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INTEGRI PROCEDAMUS

ASSESSMENT OF CLIMATE CHANGE, FLOOD RISKS AND RISK REDUCTION MEASURES IN THE LOWER VOLTA RIVER BASIN IN GHANA

BY

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DECLARATION

I, Eric Kofi Afornorpe, hereby declared that except for references to other authors and their works which I have duly acknowledged, this is the result of my scientific research project carried out under the supervision of Prof. Opoku Pabi, Prof. Daniel Nukpezah and Prof. Albert Ahenkan.

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DEDICATION

To God be the Glory, Families, Colleagues and Friends.

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ABBREVIATIONS

AFOLU	Agriculture, Forestry and other Land Use
AMO	Atlantic Multi-decadal Oscillation
CBOs	Community-Based Organisation
CDA	Classification Distribution Analysis
CH_4	Methane
CO_2	Carbon dioxide
CSoVI	Coastal Social Vulnerability Index
CSOs	Civil Society Organisations
CPT	Coastal Planning and Risk Management Techniques
CTD	Conductivity Temperature Depth
CV	Consistency Ratio
CV	Coefficient of Variation
DEM	Digital Elevation Models
DSM	Digital Surface Model
EPA	Environmental Protection Agency
ENSO	El Niño-Southern Oscillation
FAO	Food and Agriculture Organisation
FRM	Flood Risk Management
FGDs	Focus Group Discussions
GWP-WA	Global Water Partnership in West Africa
GES	Ghana Education Services
GIS	Geographic Information Service
GHG	Greenhouse Gases
GMeT	Ghana Meteorological Agency
GSS	Ghana Statistical Services
HES	Hard Engineering Solution

IPCC	Intergovernmental Panel on Climate Change
LMSL	Local Mean Sea Level
LULC	Land Use and Land Cover
MSETI	Ministry of Science, Environment, Technology and Innovation
MMDAs	Metropolitan, Municipal and District Assemblies
MoFA	Ministry of Food and Agriculture
MLGRD	Ministry of Local Government and Rural Development
NADMO	National Disaster Management Organisation
OECD	Organisation for Economic Cooperation and Development
PDO	Pacific Decadal Oscillation
PCA	Principal Component Analysis
RCP	Representative Concentration Pathways
SLR	Sea Level Rise
SSP	Share Socio-economic Pathway
SOVI	Social Vulnerability Index
SID	Small Island Developing States
SNA	Social Network Analysis
SPSS	Statistical Package for Social Science
SES	Software Engineering Solution
UNFCCC	United Nation Framework Convention on Climate Change
UNDP	United Nation Development Programme
UN	United Nation
UNSDGs	United Nation Sustainable Development Goals
VBA	Volta Basin Authority
WMO	World Meteorological Organisation

ABSTRACT

Introduction: Climate change-induced extremes, particularly flooding and sea-level rise, pose escalating risks to low-lying coastal systems globally, with current and future disproportionate impacts on vulnerable communities in sub-Saharan Africa. In Ghana, the Lower Volta River Basin and around its Delta, including the Keta Lagoon Zone, has experienced recurrent and compound flooding driven by climate change and variability, sea-level rise, coastal erosion, land-use change, and socio-economic exposures and vulnerabilities. While existing studies have largely emphasised flood hazards and biophysical exposures, there remains a critical gap in integrated assessments that simultaneously consider the hazards, exposures, vulnerabilities risk reduction measures.

Method: This study evaluates changes and variabilities in the climatic conditions, flood projections, and flood risk reduction measures in the Lower Volta River Basin, concentrating on the Ada East District, Anloga District, Keta Municipality, and Ketu South Municipality. A mixed-methods approach was employed, integrating quantitative climatic and spatial analyses with qualitative socio-economic assessments. Long-term rainfall and temperature data (1960–2023) were analysed using trend and variability techniques, including the Mann–Kendall test. Flood hazards and inundation were modeled using GIS-based methods, applying a bathtub approach with a 12 m digital surface model under IPCC SSP2-4.5 and SSP5-8.5 scenarios for three-time horizons: 2020–2040, 2040–2060, and 2080–2100. Flood risk mapping combined the GIS/Analytic Hierarchy Process for weighted and anlysis of risk map, and Principal Component Analysis to load rotate, to present variables on hazards, exposure and vulnerability link to hydro-geomorphological and socio-economic components. Community survey questionnaires based on systematic sampling, focus group discussions, and key informant interviews were used to assess knowledge of hazards, exposure, vulnerability, risk reduction measures and practices.

Results: study findings revealed significant interannual variability in rainfall and a rising temperature trend particularly in Keta on average but more warming in Ada by its daily maximum temperatures, alongside strong seasonal intensive rainfall patterns closely linked to recurrent flooding. Sea-level rise projections indicate substantially higher inundation extents under SSP5-8.5 business as usual, with increasing uncertainty toward High-emission scenarios project the inundation of up to 39.1% of the basin's land area by end of this century. Flood risk hotspots correspond with low-lying zones, dense settlements, degraded ecosystems, and areas with limited adaptive capacity. Despite widespread community awareness of flood hazards, risk reduction efforts remain fragmented, with a heavy reliance on structural defences and emergency responses and a limited integration of land-use planning, ecosystem-based approaches, and early warning systems. A strong emphasis on dredging the lagoon and some extent the river was strongly preferred over the physical measures, something that was not adequately visible in existing literatures.

Conclusion: The study concludes that flood risk in the Lower Volta River Basin is shaped by the interaction of climate change, exposures and socio-economic vulnerability. The study emphasises the necessity for a comprehensive approach to flood risk management that incorporates climate projections, spatial planning, dredge, ecosystem restoration, early warning systems and infrastructure.

CHAPTER ONE

INTRODUCTION

1.0 Introduction

This chapter delves into various critical elements of the study. It begins with an overview of the study background, providing context and laying the foundation for understanding the research. This is followed by a detailed problem statement that identifies the specific issues the research aims to address. The chapter then outlines the study objectives, clearly defining the goals and what the research intends to achieve. Additionally, it justifies the significance of the work, explaining the rationale behind the research and its potential impact. The scope of the work was discussed, delineating the boundaries of the study and what it encompassed. Furthermore, it acknowledges any limitations that may affect the research process or findings. Finally, the chapter is structured to provide a roadmap for the entire thesis, detailing how the content is organized and presented to guide the reader through the research journey.

1.1 Background of the Study

Climate change is largely driving an increase in extreme weather events, sea-level rise, and coastal flooding, which together with other environmental degradation and socio-economic challenges significantly elevate flood risks for coastal communities (Schlegelmilch et al, 2025). Nations with high climate hazards, biophysical and demographic exposures and socio-economic vulnerabilities will be characterised by higher risks, including future impacts and damages to properties, assets and lives, thus a threat to sustainable development, climate mitigation and adaptation (U.S.Environmental Protection Agency, 2025). Tidal related coastal flooding is occurring more frequently, storm surges intensifying, and rising seas level worsen risks for coastal infrastructure, economic assets and public health. The changes in climate, along with the associated extreme events such as warming, storms, floods, and rising sea levels are having variable and adverse effects on regions in the world, primarily due to the increase in greenhouse gas (GHG) emissions (IPCC, 2023). According to the Intergovernmental Panel on Climate Change (IPCC), climate change is a statistically significant alteration in the climate of a specific location over a span of about three decades or any direct or indirect changes in the climate predominantly caused by human activities that affect atmospheric conditions over time (IPCC, 2007; UNFCCC, 2011).

Indeed, the Earth has warmed at an accelerated rate in recent decades due to the GHG emissions, primarily resulting from anthropogenic activities, largely in developed and industrialised countries (IPCC, 2021, 2022, 2023). Global carbon concentrations have surpassed 420 parts per million (ppm), compared to less than 300ppm in the pre-industrial era (Friedlingstein et al., 2022). Corresponding warming and temperature rise have already reached a global average of 1.2°C and are projected to reach a concerning 1.4°C and 2°C by 2050 under the Shared Socio-economic Pathway (SSP1) (Friedlingstein, 2022; World Meteorological Organisation, 2021; IPCC, 2023).

The global average rainfall has shown an increase, yet this surge comes with considerable volatility, unpredictability, and intensity, which contribute to flooding events (Plank et al., 2021). The length of the rainy season changed by as much as 30% each year from 2005 to 2010 (Amekudzi et al., 2016; Yamba & Omotosho, 2010). As sea surface temperatures climb, the expansion of sea volume and the acceleration of sea level rise result in more frequent occurrences of coastal flooding, which, along with flash floods from intense rains, pluvial and fluvial flooding in coastal areas, will exacerbate the overall flooding situation (Chikoro et al., 2021; IPCC, 2021).

Again, if global warming continues unchecked and climate change proceeds at a rapid pace without adequate mitigation, rising temperatures will result in significant future impacts. A faster warming Earth will lead to more frequent occurrences of hot days, heatwaves, and various extreme weather events such as droughts and the floods. Indeed, flooding is anticipated to become both more intense and more frequent, driven by heavier rainfall in shorter periods, sea expansion and rising sea levels rise, which will particularly impact coastal communities (Almoradie et al., 2020; World Bank, 2020; IPCC, 2023).

