ASSESSING COASTAL VULNERABILITY: A CASE STUDY OF ANYAMAM AND AKPLABANYA IN THE ADA WEST DISTRICT OF GHANA

BY

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DECLARATION

I, Obed Omane Okyere, hereby declare that this thesis is my conceptualized work under supervision. This thesis has never been presented in whole or in part in this University or any other institution for the award of any degree. All sources of information cited in this thesis have duly been acknowledged.

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ABSTRACT

Akplabanya and Anyamam are the two largest coastal populations in the Ada West District in Ghana. The coastal areas remain vulnerable to coastal hazards, particularly flooding and coastal erosion. However, there is limited understanding of how biophysical and socioeconomic conditions interact to make these communities vulnerable and which of them is most at risk. This study provides further understanding of dimensions of vulnerability across the two communities and their levels of vulnerability to coastal erosion and coastal flooding. The study used a descriptive research approach, combining quantitative results with qualitative evidence for more comprehensive analysis. The overall objective of the project was to assess the vulnerability of the coastal communities of Akplabanya and Anyamam by integrating current coastal erosion trends, future coastal flooding dynamics due to projected Sea Level Rise, and social perspectives on the dynamics of vulnerability. The study assessed current coastal erosion trends using the linear regression (LRR) approach, which showed median erosion rates of approximately -1.85 m/yr ±0.23 for Akplabanya and -2.07 m/yr ±0.23 for Anyamam. The study also assessed the extent of coastal flood hazard based on IPCC SLR projections under RCP 5-8.5. Akplabanya and Anyamam., For Akplabanya, the projected inundation areas were 2210.90sqm (0.17%), 2524.53sqm (0.19%), and 41823.31sqm (3.1%), for the periods 2021 – 2040, 2041 – 2060 and 2081 – 2100, respectively. In contrast, Anyamam showed much larger projected inundation area of 6472.01sqm (0.6%), 162756.93sqm (16%) and 331,063.84 m^2 (32.54%)for the same periods. Socio-economic data was obtained from 97 face-to-face questionnaires with residents and two Focus Group Discussions to understand local vulnerability relating to exposure, sensitivity, potential impact, adaptive capacity and composite vulnerability indexes. Anyamam exhibited higher average vulnerability (0.794) compared to Akplabanya (0.191), reflecting the overall

assessment across the examined vulnerability dimensions. The results show that the two communities experience different levels of vulnerability to coastal erosion and coastal flooding due to variations in exposure, sensitivity and adaptive capacity levels. In particular, Anyamam shows relatively higher vulnerability to both hazards due to the relatively higher levels of exposure and sensitivity. The study locations will benefit from adaptive capacity-improving activities and initiation of coastal stability projects.

DEDICATION

This thesis is dedicated to my family and all lovers of education and research.

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Acronym	Meaning
BTM	Bathtub Model
CVI	Composite Vulnerability Index
DCE	District Chief Executive
DEMs	Digital Elevation Models
DSAS	Digital Shoreline Analysis System
DWB	Dry-Wet Boundary
FGDs	Focus Group Discussions
GCPs	Ground Control Points
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Position System
IPCC	Intergovernmental Panel on Climate Change
LRR	Linear Regression Rate
NADMO	Natural Disaster Management Organization
NASA	National Aeronautics and Space Administration
NGO	Non-Governmental Organization

RTK	Real Time Kinematic
SLR	Sea Level Rise
UAVs	Unmanned Aerial Vehicles
UTM	Universal Transverse Mercator
WGS	World Geodetic System

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Coastal zones are the interface between land and sea, which act as crucial buffers against extreme climatic events (Deltares, 2008; Godschalk & Burns, 2019). These zones represent complex ecosystems where concentrated populations rely on economic and social activities for development. However, these areas are continually exposed to natural hazards including erosion and flooding for centuries, necessitating investigation to assess and mitigate risks (Clare et al., 2022; Nativí-Merchán et al., 2021).

Coastal regions worldwide have faced erosion and flooding for centuries, with growing recognition of these hazards (Clare et al., 2022). Flooding is widely considered as one of the costliest hazards due to its combined socio-economic and environmental impacts, which becomes even more devastating when coupled with coastal erosion in the same location (Pollard et al., 2019). These hazards, interacting with specific pathways within vulnerable communities, become sources of significant danger. Traditionally, assessments of erosion and flood hazards have been conducted separately because of the complexities associated with the interactions between driving forces, morphological responses, and risk receptors (Alves et al., 2020; Pollard et al., 2019). However, these hazards are projected to worsen due to rising sea levels and other climate-related threats, coupled with population growth (Silver et al., 2019). This is expected to become more pronounced in developing countries, where limited data and weak early warning leave ecological systems facing particularly high risks, thereby jeopardizing vulnerable coastal communities and cities (Appeaning Addo et al., 2020).

Le Cozannet et al. (2014) predicts that most coastal locations will likely undergo several transitional stages in the coming centuries where initially, sea level rise impacts might be less significant compared to other coastal processes then, the expectation is that sea level rise will exacerbate coastal erosion. Finally, in a later stage (potentially beyond 2100), sea level rise could potentially cause water levels to increase several meters, leading to permanent inundation and drainage interferences in many low-lying areas. Also, according to Fox-Kemper et al., (2021), even under a low emissions scenario, sea level rise will rise steadily similar to current rates estimated at 3 – 8 mm per year by 2100 comparted to 3–4 mm per year in 2015. In contrast, higher emission scenarios show greater acceleration, with sea level rise exceeding five times the current rate by 2100, especially if emission levels are high and large-scale processes such as Antarctic ice sheet retreat occur. In response to these possibilities, the International Panel for Climate Change (IPCC) has formally categorized sea level projections into Representative Concentration Pathways (RCPs), which are based on different emissions scenarios across various time periods (IPCC, 2021; IPCC, 2023). While the Global South is expected to experience the largest increase in coastal population exposure under scenarios of low adaptive capacity, the Global North may see slower growth or possible decline in exposed populations. This may translate into relatively greater impacts for the Global South, given its heightened vulnerability and lower adaptive capacity compared to the North (Reimann et al., 2023). The projected coastal population growth will be spurred by various socio-economic factors (change in demography, economic development, policies and institutions), domestic migration patterns (rural-urban and inland-coastal migration), and patterns related to infrastructure development (sprawling versus compact development) (Neumann et al., 2015; Reimann et al., 2023).

With the advancement of mapping technology, including high resolution vertical and horizontal accurate drones and satellites, coastal erosion and coastal flooding hazard can be assessed on various scales depending on the level of detail and the scale of assessment required (Joyce et al., 2023; Pucino et al., 2021; Tur et al., 2020). Drones have been used as a means of obtaining high-resolution, land-based elevation products for flood and erosion hazard assessment, as well as creating orthophotos which are used to obtain the shoreline position for coastal erosion hazard assessment (Harley et al., 2011).

Research on vulnerability assessment based on coastal flooding (Cutter, 1996; Yankson et al., 2017) as well as coastal erosion (Gomez et al., 2020; Jonah et al., 2016) informed the scope of this study. Coastal vulnerability assessments provide an effective framework for outlining the potential effects of flooding and erosion by considering not only the physical drivers (e.g., wave height, tidal range, sea level rise), but also the physical characteristics of the coastline (e.g., shoreline retreat rate, dune height, beach slope) and the socio-economic conditions (e.g., population density, land use) in the exposed area (Lu et al., 2022; Oloyede et al., 2022; Re et al., 2023). This integrated approach is valuable for evaluating the resilience or susceptibility of a coastal environments to these hazards across spatial and temporal scales (Appeaning Addo, 2013; Marzi et al., 2018; Rashid et al., 2021).

Applying integrated vulnerability assessments methods for coastal erosion and coastal flooding is indispensable for building the future resilience of local communities and supporting efforts to reduce disaster risk (Cutter, 1996; Cutter, 2003). This is especially important when strategies are developed through bottom-up approaches that target interventions at the local level (community scale), which can then be scaled up to regional and global levels. Such approaches

are better aligned with social and integrated perspectives on vulnerability (Eicken et al., 2021; Markusson & Middlemiss, 2010).

Definition of Terms

Coastal flooding: is the episodic or permanent inundation of a dry land area caused by water level at sea.

Coastal erosion: is the movement of materials including sand, silt, clay and rocks from a coastal area resulting in the landward movement of the sea.

Coastal hazards: refers to phenomena including a range of events, from flooding during high storm tides, large waves, or tsunamis to more gradual issues such as coastal erosion, high-tide inundation, and rising groundwater levels due to sea-level rise (SLR) which has the ability to lead to loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (Stephens et al., 2017).

Sea level rise is the gradual increase of the water levels in the world's oceans because of global warming (IPCC, 2023).

Climate Change: is a change in the long-term usual weather conditions of a geographic area (IPCC, 2023).

Vulnerability: refers to the extent to which a socio-ecological system is either exposed to or protected from the impacts of natural hazards (Jozaei et al., 2022).

Exposure: is the extent to which people, property, systems or other valuable elements located in hazard-prone area interacts with climate events or a specific climate consequence (Coquet et al., 2019).

Sensitivity: is described as the degree to which a system will respond to the impact of a given climate change events or a specific climate consequence (Coquet et al., 2019).

Adaptive Capacity: is the ability of a system to adjust to its initial state influenced by practices, social networks, or institutional structures that will offset the potential for damage (Jozaei et al., 2022).

Vulnerability Index: is the use of formula to create a single numerical result using multiple indicators of vulnerability (Yankson et al., 2017).

1.2 PROBLEM STATEMENT

Recent research on Ghana's coast has focused on coastal vulnerability and risks, especially on coastal erosion and flooding (Alves et al., 2020; Boateng et al., 2017; Mensah & Ahadzie, 2020). These studies have examined both the perceived and actual impacts of these hazards on coastal communities, highlighting the physical vulnerabilities associated with shoreline retreat and inundation. Further findings reveal that, Ghana's mitigation and adaptation strategies have largely relied on hard engineering solutions. While these interventions, such as the Keta Sea Defense and the Ada Sea Defense, have been implemented, they are often ad-hoc (Arkhurst et al., 2022; Jonah et al., 2016; Poku-boansi et al., 2020), costly, and less sustainable, and they fail to adequately support the impoverished communities most at risk (Angnuureng & Appeaning Addo, 2013; Cudjoe & Alorvor, 2021; Salifu, 2021). .

To develop more efficient and effective adaptation solutions, particularly for marginalized and impoverished communities, it is essential to gather comprehensive vulnerability information that includes the biophysical, political, and socioeconomic dimensions of the coastal region (Cutter et al., 2003; Felsenstein & Lichter, 2014; Kirezci et al., 2023). Examining vulnerability at the local level is also vital for identifying key characteristics needed to design tailored and effective response options (Nguyen et al., 2016).

In Ghana, vulnerability assessments have typically relied on either physical assessments like the Coastal Vulnerability Index (CVI) for the coast (Appeaning Addo, 2013; Charuka et al., 2023) or purely social vulnerability methodologies (Mattah et al., 2023; Babanawo et al. 2023). For physical assessments, outputs from geophysical surveys, geomorphic investigations and sea-level rise modelling have been predominantly used to support policy formulation (Boateng, 2012; Mann et al., 2023). In contrast, social vulnerability assessments outputs from questionnaire surveys, face to face interviews, and Focus Group Discussions (FGDs) are used to inform policy makers about inherent socio-demographic dynamics but do not account for the physical properties of hazards. Yet, the ultimate vulnerability of communities is determined by their ability to cope, adapt, and recover, even when exposure to hazards is high. This therefore highlights the need for integrated assessments that combine physical and social dimensions to provide a more holistic understanding of vulnerability, showing how socioeconomic and institutional factors, in combination with biophysical characteristics and hazard behaviour, may exacerbate or mitigate risks (Boateng et al., 2017; Fu & Peng, 2019).

Addressing these challenges necessitates a bottom-up approach to index construction, engaging stakeholders in transparent dialogue to reveal underlying assumptions and ensure indicator selection reflects local contexts and complexities (Bours et al., 2022; Pereira et al., 2021).

The bottom-up methodology solves the two greatest problems facing future coastal management, i.e., including climate projections which will accurately represent past conditions at the temporal and spatial resolution required and incorporating ways to make climate projections suitable for local management (Di Francesco et al., 2020).

Along Ghana's Eastern coastline, the lack of integrated coastal vulnerability assessment may be explained by a combination of factors, including the data-sparce nature of the area (Avornyo et al., 2024). Addressing this requires a combination of multi-temporal geospatial data (e.g., satellite remote sensing, UAV/drone surveys) with complementary socio-ecological data (from household surveys and participatory mapping) to produce a multi-hazard vulnerability assessment (Tanim et al., 2022). Furthermore, another dimension of difficulty arises from integrating and analysing data from different contexts where such assessments take place (Soares et al., 2012). Given the approaches' application in the context of policy-driven assessments that aim to inform adaptation policy (Füssel & Klein, 2006), using the appropriate concepts and indicators are especially important in developing country settings, where adaptive capabilities is lower and financial resources limited. These restrictions impedes the use of integrated coastal vulnerability assessments to support evidence-based, proactive, and equitable coastal zone management strategies.

For the Ada West District specifically, no prior studies have conducted a combined assessment of physical and social vulnerability in its coastal communities . Yet, this area, located along the Eastern coastline of Ghana, has been experiencing periodic flooding induced by sea-level rise and coastal erosion in recent years (Boateng, 2012; Mann et al., 2023; Puplampu et al., 2023). It is imperative to conduct this study at this local scale to help address these challenges and

to promote coastal resilience for sustainable solutions to hazards and vulnerability in these communities (Kankam et al., 2013; Mattah et al., 2023).

1.3 RESEARCH QUESTIONS

The following research questions guide the study:

- What is the current trend of coastal erosion in Akplabanya and Anyamam?
- What will the future SLR-related coastal flooding be for the communities under different RCP projection scenarios?
- What are the perspectives of study communities on social dynamics and factors that may influence their vulnerability?
- What is the overall vulnerability index of both study communities based on coastal erosion and flooding hazards?

1.4 RESEARCH AIMS AND OBJECTIVES

The overall objective of the project is to assess the vulnerability of the coastal communities of Akplabanya and Anyamam by integrating coastal erosion hazard, future coastal flooding due to Sea Level Rise scenarios, and social perspectives on the dynamics of vulnerability.

The specific objectives of the project are to:

1) Assess current coastal erosion hazard trend occurring at the Akplabanya and Anyamam communities.
2) Assess the extent of coastal flood hazards in Akplabanya and Anyamam based on IPCC SLR projection under RCP 5-8.5.
3) Explore the social perceptions of the respondents in Akplabanya and Anyamam on vulnerability to coastal flooding and coastal erosion.
4) Quantify the vulnerability of communities to current and SLR-related coastal flooding and coastal erosion in Akplabanya and Anyamam.

1.5 JUSTIFICATION FOR THE STUDY

Coastal flood and erosion vulnerability assessment is the first step towards mitigating the adverse effects of flooding and erosion to humans and nature. This assessment considers various factors, including elevation, land-use, socio-economic data and simulation models and tools (Angnuureng et al., 2020; Mattah et al., 2023; Oloyede et al., 2022). This research will use unmanned aerial vehicles to assess coastal erosion by analyzing shoreline change and determining the rate of coastline retreat. Additionally, Unmanned Aerial Vehicles (UAVs) are excellent choice for high resolution DEMs that are important in flood hazard related projections.

The justification for this research lies in the importance of conducting a vulnerability assessment of coastal hazards, understanding their impact on local communities, and aligning these efforts with the United Nations Sustainable Development Goals (SDGs). By identifying and quantifying risks, this research will contribute to the development of strategies and policies that enhance resilience, protect coastal communities, and foster sustainable coastal development, particularly in relation to SDGs 3, 9, 11, and 13. Furthermore, this research aligns with the priorities outlined in the Sendai Framework, an agreement to which Ghana is a signatory.

1.6 THESIS ORGANIZATION

This thesis is structured into six chapters, accompanied by a list of references and Appendice. Chapter 2 covers the theoretical framework of the study, addressing concepts such as coastal erosion, coastal flooding, coastal vulnerability, and coastal hazard risk assessment. Chapter 3 provides an overview of the study area, including its location, hydrometeorological, and socio-economic methods used to achieve the study's objectives. Chapter 4 presents the findings on shoreline change detection related to coastal erosion, sea-level rise-induced flooding based on IPCC projections, vulnerability quantification, and vulnerability dynamics. Chapter 5 explores potential factors influencing shoreline change in the study area, drawing from previous research and current results. Finally, Chapter 6 concludes the research with a summary and offers recommendations for policy development and future research.

CHAPTER TWO

LITERATURE REVIEW

INTRODUCTION

This section reviews the pertinent literature related to the study topic, covering areas such as climate change and variability, coastal ecosystems, vulnerability, and community perspectives in coastal regions. Additionally, this chapter outlines the conceptual framework utilized in the study.

2.1 CLIMATE CHANGE AND COASTAL HAZARDS IN GHANA

Climate change is a significant driver of coastal hazards in Ghana (Armah et al., 2005; Salifu, 2021). It manifests primarily through rising sea levels and exacerbation of base water level for storm surges, which increase the frequency and intensity of coastal flooding and erosion (McMichael et al., 2020; Taherkhani et al., 2020). While typical ocean level fluctuations caused by tides, waves, and storm surges can mask the impact of long-term sea level rise, the cumulative effect over decades poses a serious threat (Rashid et al., 2021; Webb & Kench, 2010). The dominant mechanisms for climate change-induced sea level rise are thermal expansion of seawater due to increased atmospheric heat absorption and melting of land-based glaciers and ice sheets sea (McMichael et al., 2020; Mimura, 2013). Also global warming, largely attributed to the burning of fossil fuels and the resulting greenhouse gas emissions (primarily carbon dioxide), is a major concern contributing to climate change and its various manifestations (IPCC, 2021; Rokonuzzaman & Hattori, 2021).

Numerous studies conducted along Ghana's coastline attribute coastal hazards to climate change (Armah et al., 2005; Boateng et al., 2017; Evadzi et al., 2018). These hazards have had a profound impact on Ghana's coastal environment, altering the biophysical and socio-economic

setting. The impacts are shown as alterations in shoreline morphology (Jayson-Quashigah et al., 2019; Mann et al., 2023), heightened coastal flooding (Appeaning Addo et al., 2018; Coastal Resources Center, 2013), and the degradation of wetlands and aquatic ecosystems (Armah et al., 2005). These combined effects exacerbate coastal vulnerability and threaten the livelihoods of coastal communities (Avornyo et al., 2024).

2.2 COASTAL FLOODING

2.2.1 Coastal Flooding and Impacts

Coastal flooding is influenced by various hydro-meteorological factors, including mean sea levels, tides, atmospheric storm surges, and waves (Passeri, 2015; Seenath et al., 2016; K. Zhang et al., 2022). Depending on these conditions, wave overtopping can occur, potentially leading to significant flooding (Idier et al., 2020). Addressing flooding in the context of future storm variability, sea-level rise, and shoreline changes is a pressing issue for coastal populations (Höffken et al., 2020; Woodruff et al., 2013).

Coastal flooding represents a major hazard and a significant source of human vulnerability, often resulting in high mortality rates (Rahmstorf, 2017; M. Singh & Cai, 2023). Most flood impacts are reported as direct damages (affected areas, structures) and losses (financial, mortality) (Bhuyian & Kalyanapu, 2018). Direct impacts refer to the immediate harm caused by water interacting with people, infrastructure, and the environment. Coastal flooding can also have profound effects on mental health in coastal communities, especially among those directly affected (Boyer-Villemaire et al., 2021).

Indirect impacts stem from disruptions to physical and economic connections within the region and the costs associated with emergency responses. Examples of indirect losses include business interruptions due to halted activities and the costs of traffic disruptions when roads are blocked (Lyle & Mills, 2016). Other indirect effects include disease outbreaks, disruptions to basic utility supply, and interruptions in communication, transport infrastructure, and public services (Ansah et al., 2020).

When assessing flood consequences, key factors include flood magnitude (extent, depth, duration) and land use data (agriculture, urbanization, structures) (Bhuyian & Kalyanapu, 2018). The increase in damages from flooding, driven by coastal extreme sea-level events resulting from tides, mean sea level rise, storm surges, and waves, may be one of the costliest aspects of climate change (Hinkel et al., 2021; Rashid et al., 2021).

2.2.2 GIS and Flood Modeling for Flood Hazard Assessment

Effective flood modeling requires the acquisition, maintenance, and extensive use of spatial data. Remote sensing and geographic information systems (GIS) are valuable tools for meeting these needs (Diaconu et al., 2021; Seenath et al., 2016). However, traditional GIS lacks the modeling capabilities needed for complex hydrodynamic problems (Baby et al., 2021).

Although hydrodynamic models are beneficial for assessing coastal flood vulnerability (CFVA), their application can be limited by high computation times and the resolution of input data, particularly for large study areas or regions with sparse data (Seenath et al., 2016). High-resolution digital elevation models (DEMs) with a spatial resolution of 1 meter or less can be used as an alternative to quickly identify potential flood-prone areas (within minutes). However, using such detailed DEMs in hydrodynamic models uses substantial computational costs (Seenath et al., 2016). In summary, while hydrodynamic models provide robust flood modeling capabilities, their

computational requirements can restrict their use for large areas or data-scarce regions. Conversely, GIS techniques with high-resolution DEMs can quickly identify flood-vulnerable areas but become computationally intensive when integrated with hydrodynamic models.

2.2.3 Bathtub Models for Flood Hazard Assessment

Bathtub models are passive flood modeling approach which operates by projecting a flood surface onto a Digital Elevation Model (DEM) (Almaliki et al., 2023; L. L. Williams & Lück-Vogel, 2020). BTMs use a hydrostatic approach, which allows for computational efficiency and rapid identification of flood-prone areas based on specific floodwater levels (Anderson et al., 2018). These models are commonly used in conjunction with Geographic Information Systems (GIS) and can be executed through raster calculations (Ciro Aucelli et al., 2017; Kouakou et al., 2023). Simple GIS-based bathtub flood mapping is often employed to generate regional to large-scale flood maps, aiding in coastal risk assessment (Benavente et al., 2006; Didier et al., 2019; Kouakou et al., 2023). This approach involves overlaying total water levels (TWLs) including astronomical tide, storm surge, and wave runup/setup on DEMs until an equivalent topographic contour is achieved (Breilh et al., 2013; Patrick et al., 2015).

BTMs assume direct connectivity between adjacent and diagonal grid cells to simulate overland flows (Orton et al., 2015; Patrick et al., 2015). Because the method is a simplistic method, some weaknesses include overlooking terrain roughness (Ramirez et al., 2016), the timing and duration of events (Didier et al., 2019; Sampurno et al., 2023), and flow velocity, which affect landward propagation distance from the coast (Breilh et al., 2013; Sampurno et al., 2023). These simplifications can lead to overestimations of flood impacts, potentially exaggerating socio-economic damages and diminishing the effectiveness of flood risk management (Didier et al., 2019; Gallien et al., 2018). Nonetheless, BTMs are still utilized for large-scale assessments of

exposed populations, properties, and infrastructure under future climate change scenarios involving sea level rise (Kulp & Strauss, 2019; Kulp & Strauss, 2017; Muis et al., 2016).

2.2.4. Coastal Flood Hazard Assessment

Research on coastal hazards has predominantly utilized quantitative indexes to describe risks. These indexes quantify an area's vulnerability through arithmetic operations involving classified variables that influence hazards (Mah et al., 2023; Park & Lee, 2020). Nonetheless, conducting flood hazard assessment is complicated due to the absence of objective measures, limited data availability, and numerous unknown probability distributions (Li et al., 2012).

It is important to recognize that coastal flooding is not conceptually separate from storm surge and sea-level rise, as both contribute to flooding. Differences in hazard characterization may arise from disciplinary perspectives or efforts to address policy interests (Bukvic et al., 2020). Therefore by integrating the hazard and vulnerability, extent a hazard is impacting a system is evaluated. This assessment enables individuals and groups to take preventative or mitigating actions to reduce predicted losses (Azam & Rahman, 2022; van Aalst et al., 2008).

Hazard assessment focuses on the scope and intensity of significant flood events associated with specific exceedance probabilities. Hazard information can be overlaid with socio-economic data, such as population data, building datasets, regional gross domestic product (GDP), etc., to indicate what is exposed (Creach et al., 2016; Moel et al., 2015). Then the vulnerability assessment examines how flooding impacts particular targets, such as buildings, individuals, or infrastructure (Apel et al., 2008; Bevacqua et al., 2018).

2.2.5. Digital Elevation Models (DEMS)

The Digital Elevation Models (DEM) represents the earth's surface with trees and buildings (Fereshtehpour & Karamouz, 2018; Jafarzadegan et al., 2022). DEM data has been utilized to address a range of tectonic geomorphic applications, natural and human-caused hazards, including volcano deformation (a possible eruption precursor), active faulting, and other geomorphic processes such as coastal subsidence (indicative of flood hazard), glacier and ice sheet mass loss (a major contributor to sea level rise), and thawing permafrost (an important but poorly known contributor to greenhouse gases) (Jafarzadegan et al., 2022; Reinoso & Miranda, 2005; Usul et al., 2014) .

The resolution and accuracy of a DEM are crucial for flood-related studies, as the elevation of the land plays a key role in determining whether a location will be submerged or remain unaffected during a flood event (Jafarzadegan et al., 2021). The Digital Elevation Model (DEM) used in such analyses can significantly influence the results of studies on coastal flooding (Hinkel et al., 2014). For global DEMs, when corrected for vertical bias in datasets used for assessing flood risks, it is estimated that one billion people now occupy land less than 10 meters above current high tide lines, including 250 million below 1 meter (Kulp & Strauss, 2019). UAV-derived DEMs have been found to reliably predict flood risk situations due to their high resolution (Adesina et al., 2022; Duo et al., 2018; Yang et al., 2022).

Most studies on coastal flooding utilize a Digital Elevation Model (DEM) in conjunction with projected flood water levels to estimate flood inundation and the potential damages to property and livelihoods (Buchanan et al., 2020; Magnan et al., 2022). In low-lying deltaic regions, where land elevation variations are often just a few decimeters, even minor inaccuracies in elevation data can significantly affect the precision of risk assessments (Sande et al., 2012).

DEMs are therefore essential for hydrologic and hydraulic modeling (Karamouz & Fereshtehpour, 2019; Webster & Stiff, 2008), and the accuracy of flood inundation mapping relies heavily on the quality of these models (Xu et al., 2021). Accurate elevation data, typically provided by DEMs, is crucial for evaluating exposure, vulnerability, and risk related to both permanent and temporary flooding, as well as other impacts of rising water levels along the coast (Gesch, 2018).

2.3 COASTAL EROSION

Coastal erosion results in the permanent removal of sand from the beach-dune system and is influenced by various coastal factors, including exposure, wave climate, surge levels, sediment composition, and beach slope (Barillà et al., 2021; Yincan et al, 2017). This process includes both cross-shore and longshore erosion (Van Rijn, 2011). Coastal landforms adjust to hydrodynamic forces by shifting both perpendicular and parallel to the shore, striving to maintain their position within the energy gradient and seek to restore equilibrium (Appeaning Addo & Adeyemi, 2013).

Coastlines are categorized into types such as rocky, sandy, muddy, coral reefs, estuaries, and deltas, with each type experiencing varying impacts from waves and currents (Vousdoukas et al., 2020; Woodroffe & Leon, 2010). Cliffs and rocky shores exhibit greater resistance and change over geological timescales, while sandy shorelines are more responsive and vulnerable to erosion due to their soft geological composition (Morton, 2004; Pollard et al., 2019).

According to Luijendijk et al., (2018), 24% of the world's sandy coasts experience an erosion rate exceeding 0.5 m/year, and approximately 16% erode at a rate greater than 1 m/year. Also, Mann et al., (2023) and Manno et al., (2022) have conducted studies that suggest that

observed variations in shoreline positions can result from a single factor or a combination of interconnected factors. While spatio-temporal shoreline dynamics are influenced by natural elements such as storms, marine currents, and beach geomorphology (T. R. Allen & Hale, 2022; Puplampu et al., 2023), human-induced factors such as coastal exploitation, deforestation, and engineering activities also significantly contribute to the environmental impacts faced by coastal zones (Anfuso et al., 2021; Williams et al., 2018).

Many coasts are undergoing erosion processes, triggering coastal retreat that threatens beaches, wetlands, marshes, coastal ecosystems, buildings, and infrastructure, thereby straining local livelihoods (Bio et al., 2015; Islam et al., 2023). The regions with the greatest impact from coastal erosion are where sandy beaches are exposed to waves and lack sediment supply (Coastal Resources Center, 2013). The situation is further worsened when sandy coasts face increasing encroachment from urban development on the landward side, while waves, storms, and rising sea levels encroach from the seaward side (Vitousek et al., 2022). The extraction of sand from the sediment sharing system also causes permanent variations in beach shape and structure (Prasad & Kumar, 2014).

