	**30.4819**
	M	0.0000	0.6991	0.1386	0.0000	0.0000	0.8377	**13.6054**
	OB	0.0000	0.0000	0.0000	0.0737	0.3375	0.4112	**6.67847**
	OO	0.0000	0.0000	0.0000	0.0000	2.3558	2.3558	**38.2615**
	Total	**0.0788**	**1.1265**	**1.6365**	**0.5764**	**2.7389**	**6.1571**	**100**
	percent	**1.2798**	**18.2960**	**26.5791**	**9.3616**	**44.484**	**100**	

Appendix *E*– Multiple Comparisons between compositional/contextual factors and cognitive factors

Table 4: Multiple Comparisons between compositional/contextual factors and cognitive factors

Variable	Mean Difference	Std. Error	Sig.	95 percent Confidence Interval	
Risk Perception				**Lower Bound**	**Upper Bound**
Sex (ref: Female)					
Male	0.066	0.235	0.797	-0.364	0.559
Age (ref: Young adult)					
Middle-aged adult	0.682	0.254	0.008	0.18	1.18
Older adult	0.986	0.353	0.005	0.29	1.68
Education (ref: No formal education)					
Primary	-0.383	0.354	0.279	-1.08	0.31
Middle School/JHS	-0.387	0.327	0.237	-1.03	0.26
Secondary School and above	-0.870	0.438	0.048	-1.73	-0.01
Household monthly income (GHC) (ref: below 100)					
101-500	0.435	0.403	0.282	-0.36	1.23
501-999	0.434	0.447	0.333	-0.45	1.31
1000 and above	0.324	0.477	0.498	0.61	1.26
Hazard Experience (ref: No)					
Yes	92.289	0.259	0.000	2.434	3.452
Elevation (ref: below 4m)					
4-9m	0.275	0.278	0.323	-0.27	0.82

<9m	0.513	0.654	0.434	-0.77	1.80
Distance of house from Shoreline (ref: below 100m)					
100-300m	-1.200	0.235	0.000	-1.66	-0.74
Above 300m	0.375	0.445	0.400	-0.50	1.25
Threat Appraisal					
Sex (ref: Female)					
Male	0.886	0.357	0.347	-1.085	0.319
Age (ref: Young adult)					
Middle-aged adult	0.040	0.392	0.919	-0.81	0.73
Older adult	-0.547	0.544	0.316	-1.62	0.52
Education (ref: No formal education)					
Primary	-0.904	0.531	0.089	-1.95	0.14
Middle School/JHS	0.453	0.491	0.357	-0.51	1.42
Secondary School and above	1.072	0.657	0.104	-0.22	2.36
Household monthly income (GHC) (ref: below 100)					
101-500	-1.987	0.601	0.001	-3.17	-0.80
501-999	-2.562	0.667	0.000	-3.87	-1.25
1000 and above	-1.269	0.712	0.076	-2.67	0.13
Hazard Experience (ref: No)					
Yes	5.520	0.453	0.019	-2.430	-0.649

Elevation (ref: below 4m)					
4-9m	0.306	0.423	0.471	-0.53	1.14
<9m	-0.444	0.997	0.656	-2.41	1.52
Distance of house from Shoreline (ref: below 100m)					
100-300m	0.970	0.368	0.009	0.25	1.69
Above 300m	-0.779	0.698	0.265	-2.15	0.59
Coping Appraisal					
Sex (ref: Female)					
Male	1.364	0.343	0.244	-1.050	0.298
Age (ref: Young adult)					
Middle-aged adult	0.157	0.377	0.678	-0.58	0.90
Older adult	0.194	0.523	0.711	-0.84	1.22
Education (ref: No formal education)					
Primary	-1.148	0.516	0.027	-2.16	-0.13
Middle School/JHS	-0.804	0.478	0.093	-1.74	0.13
Secondary School and above	-0.478	0.639	0.455	-1.73	0.78
Household monthly income (GHC) (ref: below 100)					
101-500	-1.381	0.573	0.016	-2.51	-0.25
501-999	-2.585	0.636	0.000	-3.84	-1.34

1000 and above	-0.500	0.679	0.462	-1.83	0.83
Hazard Experience (ref: No)					
Yes	1.129	0.440	0.289	-1.704	0.026
Elevation (ref: below 4m)					
4-9m	0.713	0.405	0.079	-0.08	1.51
<9m	0.011	0.955	0.991	-1.87	1.89
Distance of house from Shoreline (ref: below 100m)					
100-300m	0.866	0.356	0.015	0.17	1.57
Above 300m	0.587	0.675	0.385	-0.74	1.91