The global sea levels have been rising at an accelerating rate over the past century. Records show that between 1901 and 1971, the average rate of sea level rise was approximately 1.3mm per year (IPCC, 2021, 2023). This rate increased to about 1.9mm per year between 1971 and further accelerated to 3.7mm per year between 2006 and 2018 (IPCC, 2021, 2023). Projections indicate that, if current trends continue, global mean sea level could rise by up to 1.1 metres by the year 2100 (IPCC, 2021, 2023).

Exposures and vulnerabilities are heavily dependent on increasing populations at the coast. Out of global population which has surpassed 8 billion people, approximately 29% (over 2 billion people) are living within 50km of coastlines, and nearly 1 billion individuals (≈15%) residing within 10km of the shore (Cosby et al., 2024). As population density along coastlines increases, so does exposure and vulnerability to climate-related hazards, particularly the flooding. Coastal communities host about 40% of the global population and a significant portion of global infrastructure and economic activities, making them highly vulnerable to flooding, which can cause extensive damages and displacement.

An estimated one billion people live in coastal areas at the risk of flooding (Climate Central, 2019; Neumann et al., 2015). In Sub-Saharan Africa, including countries like Sudan, around 50 million people reside in low-lying coastal zones that are increasingly threatened by land cover changes, economic hardship, and social vulnerabilities. These conditions heighten susceptibility to coastal hazards and complicate adaptation and disaster risk reduction efforts in the region. This phenomenon is contributing significantly to increased coastal erosion, which poses serious risks to coastal communities and ecosystems (Appeaning Addo, 2020; World Bank, 2020; IPCC, 2021, 2023); UN-Habitat, 2020; Nhantumbo et al., 2023).

Coastal areas are important economic centres because they host more than 80% of the world's merchandise trade by volume. In 2022, more than 900ports in liner shipping networks handled about 171 million Twenty-foot Equivalent Units (TEUs) (Global Port Infrastructure Sufficiency Index, United Nations Conference on Trade and Development, 2023). Fisheries and aquaculture sectors directly employ about 62 million people and support about 600 million livelihoods around the world. More than 80% of these jobs are in small-scale operations (Food and Agriculture Organisation & World Bank, 2024). Ports, roads, rail lines, airports, and industrial facilities are all important for transportation, trade, and connecting cities in coastal areas thus, their exposure to flood will pose a critical challenge (UNCTAD, 2023).

On the ecological front, mangrove forests cover approximately 147,360 km² globally, offering essential services such as carbon sequestration, storm buffering, and habitat provision (UNEP, 2023). Although coastal wetlands have declined by about 22%, losing around 411 million hectares since 1970, they still encompass nearly 1.4 billion hectares and deliver ecosystem services valued at up to US $39 trillion annually (Ramsar, 2025). The convergence of dense human settlements, intense socio-economic activity, and rich ecological systems makes coastal zones both indispensable and highly vulnerable to environmental change; consequently, their degradation increases the surface area exposed to flooding.

Flooding along the coasts is projected to intensify with rising sea levels, ranging from 36mm in 2010 to a projected 345mm by 2080 (Hossen et al., 2019). Floods are also expected to increase due to the rising population densities, growing economic activities, inadequate resilient infrastructure, coastal erosion, and the recession of coastlines, particularly in areas already low relative to sea level (Ansah et al., 2020; Dadson et al., 2016)..

As floods presents its dominance among hydrometeorological hazard, its damages are scary (UNSDR, 2011), and its potential adversities. Floods are projected to affect 200 million people annually, among a broader group of disaster-affected 2.5 billion people, causing approximately 500,000 deaths and losses amounting to about $700 billion (Foresight OST, 2013). Floods are major risks, and from 1970 to 2019, water-related hazards (mainly floods) made up 50% of all disasters (WMO, 2021; UNDRR, 2025; UN-Water, 2021; World Bank, 2023; Akyeampong, 2020).

Again, as flooding remains the most frequent natural disaster worldwide, significant implications for sustainable development, environmental risks, and the potential to devastate critical sectors such as health, human survival, livelihoods, and overall well-being are real (Abass et al., 2022c; Suhr & Steinert, 2022). Coastal flood loss and damage is 1% to 2% of GDP annually, or 2.9% loss in the worst case without adequate adaptation (IPCC AR6 Working Group II, 2022; Kirezci et al., 2023; OECD & IMF climate risk assessments).

Costs of flooding are projected to increase from $1.7 trillion to $3.1 trillion per year by 2050 (World Economic Forum, 2023; UN, 2018; Kumar et al, 2021). Since 2000, flooding has cost US$16 million per hour (Noy & Newman, 2023; UNEP, 2023; Carrington, 2023). Over the past fifty years, large-scale flood disasters, as documented by the World Meteorological Organization (WMO), have resulted in over 2 million deaths and economic losses exceeding $3.64 trillion, with a daily global average of 115 deaths and $202 million in losses (WMO, 2022). In Africa, about 77.3% of all disasters are flood-related, leading to substantial losses in human life and property.

In the context of Africa, studies indicate that while the continent contributes the least to global climate change, it seemingly remains the most adversely impacted continent, especially in sectors such as health, energy, water, agriculture, and food security, due to its low resilience and limited adaptive capacity (Odonkor, 2020; IPCC, 2021). Africa is second only to Asia in terms of the number of flood events, with coastal communities experiencing more severe impacts due to their low resilience (Ansah et al., 2020; Tschaker et al., 2010; Baldassarre et al., 2010).

The extreme climate events, mainly floods, are prevalent in Africa, affecting cities, coastal communities and rural areas. Africa is projected to be the continent with the highest increase in temperature and the most vulnerable to climate hazards, resulting partly from its underlying poverty, political and socio-economic instability, and rapid land degradation, among other things (IPCC, 2022; World Bank, 2021). West Africa is projected to see a significant sea-level rise of about 0.5 meters by 2050, with the potential to reach up to 2 meters more than the 1.1m global average by 2100, if high emission levels continue (IPCC, 2022). This rise will lead to increased coastal flooding and more severe storm surges. The impact will be felt acutely by around 116 million Africans living in low-lying coastal areas, who will face a growing risk of flooding by 2030 (World Bank, 2021). Already, major coastal cities such as Lagos, Abidjan, Accra, and Cape Town are experiencing more frequent and intense flooding and erosion due to the rising sea levels (UNEP, 2022).

The frequency and severity of floods in African will be driven by the climate change but also by factors such as urbanisation, land fragmentation, and the destruction of coastal ecosystems in the continent (Abass et al., 2020; Abass et al., 2022; Walker-Springett et al., 2017; Pabi et al., 2021).

In Ghana, the impacts of climate change, especially in its savanna belt, including northern Ghana, transitional zones, coastal savanna, and coastal communities, have been significant (EPA, 2020, 2016; Pabi et al., 2021). Areas such as the forest zones in the southwest and the savanna areas in the north are especially crucial for agricultural production, as they receive more reliable rainfall and have a longer growing season (EPA, 2020; Zubairu et al., 2020).

Floods in Ghana are expected to worsen due to effects of climate change evident in changes to weather patterns and rainfall, which have led to increased vulnerability, especially in urban areas. Flooding, sea level rise, and coastal erosion in Ghana have led to significant impacts, including the displacement of people, loss of lives (e.g., 150 deaths in Accra in 2015), and damage to property, with losses estimated at over $150 million (Sarkodie et al., 2015; Afornorpe, 2016). The Keta Basin, in particular, has been severely affected by flooding due to its low resilience, despite previous interventions such as relocation and sea defences (Hossen et al., 2019). The Basin's coastline, particularly the Eastern Coast, is the lowest in Ghana and has been further impacted by the development of the Volta Lake and the Akosombo Dam (Codjo et al., 2020; Jonah et al., 2016). Relief provision and broad flood risk management strategies have been the primary focus of Ghana's flood management efforts. Studies reveal that flood management has consumed approximately 85% of the National Disaster Risk Reduction budget (MESTI, 2012).

Recently, flood management efforts have concentrated on three major flood zones: the Greater Accra Metropolitan Area, areas affected by the spillover from the Bagre Dam in Burkina Faso, and the Upper Volta region. However, the Lower Volta River Basin, has received insufficient attention despite increasingly complex sources of flooding. Existing studies on flooding in the near Delta communities have primarily focused on pluvial flooding and inundation caused by rising sea levels. However, multiple forms of flooding are emerging, exposing communities to diverse risks and vulnerabilities. The dynamism of these flood events necessitates more comprehensive study and planning for both short-term and long-term responses. The Lower Volta River Basin flood challenges, would require integrating manifestation of climate change, flood risks, and the management options needed to build sustainable resilience in the region.

1.2 Problem Statement

Climate change has significantly intensified the frequency, severity, and impacts of flooding worldwide. Rising global temperatures accelerate glacial melt and sea-level rise, while shifting precipitation patterns lead to more intense and prolonged rainfall, overwhelming drainage systems and river basins (IPCC, 2023). These hydrological changes create cascading effects on both ecosystems and human settlements, particularly in low-lying coastal regions and floodplains where infrastructure is poorly equipped to manage such extremes (UNEP, 2022). Consequently, climate-induced flooding poses a growing threat to sustainable development and disaster risk management efforts globally.