Schleupner (2008), notes that coastal development hinders the natural adaptation of coasts to increased erosion rates by restricting their landward movement. This creates an environment where land is constrained by wave action, tides, rising sea levels, and development pressures, resulting in a squeeze effect. As a result, detecting and monitoring shorelines become crucial due to their significant economic and social implications, particularly considering the devastating effects of climate change on coastal areas (Alexandrakis & Poulos, 2014; Audère & Robin, 2020; Toure et al., 2019).

2.3.1 Remote Sensing and GIS for Coastal Erosion Hazard Assessment

Remote sensing and Geographic Information Systems (GIS) offer a comprehensive scientific platform with a diverse array of tools for visualizing, analyzing, and integrating spatial and non-spatial data to aid in decision-making for spatially referenced issues (Lin & Pussella, 2017). Various quantitative and qualitative studies have been conducted to predict future shoreline impacts (Castelle et al., 2018; Le Cozannet et al., 2019; Nidhinarangkoon et al., 2023). Techniques that combine remote sensing with drone imagery and GIS integrated with the Digital Shoreline Analysis System (DSAS) 4.2.1 are more effective at delineating both long-term and short-term shoreline changes compared to traditional methods (Ciritci & Türk, 2019; Himmelstoss, 2009; Roy et al., 2018).

Transect-based analysis is employed to assess shoreline changes by comparing multiple shorelines over time (Nidhinarangkoon et al., 2023; Roy et al., 2018). This method involves calculating shift rates or change measurements using techniques like the Linear Regression Rate (LRR) (Ralalage et al., 2022). These rates are derived relative to specific shore-normal transect locations by measuring the distances between each shoreline and a baseline, a unique polyline traced onshore that serves as the reference point for all transects. Due to their orthogonality at the intersection point, the baseline tracing is a crucial and sensitive step in the analysis (Manno et al., 2022).

The DSAS plugin is widely utilized for estimating shoreline changes due to its accuracy and statistical data capabilities (Baral et al., 2018; Himmelstoss, 2009). The shoreline position is assessed with minimized potential random error to obtain the LRR and ensure accuracy (Maiti & Bhattacharya, 2009). The DSAS beta forecast, utilizing the Kalman filter then provides the future predictions (Himmelstoss, 2009). In addition to estimating historical shoreline changes, this

method aids in forecasting future shorelines, which is essential for planning preventive and precautionary measures for vulnerable coastal areas (Dada et al., 2024; Lin & Pussella, 2017). A significant advantage of LRR is its utilization of all available data, its basis in accepted statistical concepts, and its computational simplicity (Dolan et al., 1991; Genz et al., 2007).

2.3.2 UAVS for Coastal Monitoring

Unmanned aerial vehicles (UAVs) have emerged as valuable tools for environmental surveying, mapping, and monitoring, including coastal monitoring applications (Duo et al., 2018; Green et al., 2018; Turner et al., 2016). Compared to traditional methods, UAVs offer enhanced accuracy by operating at low altitudes, sometimes as low as 10 meters. This capability is particularly valuable in coastal areas that are challenging to access, making UAVs ideal for analyzing shoreline changes and other coastal issues (Ishaand & Adib, 2021; Jayson-Quashigah et al., 2019; Tur et al., 2020).

Equipped with high-resolution cameras capable of capturing visible or near-infrared imagery and utilizing advanced image processing algorithms, UAV systems can quickly cover large areas with high resolution and precision (Duo et al., 2018; Yang et al., 2022). For photogrammetric flights, a global navigation satellite system (GNSS) base connected to the UAV provides accurate real-time kinematic (RTK) georeferencing for the captured images (Harley et al., 2011; Vidalis-Kelagiannis et al., 2021). Flight planning is executed in grid mode and adjusted to the terrain to ensure consistent pixel size and precision (Chapapría et al., 2022). When UAVs are integrated with the RTK GPS technique, it becomes more effective for surveying intertidal areas and cross-shore profiles, particularly in micro-tidal environments, by providing vertical corrections for UAVs (Harley et al., 2011; Joyce et al., 2023). UAV-based monitoring has proven to be highly effective due to its spatial and temporal resolution and data quality (Tur et al., 2020;

Turner et al., 2016). It contributes to scientific knowledge and sustainability by delivering detailed information and high-resolution images that can detect changes caused by ongoing natural and anthropogenic activities.

2.4 SEA LEVEL RISE (SLR)

Sea level rise (SLR) is a well-documented consequence of anthropogenic climate change, poses a significant threat to coastal populations and infrastructure globally (IPCC, 2021, 2023). Estimations of the number of people at risk from SLR vary considerably, ranging from 88 million to 1.4 billion individuals, due to differences in the defined spatial zones considered vulnerable, the temporal horizons examined, and the datasets and methodologies employed to calculate exposure (Hauer et al., 2021). It is estimated that by the end of the twenty-first century, the uncertainties associated with climate change scenarios and sea level rise projections will become more pronounced (IPCC, 2014, 2021, 2023). In Europe alone, it is estimated that on average, the variance of coastal land loss projections could diminish by almost 45% in 2050 and 26% in 2100 if accurate data on sandy beach locations and nearshore slopes were used (Athanasiou et al., 2020).

This phenomenon, driven by global warming, poses a significant threat to low-lying coastal regions around the world (Kopp et al., 2023; Moftakhari et al., 2017). Between 1902 and 2015, global mean sea levels increased by 0.12 to 0.21 meters, as reported by the Intergovernmental Panel on Climate Change (IPCC, 2021). By 2100, sea levels are projected to rise an additional 0.43 to 0.84 meters, with a likely range of 0.29 to 1.10 meters, compared to levels from 1986 to 2005 (IPCC, 2021). This is important as even gradual increases in sea level can significantly heighten the frequency and intensity of coastal flooding (Taherkhani et al., 2020; Vitousek et al., 2017).

Rising sea levels exacerbate wave and tidal activity by increasing energy dissipation along the coastline resulting in increased erosion and flooding (Appeaning Addo & Adeyemi, 2013; Idier et al., 2020; Mcleod et al., 2010). These changes may have far-reaching implications, affecting coastal flood risk management, tidal energy production, sediment transport, tidal mixing fronts, and intertidal ecology (de Almeida & Mostafavi, 2016; Hsiao et al., 2022; Neumann et al., 2015). SLR will have widespread negative impacts, not only on coastal environments but also on social and economic aspects, particularly in coastal areas and small islands (Neumann et al., 2015; Rumahorbo et al., 2023).

The extent of future SLR will depend on greenhouse gas emissions, the climate system's sensitivity to those emissions, and the dynamic response of land-based ice sheets to warming (Hall et al., 2019; IPCC, 2021; IPCC, 2023). Flood hazard assessment is critical to examine whether elevated sea levels pose significant damage and destruction to low-lying coastal areas, enabling policy makers to formulate strategies to protect coastal communities (Hall et al., 2019; Shen et al., 2022). This is because SLR is the primary oceanographic driver of changing coastal flood risk, originating from fluctuations in mean sea level, storm surges, and long-period tides (Taherkhani et al., 2020; Vitousek et al., 2017).

Rising sea levels pose significant threats to coastal zones through a variety of hazards including increased episodic marine flooding due to higher mean sea levels and extreme sea levels from storm surges and high tides (Muis et al., 2016), permanent land submergence (Pln & Kolukula, 2023), groundwater inundation in porous substrates (Nordio et al., 2023), erosion(Bird, 1996; Le Cozannet et al., 2019), loss of coastal ecosystems(Silver et al., 2019), salinization of ground and surface waters (Nordio et al., 2023), and impaired drainage systems (Magnan et al., 2022). Future changes in SLR involve uncertainties, as small-scale factors like ground subsidence

or coastal erosion/accumulation can significantly influence outcomes (Avornyo et al., 2024; Le Bars, 2018).

The IPCC has formalized guidance on uncertainty in scientific research, recognizing epistemic diversity and distinguishing likelihood and confidence since AR5 (Kopp et al., 2023). Likelihood and confidence describe quantifiable uncertainty and the degree of agreement, respectively. They are often imprecise, with increasing confidence closely paralleling decreases in uncertainty. The IPCC has proposed presenting sea-level projection uncertainty using tiered imprecise probability distributions of different confidence levels (IPCC, 2021; Kopp et al., 2023). These categorized distributions are known as Representative Concentration Pathways (RCPs), where different sea level projections are based on different probable emissions forecasts for various time periods (IPCC, 2021, 2023).

For the coast of Ghana, local sea levels are rising in accordance with the global trend at a historical rate of approximately 2 mm/yr, which is expected to potentially increase up to 6 mm/yr (Appeaning Addo, 2009). Evadzi et al, (2017) find out that for the coast of Ghana, sea level rise will be responsible for 31% of coastal erosion. Higher sea levels expose previously unreachable land to waves and currents, increasing vulnerability to erosion and coastal flooding. This shows that SLR will have an impact on the coast of Ghana especially in the coming decades.

2.5 DIMENSIONS OF VULNERABILITY

Vulnerability arises only when a system is exposed to an external threat; if the threat is absent or the system is shielded from it, the system remains unaffected. Thus, the exposure component assesses how frequently and intensely a threat can impact the system (Nájera-González

& Carrillo-González, 2022). It results from a range of factors, including awareness of hazards, patterns of settlement and infrastructure, public policies, societal development, and the capacities of institutions in disaster and risk management (Adger, 2006; Bevacqua et al., 2018; Buchanan et al., 2020).

While vulnerability is often specific to particular hazards, factors such as poverty and the absence of social support systems can exacerbate vulnerability irrespective of the hazard type. The concept of vulnerability to coastal hazards has evolved over decades, with research spanning various scales and contexts (Bevacqua et al., 2018). The primary aim of vulnerability assessment is to promote coastal sustainability by evaluating how communities' exposure and sensitivity to hazards intersect with their ability to cope, adapt, or recover from such conditions (Poku-boansi et al., 2020).

This vulnerability underscores the need for all stakeholders to plan and manage coastal areas in accordance with their natural conditions, with a focus on preserving the coastal environment and ecosystem. High levels of vulnerability indicate inadequate or inappropriate adaptations and low resilience, highlighting a direct connection between environmental challenges and societal structures and rights (Oliver-Smith, 2009).

In Ghana, dimensions of vulnerability and adaptive capacity in coastal communities encompass various aspects such as governance and leadership, coastal resource management, risk awareness and emergency response, and economic and societal factors (Kankam et al., 2013). Although climate change vulnerability is prevalent across Ghana and other developing nations, it varies based on location, occupation, gender, and the availability of support in terms of capacity building and local knowledge (Poku-boansi et al., 2020).

2.5.1 Coastal Vulnerability Assessment

Coastal vulnerability assessments are particularly useful for evaluating the potential impacts of coastal hazards. They combine physical characteristics of hazard drivers (e.g., wave height, tidal range, and sea level rise) with physical attributes of the coastal environment (e.g., annual shoreline retreat, dune height, beach slope) (Aman et al., 2019; Kantamaneni et al., 2018), and socioeconomic factors (e.g., population density, land use) (Mattah et al., 2023). With high levels of vulnerability indicate inadequate or ineffective adaptations, resulting in lower resilience to the specific hazard.

Vulnerability assessments can provide benefits from appropriate contingency planning and identify highly vulnerable areas (Nicholls & Hoozemans, 2005). They can be used to determine whether the studied environment is resilient or susceptible to hazards across a broad domain and various time scales, an evaluation is needed (Appeaning Addo, 2013). This vulnerability connects environmental hazards with societal structure and organizational aspects, highlighting how environmental issues intersect with social rights and structures (Oliver-Smith, 2009).

The main drive behind creating coastal vulnerability assessments often stems from concerns about erosion or sea level rise. Consequently, the choice of variables used in these assessments usually reflects the specific goals of the evaluation (Bryan et al., 2001; Cruz-Ramírez et al., 2024). Assessing individual behavior towards adaptation and risk perception is important for effective risk communication between government agencies and residents in hazard-prone areas and can be enhanced by understanding social vulnerability indicators, which often encompass ethnicity, gender, age (particularly elderly and children), socioeconomic status (poverty and wealth), and housing conditions (Cutter & Finch, 2008). These indicators do not adhere to a single methodological framework or discipline. Instead, vulnerability assessments are

typically interdisciplinary, with related fields such as natural hazards, disaster management, and climate change and have no clear-cut definitions (Bukvic et al., 2020).

2.5.2 Adaptive Capacity

Assessing adaptive capacity to natural events involves evaluating multiple dimensions, including economic resources, human resources, infrastructure, institutional frameworks, social capital, and natural resources (N. Adger et al., 2004; Weis et al., 2016). The ability of a system to adapt is significantly influenced by the institutional environment in which adaptation occurs, along with political factors and social networks (Jozaei et al., 2022; Rowan & Kwiatkowski, 2020). To evaluate the adaptive capacity of coastal households, the initial step is to create a set of indicators for adaptive capacity, which helps simplify complex information into numerical or straightforward forms for better comprehension (Dung et al., 2019).

Rural households, which often rely heavily on natural resources, typically exhibit low adaptive capacity, making them particularly vulnerable to shocks and negative impacts, including those driven by climate change (Hutagalung, 2023; Jiao & Moinuddin, 2016; Vallury et al., 2022). Although rural livelihood strategies are seen as adaptable and responsive to changing pressures and opportunities (Jiao & Moinuddin, 2016). At broader scales, from global to national levels, quantitative assessments using indicators like the Disaster Risk Index (DRI) from the UNDP are commonly used (Brooks et al., 2005). Approaches at the local level incorporate both quantitative and qualitative methods, contingent upon the research inquiries and data availability (Jamshed et al., 2023; Massmann & Wehrhahn, 2014).

In Ghana, the factors contributing to the vulnerability of coastal communities are linked to their ability to adapt to change. The main dimensions of adaptive capacity at the community level

include governance and leadership, coastal resource management, risk awareness and emergency response, as well as economic and social aspects (Kankam et al., 2013).

2.5.3 Exposure

In studies of vulnerability and resilience, exposure refers to people, property, systems, or other valuable elements located in hazard-prone areas and at risk of potential losses (Coquet et al., 2019; Mills et al., 2021). This highlights the interconnectedness of vulnerability and exposure in shaping our understanding of risk. The combination of vulnerability and exposure has driven the global rise in observed risk over recent decades, emphasizing the need for focused attention on these factors when formulating policies and actions to reduce disaster risk (Ishtiaque et al., 2022).

It is highly recommended that in vulnerability assessment, exposure assessment must encompass future dynamics of hazard exposure (Hinkel, 2010). The "hazard" part, including hydrological analysis and hydraulic models are used to assess flood hazards, while the "stakes" aspect involves evaluating the vulnerability and susceptibility of assets to potential damage (Eleutério, 2012) However, there is a need to consider uncertainties in assessing current exposure stem from the accuracy of elevation, population, and asset datasets used in these evaluations (Hinkel et al., 2021).

The latest IPCC definition excludes exposure from vulnerability, overlooking how socially differentiated exposure can lead to injustice (IPCC, 2023; Ishtiaque et al., 2022). Accurately defining exposed variables at the outset is essential for two main reasons including formulating research questions and establishing a clear study framework and also because research focuses on resilience and vulnerability concerning policy-relevant issues, such as developing risk mitigation plans (Dintwa et al., 2019) or creating resilient policies and adaptive strategies to reduce economic uncertainty (Modica et al., 2018). Understanding vulnerability and exposure is key to

understanding risk, as rising vulnerability and exposure have contributed to the global increase in risk over recent decades. This necessitates close attention when formulating disaster risk reduction policies. Exposure is shaped by past extreme events, current ecosystem conditions, and future climate scenarios (Monterroso & Conde, 2015).

2.5.4 Sensitivity

Sensitivity is the characteristics or condition of a system that affect how likely it is to suffer damage from a stressor related to climate change. There are various elements of sensitivity, including environmental, social, cultural, economic, and physical aspects (Weis et al., 2016).

In social systems, socioeconomic factors including age, income, handicap, and gender are major determinants of sensitivity (Babanawo et al., 2023). The degree to which people, homes, or a community relate to or depend on resources that are impacted by climate events also determines it (Babanawo et al., 2023; Bari et al., 2024).

2.5.5 Population Growth and Vulnerability.

The increase in coastal population exposure to flood risk is largely due to the concentration of assets, driven by property development in flood-prone coastal areas (Coquet et al., 2019). Future growth in coastal populations is influenced by various factors such as socio-economic development, internal migration, and spatial development patterns like demographic changes, economic expansion, and institutional frameworks. Migration trends, including rural-to-urban and inland-to-coastal migration, alongside spatial development patterns (whether sprawling or compact), also play a significant role (Burrows & Kinney, 2016; Reimann et al., 2023).

Social vulnerability is embedded within the Socioeconomic Shared Pathways (SSPs), where SSP3, marked by high exposure and low adaptive capacity, presents the greatest adaptation challenges (Muttarak, 2022). Impacts, however, vary significantly by region. Africa, Asia, Latin America, and the Caribbean are projected to see the largest growth in coastal population exposure under scenarios of low adaptive capacity, while Europe, North America, and Oceania may experience lower growth or even a decline, leading to reduced impacts in the Global North compared to the Global South (Reimann et al., 2023).

2.5.6 Scales for Vulnerability Assessment

The scale of research whether national, regional, or local is crucial when conducting vulnerability assessments, as it significantly influences the output results (Kienberger et al., 2009). Effective assessments must measure relevant factors at an appropriate scale and be supported by a strong conceptual framework (Roukounis & Tsihrintzis, 2022). On a national scale, assessments are commonly used in climate change studies to pinpoint regions where collective action is needed, with findings often contributing to policy analysis (Appeaning Addo, 2013).

At the regional level, approaches like the Coastal Vulnerability Index (CVI) are widely used to assess coastal vulnerability, providing insights into potential impacts from low to very high vulnerability (Bevacqua et al., 2018; Roukounis & Tsihrintzis, 2022).Local vulnerability studies, which focus on community-level dynamics, offer the most detailed insights and are particularly valuable for policymakers, as they reveal localized vulnerability trends and provide critical information for targeted interventions (Portelli, 2010). To discuss the vulnerability in local settings downscaling is used by decision-makers to improve decision outcomes to reduce hazard damage

(Balica et al., 2009; De Leo et al., 2019). This is important as it helps decision-makers explore various protection measures in local and regional scales (Balica et al., 2009; De Leo et al., 2019).

2.6 SOCIAL VULNERABILITY

Social vulnerability refers to the pre-existing condition or state of a system before a hazard or climate stressor occurs which is characterized by susceptibility, limitations, incapacities or deficiencies essentially an inability to resist impacts or cope with the hazard/stressor (Tang et al., 2016). Social vulnerability is multi-faceted and completed using various assessments. In Social Vulnerability Assessments (SVAs), two key framings are recognized: biophysical vulnerability, which assesses the likelihood and magnitude of the hazard, and social vulnerability, which focuses on people's capacity to cope with stress (Adger et al., 2004; Cutter & Finch, 2008).

Aspects of social vulnerability are inherent and have been developed based on their challenges for adaptation, with the highest challenges (i.e., low adaptive capacity) in areas where high exposure and vulnerability coincide (Muttarak, 2022). This means vulnerability exists on a spectrum of degrees rather than strict thresholds, which can be visualized through GIS maps using methods like standard deviations or quantiles (Fekete, 2019).

Social vulnerability arises from societal injustices, where political and cultural structures disadvantage specific groups based on characteristics such as social standing, human, and financial resources (Hauer et al., 2021; Yu et al., 2021). It reflects deeper structural inequities rather than simply a lack of resources or capacities (Jozaei et al., 2022; Rowan & Kwiatkowski, 2020; Schiavinato & Payne, 2015). Understanding this concept helps identify disadvantaged groups and

sheds light on the underlying forces perpetuating disaster-related injustices (Chakraborty et al., 2021).

Socio-spatial inequalities disproportionately affect marginalized groups like the elderly, low-income populations and those with lower education backgrounds (Dung et al., 2019; Yahia Meddah et al., 2023). However, the success of the estimation will depend on the information that is available at the level that needs to be measured (Chakraborty et al., 2021; Johnson et al., 2023). In data-scarce settings, there has been the need to tailor the selection of indicators to fit the study's objectives and the specific conditions of the study area and emphasize reflecting local conditions (Flanagan et al., 2020; Hinojos et al., 2023; Isia et al., 2023).

Social vulnerability varies based on community location, occupation, gender, and availability of support/local knowledge. Sociodemographic indicators are commonly employed, but a broader set capturing structural and institutional vulnerability and capacity dimensions is needed to identify actionable pathways for adaptation (Fekete, 2019; Li et al., 2023; Rahman et al., 2023). The poor face higher sensitivity to coastal livelihood impacts on the environment due to lower adaptive capacity from limited livelihood diversification and infrastructure (Poku-boansi et al., 2020).

Amidst complex global environmental changes and the imperative of Sustainable Development Goals (SDGs), social vulnerability research not only mitigates adverse environmental impacts on social systems but also facilitates sustainable development of national or regional resources, environments, populations, and societies. It is a pivotal aspect of building resilient societies, cities, and villages (Li & Wang, 2022). A summary of variables that demonstrate social vulnerability is shown in Table 1.

Table 1: Summary Variables that Demonstrate Social Vulnerability to Coastal Hazards.

Factors	Variables
Demography and Health	Population statistics, age groups and gender
Knowledge and skills	Educational attainment, beliefs
Housing	Types of housing, age of housing structure, Tenure
Social Capital Access	Participation in decision-making, networks, trust, community cohesion
Wealth	Household income
Information provision	Access to information, Satisfaction of information sources

2.7 INDEX-BASED APPROACH

In the realm of coastal disaster studies, the coastal vulnerability index (CVI) has garnered attention from some scholars (Appeaning Addo, 2013; Dhiauddin et al., 2019; Koroglu et al., 2019). However, others have raised concerns about its adequacy in quantifying vulnerability levels of specific locations in terms of exposure, sensitivity, or adaptive capacity and resilience (Englund et al., 2023; Gomez et al., 2020). Consequently, integrating biophysical exposure and social vulnerability is crucial for a comprehensive understanding of all contributing factors, particularly for prioritizing risk management interventions (Ballesteros & Esteves, 2021).

The index-based approach to vulnerability assessment involves a structured process of selecting, normalizing, and aggregating indicators to generate a comprehensive measure. Standardizing variables from diverse measures, indicators are typically transformed (Tapsell et al.,

2002). The primary objective is to identify proxy variables for exposure, sensitivity, and adaptive capacity, thereby addressing challenges of variable combination (Nguyen et al., 2016).

2.8 HAZARD OF PLACE MODEL CONCEPTUAL FRAMEWORK

In the hazard research discourse, 'Hazard of Place model' was developed by Cutter (1996), and it provides integrated and useful insight of examining vulnerability as a pre-existing condition. The model defines "vulnerability of a place" as a combination of social and biophysical factors. Social vulnerability factors include demographic characteristics and risk perception, while biophysical vulnerability factors relate to hazard exposure in a specific geographic area (Cutter, 1996). Together, these factors determine the overall vulnerability of a place. The hazard of place model emphasizes the importance of location, outlining the various elements contributing to vulnerability within a specific area (Ogie & Pradhan, 2019). This integrated approach to understanding vulnerability considers both the physical attributes unique to the area and the social, political, and economic processes at the local level, acknowledging that these local processes can be influenced by national and global factors.

The 'hazard of place model' was further improved by Cutter et al., (2003) to include other elements which creates vulnerability including model 'risk' which looks at the 'hazard potential' and 'mitigation' to include actions used to diminish impact. This hazard potential interacts with the geographic context, including factors such as location, elevation, and proximity, as well as social elements such as socio-economic conditions, risk perceptions, resilience, and the built environment (Dintwa et al., 2019). These interactions can either moderate or enhance the hazard potential (Burton et al., n.d.; Cutter et al., 2008). According to Cutter et al. (2000), focusing

explicitly on place allows researchers to explore the underlying social and biophysical elements that contribute to vulnerability and to assess how these factors interact and intersect.

According to Cutter (1996), four factors that dominated the selection of this model include i) the model is a compromise between many theories and models since it takes into account both social and physical elements, ii) the methodology is intrinsically more regional in nature, with the degree of vulnerability being comprehended within a particular area or geographic field, iii) this model is dynamic by nature since it recognizes the connections between all facets of danger and risk development, iv) to describe the total social vulnerability, the model considers a variety of problems and elements in the social fabric dimension which can be challenging to quantify and assess through quantitative approaches, in addition to measurable characteristics like age, gender, and educational attainment (e.g., community attitudes and experiences regarding risks and hazards, coping abilities, etc.).

This supports the use of qualitative and quantitative research methods to comprehend the viewpoints and beliefs of various players in the emergency management space (Joakim, n.d.). This makes it good for conceptualize activities for hazard assessments.

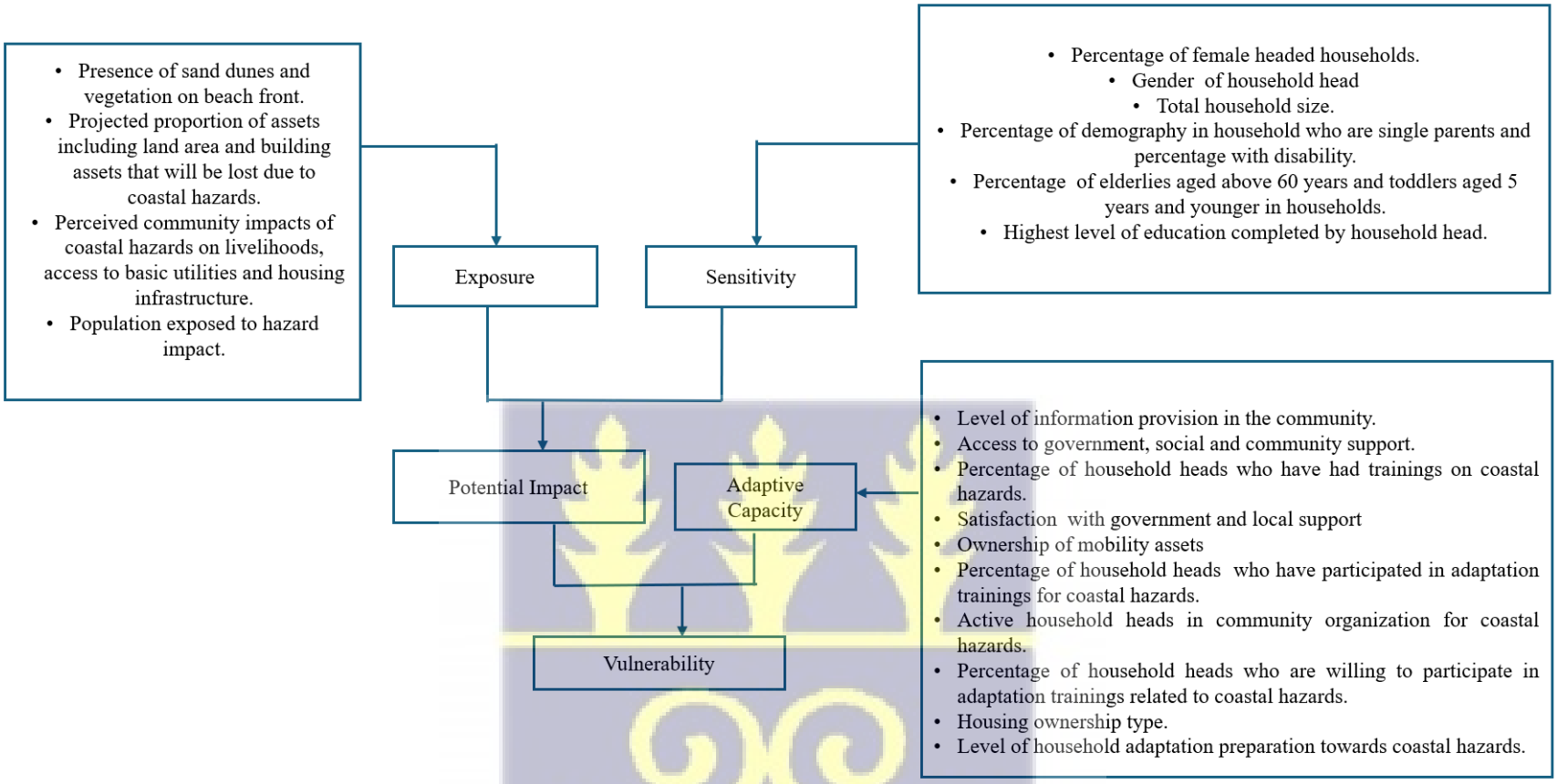

Figure 1: Conceptual Framework Variables based on the Hazard of Place Model. Adopted and Modified from Cutter et al., (1996).

CHAPTER THREE

METHODOLOGY

3.1 STUDY AREA

Akplabanya and Anyamam are the two largest coastal communities in the Ada West District, located along Ghana's Eastern coast by population (GSS, 2010). Akplabanya lies at coordinates 5°47'19.9"N 0°19'08.6"E and Anyamam at 5°47'19.9"N 0°21'08.6"E. The Eastern coastline where the study area is located is characterized by strong ocean waves and currents that significantly shape the beach front (Almar et al., 2015). The wave regime consists of moderate to high energy swell waves around 1.4 meters high with long 1.1 second periods, approaching unimpeded from the south-southwest direction (Almar et al., 2015). The tide regime is semi-diurnal with a range of about 1 meter, generating weak currents with limited impact on shoreline morphology (Appeaning Addo et al. 2008).

The study area exhibits marshy characteristics and is divided by the Akplabanya lagoon which is separated from the sea by a narrow strip of sandbar. The study area is characterized by loose quaternary sediments which are mostly deposited on the beach. The two communities exhibit contrasting beachfront characteristics. Anyamam has low-lying sand beaches with sparse vegetation. Akplabanya, on the other hand, has built-up sand dunes along the beach front and generally higher elevation. Historical and ongoing coastal erosion has been documented close to where both study areas are in Ada (Mensah & FitzGibbon, 2013). The wind regime in the general study area is considered weak, with average monthly wind speeds ranging from 1.7 to 2.6 m/s (Sorensen et al., 2003). The wind approaches in an oblique westward to eastward direction (Angnuureng et al., 2020). The erosion has been attributed to reduced sediment supply reaching the coast (Boateng et al., 2012).

The study area location is described as one of the least developed districts having less access to public utilities including sanitary, water and electricity (Ada West District Assembly, 2022). The dominant economic activity is informal artisanal fishing and related supply chains, exhibiting gendered roles with men involved in offshore fishing and women in processing, mongering and distribution.

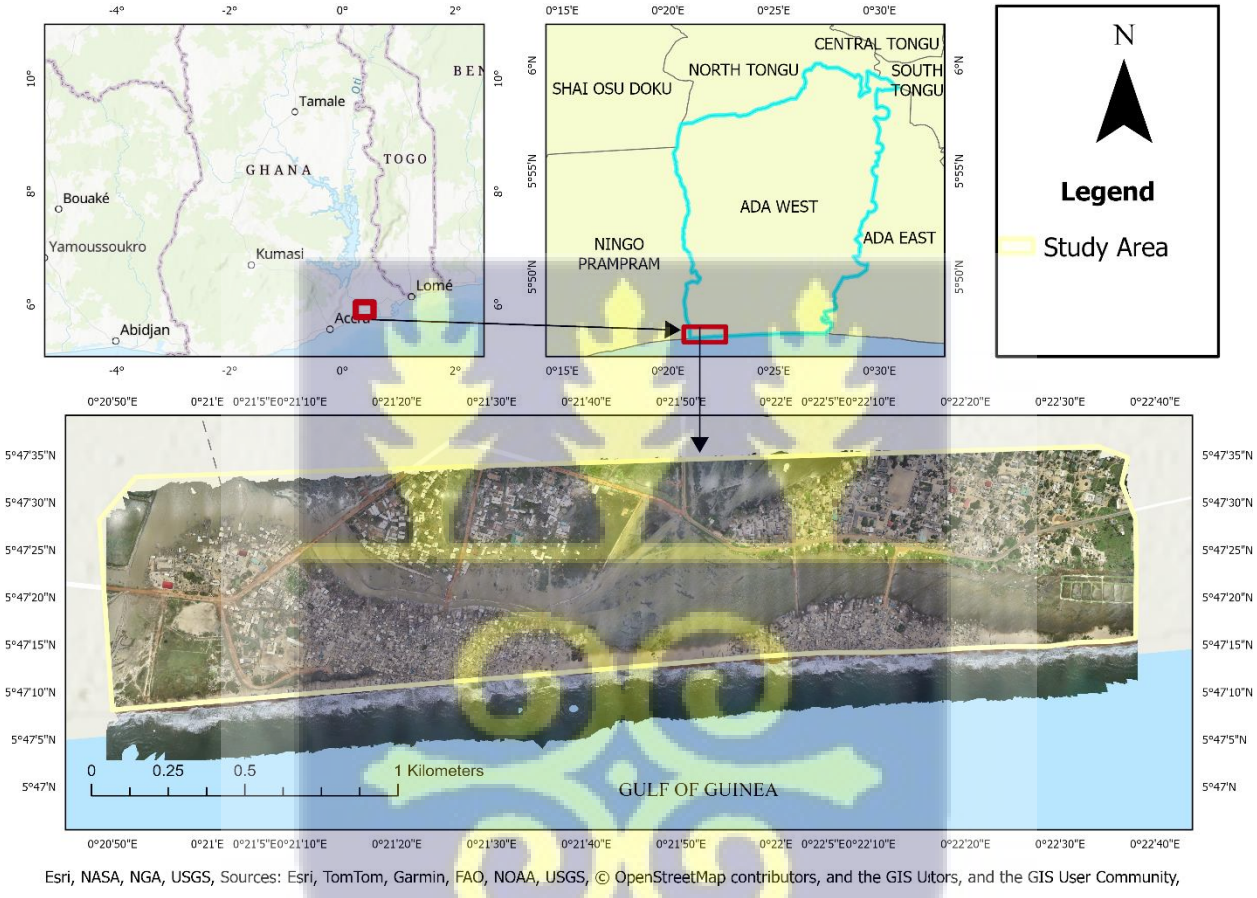

Figure 2: Study area of Akplabanya and Anyamam.

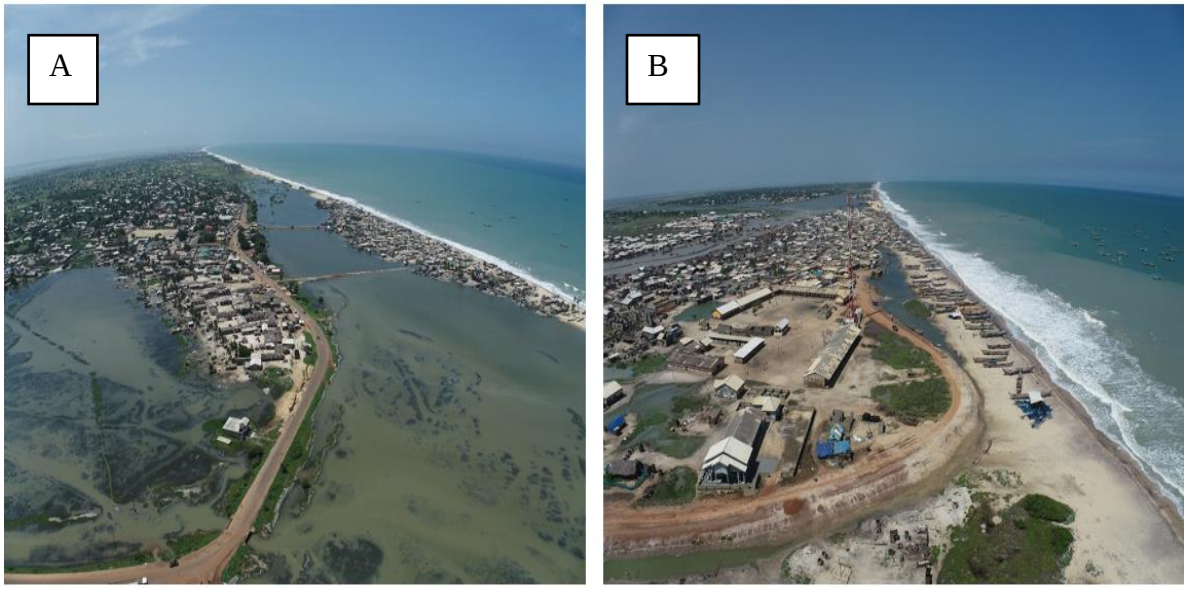

Plate 1: Aerial View of Study Area with Anyamam (A) on the left and Akplabanya (B) on the right . (Source: Author, Field work June 2023).

3.2 DATA SOURCES

The study relied on historical orthophotos available for the study area. This data was retrieved from the Coastal Processes Group at the University of Ghana. Orthophotos were acquired for the years 2005, 2015 and 2020. An additional orthophoto was acquired through field surveys using the drone for the year 2023.Also, sea level rise heights for different time periods were acquired from previous work by Avornyo et al., (2024).

3.3 RESEARCH DESIGN

3.3.1 Sampling Approach

The study adopted a mixed-method research approach, with a descriptive research design where the qualitative data explains and contextualizes the quantitative data (Blessing et al., 1998). The components for this research design are summarized and illustrated in Figure 3.

In the quantitative phase, the study assessed erosion hazards by creating hazard maps for coastal erosion, which provided estimates of future shoreline positions. It also evaluated the extent of SLR related coastal flooding and quantified community vulnerability to both erosion and flooding using index-based approaches derived from semi-structured questionnaires.

For the qualitative research, the perceptions of residents in the communities were obtained using semi- structured questionnaires and focus group discussions (FGDs). For the questionnaire, participants provided their views on vulnerability in their communities due to coastal erosion and coastal flooding (See Appendix 1 and Appendix 2). To obtain deeper context on the quantified vulnerability results, triangulation was applied by comparing questionnaire responses with insights from the FGDs. This approach is used to shed light on nuanced community response and interpretations that may not emerge when relying on a single approach (Almeida et al., 2020).

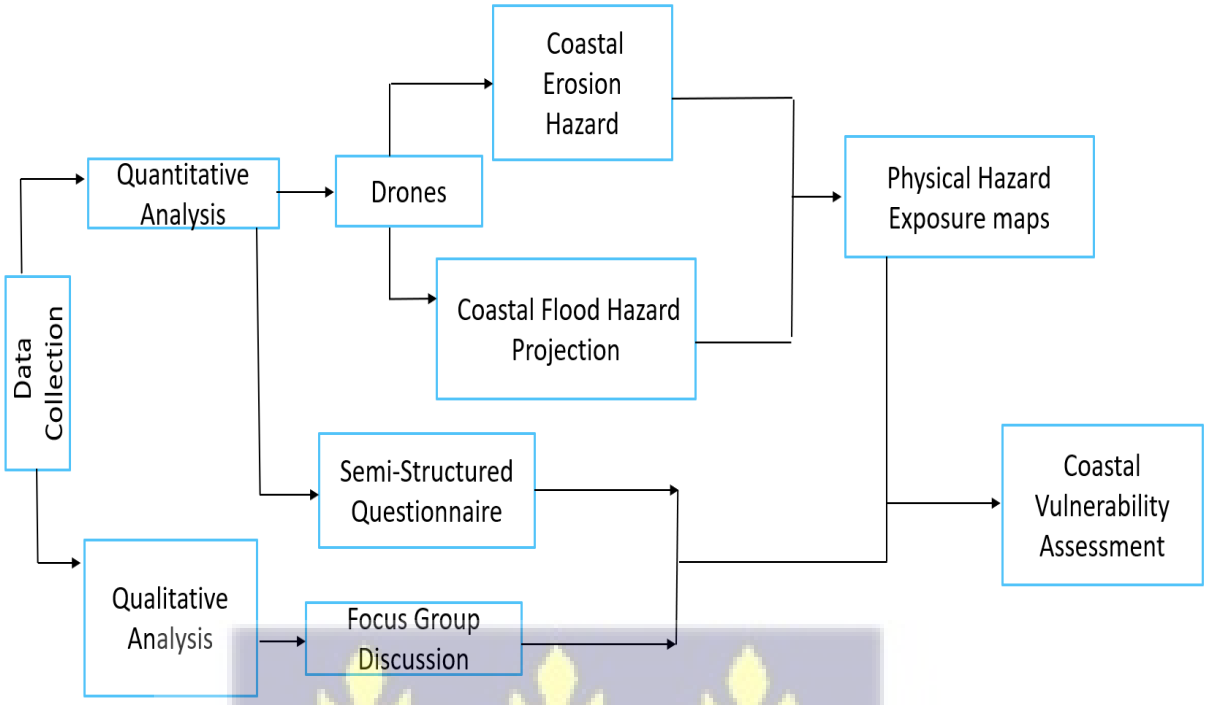

Figure 3: Methodology Workflow for Thesis work.

3.3.2 Sampling Procedure

The sampling procedure used for administering the questionnaires was stratified random sampling where each town in the study area was divided into three (3) grids totaling six (6) grids for both towns. The most eastward and westward housing structure in each town was used to calculate each grid extent. The stratified random sampling is a probability sampling method where the population is divided into distinct subgroups (i.e. grids) based on shared characteristics, and then random samples are selected from each stratum (Parsons, 2017). Expert judgement was used in estimating the number of grids assessed considering size of analysis, estimated population distribution using number of housing structures as a proxy and resources available to complete the survey. This was used to assess fine-scale integrated vulnerability from both the quantitative and

qualitative data related to both towns as it can give a very detailed perspective that is not generalized.

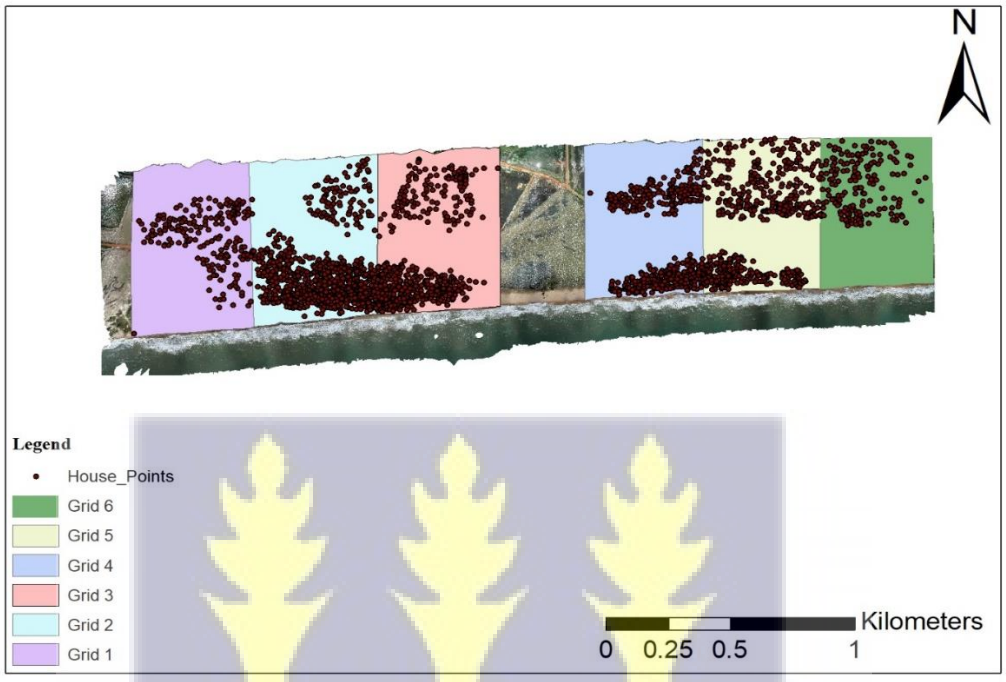

Figure 4: The Grid Extents of the Study Area and House Points.

3.4 COASTAL FLOOD HAZARD PROJECTIONS

3.4.1 Coastal erosion rates processing in ArcMap.

Data Acquisition and Pre-processing:

Three (3) historical high-resolution UAV orthophotos and a present UAV orthophoto covering the study was used. The year periods for the orthophotos are 2005, 2015, 2020 and 2023. Each orthophoto was orthorectified and georeferenced with 14 points in the orthophoto using the 2015 orthophoto as a reference to obtain corrected spatial positioning of the imagery using the Ghana Metre Grid projection coordinate.

Shoreline Digitization

The shorelines for each time from the corresponding UAV orthophoto was digitized. The dry-wet boundary was used as the proxy of the shoreline throughout the process because of its ease of use (Appeaning Addo et al., 2008; Toure et al., 2019). The corresponding year of image acquisition was used as an attribute for each digitized shoreline vector.

DSAS Setup and Analysis

The study employed the Digital Shoreline Analysis System (DSAS 4.2) developed by the United States Geological Survey (USGS) to conduct shoreline change detection analysis. This software, an extension for ArcGIS, computes rates of shoreline change at user-specified intervals along the shoreline using various computational methods.

Geodatabase Development

To help in change statistic calculations, the DSAS 4.2.1 requires that all input data are consistently organized within a geodatabase. Therefore, a geodatabase was created to store the

extracted shoreline positions, length, identification number, geometry, and quantified uncertainty values.

Baseline Construction

The DSAS 4.2.1 employs a measurement baseline method to calculate the rate of change statistics for a time series of shorelines. In this study, a baseline was constructed by automatically digitizing a line approximately 100 meters inland from the closest shoreline, considering the general orientation of the shoreline. The data was projected to the Ghana Metre Grid projection, and the baseline attributes included object identifier, geometry, length, and a user-generated identification column.

Casting Transects

Subsequently, a total of 332 transects were cast along the entire coastline stretch from east to west at a specified interval of 10 meters. This interval was chosen based on the generally homogeneous geology of the shoreline, as discussed in Section 3.3, where little variation was expected for distances less than 10 meters. The transects were cast at simple right angles from the baseline offshore, with a length of 100 meters to ensure they intersected all four shoreline positions.

Output and Analysis

There are two outputs from the DSAS 4.2.1 model which were of importance for this thesis work. The first being the erosion and accretion rates for the study area and the second being the shoreline position projections in 10 and 20 years under uncertainty.

For output 1, the calculated statistics were downloaded for each transect in the entire study area. The spatial patterns of erosion and accretion were examined by visualizing the LRR values along the coastline. Areas with significant erosion were identified based on negative values of LRR. Maps and figures were used to illustrate the spatial distribution of erosion rates and visualize shoreline changes over time using different colors or symbols to represent varying degrees of erosion and accretion.

For output 2, the extents of uncertainty were processed into a polygon layer in ArcMap 10.7.1 by tracing the outlines of projection and using the shoreline at the shoreline boundary. This was used to quantify the land area to be lost. The number of housing structures which was lost for each projection can be processed in ArcMap 10.7.1 by giving every housing infrastructure a point attribute and classified as affected based on their contact with the polygon for coastal erosion.

3.4.2. Uncertainty Quantification for Coastal Erosion

The uncertainties quantification estimates were based on research works by Crowell et al., (1991), Hapke et al., (2010) and Moore (2000). Errors associated with the imagery used in this study stemmed from several factors related to each orthophoto for each year. Four primary sources of error were identified, contributing to uncertainties: tidal range, shoreline digitization, the position of digital water bodies (DWB), and differences in resolution. Given the resolution of the orthophotos, the 1-meter standard tidal range of the area was considered a significant source of uncertainty.

To address this, the total shoreline positional error for each epoch (Ex) was calculated using the Equation 1:

$$E_x = \sqrt{(Es^2 + Ep^2 + Er^2 + Et^2)} \ldots\ldots\ldots\ldots (1)$$

Where:

Es is the error occurring from scale difference, *Ep* is the photogrammetric error, *Er* is the registration error and E_t is the error due to tides.

The assumption of this approach is that component errors are normally distributed (Dar & Dar, 2009). The total uncertainties were used as weights in the shoreline change calculations. The values were annualized to provide error estimation for the shoreline change rate at any given transect (Equation 2) and expressed as:

$$E_{ann} = \frac{\sqrt{(Ea^2 + Eb^2 + Ec^2 + Ed^2)}}{T} \ldots\ldots\ldots (2)$$

where Ea, Eb, Ec and Ed are the total shoreline position error for the various years and *T* is the 18 years' period of analysis.

3.5 COASTAL FLOOD HAZARD EXPOSURE

Selection of Projection of SLR

This study used the projection RCPs 5-8.5 based on the precautionary principle because of the high stakes involved used by most organizations in the face of uncertainty (Kriebel et al., 2001; OECD, 2023). As iterated earlier, the projections of SLR were based on the work by Avornyo et al., (2023). They utilized regional sea level rise (SLR) projections obtained from NASA's IPCC Regional Sea Level Projection Tool, based on the IPCC's Sixth Assessment Report (AR6), Working Group I. Their analysis employed the RCPs scenario 5 - 8.5, which is associated with very high greenhouse gas emissions. The probabilistic projections for SLR considered, focused on the likely range with a 67% probability (between the 17th and 83rd percentiles), and the SLR projections for time periods under RCP scenario were applied. The estimated total SLR for Ghana is shown in the Table 2.

Table 2: Total SLR Table Based on RCP 5 - 8.5

Scenario for RCPs 5-8.5 (83% extreme)	Total Sea Level Rise by 2100 (m)
2021 – 2040	0.233
2041 – 2060	0.449
2081 – 2100	1.118

Data Acquisition

The area of interest for analysis was defined and desired flight path was inputted. Sufficient overlap was programmed between images for accurate reconstruction which captures high-resolution images with consistent lighting conditions. The DJI Phantom IV RTK drone used for

the fieldwork had inbuilt camera position and orientation which automatically recorded these data during the flight using GNSS sensors.

Preprocessing

All captured images were organized and downloaded with properly labeled and accessible for processing. The images were inspected for any issues like blurriness, distortion or artifacts. All unusable images were discarded. The camera position data is corrected by georeferencing the images using Ground Control Points (GCPs) captured on the ground. The survey was planned by determining the survey grid or layout, which includes the distribution of Ground Control Points across the study area. Factors considered include the desired resolution of the DEM, accuracy requirements and terrain characteristics.

RTK and Static GPS Data Collection:

RTK and Static GPS was collected by placing the DGPS RTK Stonexx s850A GPS receiver at the selected control points within the study area for 14 total points. The receiver was allowed to collect data for 20 minutes to ensure high precision. The coordinates of the control points were recorded for identification and correction of drone collected GPS data.

Photogrammetry Workflow

Agisoft Metashape 2.1.1 was used to process the images obtained from the UAVs. The pre-processed images were loaded into the software. The software automatically identified and matched common features (key points) across overlapping images and camera parameters like focal length and distortion coefficients are refined based on feature matching and georeferencing information. The ground control points were aligned manually by aligning the points in images.

Dense point cloud was generated to create a dense 3D point cloud representing the terrain surface by reconstructing the positions of millions of points based on image information.

DEM Generation and Export

The resolution of output DEM is set to 13.5 cm resolution and processed. The filtered point cloud representing the bare earth is interpolated to create a continuous raster surface representing the Digital Elevation Model (DEM). The final DEM is exported desired in the format Tiff files with proper georeferencing information. The DEM export was set to projected coordinate system UTM Zone 31N which is the working projection.

Model Implementation:

The DEM was imported into an ArcMap 10.7.1 for generating the new raster layer representing the potential inundation extent. A personal geodatabase was created in the geodatabase environment where the GIS computation was done for the scenarios of IPCC SLR Projection. A value of 1 to cells representing areas below the projected sea level and 0 to cells above it was assigned. This was achieved using conditional statements based on DEM elevation and the chosen sea level rise value. The resulting raster was then converted to Polygon using the Raster to Polygon selection from Arctoolbox.

Analysis and Visualization:

Delineation of flooded areas was done by overlaying the inundation layer on the DEM. The potential impact was quantified by calculating the total area and proportion of the inundated zone. Inundation maps and figures were created to illustrate the spatial distribution of coastal flooding under the chosen sea level rise scenario.

3.6 SOCIAL PERCEPTIONS ON COASTAL HAZARDS

Ethical Procedure and Ethical Clearance

An important part of a social analysis is to undertake and obtain ethical clearance. Ethical clearance was obtained from the Ethics Committee from the College of Basic and Applied Sciences of the University of Ghana with reference number: ECBAS 080/22-23. The University's research code of conduct regarding ethical issues were strictly adhered to, ensuring voluntary participation of the respondents and clear purpose communication of the study to establish informed consent of the respondents.

3.6.1 Data Collection

This methodology assessed the local perception on the coastal hazards in the community relate to coastal flooding and coastal erosion. Data collection started with a reconnaissance survey to become acquainted with the study area and target population. This was followed by community entries to seek approval and build trust with community stakeholders in the study area before proceeding with data collection. These initial visits also facilitated the selection and scheduling of participants for the focus group discussions (FGDs).

Inclusion and Exclusion Criteria

Household heads with over 5 years of residence period and above 18 years of age are the target inclusion criteria.

Household Head Questionnaire Administration:

The questionnaire consisted of a mix of mostly closed-ended and a few open-ended questions. Closed-ended questions were helpful since they enabled the respondent to have greater control and precision for easier analysis (Arthur, 2006). The questions focused on assessing

participants' perceptions of vulnerability, experiences with coastal flooding and erosion, socio-economic dimensions and experiences relating to health, adaptation strategies and helped quantify vulnerability.

Confidentiality and Anonymity:

Participants' privacy and confidentiality were strictly maintained. All collected data was stored securely. No unique personal identifiable information was taken to ensure the anonymity of participants, and any potentially personal unique identifying information was kept separate from the research data.

Informed Consent

Participants were provided with a clear explanation of the study's purpose, their rights as participants, and the use of their data. Informed oral consent was obtained from participants before they began the questionnaire.

Data Collection Tool

Google Sheets, a web-based spreadsheet application, was used as the platform for administering the questionnaire. This was because of the various exportable formats that it stores data. The questionnaire was filled in Google Forms, allowing for efficient data entry, automatic data saving, and seamless data management (Raju & Harinarayana, 2016).

Sample Size Determination

Sample size determination is an important aspect of social surveys that accounts for representativeness of a universal sample with desired error level of precision (Adam, 2020; Arya et al., 2012). The generated outputs that are representative of the population based on sample size calculated (Gable, 1994; Owens, 2014). This supports the purpose of the survey and enhance

representative results based on the entire population (Ahmad et al., 2023; Martínez-Mesa et al., 2016).

According to the District report of Ada West based on the 2010 Population and Housing Census of Ghana (Ghana Statistical Service, 2014). The district has a population growth of 3.5% as shown in the District Composite Budget of 2022 (Ada West District Assembly, 2022). This was computed with the 2010 household numbers to find estimated household count for 2023 under the assumption population growth rate is equal to the household growth rate. The summary for this estimate is found in Table 3.

The formula (Equation 3) is given as:

Projected Household Count = i* (1 + Growth Rate) ^n …….(3)

Where

i = Initial Household count, n = Number of years to be projected.

Table 3: Household Count for 2010 Housing and Population Census Projected for 2023.

Town in Ada West District	2010 household count	Projected 2023 household count
Akplabanya	1040	1626
Anyamam	1060	1658
Total		3284

For this study we used the Taro-Yarmane formula (Equation 4).

1.Taro Yamane Formula

$$n = \frac{N}{1+Ne^2} \text{ (Adam, 2020)} \ldots\ldots\ldots\ldots (4)$$

Where n = sample size

N = population size

e = error

For this study we used error probability of (0.10) which means reliability level of 90%.

Calculate the Study Area Sampling Size

Using Equation (4), Anyamam and Akplabanya has 3284 households combined

$$n = \frac{3284}{1+3284(0.10)^2}$$

$$n = \frac{3284}{1+32.84}$$

$$n = \frac{3284}{33.84}$$

n = 97.04 = 97

Then the number of questionnaires to be administered per Town is calculated based on ratio as shown in Table 4.

Table 4: Questionnaire Respondent per Town.

Towns	Proportion Of Households To be Administered
Akplabanya	$\frac{1626}{3284} \times 97 = 48.02 = 48$
Anyamam	$\frac{1658}{3284} \times 97 = 48.97 = 49$

Questionnaire Analysis

For questionnaire data analysis, answers in the semi-structured questionnaire were assess social perceptions of respondents to coastal floods and erosion.

The responses of interest from the questionnaire which was used focused on perceived causes of coastal erosion and coastal flooding in the community, impacts of coastal hazards in the community, community support obtained during hazard mitigation and coping, perception of risk posed to community by coastal erosion and recommended activities and recommendations to combat these coastal hazards. Statistics were visualized and analyzed from responses of questionnaires including bar charts and boxplots using Excel 2021 software.

3.6.2 Focus Group Discussions

The Focus Group Discussions (FGDs) were conducted as part of a Participatory Rural Appraisal (PRA) approach to gain insight into and identify local indicators contributing to the communities' vulnerability to coastal hazards, specifically coastal flooding and erosion. PRA is a method that enables local communities to share, assess, and enhance their understanding of these phenomena, as well as to plan and act in response to coastal hazards. (Binta et al., 2018; Parvin et al., 2023; Rahmat et al., 2023; van Aalst et al., 2008).

The semi-structured discussion guide based on the questionnaires administered for key thematic areas and open-ended questions to guide the focus group conversation on coastal erosion and coastal flooding. We made clear that informed consent was obtained.

Data Collection

The FGD commenced following the guide, ensuring all participants have a chance to contribute and moderator asked at the end of each theme discussion if anyone else had something to add and if all participants affirmed there was nothing else to add, before moving to the next

question. The prepared audio recorder was used during the entire discussion to capture the entire discussion session.

Data Import and Transcription

The audio recording files from the recorder was transferred to the computer. The audio was transcribed with the help of a trained transcriber in verbatim from Ada Language to English text. The transcribed text file was imported into MAXQDA 2020 for further analysis.

Data Coding and Analysis in MAXQDA

A coding system based on the research questions and themes were developed based on emerging themes from the discussions. Relevant codes were applied to the transcript segments. MAXQDA's functionalities were used to explore the coded data.

Reporting and Interpretation

Based on the overall coding patterns, emerging themes and insights from the focus group discussions were identified. The findings from MAXQDA 2020 analysis were used to discuss how the focus group data supports or challenges your research questions and validate closed-ended questionnaire responses.