In Ghana, floods have become increasingly dominant hydro-meteorological hazards (Gbedema et al., 2019; Hossen et al., 2019; Tumawu et al., 2024). Between 1900 and 2021, over 26 major floods were recorded, affecting more than five million people, resulting in 522 deaths and causing property damages exceeding US$622 million (Meyer et al., 2024). In 2023 alone, over 31,000 people were affected by multiple flood events, especially in the Volta River Delta's Keta Lagoon Zone (Tetteh et al., 2024).

The Lower Volta River Basin is particularly vulnerable due to its exposure to the sea-level rise, coastal erosion, and inadequate natural accretion (Appeaning Addo et al., 2019; Brempong et al., 2023). Projections suggest that relative sea-level rise and land subsidence could submerge up to

20% of districts within the Volta River Delta by 2100 (Brempong et al., 2023). Although flooding is a national issue, coastal communities are disproportionately affected (World Bank, 2021; Asante et al., 2024). For example, half of the housing structures along the Keta Coastal Zone have deteriorated due to erosion and flooding, which have intensified since 2000 due to sea-level rise, heavier rainfall, and urban expansion (Adu-Gyamfi, 2021).

Population growth and rapid urbanization have often concentrated in flood-prone areas, exacerbate exposure and vulnerability. Informal settlements lacking proper drainage infrastructure and resilient building standards increase risk (World Bank, 2021). Socio-economic disparities further amplify vulnerabilities, as under-resourced communities have limited capacity for adaptation and recovery. Environmental degradation, such as deforestation and wetland loss, reduces natural flood buffers and worsens disaster risk (IPCC, 2023).

The Lower Volta River Basin, with a population of over 2.4 million as of 2021, has seen expanded settlements into flood-prone zones, leading to reduced drainage capacity and heightened flood vulnerability (Amoako Johnson et al., 2025). Land-use changes, converting wetlands and savannah to cropland and housing have worsened runoff and sedimentation, contributing to downstream flooding (Di Baldassarre et al., 2024; Water Resources Commission, n.d.). Poverty, few job opportunities, and poor coordination between institutions make it even harder to be resilient and respond to disaster (Smits et al., 2024).

Despite ongoing efforts, institutional fragmentation, inadequate early warning systems, poor enforcement of land-use policies, and lack of adequate funding continue to undermine disaster preparedness and resilience in the basin (Mensah & Owusu, 2022; Amoako Johnson et al., 2025). Moreover, climate change, over which Ghana has limited control, complicates national and local mitigation efforts.

While physical drivers of flooding have been widely studied, there is an urgent need to integrate socio-economic dimensions into risk assessments (Apanga et al., 2017; Baidoo, 2018; Oteng-Ababio, 2013). Current frameworks often lack climate projections, hydrological models, and socio-economic vulnerability indicators, which limits the effectiveness of disaster planning.

Studies focusing on flood risk mapping in areas such as Accra, Sunyani, and Sekondi-Takoradi have applied GIS and multi-criteria decision analysis to identify high-risk zones (Nkonu & Antwi, 2024; Tetteh et al., 2024; Danso et al., 2024). However, many of these studies are not participative and often exclude localised, community-based insights.

Furthermore, while studies such as those by Pabi et al. (2021) and Tumawu et al. (2024) have examined urban flood scenarios using modelling, there is limited research on coastal areas like the Volta Delta that integrate social vulnerability with physical risk. Reviews by Mensah and Ahadzi (2020) and Asumadu-Sarkodie et al. (2015) demonstrate the value of integrated flood management approaches involving urban planning, early warning systems, insurance, and ecosystem-based solutions.

Given the growing flood risks, especially in the Keta Lagoon Basin, there is an urgent need for more integrated, context-specific research and policy responses. Effective flood risk reduction and adaptation strategies must incorporate local knowledge, participatory planning, and inclusive decision-making frameworks (UNDRR, 2015; Forino et al., 2015).

This study seeks to address existing gaps by exploring complex, climate-influenced flood risks in the Lower Volta River Basin. It will identify the key drivers of exposure and vulnerability while evaluating evidence-based strategies for risk reduction and adaptation. The goal is to support long-term planning and resilience-building for communities in Ada, Anloga, Keta, and Ketu South through inclusive and integrated risk reduction measures.

There is more consideration for inclusive decision-making, risk knowledge, with hazards, exposure and vulnerability. Inclusive of both physical hazards, treat risk management focusing on local dynamics, qualitative and quantitative insights. Risk reduction that integrate prevention, mitigation, preparedness, response and recovery are major areas of risk reduction in this work.

1.2 Research Questions

The study is seeking to address the following questions:

1) What is the level of climate change and variability in the Lower Volta River Basin?
2) What is the level of flood hazards in the Lower Volta River Basin?
3) What are the available flood risks, including hazards, exposures, and vulnerabilities in the Lower Volta River Basin?
4) What are the flood risk reduction measures in the Lower Volta River Basin
5) What are possible recommendations for flood reduction and management options?

1.3 Aim of the Study

Generally, the study is seeking to assess the level of climate change, flood risks and flood reduction measures in the Lower River Volta Basin.

1.4 Specific Objectives

The specific objective of the study is to:

1) Analyse changes in the climatic conditions, climate variability and extremes in Lower Volta River Basin
2) Assess the level and extent of flood occurrences in the Lower Volta River Basin
3) Map and analyse hazards, exposures and vulnerabilities in the Lower Volta River Basin
4) Analyse the existing flood risk reduction measures in the Lower Volta River Basin

1.5 Propositions to the Study

1) Climate changes and variability vary temporary and spatially and contributing to flooding
2) Communities and areas with high exposures and vulnerability are increasingly and largely affected
3) Flood risk assessment and reduction measures are not adequately available

1.6 Significance of the Study

Recent flood events have underscored the urgency of addressing flood risks in Ghana. A 2015 coastal Accra floods caused extensive urban damage, and in 2017 floods affected approximately one million people in multiple regions (i.e, Greater Accra, Eastern, Central, and Western) in Ghana (Adegoke et al., 2019; IFRC, 2017). In 2023, the spillage from the Volta River/Akosombo hydro-power dam resulted in significant displacement and environmental destruction across the delta region (Gbedema et al., 2019; Abass, 2023). Projections indicate that such events will increase in both frequency and magnitude under future climate scenarios, reinforcing the critical need for robust, forward-looking strategies for managing flood risk (IPCC, 2012; World Bank, 2011).

Despite progress in global flood management through the adoption of technology, integrated planning, and adaptive governance frameworks, Africa, and Ghana in particular, lags behind in developing and implementing comprehensive flood risk strategies. Key constraints include limited use of quantitative modelling tools, weak institutional coordination, and inadequate financial resources (Almoradie et al., 2020). Furthermore, much of the research and intervention efforts have focused on urban centres like Accra, while deltaic and coastal systems such as the Lower Volta Basin remain under-researched, despite their high exposure and vulnerability to multi-dimensional flood risks.

This study is significant in its alignment with global climate adaptation goals and the IPCC's call for context-specific, evidence-based responses to climate hazards. By assessing the impacts of climate change, evaluating flood risks, and identifying risk reduction measures in the Lower Volta River Basin, this research will provide critical insights to inform spatial planning, policy formulation, and investment priorities in flood-prone coastal regions.

The study also aims to advance the scientific understanding of how climate extremes intersect with socio-economic and hydrological dynamics to shape flood vulnerability. It will contribute to the development of tailored flood risk management strategies that respond to local realities, combining technical assessments with community-based knowledge. In doing so, it will support long-term resilience building in one of West Africa's vulnerable coastal systems.

Ultimately, this research will play a vital role in guiding sustainable development and disaster risk reduction in Ghana. Its findings are intended to inform the design and implementation of inclusive, data-driven, and adaptive flood management approaches, ensuring that future interventions are responsive to both current and projected climate challenges.

1.7 Scope and Limitation of the Study

This study focuses on the Lower Volta River Basin, commonly or specifically referred to as the Volta Delta (at the close radius to the estuary), which spans approximately ten (10) Municipalities and Districts across the Volta and Greater Accra Regions of Ghana. Given the extensive spatial coverage and resource constraints, four administrative districts were purposively selected for detailed investigation: Ada East in the Greater Accra Region westward of the Estuary, and Anloga District, Keta Municipality, and Ketu South Municipality in the Volta Region towards east. For the purposes of this research, these administrative units are collectively referred to as "Districts."

The research examines climate change and variability within the Lower Volta Basin, analyzing historical and recent trends to determine patterns of change and variability. It further assesses flood risk in accordance with the Intergovernmental Panel on Climate Change's (IPCC) Fifth and Sixth Assessment Reports, emphasising the three core components of risk: hazard, exposure, and vulnerability. In addition, the study evaluates existing flood risk reduction and management practices within the selected districts, identifying gaps and opportunities for improvement.

The scope of the research is deliberately broad and integrative, encompassing multiple flood typologies (pluvial, fluvial, flash floods, and lagoon flooding) while also considering related coastal hazards, such as sea-level rise and shoreline erosion. This comprehensive approach reflects the complicated relationship among climatic, hydrological, and anthropogenic factors influencing flood risk in the deltaic environment. A mixed-methods design was adopted, enabling triangulation of data sources and perspectives. Both qualitative and quantitative techniques were employed, including household surveys, key informant interviews, and stakeholder consultations at national and local levels. Geographic Information Systems (GIS) and mathematical modelling tools were applied to map flood-prone areas, analyse spatial patterns, and estimate shoreline recession. Institutional and policy reviews complemented primary data collection, ensuring that findings are grounded in both empirical evidence and governance realities.

Despite its comprehensive design, the study encountered several limitations that warrant acknowledgement. First, the spatial coverage was restricted to four districts along a 100-kilometre stretch of the Volta Delta. While this area represents a significant portion of the basin, it does not encompass the entire deltaic system. This limitation was primarily due to time and financial constraints, which precluded a basin-wide assessment. To mitigate this challenge, Eight communities, two from each selected district, were purposively sampled to capture a diverse range of socio-economic and environmental contexts.

Second, the reliance on self-reported data for assessing community knowledge, perceptions of climate hazards, and adaptation strategies introduces potential biases. Respondents may have provided socially desirable answers or overstated their level of preparedness to align with perceived expectations of the researcher. Although triangulation with secondary data and stakeholder interviews helped reduce this bias, it cannot be eliminated. Thirdly, historical data on flood events and risk reduction measures were often incomplete or inaccessible. Institutional records were fragmented, and in some cases, data were not digitised, limiting their ability to conduct long-term trend analyses. This challenge was addressed by supplementing institutional data with remote sensing outputs and GIS-based modelling; however, the absence of comprehensive historical datasets remains a constraint.

Additional limitations include logistical challenges in accessing certain communities due to poor road infrastructure and seasonal flooding, which affected fieldwork timelines. Furthermore, financial constraints limited the deployment of advanced hydrodynamic models and high-resolution satellite imagery, which could have enhanced the precision of flood risk mapping. While these limitations influenced the scope and depth of analysis, they did not undermine the validity of the study's findings. Rather, they highlight critical areas for future research, including basin wide assessments, longitudinal studies on climate variability, and the integration of advanced modelling techniques. Addressing these gaps will more strengthen the evidence base for flood risk management and climate adaptation in Ghana's Volta Delta.

1.8 Organisation of the Study

The thesis was divided into six chapters. Chapter one (1) provides general background for the study within global, continental, and local contexts. This chapter problematises the issue of climate change extremes, coastal flooding and risk management. The chapter also contains the statement of problems, research questions, objectives, significance of the study, limitations of the study and the organisation of the study. Chapter two (2) of the study focused on the theoretical framework, an in-depth literature review on topics such as climate change extremes, coastal flooding and risk management, among others, as well as the theoretical and conceptual frameworks. Chapter three (3) constitutes the profile, methodology, materials and method of the study. Chapter four (4) contained the analysis and results of the study based on the objectives as spelt out in chapter one. Chapter five (5) focused on thematic discussions of the study and discussions of major findings of climate change, flood risks and risk reduction. Chapter six (6), the final chapter, presents the conclusions of the research and the recommendations, references and attachments.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter focused on providing the theoretical and conceptual underpinning of the study, the concepts, principles, practices and experiences of climate change, flood, risks associated with floods, adopted strategies and governance methods for managing flood incidences in the face of climate change along main water basins.

Flood risk and climate adaptation mainly risk reduction measures have become increasingly prominent issues in global environmental discussions, largely because of their deep connections with climate change, social vulnerability, and governance challenges. While a substantial body of research has explored the hydrological and climatic drivers of flooding (Hirabayashi et al., 2013; IPCC, 2023), far less attention has been paid to the social and institutional factors that influence how communities adapt particularly in African contexts.

The Lower Volta River Basin (LVRB) in Ghana offers a compelling example of a complex socio-ecological system. Here, the interplay of rising sea levels, dam operations, urban expansion, and fragile institutions creates a heightened risk of flooding (Tumawu et al, 2024, Brempong et al, 2024, World Bak, 2022). These overlapping pressures not only increase the likelihood of flood events but also weaken the capacity of local communities to respond and recover.

Although climate research in West Africa is expanding, several critical gaps remain. First, much of the existing literature is heavily focused on the physical aspects of flooding such as frequency and intensity while underexploring the socio-political dimensions of vulnerability (Adelekan, 2015). Second, uncertainties in climate models and a lack of adequate high-quality data make it difficult to generate reliable projections, which in turn hampers effective policymaking (Janzen et al, 2022). Third, flood management strategies in the region tend to be reactive, prioritizing emergency relief over long-term prevention and adaptation (Gyimah et al., 2024; Janzen et al, 2022).

This review argues that addressing flood risks in the LVRB requires a shift in perspective: moving beyond traditional hazard-focused approaches toward integrated frameworks that are both socially grounded and spatially informed. Such an approach would blend climate science, geospatial analysis, and community-based governance to build more resilient and adaptive systems.

2.0.1 Concept and Theory of Flood Risk

Systems Theory

The theoretical foundation of the risk is based on a system theory. Systems theory, pioneered by Ludwig von Bertalanffy in the mid-20th century, provides a holistic framework for understanding complex interactions within natural and human systems (von Bertalanffy, 1968). Originally developed as General Systems Theory, it emphasizes that systems consist of interconnected components whose interactions produce emergent properties that cannot be understood by analyzing parts in isolation. This perspective has been widely adopted in environmental science and disaster risk research because flood risk is inherently a product of dynamic interactions between physical hazards, human exposure, and socio-economic vulnerability (IPCC, 2021; UNDRR, 2015).

Flood-prone environments are considered complex adaptive systems, where physical subsystems (hydrology, meteorology), social subsystems (communities, governance), and built infrastructure (levees, bridges, drainage networks) interact continuously (Cutter et al., 2003; Wisner et al., 2004). These interactions generate feedback loops that influence risk trajectories. For example, positive feedback occurs when urbanisation increases impervious surfaces, amplifying runoff and flood hazard, while negative feedback emerges when investments in resilient infrastructure reduce exposure and vulnerability over time (IPCC, 2021).

A key principle of systems theory is emergence, meaning that flood resilience is not merely the sum of individual components but arises from adaptive capacities such as community learning, institutional reforms, and technological innovation (Folke, 2020). This aligns with the Pressure-and-Release (PAR) model, which conceptualises vulnerability as a progression of root causes, dynamic pressures, and unsafe conditions within a socio-ecological system (Wisner et al., 2004).

In practice, systems theory underpins integrated flood risk assessments by linking hazard probability, exposure mapping, and vulnerability analysis into a single framework (UNDRR, 2015; IPCC, 2021). Modern approaches such as the Integrated Risk Linkages (IRL) framework apply hierarchical systems thinking to quantify risk across scales, considering interactions between hazard intensity, susceptibility, and resilience (Zhou et al., 2022). This systemic perspective is essential for designing adaptive strategies under climate change, as it captures non-linear dynamics, thresholds, and cascading impacts that traditional linear models often overlook.

Despite its advantages, applying systems theory to flood risk poses challenges, including data complexity, computational demands, and the need for interdisciplinary governance (Cutter et al., 2003; UNDRR, 2015). Nevertheless, its holistic approach remains critical for understanding and managing flood risk in an era of accelerating climate variability and socio-economic change.

According to Solin and Skubinčan (2013), as early as the 1970s, issues of natural occurrences such as earthquakes, volcanic eruptions, drought, and floods, among others, gained more attraction as they strongly emerged due to their negative disastrous effects. The cause of these phenomena is natural and anthropogenic, and the impacts are due to system exposures and vulnerability, for which Wisner (2004) and Werrity (2006) informed that in studying the risks and disasters, there is the need to understand well the hazards and vulnerability.

Flood risk research spans various disciplines, including hydrology, sociology, economics, geography, and environmental science (Solin and Skubinčan, 2013). Each discipline examines flood risk assessment from its unique perspective, leading to differences in terminology, assessment methods, and management strategies (Solin and Skubinčan, 2013). This multidisciplinary approach highlights the complexity and variability in understanding and addressing flood risk (Merz et al, 2010; Møller-Jensen et al, 2023; Riedel et al, 2024).

'Risk' can have different meanings depending on the context (Field, 2021). In one sense, it can be interpreted as a hazard or a danger (Møller-Jensen et al, 2023). In another context, risk refers to the probability of suffering adverse consequences or encountering some form of loss (Ramiaramanana and Teller, 2022). Consequently, "flood risk" may refer to the existence of a flooding threat, a flood hazard or the likelihood of a flood occurrence (Ramiaramanana and Teller, 2022).

The IPCC Assessment Report Sixth (AR6) in 2022 and 2023 defines risk as the possibility of negative effects on human or ecological systems, taking into account the different values and goals that come with these systems. Adverse consequences include previous, current and potential impacts on lives, livelihoods, health, well-being, economic, social, and cultural assets, infrastructure, services, ecosystems, and species (Field et al, 2021). The definition acknowledges that risks can arise from both the potential impacts of climate change and human responses to it (IPCC, 2022). The growing visibility of current climate impacts has led to a stronger focus on managing these risks across different time scales (Rogelj et al, 2021). This discussion includes the rapid growth in attributing specific extreme weather events to climate change, the use of scientific evidence in legal cases, and discussions on resilience-building and early warning systems (IPCC, 2022, IPCC, 2023). Moreover, the scale of these risks is influenced by the responses to climate change, which can reduce risks or inadvertently create new ones (Rogelj et al, 2021). The global perspective is enriched with case studies, illustrating how risks aggregate at local or national scales and addressing distributional aspects (O'Neill et al, 2022, IPCC, 2023)

In the perspective of risks related to the IPCC (2022) informed that key risks are identified as potentially severe and particularly relevant to the interpretation of 'dangerous anthropogenic'. interference with the climate system as outlined in UNFCCC Article 2 (Stabilisation of the Carbon Emissions).