3.7 QUANTIFYING VULNERABILITY FOR COASTAL FLOODING AND COASTAL EROSION.

This methodology was used to achieve Objective 4 of the study. This methodology combined questionnaire response and hazard extent map on the grid level to achieve vulnerability quantification results of coastal erosion and coastal flooding.

Selection of Vulnerability Indicators

The vulnerability quantification was based on the Hazard of Place Model which was used as a reference. Based on literature relevant indicators that represent various aspects of the model relevant to coastal flooding and coastal erosion such as: socioeconomic (poverty, education level, housing quality, access to basic services), demography (age structure, presence of children, elderly, or disabled individuals), social capital (community cohesion, social networks, level of trust in institutions), institutional capacity (availability of emergency response services, evacuation plans, public awareness programs) through local questionnaire administration and rates and hazard extent maps of coastal flooding related to SLR and coastal erosion.

Delineation Of Extents

The polygons of the 6 grids which was used to delineate the extents was used as the boundary in ArcMap 10.7.1. the 6 grid polygons were used as an intersect function to calculate variables of exposure to coastal erosion per grids including erosion rates, land area loss per projection and housing structures to be lost per projection. The same grid polygons were used with the intersect function of calculate variables of coastal flooding due to SLR per grid including flooding extents per grid.

Index Computing

According to Kantamaneni et al., (2018) and von Szombathely et al., (2023), there is no specific laid down procedure to create a vulnerability index, hence different studies have used differing procedures. The thesis builds on Yankson et al. (2017), who applied a min-max normalization technique to create community-level vulnerability indexes. This method converts each indicator into scores between 0 and 1, aligning with IPCC vulnerability factors such as sensitivity, exposure, potential impacts, and adaptive capacities. (IPCC, 2023; Sharma & Ravindranath, 2019). Yankson et al. (2017) used the standardization procedure following the Min-Max method (Equation 5) as follows:

$$Isc = \frac{S - Smin}{S_{max} - S_{min}} \ldots\ldots\ldots (5)$$

When an index contributes to an increase in Vulnerability (Equation 6)

$$Isc = \frac{Smax - S}{S_{max} - S_{min}} \ldots\ldots\ldots (6)$$

When an index contributes to reduces the overall vulnerability

Where:

The standardized index for each community (Isc) is calculated using the observed value (S) for that community, along with the maximum (S_{max}) and minimum (S_{min}) observed values. The mean index for each factor such as sensitivity, exposure, or adaptive capacity is then determined using the formula provided in Equation (7).

$$fIsc, mean = \frac{1}{n}\sum Isc \ldots\ldots\ldots (7)$$

Where f can be either exposure (E), sensitivity (S) or adaptive capacity (A) index, and n represents the total number of indicators for the factor.

Community vulnerability indexes were finally determined by computing Potential Impact index as follows in Equation (8).

$$P = SIsc_{mean} + €Isc_{mean} \text{ ……..(8)}$$

Where:

P is the potential impact,

$€Isc_{mean}$ is the potential impact index

$SIsc_{mean}$ is the sensitivity index

The Composite Vulnerability is computed using Geometric Aggregation

Composite community vulnerability indexes were finally determined using geometric aggregation method (multiplication) from Sarra et al., (2024) and Balica et al., (2012) is illustrated in Equation (9).

$$V = \frac{€ * S}{A} \text{ ... ... (9)}$$

Where:

Exposure is (€), Sensitivity is (S) and Adaptive capacity is (A) index

Following Bathi & Das (2016), the values for vulnerability dimensions were aggregated without applying weights. As the need for applying weighting was already achieved by standardizing the individual indicators (Talukder et al., 2017). To develop the indexes using min-max method, indicator scores are transformed between zero (0) and one (1), with 0 representing

the lowest score and 1 representing the highest score. Because the final score for each index is relative to each other. It is important to note therefore that the correct conclusions are relative statements for the communities.

The outputs of this results include relative quantification of sensitivity, adaptive capacity, exposure and potential impact. of coastal erosion and coastal flooding vulnerability for Akplabanya and Anyamam. This will allow for discussions on these results.

3.8. RESEARCH LIMITATIONS

This research has limitations that are acknowledged and should be considered when interpreting the results and findings. First, it focused exclusively on the impacts of coastal flooding due to sea level rise (SLR), without factoring in other SLR-related impacts such as subsidence, saltwater intrusion, or ecosystem changes. A comprehensive vulnerability assessment ideally would address all these potential impacts. However, due to technical and financial constraints, this thesis did not have the capacity to conduct such extensive assessments (Hayes et al., 2018; Measham et al., 2011). This thesis, like many local vulnerability assessments, primarily addresses the impact of coastal flooding due to SLR.

Moreover, the use of proxies and indicators while carefully selected, may not fully capture local nuances and limitations for vulnerability quantification. Therefore, results implementations should be undertaken carefully considering the nature and limitations of these proxies.

Also, the study's assessments were based on hypothetical statistical scenarios of future SLR, without accounting for potential changes in urbanization and socioeconomic conditions, which could significantly influence community vulnerability to SLR (Fawcett et al., 2017).

Additionally, the 'bathtub' model employed in this study introduces additional layer of assessment uncertainties and errors (Elneel et al., 2024; Mcleod et al., 2010; Mimura, 2013). The study used a linear combination of SLR scenarios for the vulnerability assessments. However, sea level rise does not occur linearly, and local tidal trends may also shift. As our understanding of how local tidal levels will respond to SLR improves, this should be incorporated into future assessments. The research also concentrated solely on flood inundation from SLR, neglecting other crucial sources including storm surges and lagoonal flooding.

Finally, for coastal erosion hazard assessment shoreline recession should be analyzed in combination with subsidence data to find the actual coastal erosion hazard which was not done in the study. The study did not assess subsidence because it assumed that the subsidence rate was not significant to affect coastal erosion for the study which might not always be true.

CHAPTER FOUR

RESULTS

4.1 INTRODUCTION

This chapter begins by showing the various inputs and outputs for distribution of coastal erosion rate and estimated shoreline positions in the next 10 and 20-years for the two communities. The results show outputs for flooding related to SLR for 2021 – 2040, 2041 – 2060 for 2081 – 2100, for the socio-demographic aspects based on the questionnaire and FGD individuals linking projections to local perception and social dynamics. Finally, the last sub-section of result shows results for quantifying vulnerability with the various dimensions of vulnerability for coastal flooding and erosion including sensitivity, adaptive capacity, potential impact and composite vulnerability.

4.2. COASTAL EROSION HAZARD

Processing Results for Uncertainty Quantification of Orthophotos

Table 5 shows the resolution of the secondary data (drone orthophotos for 2005, 2015 and 2020) in addition to the primary data (drone orthophoto for 2023) used for coastal erosion assessment.

Table 5: The Description of Orthophotos used for Shoreline Change Analysis.

Year	Bands	Resolution (m)
2005	3	2.5
2015	3	0.40
2021	3	0.25
2023	3	0.13

All images were orthorectified with 2015 tiff file as the reference. All Tiff files were orthorectified with it by using 14 distributed points in both images as reference. The image orthorectification process produced these outputs for orthorectification total RMSE as shown in Table 6.

Table 6: Orthorectification Total RMSE with 2015 Orthophoto as reference.

Years of Tiff Image	Orthorectification Total RMSE
2005	0.34
2015	-
2021	0.28
2023	0.30

The orthorectification RMSE was then inputted to calculate the shoreline uncertainty. The uncertainty associated with the shorelines are calculated in Table 7.

Table 7: Uncertainty Quantification for Orthophotos.

Shoreline year	**Tidal uncertainty (m)**	**Resolution error (m)**	**Positional error (m)**	**DWB uncertainty (m)**
2005	±1.00	±2.50	±0.34	±2.50
2015	±1.00	±0.40	-	±0.40
2021	±1.00	±0.25	±0.28	±0.25
2023	±1.00	±0.13	±0.30	±0.13
Uncertainty quantified				±0.23

4.2.2 Erosion Trend Results

For the 3.32 km shoreline stretch with a 10-meter transect spanning in the Study Area, 332 transects were generated in DSAS 4.2.1 plug-in (Figure 4). The rate of change per transect was interpreted in a line graph, of the 332 total, 186 were within the boundary of the Akplabanya township and the remaining 146 were within the township of Anyamam.

The line plot (Figure 6) depicts the erosion rates (LRR) in meters per year along the longshore distance, ranging from 0 to 332 transects**.** The erosion rates vary between approximately -2.88 m/yr±0.23 and -0.89 m/yr±0.23 with varying level of fluctuations in erosion rates along the longshore transects. The average erosion rate for all transects covering both towns was -1.90m/yr±0.23.

From transect range from 0 to 50, there is minimal fluctuations of shoreline rates with decreasing erosion trend with rates around -2.25 ±0.23 to -1.5 m/yr±0.23. From transect range from 50 to 100. there was a general decreasing trend in erosion rates, reaching closer to -1.0 m/yr±0.23 at around transect 100. From 100 to 150 transect, the erosion rates of the shoreline then started to increase, reaching around -2.0 m/yr±0.23 again. From transect range 150 to 190, there was consistently high erosion rate of shoreline followed by a trend of reduced erosion rate from transect 190, this transects range shows fluctuations between -1.4 m/yr±0.23 and -2.4 m/yr±0.23. In transect range 200 to 250, there is an observable steep increase in trend of erosion rate. The highest rates of erosion in this line graph were observed here along the transect which ranges between -1.5 m/yr±0.23 and -2.9 m/yr±0.23. In transect range from 250 to 300, the rates decrease again but still high erosion rates between -1.5 m/yr±0.23 and -2.5m/yr±0.23. After transect 300,

the erosion rates of shoreline continued to show a decreasing trend with ranges between -1m/yr±0.23 to -2 m/yr±0.23.

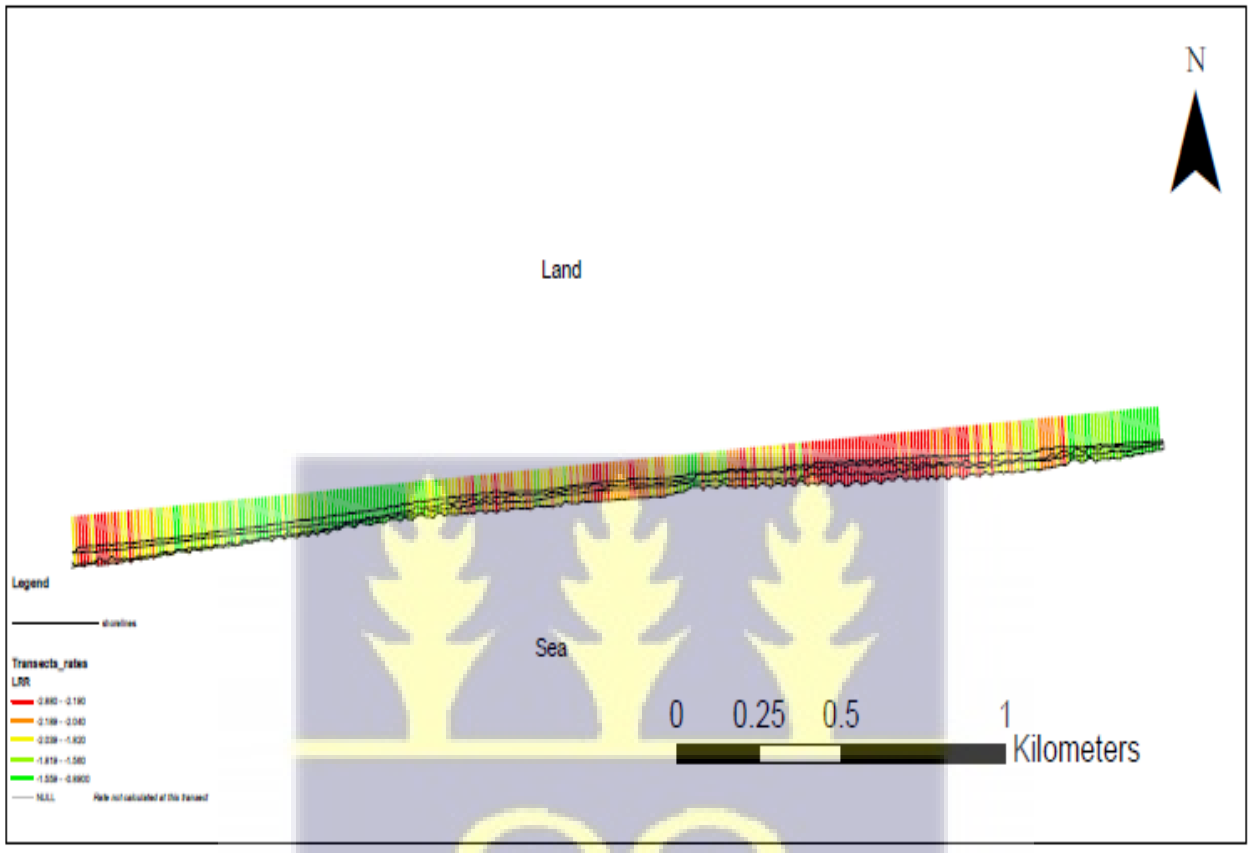

Figure 5: Transect rates in Akplabanya and Anyamam.

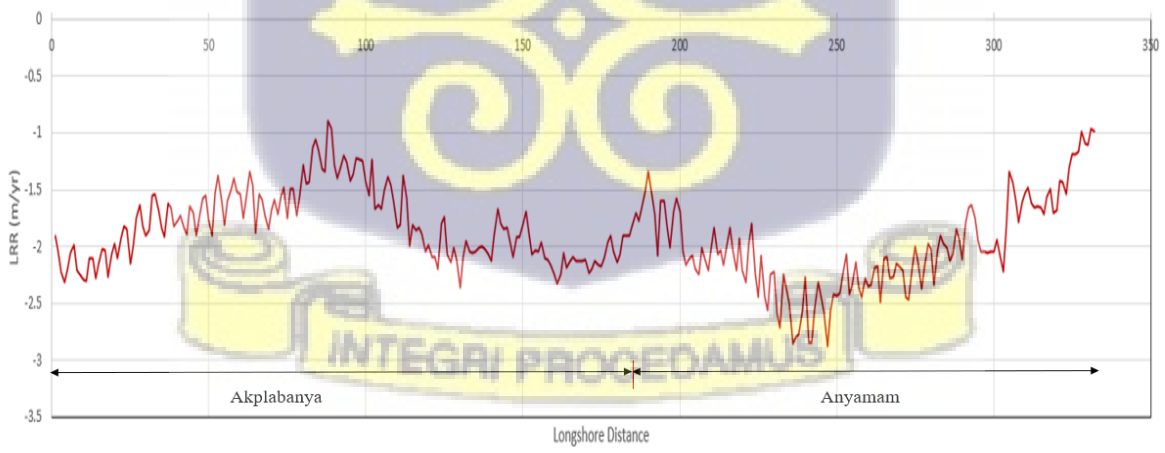

Figure 6: Line Plot Indicating Alongshore Erosion Rates in Akplabanya and Anyamam.

4.2.3. Distribution of Erosion rates per Town.

The individual erosion/accretion rate at each transect can be found in Appendix 3. In Akplabanya, the interquartile range was found to be -2.07 m/yr±0.23 for Q1 (25th percentile) ±0.23, -1.57 m/yr±0.23 for median (50th percentile) and -1.85 m/yr±0.23 for Q3 (75th percentile) which also represents the median indicating a central tendency of shoreline retreat of nearly two meters annually. The full computation extended from a minimum of -0.89 m/yr±0.23 to a maximum observed erosion rate of -2.36 m/yr±0.23.

In Anyamam, the interquartile range was found to be -2.275 m/yr±0.23 for Q1 (25th percentile), -2.07 m/yr±0.23 for median (50th percentile) and -1.7 m/yr±0.23 for Q3 (75th percentile). which also represents the median indicating a central tendency of shoreline retreat of more than two meters annually. The full computation extended from a minimum of -0.97 m/yr±0.23 to a maximum observed erosion rate of -2.88 m/yr±0.23, the highest recorded in the study. The distribution of erosion rates for Akplabanya and Anyamam in Figure 7.

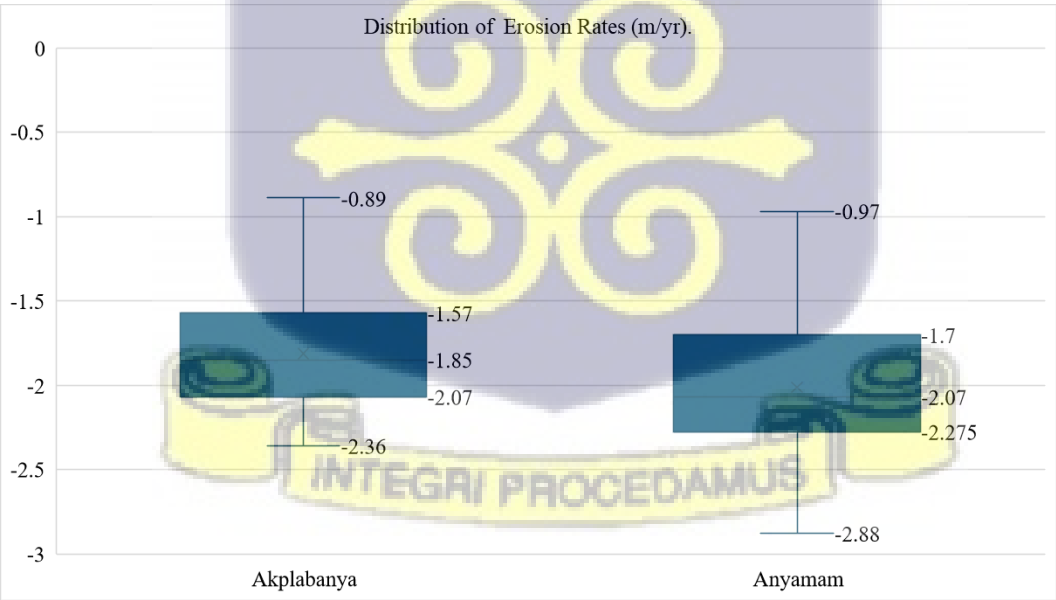

Figure 7: Distribution of Erosion Rates in Akplabanya and Anyamam.

4.2.4 Projected Shoreline Position and Estimated Land Area Loss

The DSAS 4.2.1 plugin also provided the shoreline position which was used to find the area lost under 10-year and 20-year projection with upper and lower bounds as shown in Figure 8.

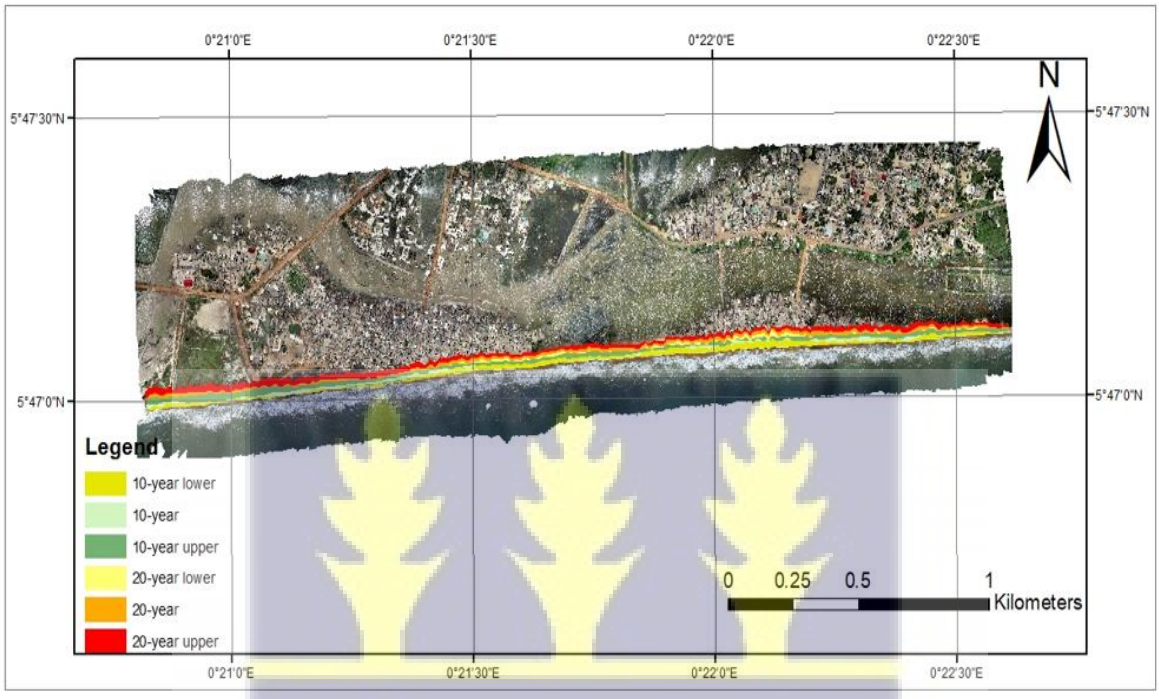

Figure 8: Projected Shoreline Positions and Land Area to be lost.

The data presents projections of land area loss under different scenarios for two towns, Akplabanya and Anyamam, over a 10-year and 20-year period. The projections were categorized into lower, middle, and upper bounds to account for uncertainty in future scenarios.

For the 10-year projection scenarios, the lower projection in Akplabanya showed a land area loss of 15,453.244 m² whiles that of Anyamam was 18,955.957 m². These numbers when combined for this projection for both towns led to a total land area loss of 34,409.20 m² for the 10-year lower projection.

For the 10-year projection for Akplabanya a land area loss of 19,664.601 m² was computed for Akplabanya with a land area loss of 20,661.985 m² for Anyamam. When combined for this projection for both towns, these computed numbers produced a projected total land area loss of 40,326.59 m². For the 10-year upper projection, Akplabanya was about 47,711.794 m² of land area while Anyamam had an estimated land area loss of 38,174.368 m². This created an estimated total loss of 85,886.16 m² when combined for land area loss for the 10-year projection.

For the 20-year projection scenario, the lower projection in Akplabanya was projected to lead to an area loss of 37,617.79 m² while that of Anyamam was projected to lead to land area loss 40,304.010 m². The combined land area loss for the 20-year lower projection for both towns was 77,921.80 m². The 20-year projection for Akplabanya was projected to lead to land area loss of 63,824.115 m² and a land area loss of 54,793.401 m² for Anyamam. For a total land area loss of 118,617.51 m². For the 20-year upper projection, 89,748.220 m² of land was lost in Akplabanya area whiles Anyamam was projected to lose land area of 74,193.349 m². This led to an estimated projected total loss of 163,941.22 m². Table 8 summarizes land area lost under each projection of shoreline position after tracing the outlines from polygons in DSAS 4.2.1.

Table 8: Summary Table of shoreline Position Projection Uncertainty.

Land Area lost under shoreline position uncertainty projection	Akplabanya (square meter)	Anyamam (square meter)	Total (square meter)
10-year lower projection	15453.244	18955.957	34409.20
10-year projection	19664.601	20661.985	40326.59
10-year upper projection	47711.794	38174.368	85886.16
20-year lower projection	37617.79	40304.010	77921.80
20-year projection	63824.115	54793.401	118617.51
20-year upper projection	89748.220	74193.349	163941.22

4.3 COASTAL FLOODING (SLR)

The data from the 14 GCPs extracted using RTKLib 2.4.3 is shown in Table 9 below

Table 9: Processed GCP Information used for DEM.

Points	Longitude (x)	Latitude (y)	Elevation (meters)	Town
Point 1	0.367739727	5.788581455	-1.4817	Anyamam
Point 2	0.369930037	5.787348857	2.3618	Anyamam
Point 3	0.372902901	5.787528209	1.0347	Anyamam
Point 4	0.370495976	5.790244938	1.8728	Anyamam
Point 5	0.373847625	5.790596072	3.0717	Anyamam
Point 6	0.365784865	5.790416503	2.8414	Anyamam
Point 7	0.36727967	5.787215839	1.4587	Anyamam
Point 8	0.361323142	5.786859894	3.8386	Akplabanya
Point 9	0.358448618	5.786692365	6.1193	Akplabanya
Point 10	0.354024814	5.786246149	3.9806	Akplabanya
Point 11	0.350226778	5.785933574	3.6902	Akplabanya
Point 12	0.350305115	5.789503139	3.8733	Akplabanya
Point 13	0.354742361	5.79071962	2.724	Akplabanya
Point 14	0.356883984	5.788529072	2.4928	Akplabanya

After processing into DEM, Figure 9 was obtained as an output for the clipped DEM of the study area excluding the sea to the south.

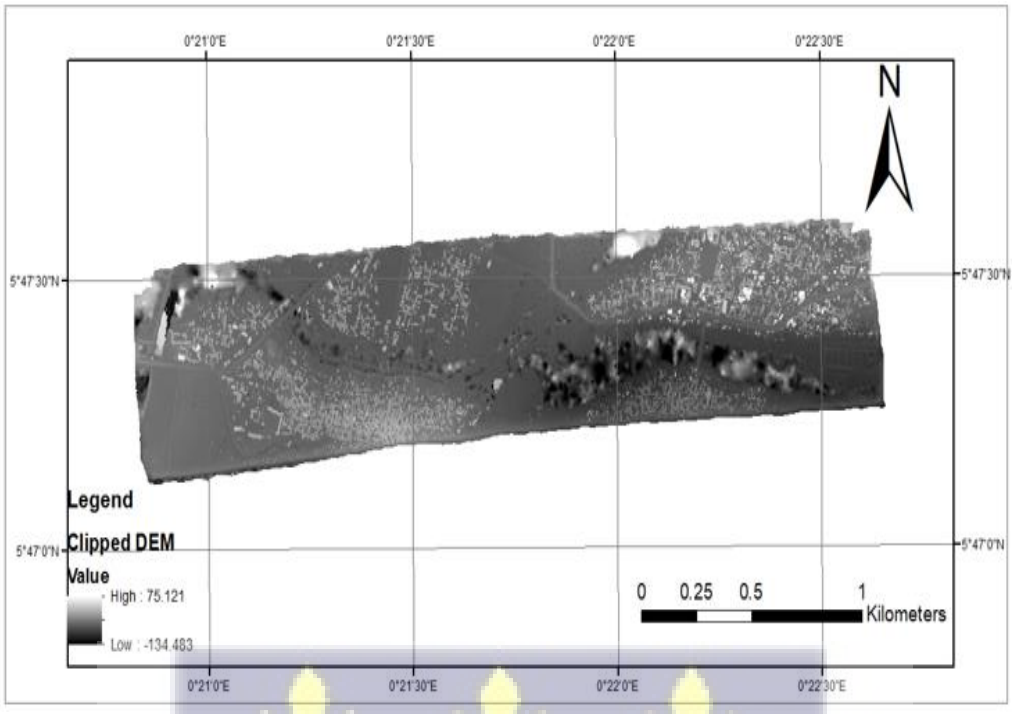

Figure 9: Resulting DEM of the Study Area.

4.3.1. Flooding due to SLR for Akplabanya and Anyamam.

For Akplabanya, the inundated area increased progressively from 2,210.90 sqm (0.17%) in 2021-2040 to 41,823.31 sqm (0.19%) in 2081 - 2100. There was an increase in inundation from 2041- 2060 to 2081 - 2100. The differential inundation in Akplabanya when using 2021-2040 as a reference showed small increases of 0.02 and 1.2 for 2041 – 2060 and 2081 - 2100 respectively.

For Anyamam, the inundated area showed a substantial increase from 6,472.01 sqm (0.6%) in 2021-2040 to 331,063.84 sqm (32.54%) in 2081-2100. The percentage of inundation grows significantly, especially between 2041-2060 (16%) and 2081-2100 (32.54%). The differential inundation in Anyamam when using 2021-2040 as a reference showed significant increases of 15.4 and 16.54 for 2041 – 2060 and 2081 - 2100 respectively.

The combined inundated area for both towns increase from 8,682.91 sqm (0.3%) in 2021-2040 to 165281.46 sqm (6.9%) for 2041-2060 and 207,104.77 sqm (8.6%) in 2081-2100. The most significant increase was observed in the later period 2081-2100. The combined differential inundation in both towns when using 2021- 2040 as a reference showed significant increases of 6.6 and 2.3 for 2041 - 2060 and 2081 - 2100 respectively. Table 10 summarizes the SLR inundation statistics for Akplabanya and Anyamam.

Table 10: SLR Inundation Statistics for Akplabanya and Anyamam.

Description	Examined Town Area (sqm)	SLR-Projection Scenario	Inundated Town Area (sqm)	Percentage Inundation Per Scenario	Differential Inundation per Town
Akplabanya	1363140	2021 – 2040	2210.90	0.17	-
		2041 – 2060	2524.53	0.19	0.02
		2081 – 2100	41823.31	3.1	1.2
Anyamam	1017480	2021 – 2040	6472.01	0.6	-
		2041 – 2060	162756.93	16	15.4
		2081 – 2100	331063.84	32.54	16.54
Total	2380620	2021 – 2040	8682.91	0.3	-
		2041 – 2060	165281.46	6.9	6.6
		2081 – 2100	207104.77	8.6	2.3

4.4 ASSESSING SOCIAL PERCEPTION RELATED TO VULNERABILITY DUE TO COASTAL HAZARDS.

4.4.1. Socio-demographic characteristics

A total of 48 questionnaires were administered to respondents in Akplabanya representing 49.48% of questionnaires administered, and to 49 respondents in Anyamam representing 50.52% of questionnaires administered. The number and distribution are based on the sample size calculation as well as the projected household count based on 2022 Ada West District Composite report (Ada West District Assembly, 2022).