The UNFCCC corresponding Paris Agreement goals (2015-2030) aim to hold the global average temperature increase to well below 2°C above pre-industrial levels, with efforts to limit the increase to 1.5°C (Paris Agreement, 2015), and it is important that:

- Understanding risks at higher levels of warming helps prepare for scenarios where efforts to limit warming might not succeed; recognising the benefits of limiting warming to lower levels (IPCC, 2023).

- There are ongoing discussions about whether the warming limits should be set at or below 2°C, with a particular focus on the 1.5°C target (IPCC, 2023).

- This includes acknowledging that key risks can also arise from changes in exposure, vulnerability, and a lack of ambitious adaptation efforts (IPCC, 2023).

The IPCC also outlined key risk areas, including those of low-lying coastal socio-ecological systems, terrestrial and ocean ecosystems, critical physical infrastructure and networks, living standards (economic impacts, poverty, inequality), human health, food security, water security and peace and human mobility, while presenting that compound risks are associated with compound hazards, which occur when multiple hazards interact to produce a more severe impact (Field, 2014; IPCC, 2014; IPCC, 202). This concept is explored in the Working Group I AR6 report, highlighting concerns such as the erosion of vulnerability, transboundary effects, and implications for climate-resilient development (IPCC, 2023). The representative key risks are mapped to the Sustainable Development Goals (SDGs), and the updated assessment of Reasons for Concern (RFC) emphasizes critical areas including unique and threatened systems, extreme events, and aggregate impacts, ultimately underscoring the risk of irreversible and abrupt transitions (IPCC, 2022).

According to Solin and Skubinčan (2013), risks are approached through single-dimension and multidimensional concepts, which quantify flood risk as the probability of exceeding a specified annual maximum discharge, often used in designing safety standards for engineering structures. In contrast, they indicated a multidimensional concept which considered not only the probability of flood events but also their potential consequences on human health, economy, environment, and cultural heritage, providing a more comprehensive approach to flood risk assessment (Solin and Skubinčan, 2013). By the multi-dimensional definition of risks, the term 'risk' is the expected loss (of lives, persons injured, property damaged, and economic activity disrupted) due to a particular hazard for a given area and reference period (UN, 1992).

In formalising the risks:

1. ***Risk = Hazard* × *Vulnerability*** (UN 1992, UNDP 2004, Birkmann 2006; UN DRR, 2017)
2. ***Risk = Probability* × *Negative Consequences*** (Meyer et al. 2007; Xu et al, 2024)
3. ***Risk = F (Hazard, Vulnerability, Deficiencies in Preparedness)*** (Villagrán de León (2004; UN DRR Africa, 2020)
4. ***Risk = F (Hazard, Exposure, Vulnerability, Capacity and Measures)*** (Bollin et al. (2003; Informatics Methodology, 2018)
5. ***Risk = F (Hazard, Vulnerability, Exposure)*** (Hori et al., 2002; ADRC, 2005; UN-SPIDER, 2020)

The number (**v**) corresponds with the IPCC Report 5th and 6th Risk Formulas, and the report extensively highlights risk assessment rather than vulnerability assessment (IPCC, 2013). The IPCC indicated that $Risk = Hazards + Exposure + Vulnerability$ (IPCC, 2007; IPCC, 2013). IPCC, 2022). By diagrammatic consideration of the IPCC Report 5th and 6th the IPCC demonstrated risk as follow:

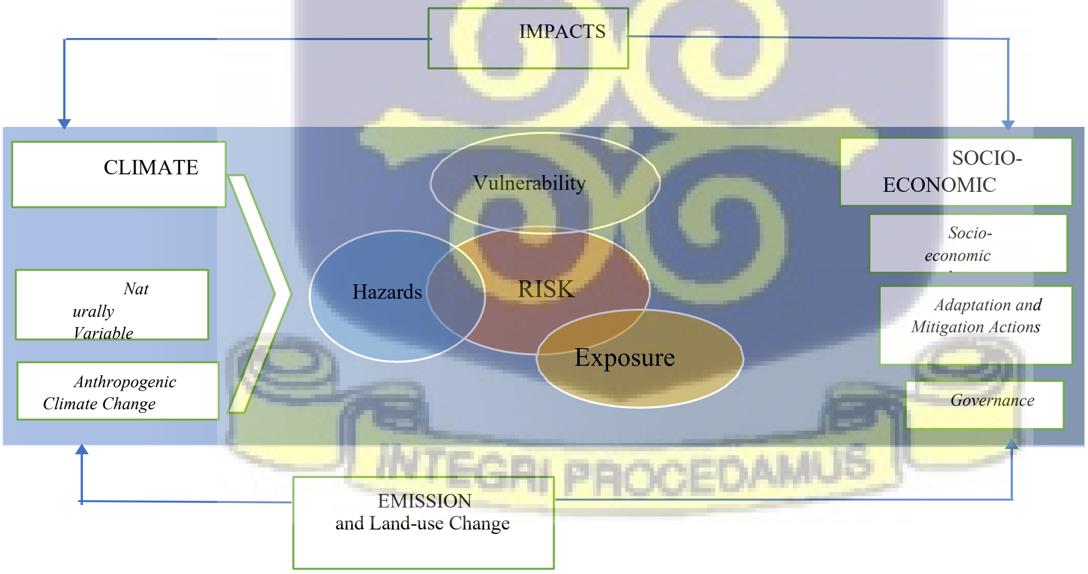


Figure 2.1: Risk Framework, IPCC Adapted from IPCC, 2021

Hazards refer to the natural processes or phenomena that can cause harm, such as floods. Floods are primarily caused by excessive rainfall, river overflow, storm surges, or the breaching of dams and levees (Wisner, 2004). These events vary in intensity, duration, and frequency, resulting in different types of floods, such as riverine floods, coastal floods, flash floods, and estuarine floods. Each type of flood poses unique challenges and requires specific management strategies (Seneviratne et al, 2021).

The World Bank (2022) indicated that hazards can be long-term, including rising sea levels, temperature increases, and land use changes. Short-term pressures include floods, droughts, and infrastructure failures. Drivers or driving forces include climate change and population growth (Turner et al, 2003).

Exposure refers to the presence of people, property, systems, or other elements in hazard-prone areas (Field, 2021). It encompasses the number and types of assets located in these areas and their value or importance to society. In the context of flood risk, exposure includes the population living in floodplains, infrastructure such as roads and bridges, agricultural lands, and critical facilities like hospitals and schools (Birkmann 2006; Meyer et al. 2007)

Vulnerability is referred to as follows:

"The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity." (IPCC, 2001)

Vulnerability is the propensity or predisposition of elements exposed to hazards to suffer adverse effects. It is influenced by various factors, including socioeconomic conditions, infrastructure quality, environmental conditions, and governance. Thus, vulnerability determines the extent to which a community or system can cope with, resist, and recover from the impacts of hazards.

"Inherent characteristics of a system that create the potential for harm but are independent of the probabilistic of event risk of any particular hazard or extreme event" (Sarawitz et al. 2003)

"The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard." (UN-Sendai Framework DRR, 2015)

Similarly, the World Bank (2022) explained same context that vulnerability as susceptibility of Exposure to hazards or threats, regardless of their origin, can damage a system or object. The Bank argued that coastal systems are most suitable for vulnerabilities analysis due to their comprehensive interactions and inclusive nature. The World Bank defines objects of vulnerability as individuals, communities, societies, ecosystems, and socioeconomic systems (Gallopin, 2006). Vulnerability analysis focuses on two main objects, including the threats likely to cause damage and the systems defined as the entities that can suffer damage (World Bank (2022).

Cited in the World Bank Report and various literature, especially in the IPCC Report 4th, 2013, vulnerability-embedded hazards, exposure, sensitivity, and adaptive capacity have also been considered as resilience (World Bank, 2022). The hazards and exposures mentioned earlier are consistent with the context here. Sensitivity indicates the impact of a phenomenon on a system, depending on two system characteristics. This attribute includes resistance, the ability to maintain structure and functionality, and secondly, absorption, the degree to which a system can return to its normal state (Tumawu et al., 2024).

Adaptive capacity refers to a system's ability to change and adapt to impacts, allowing it to return to a satisfactory state (Cardona, 2003; Oppenheimer, 2021; World Bank, 2022). Resilience is defined as the ability of a system to return to its full functional state after a disturbance. It combines resistance and adaptive capacity (World Bank, 2022).

The IPCC defines vulnerability as the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change. It is composed of susceptibility, resistance, and resilience, which together determine a system's vulnerability. Susceptibility is the passive part of vulnerability that makes a system more vulnerable. Resistance and resilience are the active parts that make a system less vulnerable. Understanding these components is crucial in managing natural disasters and promoting sustainable development (Field, 2021; IPCC, 2022).

Convergence between Risks and Vulnerability:

The literature is clear on the difference between risk and vulnerability. While some authors still argued that the two are not the same, others continue to narrow the difference (Frazier et al. (2014) argued that risk is related to vulnerability but not synonymous with it, arguing that vulnerability depends on exposure (E), sensitivity (S), and adaptive capacity (AC), while risk subsumes vulnerability in addition to hazards and exposures (IPCC, 2014):

$\boldsymbol{V} = \boldsymbol{f}(\boldsymbol{E}, \boldsymbol{S}, \boldsymbol{AC})$ (Solin and Skubinčan, 2013; Bollin et al., 2003)

The risk is defined as follows: R = Risk, H = Hazard, E = Exposure, and V = Vulnerability (IPCC, 2022; Solin and Skubinčan, 2013).

$\boldsymbol{V} = \boldsymbol{f}(\boldsymbol{H}, \boldsymbol{E}, \boldsymbol{V})$ (IPCC, 2022; Solin and Skubinčan, 2013)

The concept of vulnerability and risk has evolved, with the Intergovernmental Panel on Climate

Change (IPCC) providing working definitions in its Fourth and Fifth Assessment Reports (AR4 and AR5). While the terminology used in the two reports differs, the underlying assumptions and logic are similar. Both reports emphasise the importance of considering internal and external elements when assessing vulnerability and risk (Adger et al, 2007; Wong, 2024).

Based on the Intergovernmental Panel on Climate Change (IPCC) definition of vulnerability in the Fourth Assessment Report (AR4) as 'the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change, including climate variability and extremes' (IPCC, 2007; Hess et al., 2023; Sun et al, 2023), the term 'vulnerability' is used to refer to the vulnerable system itself (e.g., low-lying islands or coastal cities) and the impact to this system (e.g., flooding of coastal cities and agricultural lands) (Parry et al, 2007). Again, according

to IPCC AR4, vulnerability is a function of three factors which are exposure, sensitivity, and adaptive capacity (Hahn et al, 2009; Parry et al, 2007; Brimicombe et al., 2023) Exposure in AR4 is the magnitude and duration of the climate-related stress, such as a drought or change in precipitation, whereas sensitivity is the degree to which the system is affected by the climate-related stress or extreme events. Adaptive capacity in AR4 refers to the system's ability to withstand or recover from the extreme events/damage (Hahn et al, 2009; Fritzsche et al, 2014; Parry et al, 2007; Ebi et al, 2006). It has to be noted that the adaptive capacity of a system determines the vulnerability by modulating exposure and sensitivity (Adger et al, 2007; Brimicombe et al., 2023).

Furthermore, the Fifth Assessment Report of the IPCC (AR5) introduces a new approach and terminology. This approach is similar to the concept of disaster risk, which differs from the current understanding of vulnerability as mentioned in the IPCC AR4 (Fritzsche et al, 2014). IPCC AR5 defines risk as "the potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values." It is often represented as the probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur' (IPCC, 2014; Sun et al., 2023).

The term 'risk' is used primarily to refer to the risks of climate-change impacts (Oppenheimer et al, 2014). Also, the concept of vulnerability juxtaposed with exposure conveys commonality but is used differently in IPCC AR4 and AR5. Exposure is 'the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected', and vulnerability is 'the propensity or predisposition to be adversely affected' (IPCC, 2007; Sun et al., 2023).

As mentioned earlier, the key difference is that vulnerability in AR5 includes the concepts of sensitivity (susceptibility to harm) and adaptive capacity. When vulnerability is compared to Hazards in a related context, it is considered a new term in AR5 and defined as 'the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources' (IPCC, 2007).

Meanwhile, the IPCC's Assessment Report Fourth (AR4) and Assessment Report Fifth (AR5) reports converge on the idea that vulnerability and risk include both internal and external components.

The internal component comprises moderating attributes such as socioeconomic, physical, or environmental factors, while the external component represents climate-related stress or hazards. This convergence is evident in the reports' emphasis on the interplay between exposure, sensitivity, and adaptive capacity in determining vulnerability and risk (Das et al, 2020) (Figure 2.0.1).

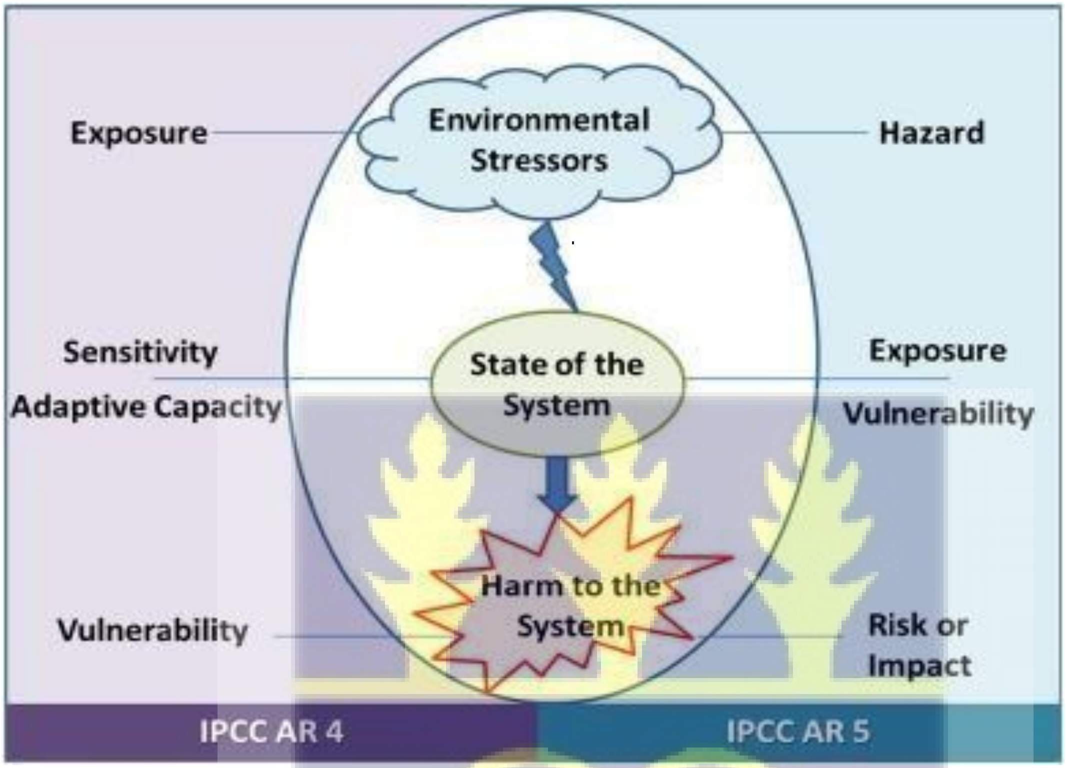


Figure 2.2 Convergence between Vulnerability and Risk Source: Das et al, 2020

2.1 Theoretical Perspectives of Climate Change

2.1.1 Overview of climate change (focus on emission trends & physical dimensions)

Over the last million years, the Earth's climate system has evolved with clear evidence from natural sources and presents the perspective of the observed changes and projected changes for the subsequent centuries (Masson-Delmotte et al, 2021; IPCC, 2021). The varied level of reconstructions of the climate of the past correspondingly indicates a correlation between carbon concentration and surface temperatures as gathered by multiple models over multiple time scales. The level of changes in the global atmospheric climate which were not experienced in the last one million years are now copiously experienced since the industrial revolution as per the current emission pathways (Allen et al, 2019; IPCC, 2023).

2.1.1.1 Physical Science and Long-Term Projection of Climate Change

2.1.1.2 Definition and Cause or Sources of Climate Change

There is growing global consensus that climate change is not only real but primarily driven by human activity, despite ongoing public and political debates in some regions. The definition of climate change varies depending on institutional context. The Intergovernmental Panel on Climate Change (IPCC) adopts a broad interpretation, describing it as any change in climate over time, whether due to natural variability or human activity (IPCC, 2001b). In contrast, the United Nations Framework Convention on Climate Change (UNFCCC) defines it more narrowly as a change in climate specifically attributable to human activities that alter the atmospheric composition (UNFCCC, 1992). The IPCC's inclusive definition is more widely adopted in contemporary research because it reflects the complexity of climate systems and the interplay between natural variability and anthropogenic influence.

Yet, the overwhelming body of scientific evidence increasingly supports the argument that recent and projected climate change is overwhelmingly anthropogenic in origin. While natural climate variability has always influenced Earth's systems, the rate, scale, and pattern of warming since the Industrial Revolution cannot be explained by natural processes alone (IPCC, 2023; National Academy of Sciences, 2020). Historical data derived from thermometer records, tide gauges, and proxy sources such as ice cores and ocean sediments demonstrate that current warming trends far exceed those observed over millennia of natural fluctuations (Houghton, 2004; Leob et al., 2021).

2.1.1.2.1 Human-Influenced (Anthropogenic) and Natural Causality of Climate Change

The scientific community has established clear evidence that human activities are now the dominant force driving climate change, particularly through the emission of greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (IPCC, 2023; Hansen, 2004). These emissions result largely from fossil fuel combustion, deforestation, industrial processes, and land-use change. The hypothesis of anthropogenic warming, once speculative in the mid-20th century, is now an empirically validated reality supported by decades of research (Stocker et al., 2013; IPCC, 2014).