For the gender distribution among the household head respondents, males composed 57.73% whiles females were 42.27% of respondents. The ages of household heads are categorized into five groups between 18 – 29 (5.15%), 30 – 39, (14.43%), 40 – 49 (19.59%), 50 – 59 (24.74%), and above 60 (36.08%) were categorized as such. There is an increase in the number of respondents as age group increases. Most household heads are aged 50 and above (60.82%) of with the largest single group being those above 60 years old. This trend is expected as traditional household headship is determined by age, wealth and social relations.

The education levels of the respondents are diverse. In all, 25 respondents representing 25.77% of the sample reported having No Education level completed. 26 respondents representing 26.80% have completed Basic Level education. 29 respondents representing 29.89% reported completion of Junior High School level education. A further 13 respondents representing 13.40% reported completion of Senior High School level education. Finally, 4 respondents representing

4.12% reported completion of Tertiary Level education. Most respondents have completed basic or Junior high school, while a small percentage have attained tertiary education.

The monthly total household income is distributed as follows.12 respondents (12.37%) said they preferred not to say their monthly household income. 5 respondents (5.15%) reported that their household income was between 0 – 699 cedis. 8 respondents (8.25%) reported household income in the bracket of 700 – 1499, while 37 respondents (38.14%) reported total monthly earnings between 1500 – 2999. 27 respondents (27.84%) reported total household earnings in 3000 – 4999 range. Finally, 8 respondents (8.25%) reported household earnings above 5000 cedis. Majority of households have an income range of 1500 - 4999, with 38.14% earned between 1500 - 2999 and 27.84% earn between 3000 - 4999. The summary of the socio-demographic characteristics in each town is shown in Table 11.

Table 11: Socio-demographics of Questionnaire Participants.

Description	Variable	Frequency	Percentage
Towns	Akplabanya	48	49.48
	Anyamam	49	50.52
Gender	Males	56	57.73
	Females	41	42.27
Age Of Household Heads	18 – 29	5	5.15
	30 – 39	14	14.43
	40 – 49	19	19.59
	50 – 59	24	24.74
	Above 60	35	36.08
Education Level Completed	No Education	25	25.77
	Basic Level	26	26.80

Description	Variable	Frequency	Percentage
	Junior High School	29	29.89
	Senior High School	13	13.40
	Tertiary Level	4	4.12
Monthly household income range	Prefer not to say	12	12.37
	0 – 699	5	5.15
	700 – 1499	8	8.25
	1500 – 2999	37	38.14
	3000 – 4999	27	27.84
	Above 5000	8	8.25

4.4.2 Socio-demographics of FGD Participants

Two FGDs were conducted, one for each of the study communities. The groups involved household heads who are community members who have stayed in the region for several years. In the section of the table present the socio-demographics of the FGDs participants. 7 participants were interviewed in both towns. In Akplabanya, the occupation of female participants included petty traders, fish mongers and smokers with 67% having basic level education attainment whiles the men were fishermen and Local leadership with 50% having basic education attainment. For Anyamam, the FGD respondents constituted females who were petty traders, fish smokers and fish mongers with 67% having basic level education attainment. For the men, occupations they were involved in included fishermen, boat repairers and Local leadership positions with 50% having basic education attainment. In both towns, the most educated in the group were males who were also in Local Leadership positions with Senior High School Level completion and Tertiary Level

education completed in Akplabanya and Anyamam respectively. The summary of the socio-demographics of FGD participants is shown in Table 12.

Table 12: Summary Socio-demographic Table for FGD Respondents.

Town	Gender	Occupation(s)	Education Level Completed
Akplabanya	Male	Local representative, Fisherman	Senior High School
	Female	Fish monger , Fish smoker	Junior High School
	Male	Fisherman	Basic Education
	Male	Fisherman	Basic Education
	Female	Petty trader	Basic Education
	Female	Fish smoker , Fish monger	Basic Education
	Male	Fisherman	Junior High School
Anyamam	Male	Fisherman, Boat repairer	Junior High School
	Male	Fisherman	Basic Education
	Female	Fish business	Basic Education
	Male	Fisherman	Basic Education
	Female	Petty trader, Fish monger	Junior High School
	Female	Fish monger, Fish smoker	Basic Education
	Male	Fisherman, Local Unit Leader	Tertiary Education

4.4.3 Questionnaire Analysis

Natural events that pose a risk to the community

The respondents in Akplabanya and Anyamam were asked to name natural events that pose a risk to the community. The essence of the question was to ascertain the reality on the ground in terms of coastal hazards that they were aware was impacting them. The coastal hazards mentioned

were coastal flooding, coastal erosion, rainfall, flash flood and strong winds. The summary for the results was shown in Figure 10.

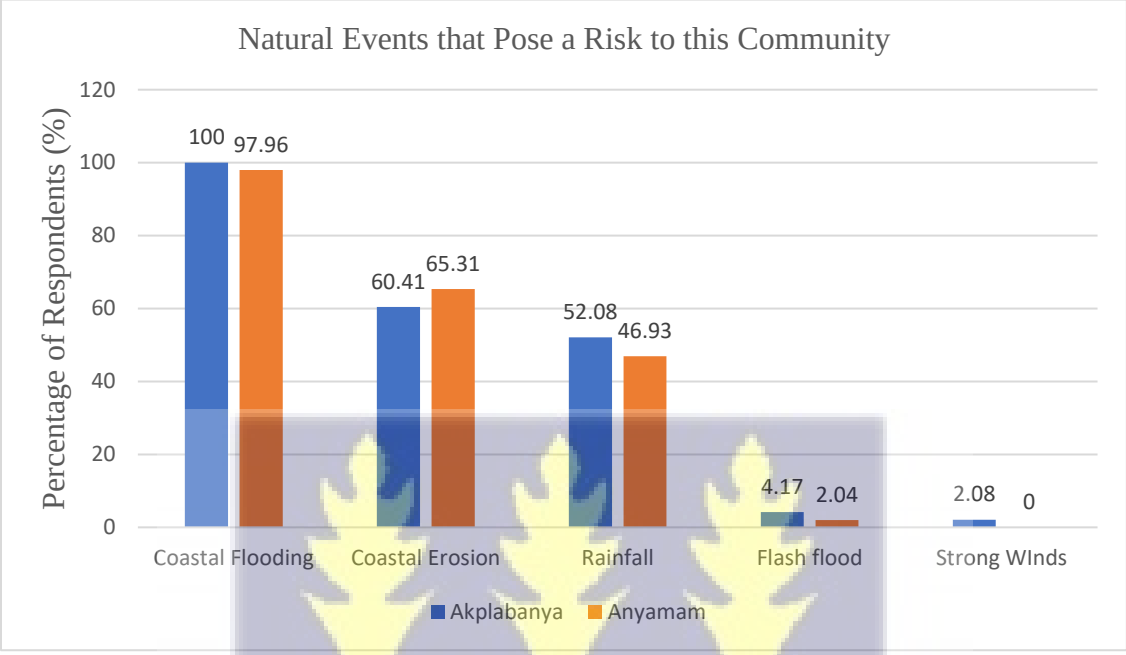

Figure 10: Illustration of Responses on Natural events that Pose a Risk to the Community.

Causes of Coastal Flooding

In Akplabanya, the respondents indicated that Coastal Flooding was attributed to three specific causes: Anthropogenic (41.67%), Hydrodynamic (47.91%) and Divine / Supernatural (35.42%). In Anyamam, Supernatural / Divine was mentioned the most (55.1%) followed by Hydrodynamic (44.89%) and Anthropogenic (34.69%). The results for the perceived causes of coastal flooding are summarized in Figure 11.

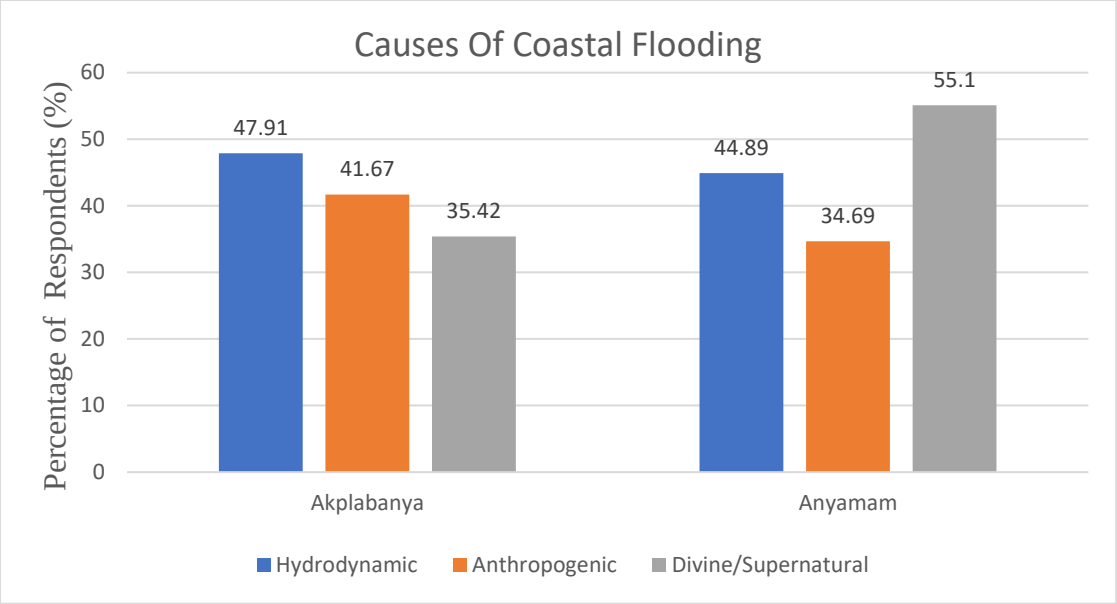

Figure 11: Illustration of Responses on the Causes of Coastal Flooding.

Causes of Coastal Erosion

In Akplabanya, the respondents indicated that coastal erosion was attributed to four specific causes: Anthropogenic (35.41%), Hydrodynamic (52.08%), Divine / Supernatural (12.5%) and Tectonic causes (2.08%). In Anyamam however, coastal erosion was attributed to three causes namely Supernatural / Divine (48.98.19%) Anthropogenic (44.9%) and Hydrodynamic causes (59.18%). The results on the causes of coastal erosion are illustrated in Figure 12.

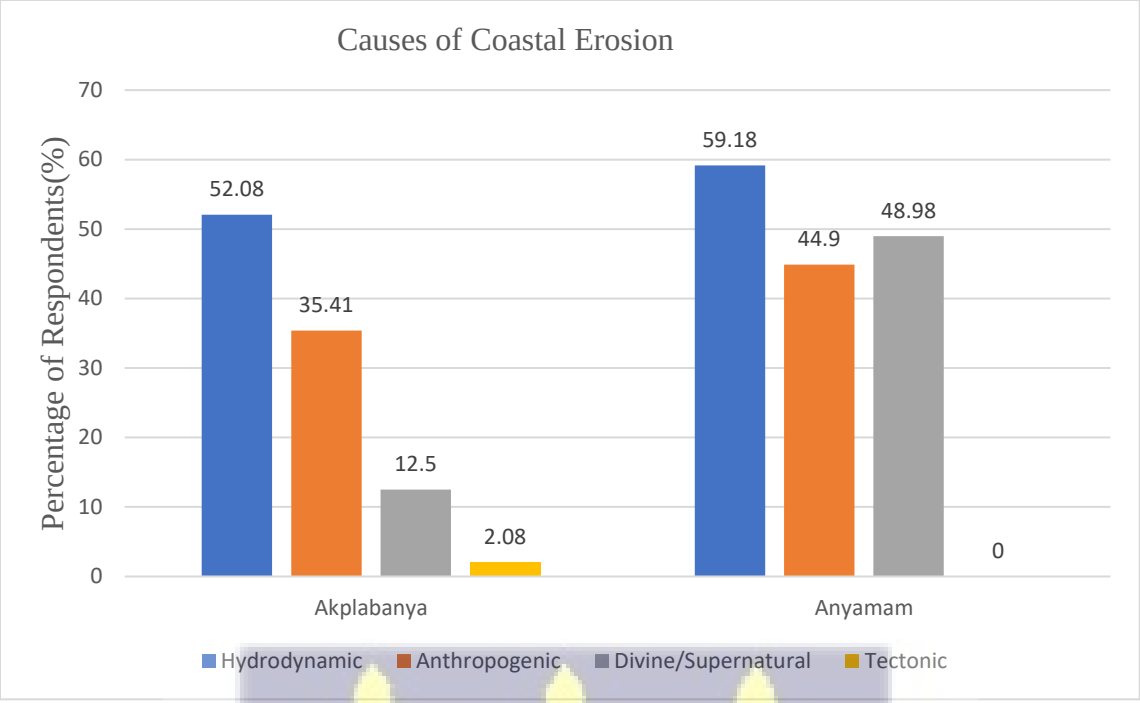

Figure 12: Illustration of Responses on the Causes of Coastal Erosion.

Opinion inclusion in Addressing Coastal Hazards.

Respondents in Akplabanya and Anyamam evaluated if their opinions were taken in consideration in efforts to deal with coastal hazards. In Akplabanya, Yes (10.42%) and No (89.02%). Anyamam also recorded respondent perception of if their opinions were taken into account at Yes (4.08%) and No (95.92%). The results for if opinions were taken into consideration about coastal hazards are shown in Figure 13.

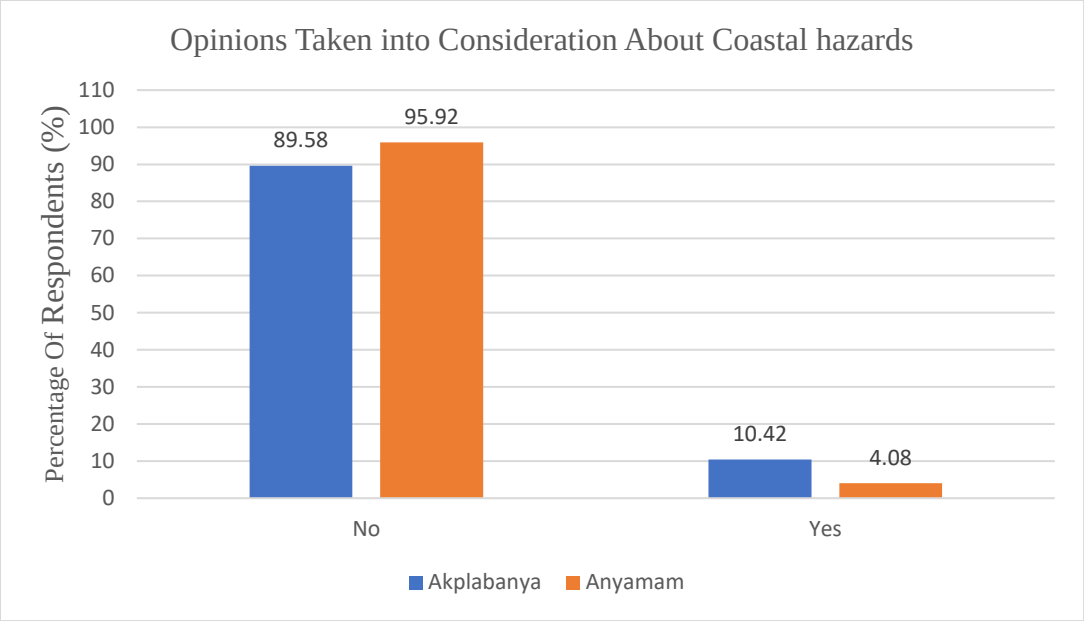

Figure 13: Responses on Opinions Taken into Consideration to deal with Coastal Hazards.

Perception on Town Preparation to Reduce Impact to Coastal Hazards

In Akplabanya, more respondents perceived they were unprepared to deal with coastal erosion than those who were prepared. The percentages were Very Prepared (10.41%), Prepared (16.67%) Unsure (0%), Unprepared (25%) and Very Unprepared (47.92%). For coastal flooding, more respondents were mostly unprepared to deal with coastal erosion. The percentages were Very Prepared (10.41%), Prepared (18.75%) Unsure (4.16%), Unprepared (14.75%) and Very Unprepared (52.08%).

In Anyamam, respondents perceived that they were nearly equally prepared to unprepared for coastal erosion. The percentages were Very Prepared (30.61%), Prepared (18.37%) Unsure (2.04%), Unprepared (20.4%) and Very Unprepared (28.57%). For coastal flooding, respondent percentages were Very Prepared (26.53%), Prepared (22.45%), Unsure (4.08%), Unprepared

(20.4%) and Very Unprepared (26.53%). The results are visualized in Figure 14 and Figure 15 for coastal erosion and coastal flooding respectively.

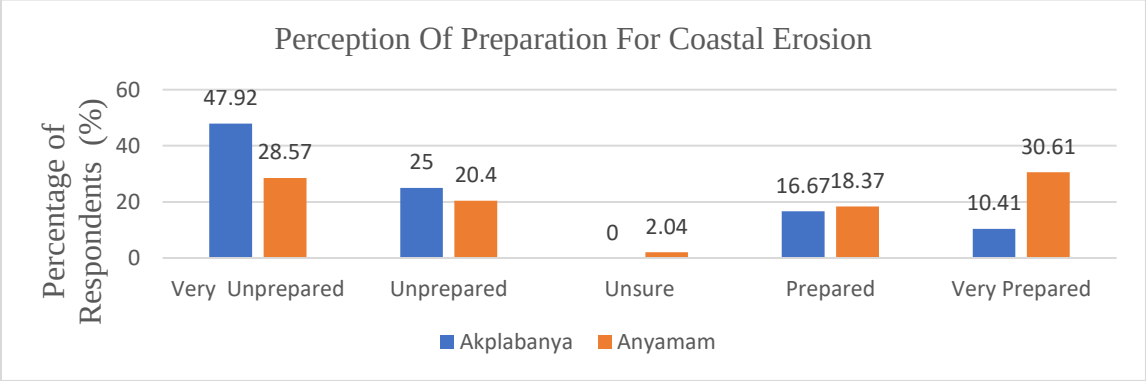

Figure 14:Illustration on Perceived Preparation for Coastal Erosion.

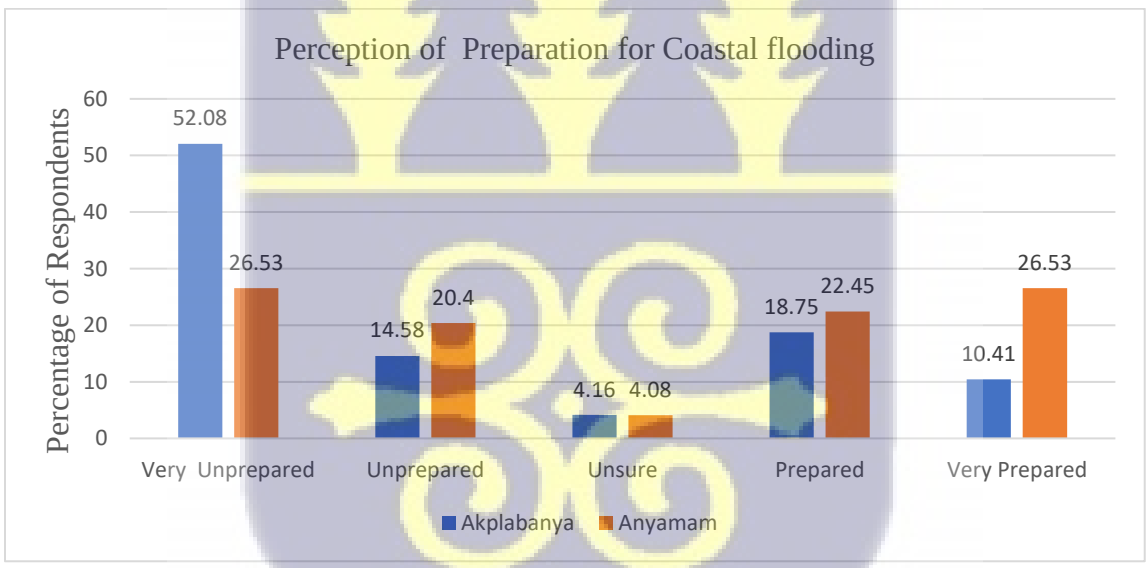

Figure 15: Illustration on Responses on Perception of Preparation for Coastal Flooding.

Partaking in trainings in the past 5 years on how to deal with coastal flooding and coastal erosion.

This question aimed to analyze if respondents had undertaken trainings related to coastal erosion and coastal flooding. In Akplabanya, responses for partaking in trainings for coastal erosion were Yes (6.25%), No (89.58%) and Unsure (4.17%). For coastal flooding, the responses were Yes (4.17%), No (91.67%) and Unsure (4.17%).

In Anyamam, respondents perceived that they were nearly equally prepared to unprepared for coastal erosion. In Anyamam, responses for partaking in trainings for coastal erosion were Yes (93.88%), No (2.04%) and Unsure (2.04%). For coastal flooding, the responses were Yes (4.08%), No (9%), and Unsure (2.04%). The results for participation in training related to coastal hazards are shown in Figure 16.

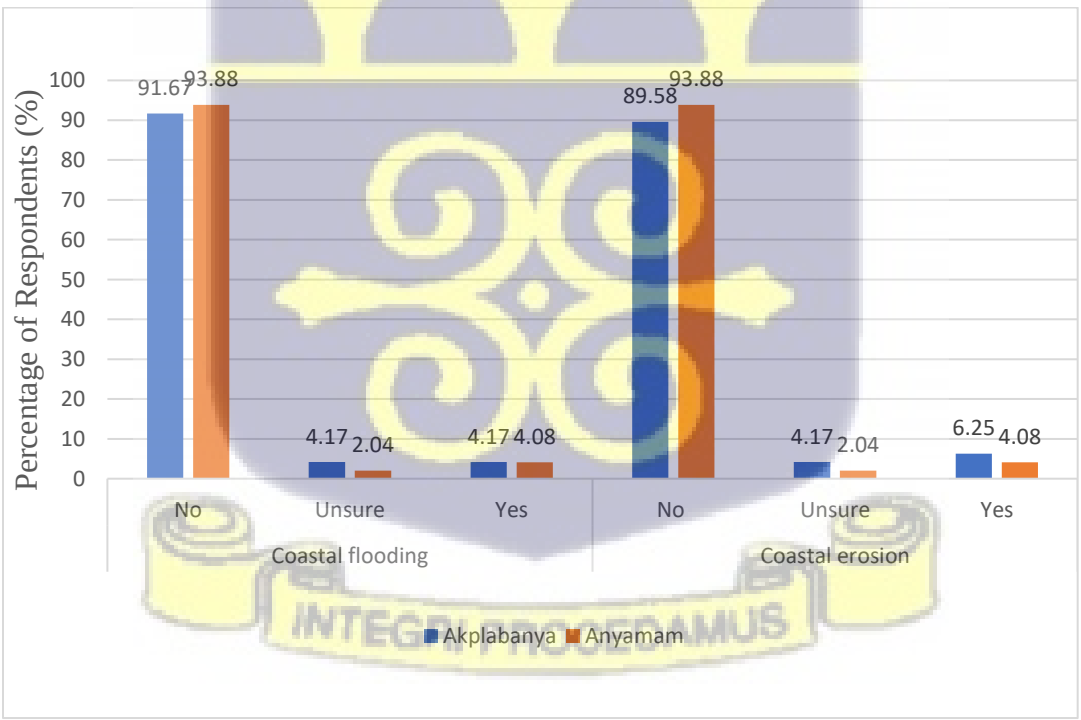

Figure 16: Illustration of Responses on Participation in Training Related to Coastal Hazards in the past 5 years.

Perceived Negative Impacts of Coastal Hazards

The perceived negative impacts of coastal erosion and coastal flooding was assessed in Akplabanya and Anyamam under three main themes: (i) Impact on Housing Infrastructure, (ii) Impact of Income and (iii) Impact on Access to Basic Utility.

For perceived negative impacts of coastal flooding in Akplabanya, the percentages were Very Significant (77.08%), Significant (16.67%) Unsure (0%), Unsignificant (6.25%) and Very Unsignificant (0%) for Impact on Housing Structure. The percentages were Very Significant (60.41%), Significant (14.58%) Unsure (8.33%), Unsignificant (16.67%) and Very Unsignificant (0%). for Impact on Income. The percentages were Very Significant (60.41%), Significant (22.92%) Unsure (4.16%), Unsignificant (12.5%) and Very Unsignificant (0%). for Impact on Access to Basic Utility.

For perceived negative impacts of coastal erosion in Akplabanya, the percentages were Very Significant (81.25%), Significant (12.5%) Unsure (0%), Unsignificant (6.25%) and Very Unsignificant (6.25%) for Impact on Housing Structure. The percentages were Very Significant (83.53%), Significant (10.42%), Unsure (0.00%), Unsignificant (6.25%) and Very Unsignificant (0%). for Impact on Income. The percentages were Very Significant (70.83%), Significant (14.58%) Unsure (6.25%), Unsignificant (8.33%) and Very Unsignificant (0%). for Impact on Access to Basic Utility.

For perceived negative impacts of coastal flooding in Anyamam, the percentages were Very Significant (85.71%), Significant (10.2%) Unsure (2.04%), Unsignificant (4.08%) and Very Unsignificant (0%) for Impact on Housing Structure. The percentages were Very Significant

(65.31%), Significant (22.45%) Unsure (6.12%), Unsignificant (2.04%) and Very Unsignificant (4.08%). for Impact on Income. The percentages were Very Significant (73.47%), Significant (22.45%), Unsure (2.04%), Unsignificant (2.04%) and Very Unsignificant (0%). for Impact on Access to Basic Utility.

For perceived negative impacts of coastal erosion in Anyamam, the percentages were Very Significant (83.64%), Significant (14.29%), Unsure (2.04%), Unsignificant (0.00%) and Very Unsignificant (0.00%) for Impact on Housing Structure. The percentages were Very Significant (81.63%), Significant (14.29%), Unsure (4.08%), Unsignificant (6.25%) and Very Unsignificant (0%). for Impact on Income. The percentages were Very Significant (75.51%), Significant (18.37%) Unsure (6.12%), Unsignificant (0.00%) and Very Unsignificant (0.00%). for Impact on Access to Basic Utility.

The percentages were Very Significant (30.61%), Significant (18.37%) Neutral (2.04%), Unsignificant (20.4%) and Very Unsignificant (28.57%). For coastal flooding, respondent percentages were Very Significant (26.53), Significant (22.45), Neutral (4.08), Very Unsignificant (20.4) and Very Unsignificant (26.53). The results are summarized below in Figure 17 and Figure 18 for perceived negative impacts of both coastal erosion and coastal flooding.

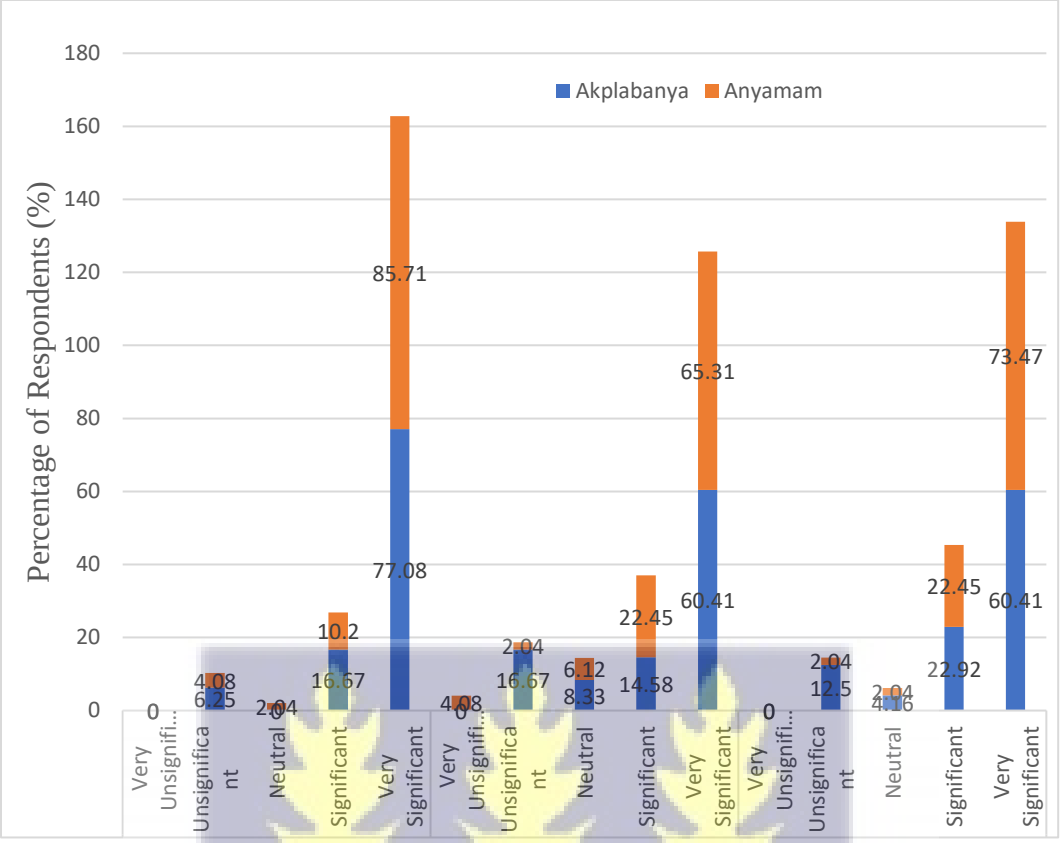

Figure 17: Illustration of Responses on Perceived Negative Impact of Coastal Erosion across Households.

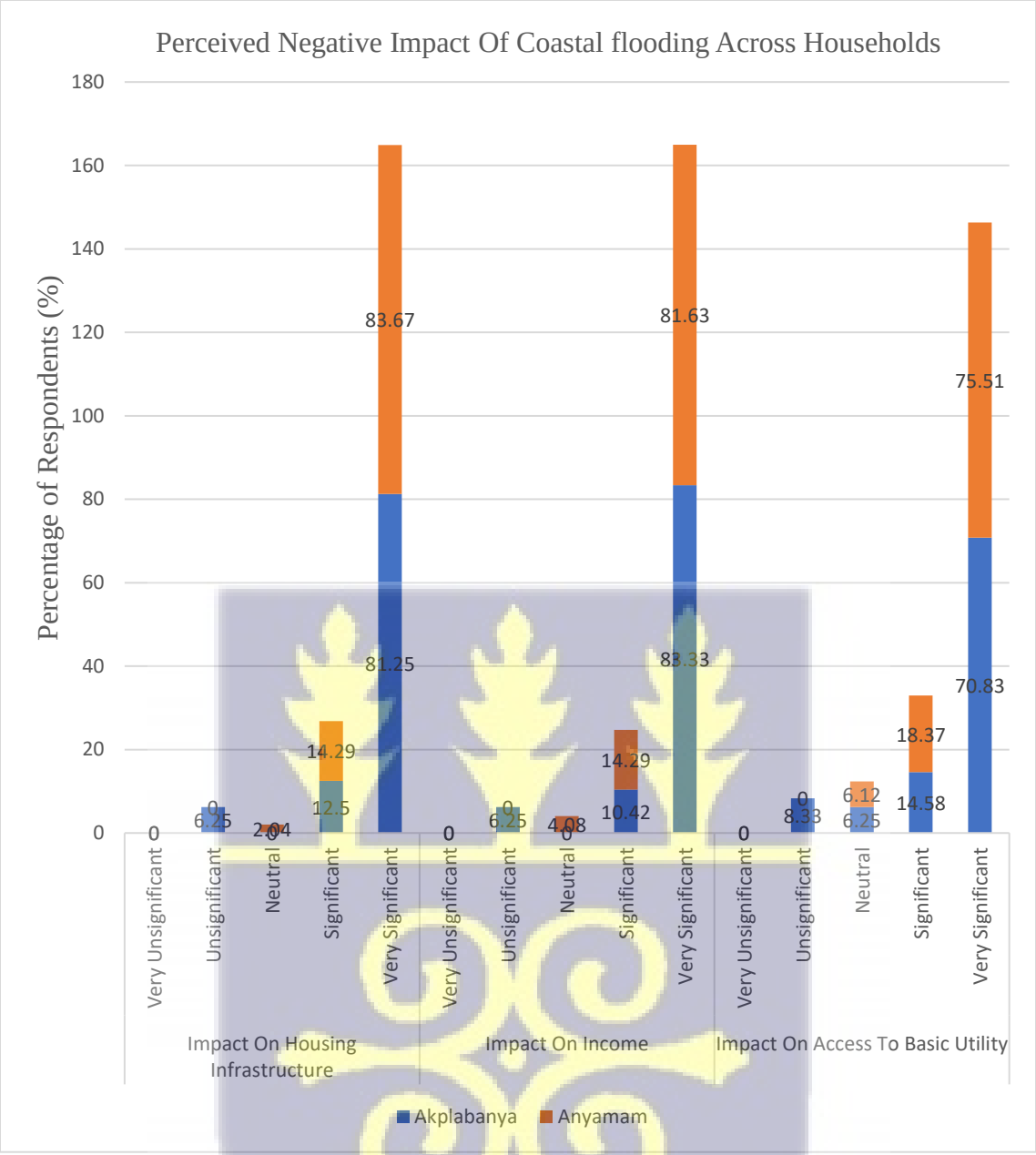

Figure 18: Responses on Perceived Negative Impact of Coastal Flooding across Households.

Recommendations to reduce Coastal hazard risk

The recommendations to reduce coastal hazard risk were classified into four main themes based on respondents' opinions: (i) Improve Education and Awareness, (ii) Undertake Physical Construction, (iii) Introduce Early Warning Systems and (iv) Monitoring of the Community.

In Akplabanya, the highest recommendations were the need to Improve Education and Awareness (79.17%), Undertake physical construction (35.42%), Introduce Early Warning Systems (43.75%), Undertake Physical Construction and Monitoring of the Community (22.75%).

In Anyamam, respondents mentioned to Improve Education and Awareness (59.18%), Undertake physical construction (22.45%), Introduce Early Warning Systems (30.61%) and Monitoring of the Community (49.98%). The summary for recommendations to reduce Coastal Hazard Impact are shown in Figure 19.

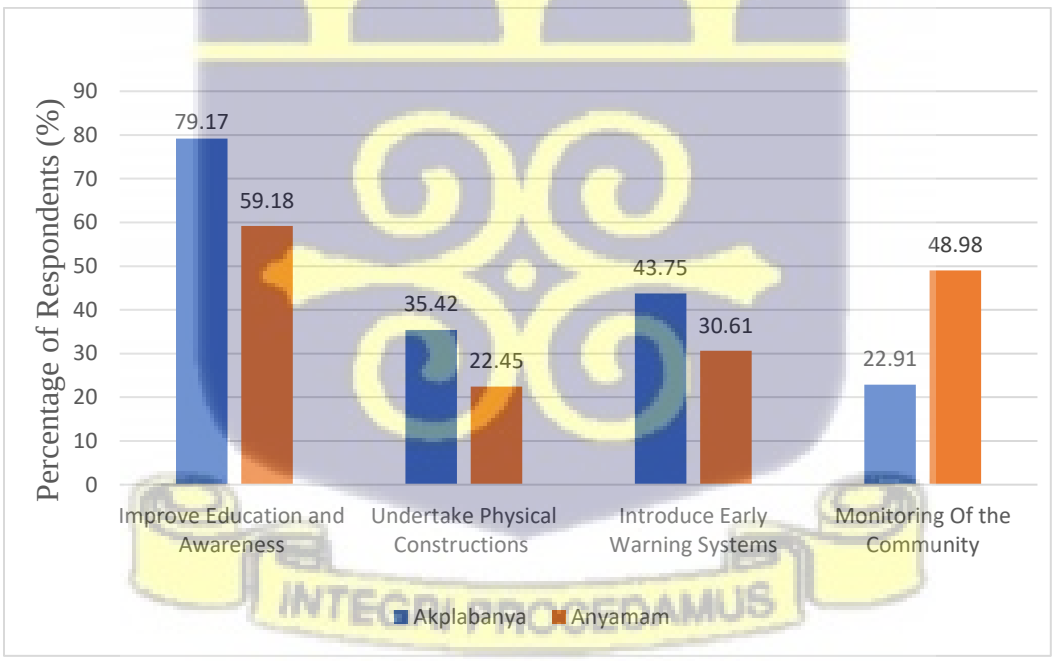

Figure 19: Respondents Recommendations to Reduce Coastal Hazard Risk.

Perception on Performance of Authorities.

In the 2 towns it was assessed if respondents think the authorities are doing enough in reference to coastal hazards. Respondents in Akplabanya and Anyamam evaluated if their opinions were taken in consideration in efforts to deal with coastal hazards. In Akplabanya, Yes (4.17%) and No (95.83%). Anyamam also recorded respondent perception of if their opinions are taken into account at Yes (0%) and No (100%). The results are illustrated in Figure 20.

Figure 20: Illustration of Perception on Performance of Authorities related to coastal hazards.

4.4.5 FGD RESULTS

Causes of coastal flooding

This theme was chosen for discussion to shed light on the respondents' perception on the causes of coastal flooding. In general, FGD participants attributed coastal flooding to hydrodynamic, Anthropogenic causes, and Divine/Supernatural causes. Significant participants attributed coastal flooding in the communities to be mainly caused by Anthropogenic causes in conjunction with Hydrodynamic causes.

A participant in Anyamam said:

> *"My opinion is that, the Tema harbor is a major cause of the coastal flooding in this community. This is because, the position of the harbor has caused a re-direction of the heavy sea waves, to the downdrift, where we find ourselves now. So, this heavy sea waves have been re-directed, which brings some mighty force as part of the normal sea waves we have here unto the land and washes away some mass quantity of the beach (sea sand). This happens often which is very alarming because the sea water enters our communities when the sea level rises and the waves are super heavy."*

This was also echoed in a contribution by a participant in Akplabanya who said:

> *"I think coastal flooding is natural, but it is increasing in intensity because of activities of man this time . The sea is now hitting us so much to the extent of it getting into our communities and destroying our properties and there's nothing to do about it. There's a lagoon here too and I think it exacerbated the impact when the sea comes into the community. "*

Another cause was attributed to Divine/Supernatural causes. This cause was unique to only a female respondent in Akplabanya.

The female participant said:

> *"For me, I noticed that coastal flooding events occur usually when someone dies in the sea. So I see it as a response of the sea to the occurrence of someone dying in the sea."*

The cause of coastal erosion in the community.

This theme was chosen for discussion because of the need for understanding the local perception of the cause of coastal erosion reflects how respondents deal and understanding the dynamics of their exposure.

In both study towns, the output sub-theme for the cause of coastal erosion was opined to be from Anthropogenic and hydrodynamic causes. Generally, respondents attributed coastal erosion as a combination of hydrodynamic and Anthropogenic causes. This is shown when in Akplabanya a FGD participant opined that:

> *"The powerful waves produced by the sea is what causes the coastal erosion. To continue, I think we the inhabitants are the cause of it because we also fetch some of the sand from the coastal land."*

Another participant supported this by giving this input:

> *" What I see as a cause also is the harbours built in neighbouring lands. It places pressure on the sea sand, because when the sea flooding happens, it collects some quantity of the*

sea sand to a particular direction combined with the one which the harbour has covered. So, we in the middle of this lose the little sand we have here."

Community intervention to reduce impact of coastal hazards.

This theme looked at the different interventions aimed at reducing impacts due to coastal hazards. The responses were as follows.

In Akplabanya, one respondent said:

"The flood that comes in is much heavier than us, so we have no measures put in place to fix such problems. All we must do is to wait patiently for it to move back into the sea. What can only stop this is a sea defense, but as it stands, there's nothing we do."

Another theme which was mentioned was Relocation and evacuation. This was expressed by a contribution in Anyamam where the respondent said:

"My opinion is, when it happens this way, we calculate the days when the sea level rises, and the waves are heavy, so we make adaptive measures to avoid them. But our measures put in place do not work after the measurement, so our only option is to relocate and evacuate which is not always the best option though but necessary. This is because the sea waves do not prompt when coming in and it goes to the extent of bringing structures down unexpectedly."

This was also expressed by a contribution in Anyamam where the respondent said:

The next option has been the use of sandbags.

"As said earlier with the sea defense, the elders in our communities bring up suggestions that we load sacks with sand and use them as sea defense. But as said earlier also, when the sea level rises mightily, the waves wash away the sand from the sacks and takes away the sacks into the sea. So, this very small measure we put in also comes into a null and void state. And also, they've brought up a law that no one should fetch sand from the beach and that anyone caught will be fervently dealt with. These are some measures the elders put in place in respect of sea defense."

Another intervention mentioned had to do with Drains. This was expressed by a contribution in Akplabanya where the respondent said:

"Natives have nothing to do about the flooding. Some time ago, we asked for a drainage to give way for the flood to go back speedily after a flooding which has been mitigating the magnitude little by little."

Experiences with coastal hazards

This theme assessed the experiences of respondents to coastal flooding. Experiences ranged across Mental stress, Business disruption, Destruction of properties and retreat.

The first experience discussed is mental health. For mental stress a respondent from Anyamam said:

"It is a headache for us all. Why is this so? We cannot predict flooding unto our lands, so we do not prepare for any disruptions. But when it happens this way and you have nothing to do, it tends to put too much stress on your brain causing mental health problems sometimes."

This point was further enhanced by a participant in the same FGD group.

> *"Additionally, it becomes so painful when you are a breadwinner, because all those around you expect something from you but there's nothing to offer because all has been damaged by the sea. This is so heart breaking. It is affecting us so much."*

Another theme that came up during the discussion on the experiences include Business disruption.

One FGD participant from Anyamam had this to say about Business disruption.

> *"It destroys our businesses also because no one expects anything of such sort to happen but unexpectedly it happens and takes you by shock or surprise. Our businesses are all over the coast and if this happens it destroys everything. Losing such huge capital invested in a business for all to be lost in a short time is very disheartening."*

Another participant had a similar opinion on Business disruption caused by coastal hazards in Akplabanya. The output was

> "*The coastal hazards make us lose our businesses in such a way that, some of us are fish mongers, some are fishers, etc. and we lose our canoes and machines all the time to the sea and it has even made our finances very weak."*

Another experience discussed is Destruction of properties. A respondent from Akplabanya had this to say about this sub-theme.

> *"The hazard events have now gotten us so very much that some of us have nowhere to lay our heads because the floods and erosion have destroyed all our buildings and broken down our structures as well."*

Another respondent in Anyamam had this to say about destruction of properties.

> "*These coastal events destroy our houses and livestock. We lose them when suddenly a hazard event happens."*

Another experience that came up during the FGD discussion was Retreat during Coastal hazard event.

A participant in Akplabanya said:

> *"My opinion is, it is a very huge problem for us because we sometimes move into the homes of others, and that does not favor most of us. We are just pleading for the government to come to our aid so we can be able to live here peacefully."*

Providers of relief to the community

The community level providers of relief in the face of coastal hazards was discussed. The FGD participants mentioned providers of relief to include State Government, NADMO and local government.

For the State Government as a relief provider one FGD participant in Anyamam said:

> *"The government deploys people to our aid, but the assistance and support we need is more than the authorities the government deploys. So all we ask for the government to do now is to build a sea defense for us, that alone will be more than enough for us.*"

Another provider of relief mentioned was NADMO. A participant in Anyamam said:

"NADMO comes to our aid, but with insufficient assistance as compared to the destruction caused. For instance, 2 mattresses which they bring for about 10 homes who have lost shelter is never enough for us. Again, how would 10 homes share 2 bags of rice, it is not possible. They help though but we get less assistance from them."

This was also supported by a participant in Akplabanya who said:

"We do get some relief items like rice, bedding and clothing from NADMO but the items they bring is nowhere near enough t to cater for the significant number of households affected by coastal hazards events."

Another provider of relief mentioned is the District Chief Executive and the Local Assembly.

A participant in Akplabanya said:

"*We mostly call upon DCE and Assembly in addition to NADMO, but they both give us assurance with no hope. The flood destroys our livestock and sends into the sea, our firewood we use domestically. This and many others are what we face."*

Stakeholders' performance to reduce impact of coastal hazards through training and awareness.

This question was seeking to assess the local perception on effort of stakeholders to mitigate impact of coastal hazards through awareness and provision of training. Consensus perception shows that stakeholders had low performance in that field.

A participant from Akplabanya said:

"They only ask us not to fetch pebbles from the beach, that's all they ask us to do and nothing else. So we call on them, they come to write down our needs alright but go and return with no good response."

Another participant from Akplabanya echoed this sentiment by saying:

"They give us no training, but I believe some time past, they didn't fetch sand and stones, but they also faced flooding and erosions, so I don't think restrictions on sand and pebbles fetching only is enough."

The sentiment was re-echoed in Anyamam. A participant from there also said:

"They give us no training to mitigate such situations. They hear our cry very well but don't feel our pain here so I think that's why they don't bring us the training needed to assist in the sea defending. No good thing comes in for us here."

Local input consideration on reducing hazard input.

This theme had to deal with their perception on how much their inputs are taken into consideration when dealing with coastal hazards. The themes mentioned here is no which shows that participants do not think their inputs are not considered when authorities must deal with coastal hazards.

A participant in Anyamam had this to say:

"With one thought for all, I say, when they go and return no more, it is very obvious then, that they don't consider our inputs."

Another participant agreed with this line of thought by contributing this to the discussion.

"They don't work with our inputs, because there are bye-laws established to help mitigate impacts of coastal hazards. These bye-laws are approved by the authorities in the government, but the implementation and enforcement has not been up to par although we communicate about it. We get no approvals from them even after they have come to see us in our suffering states. So I don't think they are working with our inputs or suggestions."

Recommendations on dealing with coastal flooding and coastal erosion.

This question aims to reflect what respondents think should be done to reduce the impact of coastal hazards. The themes included building of sea defense, integration of law and monitoring.

For sea defense, one participant from Anyamam said:

"It was said earlier that we have become the valley between the hills or mountains, when it comes to erosion and flooding, so what we need is that the sea defense should be built, then I think we will be good over here in the coastal land."

This sentiment was also echoed in Akplabanya where a participant said:

"From Tema Harbour to Sakumono, they have built up sea defenses which are protecting them. If they didn't build up such defenses there I don't think they would've still been living there. Government knows the solutions to our problems but does not come to our aid with reasons best known to them. We plead with the government that they should support us with the sea defense."

Another recommendation mentioned is the combination of enforcement, a participant from Anyamam said:

"We will need legislations, bye-laws that will be very effective to build strong rules and regulations together with punishments associated when such rules are not obeyed. If we get securities monitoring all these activities, I think as time goes on, we will have such rules obeyed for peace to reign."

This was echoed in Akplabanya, where one participant said:

"We are also enforcing laws on the restrictions of fetching of sand and stones. The other solution we must provide are all about funds which we do not have so we plead with the government to help us. We are about 10,000 people in this community, if the government doesn't come to our aid, where do they expect us to relocate? If they don't come to our aid, there will be a time when we won't be part of the nation."

Summary of Results from FGD.

The FGD administered in both towns shed light on various themes related to coastal hazards and community vulnerability dynamics. This is shown in summary table 13 below.

Table 13: Summary Outcomes of Thematic Outputs from the FGD Participants.

Questions	Themes
What are the causes of Coastal Flooding	Hydrodynamic causes
	Anthropogenic causes
	Divine/ Supernatural causes
What are the causes of Coastal Erosion	Hydrodynamic causes
	Anthropogenic causes
What are some community adaptation measures in place to reduce impact of coastal hazards	Drains
	Sand sacks
	Community ban on sand winning
	Retreat
What are your experiences with coastal flooding and coastal erosion	Business Disruption
	Relocation
	Discomfort and helplessness
	Mental health
	Destruction of properties
Who are the providers of relief during hazard events	NADMO
	State Government
	Local government
Do you think stakeholders doing enough	Maybe
	No
What do you think about local inputs consideration in the face of coastal hazards.	Not considered
How prepared do you think the town is in dealing with coastal flooding	Prepared but not adequate
	Not prepared
How prepared do you think the community is in dealing with coastal erosion	Prepared but not adequate
	Not prepared
What are your recommendations on how to deal with coastal hazards	Monitoring and Evaluation
	Hard Technological Structures (sea defense)
	Government financial aid
	Policies and Laws

4.5 VULNERABILITY DIMENSION QUANTIFICATION.

4.5.1. Processing Data Results for Vulnerability Assessment

As said earlier, for computing vulnerability on a finer scale, we utilize 6 grids, 3 for each town. The ratio for each grid is calculated as number of housing structures per grid divided by the total number of housing structure per grid expressed as a proportion of the town allocation. The computed statistics are shown in Table 14. The variables for the dimensions of vulnerability due to SLR-related coastal flooding and coastal erosion are then computed based on the results for each town.

Table 14: Questionnaire Respondent per Grid

Towns	Grids	Number of housing structure per Grid	Total number of housing structure per Town	Sample Questionnaire for Each Grid
Akplabanya	Grid 1	190	1235	$\frac{190}{1235} \times 48 = 7.38$ ¬7
	Grid 2	633		$\frac{633}{1235} \times 48 = 24.60$ ¬25
	Grid 3	412		$\frac{412}{1235} \times 48 = 16.01$ ¬16
Anyamam	Grid 4	370	987	$\frac{370}{987} \times 49 = 18.37$ ¬19
	Grid 5	450		$\frac{450}{987} \times 49 = 22.33$¬22
	Grid 6	167		$\frac{167}{987} \times 49 = 8.3$¬8

4.5.2 Vulnerability Variables Quantification for Coastal Erosion

The dimensions of vulnerability based on IPCC guidelines which are sensitivity, adaptive capacity and exposure were used to quantify coastal erosion vulnerability. Table 15, 16 and 17 illustrates the sensitivity, adaptive capacity and exposure indicator scores respectively

Table 15: Variables for Sensitivity Dimension of Vulnerability for Coastal Erosion.

	Sensitivity	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6	Min	Max
1	Proportion of Households headed by Females	0.286	0.4	0.1875	0.5789	0.6364	0.125	0.125	0.6364
2	Proportion of Households with constituents older than 65 years	0.286	0.76	0.6875	0.8421	0.5909	0.625	0.286	0.8421
3	Proportion of Households with constituents less than 5 year	0.7143	0.92	1	0.7368	0.9091	1	0.7143	1
4	Proportion of Households with disability	0.1429	0.24	0.1875	0.3158	0.4545	0.5	0.1429	0.5
5	Proportion of household with single parents	0.1429	0.76	0.6875	0.6842	0.9091	0.25	0.1429	0.9091
6	Average size of household	17.57	22.32	13.6875	15.5789	14.8636	18.75	13.6875	22.32
7	The proportion of household heads with no education	0.0286	0.28	0.1875	0.2632	0.3636	1	0.0286	1
8	The proportion of household heads without secondary occupation.	0.0286	0.28	0.1875	0.2632	0.4545	0.5	0.0286	0.5

Table 16: Variables for Adaptive Capacity of Vulnerability for Coastal Erosion.

	Adaptive Capacity	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6	Min	Max
9	Proportion of households who have not received training on coastal hazards	1	0.92	1	0.894	0.9545	1	0.894	1
10	Proportion of households that think they will be able to relocate in the face of coastal hazard	0.285	0.72	0.5625	0.7368	0.4091	0.75	0.285	0.75
11	Proportion of household heads who are not willing to take a training on coastal hazards.	0.1429	0.04	0.0625	0.1053	0.4545	0.125	0.04	0.4545
12	Proportion of household heads who believe that do not receive help from family outside communities	0.5714	0.28	0.25	0.7368	0.5	0.75	0.25	0.75
13	Proportion of household heads who believe that do not receive help from friends outside the community	1	0.96	0.9474	0.8947	0.6818	0.875	0.6818	1
14	Proportion of household heads who believe that do not receive help from social groups.	1	0.96	0.9474	1	0.9091	0.875	0.875	1
15	Average age of housing infrastructure	41	63	52.8125	46.7895	46.5455	37.125	37.125	63
16	The proportion of households who lived in a rented housing infrastructure	0	0.08	0.0625	0.0526	0.1364	0.25	0	0.25
17	Average residence period in the community	42.4285	36.68	29.1875	33.7894	41.0454	43.75	29.1875	43.75
18	Proportion of households not satisfied by provision of information from Local government on coastal erosion	1	0.96	1	1	1	1	0.96	1
19	Proportion of households not satisfied by provision of information by NGOs on coastal erosion	1	1	1	1	1	1	1	1
20	Proportion of households not satisfied by provision of information by Government on coastal erosion	1	1	1	1	1	1	1	1

21	The proportion of household heads that are not actively involved in community discussions on coastal hazards	0.142	0.24	0.25	0.2362	0.4545	0.5	0.142	0.5
22	The proportion of household heads that think their views are not considered in community interventions for coastal erosion	0.8571	0.92	0.8125	0.947	0.9545	0.75	0.75	0.9545
23	The proportion of households who are not satisfied by relevant authorities on coastal hazards.	1	0.76	0.8125	0.8421	0.5	0.75	0.5	1
24	Proportion of households without traveling assets	0.2857	0.48	0.25	0.4734	0.5	0.625	0.25	0.625

Table 17: Variables of Exposure for Vulnerability for Coastal Erosion.

	Exposure	**Grid 1**	**Grid 2**	**Grid 3**	**Grid 4**	**Grid 5**	**Grid 6**	**Min**	**Max**
25	Portion of land area lost under 10-year lower uncertainty projection	0.0103	0.008	0.0185	0.0243	0.017	0.0116	0.008	0.0243
26	Portion of land area lost under the 10-year projection	0.0142	0.0143	0.0184	0.0291	0.024	0.0123	0.0123	0.0291
27	Portion of land area lost under the 10-year upper projection uncertainty	0.042	0.0323	0.0374	0.0411	0.0451	0.0338	0.0323	0.0451
28	Portion of land area lost under 20-year lower uncertainty projection	0.0244	0.0202	0.041	0.0508	0.0438	0.0297	0.0202	0.0508
29	Portion of land area lost under the 20-year projection	0.0542	0.0402	0.0562	0.0642	0.0653	0.0451	0.0402	0.0653
30	Portion of land area lost under the 20-year upper uncertainty projection	0.0781	0.062	0.0703	0.0827	0.0876	0.0652	0.062	0.0876
31	Portion of houses lost under the 10-year lower uncertainty projection	0	0	0.0146	0.0189	0.0133	0	0	0.0189
32	Portion of houses lost under the 10-year projection	0.0053	0.0016	0.034	0.0405	0.02	0	0	0.0405

33	Portion of houses lost under the 10-year upper projection	0.0053	0.0111	0.051	0.0676	0.0422	0	0	0.0676
34	Portion of houses lost under the 20-year lower uncertainty projection	0.0053	0.0016	0.0533	0.1162	0.0533	0	0	0.1162
35	Portion of houses lost under the 20-year projection	0.0053	0.0174	0.1092	0.1838	0.1156	0	0	0.1838
36	Portion of houses lost under the upper uncertainty 20-year projection	0.0053	0.0395	0.1675	0.2443	0.1711	0	0	0.2443
37	Average erosion rate	-1.8426	-1.446	-1.9464	-2.1573	-2.25	-1.6304	-2.25	-1.446
38	Absence Of Sand Dunes	0	0	0	1	1	1	0	1
39	Absence Of Vegetation features	0	1	1	1	1	1	0	1
40	Proportion of household head who believe coastal erosion has an impact on their household income	0.7142	0.8	0.6875	0.6842	0.909	1	0.6842	1
41	Proportion of household head who believe coastal erosion has an impact on housing structure damage	1	0.8	0.875	0.9473	0.9545	1	0.8	1
42	Proportion of household head who believe erosion has an impact on utility infrastructure	0.857	0.84	0.8125	0.9473	0.9545	1	0.8125	1
43	Proportion of household heads who believe coastal erosion rates are increasing	0.857	0.96	0.9375	0.9473	0.9545	0.875	0.857	0.96

4.5.3 Results for Computed Vulnerability to Coastal Erosion.

Table 18 presents the vulnerability dimensions for coastal erosion across six grid cells, divided into two towns: Akplabanya (Grids 1-3) and Anyamam (Grids 4-6). The indicators include sensitivity, adaptive capacity, exposure, potential impact, composite vulnerability, and average vulnerability per town.

The values of sensitivity were 0.096, 0.6231 and 0.3976 for Grids 1, 2 and 3 respectively with an average sensitivity of 0.372 in Akplabanya. The values of sensitivity were 0.5144, 0.686 and 0.667 for Grids 4,5 and 6 respectively with an average sensitivity of 0.622 for Anyamam. The sensitivity dimension has ranges between 0.096 (Grid 1) in Akplabanya to 0.686 (Grid 5) in Anyamam. The values of adaptive capacity were 0.598, 0.564 and 0.517 for Grids 1, 2 and 3 respectively with an average sensitivity of 0.559 in Akplabanya. The values of adaptive capacity were 0.642, 0.633 and 0.707 for Grids 4,5 and 6 respectively with an average adaptive capacity of 0.661 for Anyamam. For the adaptive capacity, computed ranges from 0.517 (Grid 3) to 0.707 (Grid 6) in Akplabanya and Anyamam respectively.

For exposure, values computed were 0.0326, 0.233 and 0.506 for Grids 1, 2 and 3 respectively with an average exposure of 0.355 in Akplabanya. The values of exposure were 0.80, 0.717 and 0.353 for Grids 4, 5 and 6 respectively and an average exposure of 0.623 in Anyamam. The values for exposure ranges 0.223 (Grid 2, Akplabanya) to 0.80 (Grid 4, Anyamam). The values of potential impact were computed to be 0.422, 0.145 and 0.836 for Grids 1,2 and 3 respectively with an average potential impact of 0.4677 in Akplabanya.