Since the 1970s, climate science has advanced from theoretical modelling to concrete attribution studies, identifying human fingerprints on climate change with increasing certainty (Karger et al., 2017). Anthropogenic aerosols, land-use change, and the release of non-CO_2 GHGs were all recognised by the 1970s as significant contributors (Lynas et al., 2021). Importantly, global temperatures have already risen by approximately 1.2°C since pre-industrial times, with an average increase of 0.18°C per decade since 1981 (NOAA, 2024; Global Carbon Project, 2023). These changes are neither random nor cyclical, but rather tightly correlated with the steep increase in anthropogenic GHG emissions. The chemical mechanisms are well-documented. For instance, the combustion of fossil fuels produces carbon dioxide:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$

Similarly, microbial processes in landfills and agriculture generate methane:

$CH_3COOH \rightarrow CH_4 + CO_2$ (Solomon et al., 2007; IPCC, 2013)

These gases trap heat in the Earth's lower atmosphere, altering the radiative balance and intensifying the greenhouse effect without which the Earth’s average temperature would be -18°C rather than the current average of ~15°C (Le Treut, 2007; Leob et al., 2021).

While natural forces such as solar variability, orbital cycles, volcanic activity, and oceanic oscillations (e.g., El Niño and La Niña) continue to influence short-term climate fluctuations, they cannot account for the scale and consistency of current warming trends (Crowley, 2000; National Climatic Data Centre, 2002; Barnes & Hartmann, 2013). For instance, if solar output were the primary driver, warming would occur uniformly across all layers of the atmosphere. However, observational data reveal a warming of the lower atmosphere and surface, alongside cooling in the upper atmosphere, a pattern consistent only with greenhouse gas forcing (NASA, 2010; Storelvmo et al., 2016).

Additionally, the disruption of atmospheric processes due to increased aerosol concentrations has secondary effects (Fang et al, 2023; Huynh &McNeill, 2024):

- Stratospheric cooling, altering jet streams and monsoon patterns (Solomon et al., 2007)
- Ozone depletion, increasing UV radiation exposure (WMO, 2018)
- Shifts in atmospheric circulation, resulting in more extreme weather events such as heatwaves and torrential rainfall (Barnes & Hartmann, 2013; Shepherd, 2014)

While natural phenomena are part of Earth’s climate system, they do not adequately explain the magnitude, pace, and global synchrony of recent climate change. Human influence is no longer a hypothesis it is a scientifically validated fact. Denying or downplaying this reality delays urgently needed adaptation and mitigation strategies, particularly in vulnerable regions like West Africa.

2.2 The Climate Change Pathways and Projections

Understanding the future trajectory of climate change is essential for policy, planning, and adaptation, particularly in vulnerable regions. The Intergovernmental Panel on Climate Change (IPCC) established in 1988 as the world's leading scientific body on climate change conducts comprehensive assessments approximately every seven years. These assessments not only review the current state of climate science but also provide short-, medium-, and long-term projections of greenhouse gas (GHG) emissions and global temperature increases (IPCC, 2021).

In earlier reports, the IPCC developed Representative Concentration Pathways (RCPs) as a framework for modelling future climate scenarios. The Fifth Assessment Report (AR5) originally included four pathways (RCP2.6, RCP4.5, RCP6.0, and RCP8.5), later expanded with RCP1.9, RCP3.4, and RCP7. These scenarios represented different levels of radiative forcing essentially, the heat retained in the Earth's system due to GHGs by the year 2100 (IPCC, 2014; IPCC, 2023).

The Sixth Assessment Report (AR6) introduced an improved, more integrated approach known as the Shared Socioeconomic Pathways (SSPs). These pathways offer narrative-based and data-driven projections of potential global development trajectories through to 2100, reflecting how different levels of social, economic, and technological change could influence emissions and climate outcomes (IPCC, 2021; 2023). SSPs provide a critical framework for understanding the intersection between development choices and climate impacts.

2.2.1 The Five SSP Scenarios: Development and Climate Outcomes

Each SSP scenario outlines a different socioeconomic future, paired with varying emissions trajectories and climate outcomes:

SSP1 – Sustainability ("Taking the Green Road"): This scenario envisions a shift toward sustainable practices, social equity, and strong environmental policy. CO_2 emissions are cut to net-zero by ~2050, with projected warming of 1.0–1.8°C by 2100 (IPCC, 2021; 2023). It represents the most optimistic pathway, aligned with the Paris Agreement's 1.5°C target.

SSP2 – Middle of the Road: This pathway assumes a continuation of existing trends. CO_2 reaches net-zero by ~2075, with warming estimates between 1.3–2.4°C by 2100. It reflects a world with modest mitigation and adaptation efforts.

SSP3 – Regional Rivalry ("A Rocky Road"): A fragmented world with limited international cooperation and rising nationalism. Emissions stay high until mid-century and decline slowly, but net-zero is not achieved. Warming ranges from 2.4–3.6°C, posing significant risks for ecosystems and societies.

SSP4 – Inequality ("A Road Divided"): Marked by rising disparities between and within nations, this scenario features high emissions, particularly from industrialised countries. CO_2 emissions could double by 2100, with warming between 2.8–4.6°C (IPCC, 2023), disproportionately impacting the world's poorest.

SSP5 – Fossil-Fuelled Development ("Taking the Highway"): This high-growth, high-emissions pathway prioritises economic expansion over environmental sustainability. Emissions triple by 2075, with projected warming of 3.3–5.7°C, posing catastrophic risks to global stability, biodiversity, and food security.

Despite the wide range of possible futures, the SSP framework underscores a central argument: our choices today will shape the climate of tomorrow. The Paris Agreement (2015), under the UNFCCC, set a global goal to limit warming to 1.5°C above pre-industrial levels. Many Least

Developed Countries (LDCs) and Small Island Developing States (SIDS), fearing existential threats from sea-level rise and extreme weather, have committed to low-emission pathways aimed at achieving net-zero by 2050 (Rosentreter & Mundin, 2024). However, the burden of emission reductions falls heavily on developed countries, many of which face political and economic resistance to drastic cuts, especially within energy-intensive sectors (Stiell, 2024). This raises questions of climate justice, equity, and responsibility, particularly as developing nations bear the brunt of climate impacts despite contributing the least to historical emissions.

Recent trends in GHG emissions remain deeply concerning. Since 1750, atmospheric CO_2 levels have increased by about 48%, while methane (CH_4) concentrations have surged by 160% (Luomi et al., 2021). The current concentration of CO_2 is higher than at any point in the last two million years, signaling a radical shift in Earth's atmospheric composition (Manabe, 2019; Arias et al., 2021).

Moreover, fossil fuel use, deforestation, and agricultural expansion continue to increase, accelerating emissions (Luomi et al., 2021). Compounding this issue, carbon sinks, such as forests and oceans are expected to lose capacity to absorb CO_2 in the latter half of the 21st century (IPCC, 2022; 2023). This could lead to positive feedback loops, such as:

Increased CH_4 release from thawing permafrost,

Wildfires reducing forest cover,

Land-use changes destroying natural carbon sinks (Boa et al., 2014; UN FAO, 2016).

These feedback could result in self-reinforcing climate change, pushing the Earth system closer to dangerous tipping points. Some arguments challenge the permanence of climate warming trends, pointing to short-term cooling effects caused by volcanic eruptions, which can release aerosols that temporarily reduce solar radiation (National Research Council, 2012). However, while these natural events can influence climate variability, they are episodic and do not account for long-term trends. The sustained rise in global temperatures is not consistent with patterns expected from natural forces alone.

2.3 Temperature and Precipitation Manifestation and Trends

The impacts of climate change are most visibly and measurably manifested through changes in temperature and precipitation patterns, which significantly influence ecosystems, water resources, and human livelihoods. As climate science has advanced, so too have the tools for detecting and projecting these trends. Modern climate models, built on decades of atmospheric, oceanic, and biogeochemical data, now offer increasingly precise representations of the physical and chemical processes governing Earth's climate (Jakob et al., 2023).

2.3.1 Temperature Trends: Historical and Contemporary Insights

Reconstructing Earth's temperature history through ice cores, tree rings, and sediment records reveals that long before modern human civilisation, the planet experienced higher temperatures and abrupt shifts, including events like the Palaeocene-Eocene Thermal Maximum (~55 million years ago) (Kaufman et al., 2020). However, during the Anthropocene the epoch defined by significant human influence on Earth's systems, temperature variability has narrowed, with observable trends toward rapid warming since the onset of the Industrial Revolution (IPCC, 2021). From the 18th century to the 1970s, global temperatures rose slowly due to a balancing effect between warming from greenhouse gas emissions and cooling from sulphur dioxide aerosols (Lindsey & Dahlman, 2023). However, post-1970s, this balance shifted, and global warming has since accelerated. Nearly all regions have experienced rising temperatures, with an increase in record high temperatures far exceeding new record lows (USGCRP, 2017; IPCC, 2021).