The values for Anyamam were 1.314, 1.403 and 1.02 for Grids 4, 5 and 6 respectively with an average potential impact of 1.246 was computed in Akplabanya. The potential impact ranges

from 0.506 (Grid 1) in Akplabanya to 1.4 (Grid 6) in Anyamam. For the composite vulnerability, Grids 1, 2 and 3 in Akplabanya had computed values of 0.053, 0.246 and 0.390 respectively. In Anyamam, values of composite vulnerability are 0.640, 0.777 and 0.333 for Grids 4,5 and 6 respectively. The composite vulnerability ranges from 0.246 (Grid 2) in Akplabanya to 0.777 (Grid 5) in Anyamam. The overall relative vulnerability per town due to erosion was 0.230 for Akplabanya and 0.583 in Anyamam.

Table 18: Summary table for computed dimensions of coastal erosion.

	Coastal erosion					
Variable	Akplabanya				Anyamam	
	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6
Sensitivity	0.096	0.623	0.398	0.514	0.686	0.667
Average Sensitivity		0.372			0.622	
Adaptive Capacity	0.598	0.564	0.517	0.642	0.633	0.707
Average Adaptive Capacity		0.559			0.661	
Exposure	0.326	0.223	0.506	0.80`	0.717	0.353
Average Exposure		0.355			0.623	
Potential Impact	0.422	0.145	0.836	1.314	1.403	1.02
Average Potential Impact		0.4677			1.246	
Composite Vulnerability	0.053	0.246	0.390	0.640	0.777	0.333
Vulnerability per Town		0.230			0.583	

4.5.4 Vulnerability Quantification for Coastal Flooding

This sub-section presents the results for computed proportions of variables and indicators used for calculating coastal flooding vulnerability index in the study towns. Table 19, 20 and 21 below represents computed variables for sensitivity, adaptive capacity and exposure respectively for coastal flooding.

Table 19: Variables of Sensitivity for Coastal Flooding.

	Sensitivity	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6	Min	Max
1	Proportion of Households headed by Females	0.286	0.4	0.1875	0.5789	0.6364	0.125	0.125	0.6364
2	Proportion of Households with constituents older than 65 years	0.286	0.76	0.6875	0.8421	0.5909	0.625	0.286	0.8421
3	Proportion of Households with constituents less than 5 year	0.7143	0.92	1	0.7368	0.9091	1	0.7143	1
4	Proportion of Households with disability	0.1429	0.24	0.1875	0.3158	0.4545	0.5	0.1429	0.5
5	Proportion of household with single parents	0.1429	0.76	0.6875	0.6842	0.9091	0.25	0.1429	0.9091
6	Average size of household	17.57	22.32	13.6875	15.5789	14.8636	18.75	13.6875	22.32
7	The proportion of household heads with no education	0.0286	0.28	0.1875	0.2632	0.3636	1	0.0286	1
8	The proportion of household heads without secondary occupation	0.286	0.28	0.1875	0.2632	0.4545	0.5	0.0286	0.5

Table 20: Variables of Adaptive Capacity for Coastal Flooding

	Adaptive Capacity	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6	Min	Max
9	Proportion of households who have not received training on coastal hazards	1	0.92	1	0.894	0.9545	1	0.894	1
10	Proportion of households that do not have the ability to relocate in the face of coastal flooding	0.285	0.72	0.5625	0.7368	0.4091	0.75	0.285	0.75
11	Proportion of household heads who are not willing to take a training on coastal hazards.	0.1429	0.04	0.0625	0.1053	0.4545	0.125	0.04	0.4545
12	Proportion of household heads who believe that do not receive help from family outside communities	0.5714	0.28	0.25	0.7368	0.5	0.75	0.25	0.75
13	Proportion of household heads who believe that do not receive help from friends outside the community	1	0.96	0.9474	0.8947	0.6818	0.875	0.6818	1
14	Proportion of household heads who believe that do not receive help from social networks	1	0.96	0.9474	1	0.9091	0.875	0.875	1
15	Average age of housing infrastructure	41	63	52.8125	46.7895	46.5455	37.125	37.125	63
16	The proportion of households who lived in a rented housing infrastructure	0	0.08	0.0625	0.0526	0.1364	0.25	0	0.25
17	Average residence period in the community	42.4285	36.68	29.1875	33.7894	41.0454	43.75	29.1875	43.75
18	Proportion of households not satisfied by provision of information from Local government on coastal flooding	1	1	0.8125	0.7368	0.4545	0.75	0.4545	1

19	Proportion of households not satisfied by provision of information by NGOs on coastal flooding	1	1	1	1	0.9545	0.875	0.875	1
20	Proportion of households not satisfied by provision of information by Government on coastal flooding	1	1	1	1	1	1	1	1
21	The proportion of household heads that are not actively involved in community discussions on coastal hazards	0.142	0.24	0.25	0.2362	0.4545	0.5	0.142	0.5
22	The proportion of household heads that think their views are not considered in community interventions for coastal erosion	0.8571	0.92	0.8125	0.947	0.9545	0.75	0.75	0.9545
23	The proportion of households who are not satisfied by relevant authorities on coastal hazards.	1	0.76	0.8125	0.8421	0.5	0.75	0.5	1
24	The proportion of household heads who have not been involved in evacuation	0.2857	0.32	0.4375	0.211	0.1364	0.25	0.1364	0.4375
25	Proportion of households without traveling assets	0.2857	0.48	0.25	0.4734	0.5	0.625	0.25	0.625

Table 21: Variables of Exposure for Coastal Flooding.

	Exposure	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6	Min	Max
26	Portion of land area lost under SLR projection 2020-2040	0.0035	0.0001	0	0.0041	0.003	0.0129	0	0.0129
27	Portion of land area lost under SLR projection 2040-2060	0.0041	0.0001	0	0.0059	0.1769	0.349	0	0.349
28	Portion of land area lost under SLR projection 2080-2100	0.0069	0.0024	0	0.348	0.2394	0.4069	0	0.4069
29	Absence Of Sand Dunes	0	0	0	1	1	1	0	1
30	Absence Of Vegetation features on beach.	0	1	1	1	1	1	0	1
31	Proportion of household head who believe coastal flooding has an impact on their household income	1	0.96	0.875	1	0.9545	0.875	0.875	1
32	Proportion of household head who believe coastal flooding has an impact on housing structure damage	1	0.96	0.875	1	0.9545	1	0.875	1
33	Proportion of household head who believe coastal flooding has an impact on utility infrastructure	0.8571	0.96	0.6875	1	0.9545	0.875	0.6875	1
34	Proportion of household heads who believe coastal flooding frequency has increased in the last 5 years	0.8571	0.64	0.625	0.7894	0.8636	0.5	0.5	0.8636

4.5.5 Computed vulnerability due to SLR coastal flooding

Table 22 presents the vulnerability dimensions for coastal flooding across six grid cells, divided into two towns: Akplabanya (Grids 1-3) and Anyamam (Grids 4-6). The indicators include sensitivity, adaptive capacity, exposure, potential impact, composite vulnerability and average vulnerability per town.

The values of sensitivity were 0.096, 0.6231 and 0.3976 for Grids 1, 2 and 3 respectively with an average sensitivity of 0.3722 in Akplabanya. The values of sensitivity were 0.5144, 0.686 and 0.667 for Grids 4,5 and 6 respectively with an average sensitivity of 0.622 for Anyamam. The sensitivity dimension ranges between 0.096 (Grid 1) in Akplabanya to 0.686 (Grid 5) in Anyamam. The values of adaptive capacity were 0.592, 0.625 and 0.525 for Grids 1, 2 and 3 respectively with an average adaptive capacity of 0.5806 in Akplabanya. The values of adaptive capacity were 0.591, 0.516 and 0.602 for Grids 4,5 and 6 respectively with an average adaptive capacity of 0.57 in Anyamam. For the adaptive capacity, computed ranges range from 0.516 (Grid 5) in Anyamam to 0.625 (Grid 2) in Akplabanya.

For exposure, values computed were 0.41, 0.403, 0.14 for Grids 1, 2 and 3 respectively with an average sensitivity in Akplabanya. The values of exposure were 0.744, 0.694 and 0.733 for Grids 4, 5 and 6 respectively with an average exposure of 0.7237 in Anyamam. The values for exposure ranges 0.14 (Grid 2) in Akplabanya to 0.744 (Grid 4) in Anyamam. The values of potential impact were computed to be 0.506, 1.026 and 0.538 for Grids 1,2 and 3 respectively with an average potential impact of 0.69 in Akplabanya. The values for Anyamam were 1.258, 1.38 and 1.4 for Grids 4, 5 and 6 respectively for an average potential impact of 1.346. The potential impact ranges from 0.506 (Grid 1) in Akplabanya to 1.4 (Grid 6) in Anyamam. For the composite

vulnerability, Grids 1, 2 and 3 had computed values of 0.066, 0.402, 0.106 respectively and an average sensitivity in Akplabanya in Akplabanya. In Anyamam, values of 0.648, 0.992 and 0.812 for Grids 4,5 and 6. The composite vulnerability ranges from 0.066 (Grid 1) in Akplabanya to 0.922 (Grid 6) in Anyamam. The overall relative vulnerability per town due to coastal flooding was 0.434 for Akplabanya and 0.843 in Anyamam.

Table 22: Summary Table for Computed Dimensions of Vulnerability to Coastal Flooding.

Coastal flooding						
	Akplabanya				Anyamam	
	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6
Sensitivity	0.096	0.6231	0.3976	0.5144	0.686	0.667
Average Sensitivity		0.3722			0.622	
Adaptive Capacity	0.592	0.625	0.525	0.591	0.516	0.602
Average Adaptive Capacity		0.5806			0.57	
Exposure	0.41	0.403	0.14	0.744	0.694	0.733
Average Exposure		0.318			0.7237	
Potential Impact	0.506	1.026	0.538	1.258	1.38	1.4
Average Potential Impact		0.69			1.346	
Composite Vulnerability	0.066	0.402	0.106	0.648	0.922	0.812
Vulnerability per Town		0.191			0.794	

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CHAPTER FIVE

DISCUSSION

5.1 INTRODUCTION

Vulnerability to coastal hazards, influenced by a range of factors, is evident throughout Ghana's coastline, influenced by a range of factors. This chapter explores the trends in coastal erosion, sea level rise (SLR) dynamics, and the social perspectives on coastal vulnerability in Akplabanya and Anyamam. It quantifies the factors affecting observed trends along the coast hydrodynamic causes and anthropogenic causes that may influence coastal erosion in Akplabanya and Anyamam. Additionally, it delves into local perceptions of coastal hazards and provides a quantitative assessment of vulnerability to both coastal erosion and flooding.

5.2 CURRENT COASTAL EROSION TREND IN STUDY TOWNS

The erosion patterns observed in Akplabanya and Anyamam reflect the inherently dynamic nature of sandy coastlines, which constantly adjust to shifting weather patterns, tides, waves, and sediment supply. In both towns, the coastline segments exhibited negatively skewed erosion rates, indicating that shoreline retreat was not only widespread but also consistently more severe, with no evidence of accretion to balance the losses. This suggests a unidirectional trend of coastal degradation rather than the natural alternation between erosion and deposition often seen along sandy beaches. The slightly higher erosion rates at Anyamam compared to Akplabanya may point to site-specific dynamics. When compared to earlier studies along the Accra coast an average erosion rate at -1.13m/year ±0.17 (Appeaning Addo et al., 2008), , but less than one-fourth of the erosion rate when compared to the average erosion rate at -9m/year for the whole Eastern coastline

(Pumplampu et al., 2023). the more pronounced rates recorded here suggest an intensification of coastal change that could be linked to broader climatic shifts as well as localized factors.

Factors that control coastal erosion include shape and location of the beach (Guerrera et al., 2021; Jonah et al., 2016; Yincan et al, 2017), relative sea-level change (Evadzi et al., 2018), wave energy (Mann et al., 2023) sediment supply and net longshore drift (Appeaning Addo et al., 2020). Within the eastern coastline, very active hydrodynamic actors which can dislodge the loose quaternary sediments upon impact on the narrow beach. The coastlines of both study towns have a straight configuration which will facilitate alongshore sediments movement out of the study area in the easterly direction (Appeaning Addo, 2018; Mann et al., 2023).

Erosion in the study area has been most likely compounded by the continuous stretch of sandy beaches and less compact nature of sediments which is easily influenced by currents, tides and waves (Ondoa, n.d.; Schlacher et al., 2007). As noted earlier, Akplabanya has generally higher elevation beach face and a relatively wider beach width than Anyamam. Research by Koroglu et al., (2019) and Masselink et al., (n.d.) points out that these features will serve as a buffer in the littoral zone hence the capability to reduce erosion. In Anyamam however, the beach front is characterized by low lying and a less wide beach width which may have led to reduced littoral buffering against the impact of waves and winds

5.3 SHORELINE TRANSECT RATES IN AKPLABANYA AND ANYAMAM

Along the examined coastline, segments of the shoreline are undergoing different rates of erosion with Akplabanya experiencing a milder rate of erosion with lower variability than Anyamam, which was shown to experience a higher variability in erosion rates in the transect segments. Anyamam exhibits characteristics of coastal land squeeze factor where the

underdeveloped fringes with no houses in perpendicular to the shore has lower rates of erosion compared to the transects which have human settlements in perpendicular from longshore distance. This means that for Anyamam, erosion is going to pose a risk to assets along the stretch including household infrastructure and fish landing sites.

The study towns are partially separated by the Akplabanya lagoon which is located eastward of Akplabanya and westward of Anyamam lagoon and constrained in the south by the Gulf of Guinea. As noted by Schleupner (2008), coastal development hinders the natural adaptation of coasts to rising erosion rates by restricting their ability to shift landward. In areas where development is concentrated on sandbars near the coastlines, such as those constrained by lagoons, the land cannot move inland to adjust to sea level rise. Consequently, the limited land available faces competing pressures from both wave action and development, leading to a situation of coastal squeeze.

5.4 PROJECTED SEA LEVEL RISE AT AKPLABANYA AND ANYAMAM

Based on projected extents of SLR for the periods 2021 - 2040, 2041 – 2060 and 2081 – 2100, data indicates a greater extent of land inundation for Anyamam than for Akplabanya. In Akplabanya, the values of percentage inundated area are lower compared to Anyamam. This suggests that Anyamam is expected to be more affected by flooding due to sea level rise compared to Akplabanya. This is of significance considering with consequence especially on the long term as research by Appeaning Addo & Adeyemi, (2013), estimated that the rate of SLR for Ghana will

be approximately 2mm per year. This rate although not rapid can have a devastating impact in the long term in the study communities.

Given that the coasts and low-lying areas are the most susceptible to the increasing risk of rising sea level due to the coastal geomorphology and elevation difference. The geomorphological and elevation difference between Anyamam which has a relatively lower elevation compared to Akplabanya influenced the results for higher extents in Anyamam. This supports results on SLR impacts by Romine et al., (2016) which notes that impacts of SLR will be based on geomorphological difference even on a local scale.

When the sea level rise statistics is appraised for the study area, varying levels of changes in the coastal landscape are expected. For Akplabanya, SLR inundation percentage show minimal hazard extent across the projected scenario timelines. For Anyamam however, a large part of the coastal area will become submerged with various possible consequences including reduction in the land area, saltwater intrusion of surface water like the Akplabanya lagoon, displacement and a loss of properties especially in the middle and long term.

SLR inundation is expected to lead to accelerated coastal erosion in Anyamam more than Akplabanya considering research by Evadzi et al., (2018) on the coast of Ghana, which estimated that SLR will account for up to 31% of coastal erosion in the long term. Highlighting the medium term and long term, more land sections in Anyamam at relatively higher elevation with lower exposure to the impacts of SLR may be exploited to accommodate growing number of inhabitants especially further inland. The outcome would be the transformation of vegetation fields and lagoon floodplains into built-up regions which will impact local ecosystems and organisms that depend on them.

Coastal infrastructure and property could also be negatively affected. For instance, reduced space for fishing-related activities including land sites, gathering sites and trading sites could become a major problem especially when exacerbated by population growth. This will undoubtedly have an impact on the social life and local economy of the respondents in the communities.

5.5 SOCIAL PERCEPTIONS OF COASTAL HAZARDS

The outcome of the study communities were more concerned about coastal erosion and coastal flooding than all other coastal hazards in the Akplabanya and Anyamam which suggests that it is the hazard they most likely frequently interacted with as lived experiences. This outcome is expected and in accordance with physical vulnerability studies on coastal hazards in the Eastern coastline of Ghana where the study area is found to be susceptible to coastal erosion and coastal flooding (Boateng, 2012; Mann et al., 2023). This finding is in line with social vulnerability assessments by Dada et al., (2023) on the Anlo beach in Ghana which found the same dominant hazard concerns by locals in relation to coastal hazards. This suggests that the study communities experience these hazards as part of events in their geographic location and have developed this concerns as it has continued to pose risk and impact their houses, land area and livestock which stand threatened by erosion and flooding.

The respondents attributed coastal flooding to hydrodynamic, divine/supernatural and anthropogenic causes. They perceived coastal flooding primarily as a natural hydrodynamic process that is exacerbated by anthropogenic events like coastal developments including harbors and even sea defenses. This outcome is consistent with similar studies from Babanawo et al.,

(2023) which identified similar opinions in a study in Ketu South District of Ghana which highlights the interconnected nature on the Eastern coastline in terms of hydrodynamic forcings. This response also showed that locals were aware, possibly from long term observation of coastal hazard behaviour before and after siting of sea defense structures, about how sea defense systems work by changing transferring the problem to another location close. This respondent outcome is in line with studies from Angnuureng & Appeaning Addo (2013) and Vieira et al., (2020) about how hard structures like sea defense only transfer the problem from one site to the other.

Respondents also attributed coastal erosion to hydrodynamic causes, anthropogenic causes, divine causes and surprisingly tectonic causes. They also perceived coastal erosion as a natural hydrodynamic process caused by waves and surges that is exacerbated by anthropogenic activities like coastal developments including harbors, sea defenses and local sand mining. Jonah et al., (2016) and Appeaning Addo & Appeaning Addo (2016), identified similar opinions to causes of coastal erosion in the Elmina-Cape Coast-Moree stretch and coasts of Accra respectively both in Ghana. The responses suggested that locals were aware from long term observation about how sea defense systems work by changing transferring the erosion to another location close as highlighted by Angnuureng & Appeaning Addo (2013) and Vieira et al., (2020), and how it can be exacerbated by coastal development . The divine cause attributed to coastal erosion in the study area highlights how indigenous practices and belief may influence understanding of coastal hazards in Ghana as highlighted by Arkhurst et al., (2022).

The predominant response of locals being mainly unprepared to deal with coastal erosion and coastal flooding suggests that their propensity to undertake efficient adaptive measures was very low for both hazards considering a lack of awareness, effective training and a lack of trust of community measures put into place in the communities. These outcomes highlight and may

possibly suggest linkage, where for proper local adaptive capacity preparation, there is a need for sound coastal hazard awareness with related tailored and frequent community specific trainings that will inform strategies for effective community resilience. Without these undertakings, communities are expected to have increased hazard impacts especially in the face of coastal hazards with different intensities and frequencies (Dada et al., 2022).

Respondents claimed that they were generally not putting in efforts into place to mitigate neither coastal erosion nor coastal flooding because they viewed them as large-scale natural events whose scope cannot be mitigated by small-scale interventions although they identified hazards occurring in the communities. This outcome highlighted research outcome by Okaka & Odhiambo, (2019) and Dada et al., (2023) that suggests that mitigation actions and countermeasures do not always respond to perceived threats. Previous studies also found no connection between people's risk perception and their intentions to take mitigation measures to coastal hazards (Bubeck et al., 2012; Mattah et al., 2023; Ruz et al., 2020). Therefore, to effectively highlight the importance of self-protection in Akplabanya and Anyamam, Diakakis et al., (2018) recommends that future public community campaigns should emphasize the importance of self-protection measures, rather than only focusing solely on risks, to achieve the greatest positive impact.

Respondents perceived that their opinions were not taken into consideration in community discussions which may put them in disadvantages about communicating community priorities. This can be a source of concern for future interventions in the study towns, given that the effectiveness of all interventions will require both local input, acceptance and safeguarding as respondents also have a role to play in conjunction with government to address coastal hazards (Vasileiou et al., 2022). Wisner et al., (2004), noted that individuals that consider themselves disadvantaged with low considerations in decision making may lose trust in their means of self-

protection and become less confident, especially if they perceive insufficient intervention from authorities and other stakeholders.

The respondents believe that the government should be a key actor who should take up more responsibility for the mitigation and adaptation efforts. Respondents were mostly in favor of including improving education and awareness, structural technologies, early warning systems, monitoring the community, formulating and enforcement of bye-laws and the provision of credits for respondents were mentioned. The recommendations from respondents highlight the acknowledgement of inefficient social systems whiles also reflecting the needs of the community for sustainable implementation of measures to mitigate and adapt to coastal hazards and therefore reduce vulnerability. Sea defense as a coastal protection measure which was heavily favored by respondents have always been criticized as a nigh-risk solution which does not entirely solve the problem but transfers it (Angnuureng & Appeaning Addo, 2013; Vieira et al., 2020). The outcome highlights the need for more awareness on less cost and sustainable coastal protection alternatives that will better serve the communities to reflect proactive and sustainable approaches like nature-based solution alternatives ,

5.6 FACTORS INFLUENCING COASTAL EROSION

5.6.1 Anthropogenic Causes of Coastal Erosion in Akplabanya and Anyamam

The intensity and development of coastal erosion largely depend on the equilibrium of coastal dynamics and beach stability (Cai et al., 2009). Natural factors affecting the Akplabanya and Anyamam coastlines like all other coastlines globally include sea level rise and the actions of waves, alongshore currents, rip currents, and overwash (Luijendijk et al., 2018; Schlacher et al.,

2007). These factors often lead to short-term variations in beach sand volume, a normal part of the beach's equilibrium with its environment (Blue & Kench, 2017; Hanslow, 2007).

While sea levels have been rising gradually for the past century leading to coastline recession (Le Cozannet et al., 2014), beaches naturally adjust their shape and extent in response to storms and variations in wave climate and currents (González Rodríguez et al., 2024; Jiang et al., 2024). However, in Ghana, unregulated human activities including poor land planning and sand mining have exacerbated these natural factors (Appeaning Addo, 2009). These activities are observed both in Akplabanya and Anyamam therefore most possibly contributing to the coastline coastal recession and coastal deterioration which was observed in the Akplabanya and Anyamam. This finding also aligns with research by Ofosu Anim et al., (2013) which noted that intense coastal development, driven by economic growth, has led to widespread modifications of sandy beach ecosystems with many governments, organizations, and individuals often disregarding environmental regulations, especially those related to coastal zones.

Jonah et al. (2016) and Appeaning Addo (2009) also noted that in Ghana, some human activities intended to control erosion can, in fact, exacerbate coastal damage. For example, using beach sandbags method which was prevalent in Anyamam and Akplabanya can destabilize geomorphology and accelerate erosion rates. These activities are likely related to the coastal land recession and degradation observed in both towns.

5.6.2 Hydrodynamic Causes of Coastal Flooding in Akplabanya and Anyamam.

The study area experiences high-energy beach conditions due to active wave action. The prevailing southwesterly winds cause waves to approach the shoreline at an angle, resulting in

eastward littoral transport. This process removes sand from the unconsolidated quaternary sediments at the coastline and carries it to the littoral zone, contributing to shoreline retreat. Because of the straight configuration of the study area (Figure 4) with no headlands to obstruct littoral transport, it is expected to be a reason for the erosion rates along this section of coastline (Boateng, 2009).

Additionally, the predominantly sandy nature of the Ada West District leads to accelerated coastal erosion, because mobile sand offers little resistance to wave action (Vousdoukas et al., 2020). The sand is easily displaced and transported by coastal drift. Reducing sediment supply from sources which may contribute to erosion along the coast.

5.7 COMMUNITY VULNERABILITY INDEX

In the Eastern coastline where the study area is located, communities have been previously identified as vulnerable to coastal hazards (Boateng, 2012: Avornyo, 2023), but the specifics are different for each location and the extent of various hazard vulnerability is not known on the local scale. Based on the IPCC vulnerability factors i.e. exposure, sensitivity, potential impacts and adaptive capacity, vulnerability index at community levels resulted in composite vulnerability scores.

5.7.1 Community Vulnerability for Coastal Erosion at Akplabanya and Anyamam.

In Anyamam, the grids that showed higher sensitivity to coastal erosion compared to Akplabanya, suggesting that the contributory variables, mainly linked to demographic characteristics, present greater risks in those areas of Anyamam.

For exposure, the grids in Akplabanya exhibited relatively lower levels of exposure, suggesting that elements that were used in computing including land area, erosion rates and protective features were more affected in Anyamam than in Akplabanya. In a previous study in Gambia by Gomez et al., (2020), similar local indicators contributing to high exposure to coastal erosion were identified in Gunjur, a town in Gambia. Also, according to the Department for Environment (2014), factors such as the quantity and value of elements at risk, their susceptibility and their exposure to hazards determine erosion vulnerability. This suggests that Anyamam with higher exposure scores has a higher number of elements at risk and experience more significant negative impacts from coastal erosion.

The adaptive capacity in both towns were observed to be similar with average adaptive capacity. This suggests the contributing factors including household access to support, access of information, past participation in training programs related to coastal erosion, willingness to partake in future training in respect to coastal hazards, ownership of travelling assets and community activity participation were similar for respondents in both towns.

When combining the two vulnerability components for potential impact, sensitivity and exposure in all the grids had alternating contributions between sensitivity and exposure for all grids. This observation aligns with Barillà et al., (2021), who found that the dominant factor in determining high potential impact can alternate between sensitivity and exposure depending on the community.

For composite vulnerability score, the interaction between sensitivity and exposure as a function of the adaptive capacity resulted in varied composite vulnerability scores across the grids which is consistent with the findings of Alexandrakis & Poulos (2014) and Lin & Pussella (2017), where different areas studied exhibited different levels of vulnerability. The composite

vulnerability due to coastal erosion was greater on average at Anyamam than Akplabanya meaning it was more vulnerable to coastal erosion using the index deployed.

An important outcome across the grids to note is the general similarity for both the composite adaptive capacity and sensitivity index, whose quantification were obtained from the social assessment but conspicuously varying composite exposure index which was obtained mostly from physical assessment. This highlights the need for integrated vulnerability assessment to understand the holistic assessment of coastal erosion in the system being examined. This outcome also sheds light on the importance of the exposure raised by Ishtiaque et al., (2022) about the importance of the exposure assessment in vulnerability assessment to reduce injustice in coastal vulnerability assessment.

5.7.2 Community Vulnerability for Coastal Flooding in Akplabanya and Anyamam.

For the grids in Anyamam, sensitivity to coastal flooding was generally higher than Akplabanya. This means that the sensitivity contributory variables which are mostly related to demographic characteristics are more at risk in Anyamam than Akplabanya. This suggests that Anyamam with generally higher sensitivity is demographically vulnerable than Akplabanya.

For exposure, Akplabanya scored relatively lower compared to Anyamam. This means that contributory elements used in computing including land area, erosion rates and protective features were more impacted in Anyamam than in Akplabanya. It was noted by Yankson et al., (2017), that the flood vulnerability of an area is determined by the quantity and value of elements at risk, their susceptibility, and their exposure to flooding. Anyamam with higher exposure scores have more people and assets at risk from flood events, resulting in more severe impacts compared to Anyamam.

Very similar levels of adaptive capacity were observed in the study towns. On average, relatively higher adaptive capacity levels were observed in Akplabanya than Anyamam. Contributing variables include household access to support, provision of information, past participation in trainings related to coastal flooding, willingness to partake in future training in respect to coastal flooding, relocation history, past evacuation participation, access to travelling assets, partaking in community discussions with respect to coastal hazards and perceived satisfaction with interventions by government on coastal hazards received similar scores in both towns.

When combining sensitivity and exposure components for potential impact, both variables showed dynamic contributions to the scores. Žurovec et al., (2017), identified sensitivity as the main contributor to potential impact scores in rural Bosnia and Herzegovina. However, the general outcome is in line with Babanawo et al. (2022) and Yankson et al. (2017), who found that the dominant factor for high potential impact can vary between sensitivity and exposure depending on the community.

For composite vulnerability score, the interaction between sensitivity and exposure as a function of the adaptive capacity resulted in varied composite vulnerability scores across the grids. This corresponds to findings from Yankson et al. (2017) and Babanawo et al., (2022), which showed different levels of vulnerability across studied communities and that no one vulnerability dimension is a dominant determinant of vulnerability to coastal flooding. Overall, Anyamam exhibited higher average vulnerability compared to Akplabanya, reflecting the overall assessment of the examined vulnerability dimensions.

An important outcome to note is the general similarity for both the composite adaptive capacity and sensitivity index across the grids, whose quantification were obtained from the social assessment but varying composite exposure index which was obtained mostly from physical assessment. This highlights the need for integrated vulnerability assessment to understand the holistic assessment of coastal flooding in the system being examined. This outcome also sheds light on the importance of the exposure raised by Ishtiaque et al., (2022) about the importance of the exposure assessment in vulnerability assessment to reduce injustice in coastal vulnerability assessment especially with vulnerable communities like Akplabanya and Anyamam.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION

The overall objective of the project was to assess the vulnerability of the coastal communities of Akplabanya and Anyamam by integrating current coastal erosion trends, future coastal flooding dynamics due to Sea Level Rise, and social perspectives on the dynamics of vulnerability. The specific objectives of the study were to; i) Assess current coastal erosion hazard trends occurring at the Akplabanya and Anyamam communities. ii) Assess the extent of coastal flood hazard related to IPCC projection of SLR under RCP 5 - 8.5 of Akplabanya and Anyamam. iii) Explore the social perceptions of the respondents in Akplabanya and Anyamam on vulnerability to coastal flooding and coastal erosion. iv) Quantify the vulnerability of communities to SLR-related coastal flooding and coasStal erosion in Akplabanya and Anyamam.

The findings from the study show that the coastlines of both Akplabanya and Anyamam are eroding at rapid and moderate rates, but Akplabanya has comparatively lower rates of erosion that Anyamam. This means that coastal erosion will be responsible for loss and degradation of assets in the communities in the communities in the foreseeable future if rates remain the same.

The findings from the study also show that, Akplabanya was relatively far less exposed to SLR-related coastal flooding than Anyamam in all the projection scenarios assessed. Therefore, it is expected that future coastal flooding events will be far more intense in Anyamam than Akplabanya as climate change causes further increase in SLR which is the base for most coastal inundation.

Furthermore, the key natural events that has most impact on the local communities are coastal erosion and coastal flooding. They attributed coastal flooding and coastal erosion to natural causes exacerbated by anthropogenic causes and that their adaptive capacity was low due to inadequate institutional support. Communities indicate that they require Early Warning Systems, building of hard structures especially sea defense, financial support and bye-laws to help mitigate coastal hazards. Efforts to reduce vulnerability will therefore require dynamic approach that is inclusive and flexible.

Finally, the findings from the study show that community vulnerability indexes were constructed using the IPCC vulnerability factors, exposure, sensitivity, potential impacts and adaptive capacity for coastal erosion and coastal flooding. Based on indexes including sensitivity, exposure and adaptive capacity showed that both towns were vulnerable, but Anyamam was more vulnerable to both coastal flooding and coastal erosion than Akplabanya. Therefore, current coastal hazards have a negative effect on the environment and socio-economic dynamics for residents in Akplabanya more than Anyamam.

6.2 RECOMMENDATIONS

To mitigate coastal erosion hazard in the communities, the Ghanaian government, particularly stakeholders at the Environmental Protection Agency (EPA) and Ministry of Environment, Science, Technology and Innovation (MESTI) should spearhead efforts to incorporate nature-based solutions including mangrove and coconut projects with local participation and enforced monitoring as highlighted in the community discussions.

Also, local government authorities including chiefs and assembly men, NADMO and the District police can lead effective monitoring regime in the study communities that are backed by law and enforced to reduce activities that increase coastal erosion like sand winning. This will reduce sand winning activities on the beaches.

The government of Ghana must put into place Early Warning System which that can help the communities anticipate and prepare for coastal floods. This will reduce losses and impacts of coastal flooding in Akplabanya and Anyamam.

NADMO and the local government must set up a taskforce by the 2025 to assess the severity of post-event impacts from coastal floods and the economic value of exposed facilities and elements. This will aid in planning and developing robust adaptation strategies tailored to the needs of the communities that will reduce the impact of coastal flooding and coastal erosion.

The chiefs, Assemblymen and District Chief Executives must be proactive and ready to escalate community needs to the state government in relation to coastal hazards in Akplabanya and Anyamam. Local participation is key for success of all projects and must be emphasized and

incorporated as much as possible in all activities aimed at reducing vulnerability to coastal hazards as mentioned in the discussion.

Given the varying levels of vulnerability to coastal flooding and erosion, stakeholders such as the National Disaster Management Organization (NADMO), District Assemblies, and local councils should focus on enhancing the adaptive capacity of communities. This can be achieved by providing accurate hazard information, establishing early warning systems, expanding interventions to underserved vulnerable communities, and offering training and support to improve awareness and preparedness.

6.3 SUGGESTIONS FOR FURTHER RESEARCH

This study has assessed the coastal vulnerability for the two largest communities in the Ada West District, but a complete assessment of the district is also possible using census reports for socio-economic data, satellite data for coastal erosion hazard assessment and open-source DEM. Also, since vulnerability is an evolving phenomenon, frequent follow-ups assessments are required to update the information obtained.

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APPENDICES

APPENDIX 1: COASTAL EROSION VARIABLES AND JUSTIFICATION.

Number	Variable	Justification	Vulnerability Dimension
Sensitivity			
1	Proportion of households headed by Females	Female-headed households are particularly vulnerable to erosion due to the limited resources they often have at their disposal. This can include restricted access to financial resources, lower levels of social support, and fewer livelihood opportunities (Jozaei et al., 2022; Wu et al., 2016)	+
2	Proportion of Households with constituents older than 65 years	Elderly groups are known to not have less physical and economic means to respond effectively in the face of coastal hazards (Mavhura, 2019; Tragaki et al., 2018).	+
3	Proportion of Households with constituents less than 5 year	Young children are resource dependent. Most often not being able to respond to disasters without assistance and they are more susceptible to significant physical and psychologicalimpacts (Tragaki et al., 2018).	+
4	Proportion of Households with disability	Mentally or physically disable require assistance to be able to respond to a disaster effectively during hazard event (Cutter, 1996).	+
5	Proportion of household with single parents	A high proportion of single parents with dependents means a stretch of limited resources (Flanagan et al., 2020).	+
6	Average size of household	In high-density areas, there is less probability of obtaining effective and satisfactory help as limited resources are meant for a large number of people (Gomez et al., 2020).	+

7	The proportion of household heads with no education	Households with low level of educational attainment are usually less proficient in written languages of communication and are less likely to access emergency information without assistance (Gomez et al., 2020)	+
8	The proportion of household heads without secondary occupation.	Secondary occupation is a determinant for the lack of avenues to obtain resources and general social security (Derakhshan et al., 2022; Dintwa et al., 2019).	+
Adaptive Capacity			
9	Proportion of households who have not received training on coastal hazards	Trainings are important for dissemination of best practices and systematic procedures to increase the resilience to coastal hazards (Wu et al., 2016).	+
10	Proportion of households that are able to relocate in the face of coastal hazard	Retreat option can reduce the risk of the event and limit its potential effects (Ahmad et al., 2021; Barillà et al., 2021).	+
11	Proportion of household heads who are not willing to take a training on coastal hazards.	This represents a gap in resilience to vulnerability as the population who are not willing to take training will be more vulnerable (Wu et al., 2016).	+
12	Proportion of household heads who believe that do not receive help from family outside communities	Support is a very important means to increase resilience to vulnerability. Adequate support can mitigate the impacts of coastal hazards (Allen, 2006; Bukvic et al., 2018).	+
13	Proportion of household heads who believe that do not receive help from friends outside the community.		+
14	Proportion of household heads who believe that do not receive help from social groups.		+

15	Average age of housing infrastructure	Older housing infrastructure can mean less structural integrity and outdated factors put into place during building process which can make it more affected to coastal hazards (Rowan & Kwiatkowski, 2020; Sayers et al., 2018).	+
16	The proportion of households who lived in a rented housing infrastructure	Households living in rented housing are less likely to put in intervention measures due to limited resources and place association from sense of ownership (Jarnkvist, 2020) .	+
17	Average residence period in the community	Experiences with coastal erosion will most likely lead to the increase of private erosion mitigation measures, positive influence on preparedness (Tragaki et al., 2018).	-
18	Proportion of households not satisfied by provision of information from Local government on coastal erosion	Information that is usually related to the current state of community susceptibility in relation to pre and post hazard information can help reduce vulnerability (Dada et al., 2023, 2024).	+
19	Proportion of households not satisfied by provision of information by NGOs on coastal erosion		+
20	Proportion of households not satisfied by provision of information by Government on coastal erosion		+
21	The proportion of household heads that are not actively involved in community discussions on coastal hazards	Participation in community discussion related to coastal hazards is important to identify (Coelho et al., 2023; van Aalst et al., 2008).	+

22	The proportion of household heads that think their views are not considered in community interventions for coastal erosion	Participation in community discussion related to coastal hazards is important to identify areas of interests that are inclusive and just (Faisal et al., 2021; Parvin et al., 2008).	+
23	The proportion of household heads who are not satisfied by relevant authorities on coastal hazards.	Less satisfaction means a perceived lack of trust of authorities and sentiment which can reduce cohesion and an increase of coastal vulnerability (van der Plank et al., 2022).	+
24	Proportion of households without traveling assets	Is an indication of low-income level and less mobility options in an event of coastal erosion (Tasnuva et al., 2021).	+
Exposure			
25	Portion of land area lost under 10-year lower uncertainty projection	These physical computations represent the land assets that will be lost increase vulnerability by reducing resource availability that is available to local communities.	+
26	Portion of land area lost under the 10-year projection		+
27	Portion of land area lost under the 10-year upper projection uncertainty		+
28	Portion of land area lost under 20-year lower uncertainty projection		+
29	Portion of land area lost under the 20-year projection.		+

30	Portion of land area lost under the 20-year upper uncertainty projection.		+
31	Portion of houses lost under the 10-year lower uncertainty projection	These physical computations represent the assets to be lost increase vulnerability by reducing resource availability that is available to local communities.	+
32	Portion of houses lost under the 10-year projection		+
33	Portion of houses lost under the 10-year upper projection		+
34	Portion of houses lost under the 20-year lower uncertainty projection		+
35	Portion of houses lost under the 20-year projection		+
36	Portion of houses lost under the upper uncertainty 20-year projection		+
37	Average erosion rate		+
38	Absence Of Sand Dunes	The absence of sand dunes increases the magnitude of coastal erosion process by reducing leading to an increase in coastal erosion exposure (Figlus & Armitage, 2014; Jackson et al., 2019).	+
39	Absence Of Vegetation features	This reduces the magnitude of coastal erosion process by hydrodynamic impacts. An absence therefore means an increase in coastal erosion exposure and vulnerability (Chen et al., 2022; Wells et al., 2006).	+

40	Proportion of household head who believe coastal erosion has an impact on their household income.	These represents perspectives that are being directly impacted by coastal erosion.	+
41	Proportion of household head who believe coastal erosion has an impact on housing structure damage.		+
42	Proportion of household head who believe erosion has an impact on utility infrastructure.		+
43	Proportion of household heads who believe coastal erosion rates are increasing.		+

APPENDIX 2: COASTAL FLOODING VARIABLES AND JUSTIFICATION

Variable Number	Variable	Justification	Vulnerability Contribution
Sensitivity			
1	Proportion of Households headed by Females	Female-headed households have been known to be relatively less socially privileged than males which will also translate in vulnerability reception (Mavhura, 2019; Zhang et al., 2013).	+
2	Proportion of Households with constituents older than 65 years	Elderly groups are known to be less physically capable even though they sometimes they are wealthy. They are therefore more likely to have less physical capability necessary to respond to a disaster efficiently and effectively (Holand et al., 2011; Mavhura, 2019). This is put into perspective especially considering the stress that evacuation and relocation brings,	+
3	Proportion of Households with constituents less than 5 year	This group of demography are often not able to respond to hazard events without assistance and supervision and hence are more susceptible to the impacts of coastal hazards. (Lee & Vink, 2015; Turesson et al., 2024)	+
4	Proportion of Households with disability	People with mentally or physically disability do not have the capability to be able to respond effectively during hazard events because they require additional assistance (Lee, 2014) .	+
5	Proportion of household with single parents	A high number of single parents with dependents mean a stretch of limited resources (Cutter, 1996; Dintwa et al., 2019).	+
6	Average size of household	For areas with high number of people in a household, there is limited opportunity and resources to account and manage everyone in a household and less probability of evacuation and the higher risk of death (Dintwa et al., 2019; Hadipour et al., 2020).	+

7	The proportion of household heads with no education	Household heads with low level of educational attainment are less likely to access emergency information and make decisions accordingly considering the small window to react during such events (Englund et al., 2023; Holand, 2015).	+
8	The proportion of household heads without secondary occupation	No secondary occupation is proxy for lack of diversity to obtain resource and general social security (Babanawo et al., 2023; Mattah et al., 2023).	+
Adaptive Capacity			
9	Proportion of households who have not received training on coastal hazards	Trainings are important for dissemination of best practices and systematic procedures to increase the resilience to coastal hazards (Bonati, 2022).	+
10	Proportion of households that do not have the ability to relocate in the face of coastal flooding	Retreat option can be in the form of relocating away from the hazard and hence the ability to reduce the risk of the event and limit its potential effects (Boateng, 2012).	+
11	Proportion of household heads who are not willing to take a training on coastal hazards.	This represents a gap in resilience to vulnerability as the population who are not willing to take training will be more vulnerable.	+
12	Proportion of household heads who believe that do not receive help from family outside communities	Support is a very important means to increase resilience to vulnerability. Adequate support can go a long mitigate impacts of coastal hazards (Brandt et al., 2021; Holand et al., 2011).	+
13	Proportion of household heads who believe that do not receive help from friends outside the community		+
14	Proportion of household heads who believe that do not receive help from social association groups		+

15	Average age of housing infrastructure	Older housing infrastructure can mean less structural integrity and outdated factors put into place during building process which can make it more affected to coastal hazards (Rowan & Kwiatkowski, 2020; Sayers et al., 2018).	+
16	The proportion of households who lived in a rented housing infrastructure	Households living in a rented housing are less likely to put in intervention measures due to limited resources and association. This can limit seeking out private flood mitigation measures which have a positive relationship on preparedness (Buchanan et al., 2020; Holand et al., 2011; Rowan & Kwiatkowski, 2020).	+
17	Average residence period in the community	This can translate to experience with coastal hazards like flood that increases people's adaptiveness and can lead to the generation of private flood mitigation measures which can influence preparedness(Parvin et al., 2023; von Szombathely et al., 2023).	-
18	Proportion of households not satisfied by provision of information from Local government on coastal flooding	Information that is related to the current state of community pre and post hazard can help reduce vulnerability. This includes information on protection, accommodation and retreats (C. C. Anderson et al., 2021; Rowan & Kwiatkowski, 2020).	+
19	Proportion of households not satisfied by provision of information by NGOs on coastal flooding		+
20	Proportion of households not satisfied by provision of information by Government on coastal flooding		+
21	The proportion of household heads that are not actively involved in community discussions on coastal hazards	Not actively participating in community discussions makes decision making in relation to coastal flooding not inclusive enough to make progress that benefits everyone (Ahsan & Warner, 2014; Parvin et al., 2023).	+

22	The proportion of household heads that think their views are not considered in community interventions for coastal flooding.	When people feel that their views are not concerned, they can create an avenue that affects community cohesion (Ahsan & Warner, 2014; Parvin et al., 2023).	+
23	The proportion of households who are not satisfied by relevant authorities on coastal hazards.	Dissatisfaction with authorities can lead to litigation and hence reduce community resilience to coastal flooding (Sinthumule et al., 2019; van Aalst et al., 2008).	+
24	The proportion of household heads who have not been involved in evacuation	Involvement in evacuation can increase community trust and also drawing on experiences to reduce vulnerability (Vink et al., 2014).	+
25	Proportion of households without traveling assets	Travelling assets demonstrate wealth and potential assets that can be transformed during moments of crisis	+
Exposure			
26	Portion of land area lost under SLR projection 2021-2040	This physical computation of land area shows what land assets may be lost to SLR.	+
27	Portion of land area lost under SLR projection 2040-2060		+
28	Portion of land area lost under SLR projection 2080-2100		+
29	Absence of Sand Dunes on beachfront	This reduces the magnitude of coastal flooding impact by serving as a buffer. An absence therefore means an increase in coastal erosion vulnerability (Handiani et al., 2022; Pethick & Crooks, 2000)	+
30	Absence Of Vegetation features on beach.	This reduces the magnitude of coastal erosion process by hydrodynamic impacts. An absence therefore means an increase in coastal flooding exposure and vulnerability (Gijsman et al., 2021; Gilman et al., 2008).	+
31	Proportion of household head who believe coastal flooding has an impact on their household income	These represents perspectives that are being directly impacted by coastal flooding (Babanawo et al., 2023).	+

32	Proportion of household head who believe coastal flooding has an impact on housing structure damage		+
33	Proportion of household head who believe coastal flooding has an impact on utility infrastructure		+
34	Proportion of household heads who believe coastal flooding frequency has increase in the last 5 years	This shows perception of exposure within the locations.	+

APPENDIX 3: EROSION RATES PER TRANSECT

LRR Transect Rates for Coastline Erosion for Akplabanya and Anyamam (2005 – 2023).

Transect Count	Town	Erosion rate (meters/year)	Town	Erosion rate (meters/year)
1	Akplabanya	-1.9	Anyamam	-1.66
2	Akplabanya	-2.04	Anyamam	-1.51
3	Akplabanya	-2.22	Anyamam	-1.34
4	Akplabanya	-2.31	Anyamam	-1.51
5	Akplabanya	-2.2	Anyamam	-1.72
6	Akplabanya	-2.06	Anyamam	-2.08
7	Akplabanya	-1.99	Anyamam	-1.6
8	Akplabanya	-2.21	Anyamam	-1.6
9	Akplabanya	-2.24	Anyamam	-1.82
10	Akplabanya	-2.29	Anyamam	-2.01
11	Akplabanya	-2.3	Anyamam	-1.69
12	Akplabanya	-2.1	Anyamam	-1.57
13	Akplabanya	-2.1	Anyamam	-1.69
14	Akplabanya	-2.28	Anyamam	-2.04
15	Akplabanya	-2.15	Anyamam	-2.16
16	Akplabanya	-2.02	Anyamam	-2.1
17	Akplabanya	-2.03	Anyamam	-2.08
18	Akplabanya	-2.27	Anyamam	-2.2
19	Akplabanya	-2.07	Anyamam	-2.24
20	Akplabanya	-1.98	Anyamam	-2.01
21	Akplabanya	-2.1	Anyamam	-2.11
22	Akplabanya	-1.93	Anyamam	-2.21
23	Akplabanya	-1.82	Anyamam	-2.01
24	Akplabanya	-1.85	Anyamam	-1.84
25	Akplabanya	-2.15	Anyamam	-2.07
26	Akplabanya	-1.99	Anyamam	-2.03
27	Akplabanya	-1.75	Anyamam	-2.16
28	Akplabanya	-1.64	Anyamam	-1.97
29	Akplabanya	-1.82	Anyamam	-1.83
30	Akplabanya	-1.91	Anyamam	-2.03
31	Akplabanya	-1.86	Anyamam	-2.21
32	Akplabanya	-1.55	Anyamam	-1.93
33	Akplabanya	-1.54	Anyamam	-2.21
34	Akplabanya	-1.68	Anyamam	-2.32
35	Akplabanya	-1.83	Anyamam	-1.97

36	Akplabanya	-1.92	Anyamam	-1.8
37	Akplabanya	-1.62	Anyamam	-2.25
38	Akplabanya	-1.66	Anyamam	-2.45
39	Akplabanya	-1.82	Anyamam	-2.08
40	Akplabanya	-1.78	Anyamam	-2.45
41	Akplabanya	-1.73	Anyamam	-2.56
42	Akplabanya	-1.83	Anyamam	-2.24
43	Akplabanya	-1.89	Anyamam	-2.22
44	Akplabanya	-1.65	Anyamam	-2.59
45	Akplabanya	-1.71	Anyamam	-2.71
46	Akplabanya	-1.91	Anyamam	-2.25
47	Akplabanya	-1.75	Anyamam	-2.38
48	Akplabanya	-1.57	Anyamam	-2.5
49	Akplabanya	-1.55	Anyamam	-2.86
50	Akplabanya	-1.76	Anyamam	-2.8
51	Akplabanya	-1.91	Anyamam	-2.77
52	Akplabanya	-1.53	Anyamam	-2.58
53	Akplabanya	-1.38	Anyamam	-2.27
54	Akplabanya	-1.59	Anyamam	-2.85
55	Akplabanya	-1.81	Anyamam	-2.84
56	Akplabanya	-1.6	Anyamam	-2.55
57	Akplabanya	-1.51	Anyamam	-2.32
58	Akplabanya	-1.4	Anyamam	-2.44
59	Akplabanya	-1.52	Anyamam	-2.59
60	Akplabanya	-1.54	Anyamam	-2.88
61	Akplabanya	-1.75	Anyamam	-2.56
62	Akplabanya	-1.57	Anyamam	-2.42
63	Akplabanya	-1.34	Anyamam	-2.43
64	Akplabanya	-1.46	Anyamam	-2.41
65	Akplabanya	-1.88	Anyamam	-2.24
66	Akplabanya	-1.54	Anyamam	-2.07
67	Akplabanya	-1.59	Anyamam	-2.42
68	Akplabanya	-1.73	Anyamam	-2.34
69	Akplabanya	-1.85	Anyamam	-2.14
70	Akplabanya	-1.68	Anyamam	-2.36
71	Akplabanya	-1.59	Anyamam	-2.45
72	Akplabanya	-1.72	Anyamam	-2.28
73	Akplabanya	-1.56	Anyamam	-2.35
74	Akplabanya	-1.48	Anyamam	-2.34
75	Akplabanya	-1.75	Anyamam	-2.19

76	Akplabanya	-1.49	Anyamam	-2.18
77	Akplabanya	-1.49	Anyamam	-2.49
78	Akplabanya	-1.73	Anyamam	-2.1
79	Akplabanya	-1.55	Anyamam	-2.09
80	Akplabanya	-1.28	Anyamam	-2.28
81	Akplabanya	-1.45	Anyamam	-2.27
82	Akplabanya	-1.43	Anyamam	-2.15
83	Akplabanya	-1.13	Anyamam	-2.17
84	Akplabanya	-1.06	Anyamam	-2.21
85	Akplabanya	-1.15	Anyamam	-2.45
86	Akplabanya	-1.32	Anyamam	-2.47
87	Akplabanya	-1.34	Anyamam	-2.19
88	Akplabanya	-0.89	Anyamam	-2
89	Akplabanya	-0.97	Anyamam	-2.14
90	Akplabanya	-1.28	Anyamam	-2.37
91	Akplabanya	-1.4	Anyamam	-2.17
92	Akplabanya	-1.29	Anyamam	-1.98
93	Akplabanya	-1.2	Anyamam	-2.02
94	Akplabanya	-1.26	Anyamam	-2.34
95	Akplabanya	-1.42	Anyamam	-2.03
96	Akplabanya	-1.36	Anyamam	-1.91
97	Akplabanya	-1.22	Anyamam	-1.97
98	Akplabanya	-1.24	Anyamam	-2.01
99	Akplabanya	-1.25	Anyamam	-2.13
100	Akplabanya	-1.42	Anyamam	-2.07
101	Akplabanya	-1.55	Anyamam	-1.85
102	Akplabanya	-1.24	Anyamam	-1.94
103	Akplabanya	-1.67	Anyamam	-2.12
104	Akplabanya	-1.64	Anyamam	-1.79
105	Akplabanya	-1.67	Anyamam	-1.66
106	Akplabanya	-1.51	Anyamam	-1.63
107	Akplabanya	-1.39	Anyamam	-1.75
108	Akplabanya	-1.46	Anyamam	-1.95
109	Akplabanya	-1.61	Anyamam	-2.04
110	Akplabanya	-1.83	Anyamam	-2.05
111	Akplabanya	-1.81	Anyamam	-2.06
112	Akplabanya	-1.38	Anyamam	-2.05
113	Akplabanya	-1.57	Anyamam	-2.05
114	Akplabanya	-2	Anyamam	-1.94
115	Akplabanya	-1.81	Anyamam	-2.07

116	Akplabanya	-1.86	Anyamam	-2.22
117	Akplabanya	-1.83	Anyamam	-1.83
118	Akplabanya	-1.89	Anyamam	-1.34
119	Akplabanya	-2.04	Anyamam	-1.43
120	Akplabanya	-1.99	Anyamam	-1.59
121	Akplabanya	-2.09	Anyamam	-1.79
122	Akplabanya	-2.09	Anyamam	-1.61
123	Akplabanya	-2.2	Anyamam	-1.53
124	Akplabanya	-1.8	Anyamam	-1.48
125	Akplabanya	-1.74	Anyamam	-1.62
126	Akplabanya	-2.07	Anyamam	-1.66
127	Akplabanya	-2.14	Anyamam	-1.65
128	Akplabanya	-2.01	Anyamam	-1.66
129	Akplabanya	-2.12	Anyamam	-1.72
130	Akplabanya	-2.36	Anyamam	-1.56
131	Akplabanya	-2.09	Anyamam	-1.49
132	Akplabanya	-1.95	Anyamam	-1.71
133	Akplabanya	-2.05	Anyamam	-1.68
134	Akplabanya	-2.06	Anyamam	-1.42
135	Akplabanya	-2.05	Anyamam	-1.44
136	Akplabanya	-2.01	Anyamam	-1.54
137	Akplabanya	-2	Anyamam	-1.31
138	Akplabanya	-2.02	Anyamam	-1.19
139	Akplabanya	-2.07	Anyamam	-1.19
140	Akplabanya	-2.13	Anyamam	-1.17
141	Akplabanya	-1.89	Anyamam	-0.99
142	Akplabanya	-1.67	Anyamam	-1.09
143	Akplabanya	-1.8	Anyamam	-1.11
144	Akplabanya	-1.85	Anyamam	-0.97
145	Akplabanya	-1.83	Anyamam	-0.99
146	Akplabanya	-1.96		
147	Akplabanya	-2.09		
148	Akplabanya	-1.92		
149	Akplabanya	-1.92		
150	Akplabanya	-1.82		
151	Akplabanya	-1.69		
152	Akplabanya	-1.88		
153	Akplabanya	-2.07		
154	Akplabanya	-2.03		
155	Akplabanya	-2.05		

156	Akplabanya	-1.96
157	Akplabanya	-2.1
158	Akplabanya	-2.12
159	Akplabanya	-2.16
160	Akplabanya	-2.24
161	Akplabanya	-2.33
162	Akplabanya	-2.25
163	Akplabanya	-2.06
164	Akplabanya	-2.19
165	Akplabanya	-2.13
166	Akplabanya	-2.09
167	Akplabanya	-2.13
168	Akplabanya	-2.13
169	Akplabanya	-2.13
170	Akplabanya	-2.12
171	Akplabanya	-2.23
172	Akplabanya	-2.2
173	Akplabanya	-2.13
174	Akplabanya	-2.16
175	Akplabanya	-2.18
176	Akplabanya	-2.11
177	Akplabanya	-1.96
178	Akplabanya	-1.91
179	Akplabanya	-2.04
180	Akplabanya	-2.14
181	Akplabanya	-2.07
182	Akplabanya	-1.91
183	Akplabanya	-1.91
184	Akplabanya	-1.9
185	Akplabanya	-1.81
186	Akplabanya	-1.71
187	Akplabanya	-1.78

APPENDIX 4: QUESTIONNAIRE PERMISSION PROCEDURE

Consent Procedures

Procedure for Oral Acceptance of Consent for Questionnaire Assessing Impacts of Coastal Erosion and Coastal Flood Hazard on Respondents of Akplabanya and Anyamam.

Introduction

The goal of this consent process is to make sure that participants were aware of the goals and dangers of the questionnaire study evaluating the effects of coastal erosion and coastal flood risk on respondents of Akplabanya and Anyamam. The consent procedure recognizes the oral acceptance of consent as a valid technique of getting consent and the use of the Adangbe language for communication.

Sharing of Information:

The researcher spoke to possible participants and describe the study's goals, objectives, and anticipated results. These explanations were given in Adangbe, ensuring that participants comprehend the information completely.

Communication of Voluntary Participation

Participants were made aware of the fact that their participation is entirely optional. They were free to refuse participation or leave the study at any moment without compulsion. The value of making informed decisions and the absence of compulsion were emphasized.

Confidentiality Assurance

Participants were given the assurance that their answers and other personal information were treated in absolute confidence. All data were anonymised and reported in a way that protects personal information. The information will only be accessible to approved researchers and utilized for research.

Risk and Benefits

Participants were made aware of any possible dangers related to study participation, such as talking about painful or upsetting experiences related to coastal erosion and floods. The advantages of taking part were also being emphasized, including how it might help us understand coastal vulnerabilities and possibly make improvements to coastal management in their community.

Opportunity for Questions

Participants had the chance to ask any questions they might have about the study, its methods, or their participation. Before participants provided their agreement, the researcher answered these concerns to ensure they fully understood the study.

Oral Acceptance

Oral acceptance was used to acquire consent. Verbal consent to participate in the study was requested from participants.

Contact Information

Participants will be able to reach the author through the local guides who are respondents in the towns.

APPENDICE 5: FIELD PICTURES

Fish caught in Akplabanya lagoon

A man fishing in the Akplabanya lagoon.

Community drain in Akplabanya that was built to relief coastal flooding and rainfall.

Author undertaking FGD in Akplabanya.

Picture depicting abandoned homes close to the coastline in the study area.