Between 2013 and 2022, global average temperatures were approximately 1.15°C above pre-industrial levels, rising at an average rate of 0.2°C per decade (Allen et al., 2018). Notably, while year-to-year variability influenced by internal climate dynamics such as the Pacific Decadal Oscillation (PDO) and Atlantic Multi-Decadal Oscillation (AMO) may lead to temporary slowdowns (e.g., the 1998–2013 "global warming hiatus"), the long-term trend remains unequivocally upward (Foster et al., 2023; McGrath, 2014).

The year 2023 recorded some of the highest monthly global temperatures ever, marking a sharp reversal from earlier slowdowns (Seip et al., 2023; WMO, 2024). Projections show this trend will likely continue, driven by amplified Arctic warming, thermodynamic changes, increased atmospheric water vapour, and evaporative demand, all contributing to altered spatial and seasonal temperature distributions (Fu & Feng, 2014; Pithan & Mauritsen, 2014; IPCC, 2023).

According to CMIP6 model projections, future warming will depend on GHG emission scenarios:

- 1.0–1.8°C increase under low emissions,
- 2.1–3.5°C under intermediate emissions,
- 3.3–5.7°C under high emissions by 2100 (IPCC, 2023).

There is also a 48% chance that global temperatures could exceed 1.5°C above pre-industrial levels in at least one year between 2022–2026 (WMO, 2023).

2.3.2 Precipitation Trends: Intensity, Frequency, and Extremes

Climate change is not only warming the planet but also significantly altering precipitation patterns. While precipitation varies regionally, its intensity and frequency are closely tied to temperature increases, which enhance the water-holding capacity of the atmosphere via the Clausius–Clapeyron relationship (IPCC, 2023). The general rule is for every 1°C of warming, atmospheric water vapour increases by 7%, which can lead to more extreme rainfall events (Shepherd, 2014).

However, real-world manifestations of this relationship are more complex. Regional weather regimes, land-ocean temperature contrasts, and changes in vertical and horizontal temperature distributions affect how water vapour is transported and released (Byrne & O'Gorman, 2018). These thermodynamic factors influence the frequency and strength of synoptic weather systems, including tropical cyclones, extratropical cyclones, mesoscale convective systems, and thunderstorms (Sun et al., 2021; Fischer & Knutti, 2016).

Multiple studies show that precipitation extremes are intensifying, with climate models projecting increases of 4–8% in extreme rainfall per 1°C of warming (Pfahl et al., 2017; Trenberth et al., 2015). This intensification is driven by:

Extra latent heat from increased moisture in the atmosphere (Willison et al., 2013),
Warmer ocean temperatures, leading to heavier rainfall and snowstorms (Molnar et al., 2015),
Moisture convergence over land, amplifying localised flooding. Despite uncertainties in regional projections due to dynamic atmospheric interactions, the overarching trend is clear: climate change is making precipitation more extreme.

2.3.3 Regional Projections and Impacts

According to the IPCC (2021): Heavy precipitation and flooding will become more frequent and intense in Africa, Asia, North America, and Europe. Agricultural and ecological droughts will also worsen in most inhabited continents except parts of Asia (IPCC, 2022).

In West Africa, while rainfall has generally increased since the 1980s due to GHG-driven monsoon strengthening, some models project sharp reductions in rainfall under 4°C warming scenarios (Akinsanola & Zhou, 2019; Han et al., 2019). Moreover, consecutive dry days and drought risk increase under higher warming scenarios, further threatening agriculture and water security (Klutse et al., 2018). Human influence has already altered global precipitation patterns, particularly since the mid-20th century. For example: Decreases in monsoon rainfall between the 1950s–1980s were partly driven by aerosols from the Northern Hemisphere, Subsequent increases are largely attributed to GHG forcing and natural variability (Kossin et al., 2020; Knutson et al., 2019).

By 2081–2100, under various emission scenarios, global land precipitation is projected to increase by:

- 0–5% under very low emissions,
- 1.5–8% under intermediate emissions,
- 1–13% under very high emissions (IPCC, 2023).

2.3.4 Uneven Distribution and Future Uncertainty

Projections indicate increased precipitation in high latitudes, the equatorial Pacific, and parts of the monsoon regions, but declines in some subtropical and tropical areas (Nevermann et al., 2023). Meanwhile, the intensity of both wet and dry extremes is expected to increase, depending on regional atmospheric circulation changes, including monsoons and mid-latitude storm tracks.

It is also very likely that rainfall variability associated with the El Niño–Southern Oscillation (ENSO) will be amplified by the second half of the 21st century (Li et al., 2022). Monsoon rainfall is projected to increase in regions like South and Southeast Asia, East Asia, and West Africa excluding the far western Sahel (Siabi et al., 2023). Overall, future trends point to a dual threat: more frequent and severe flooding in some regions, and heightened drought risk in others, particularly those distant from storm tracks (Wang et al., 2017; Stocker et al., 2013).

2.3 Ghana's Climate Change Trend

Ghana's tropical climate is significantly shaped by the West African monsoon system, with local variations influenced by topography and regional geography (Wurtemberger et al., 2011). Rainfall patterns vary widely, from approximately 1,100 mm annually in the north to around 2,100 mm in the southwest (Wurtemberger et al., 2011; EPA, 2020). The north experiences a single rainy season (May–September), while the south has a bimodal rainfall regime (April–July and September–November). A pronounced dry season (December–March), marked by the harmattan winds from the Sahara, brings low humidity, daytime temperatures above 25°C, and cooler nights below 20°C (EPA, 2020; Aidoo et al., 2021). Average annual temperatures hover around 27°C, with higher extremes in northern Ghana, where dry-season temperatures range between 32–38°C (EPA, 2016; World Bank, 2021). The forest–savanna transition zone in central Ghana remains a critical agricultural belt, benefitting from relatively consistent rainfall and an extended growing season (USAID, 2017; MESTI, 2021).

2.3.1 Observed and Projected Temperature Trends

Ghana is warming and doing so at an accelerating rate. Between 1960 and the present, the mean annual temperature has increased by 1.0°C (Klutse et al., 2021). Observational data show that:

The number of hot days per year has increased by 13.2%, hot nights have risen by 20%, cold days and nights have declined by 3.3% and 5.1% respectively (EPA, 2016; Klutse et al., 2021).

These trends are projected to intensify by 2050, with mean temperatures to rise by 1.0°C to 3.0°C, and by 2100, they may rise by 2.3°C to 5.3°C, with northern Ghana warming faster than coastal regions (EPA, 2020; MESTI, 2021). Such warming threatens water security, food systems, and human health, especially in climate-sensitive sectors like agriculture and livestock, which are vital in the north.

2.4.2 Rainfall Trends and Variability

Rainfall in Ghana has become increasingly erratic, volatile, and spatially unpredictable. Although total annual rainfall shows no consistent long-term trend, the intensity and variability of rainfall have increased significantly (Klutse et al., 2021; Tueber et al., 2023). From 2005 to 2010, the onset and cessation of rains varied by up to a full year, affecting planting cycles and agricultural productivity (EPA, 2020).

While heavy rainfall events have increased in some regions, other areas are experiencing decreases, complicating water resource management and increasing both flood and drought risks. Climate projections further suggest that monsoon rainfall in West Africa may continue to rise, although some coastal and Sahelian areas may become hotter and drier, especially under higher emissions scenarios (Akinsanola & Zhou, 2019; IPCC, 2023).

2.3.3 Sectoral Emissions and Energy Trends

Despite its relatively small global carbon footprint, Ghana’s greenhouse gas (GHG) emissions are rising rapidly. The AFOLU sector (Agriculture, Forestry, and Other Land Use) is the largest emitter, accounting for 54.4% of national emissions in 2016, followed by energy (35.6%) and waste (7.5%) (EPA, 2016; MESTI, 2021). Notably:

- CO_2 emissions from energy-related fuel combustion reached 21.4 million tonnes, a 332% increase in per capita emissions since 2000 (EPA, 2020).
- The transportation sector alone contributed 47% of these emissions, followed by electricity and heat production (34%).
- The burning of oil remains the leading source of CO_2 emissions in Ghana, accounting for 66% of all energy-related emissions (MESTI, 2021).

This trend raises concerns about Ghana's trajectory under the Paris Agreement, given its growing dependence on fossil fuels. There is an urgent need to transition to cleaner energy sources, improve efficiency in transport and electricity generation, and enforce mitigation policies.

2.3.4 Gas Flaring and Industrial Contributions

Ghana's aspiration to become a major oil-producing country sparked by the Jubilee offshore field, which came online in 2010 has generated significant emissions through gas flaring, which is conducted due to the lack of sufficient storage and processing infrastructure. Current flaring practices at Jubilee alone emit approximately 1.5 million tonnes of CO_2 annually, representing 7% of Ghana's total emissions (MESTI, 2021; EPA, 2020).

Without accelerated investment in infrastructure, Ghana risks locking itself into a high-emission development pathway, which would be incompatible with global low-carbon goals and increase its vulnerability to climate-related shocks.

2.3.5 Sea Level Rise, Land Cover, and Long-Term Climate Risks

Ghana's coastal regions, already densely populated and economically critical, face an escalating threat from sea level rise and coastal erosion. Data from the past three decades show an average sea-level rise of 2.1 mm/year, with projections estimating increases of:

- 5.8cm by 2020,
- 16.5 cm by 2050,
- 34.5 cm by 2080 (EPA, 2020; MESTI, 2021).

In parallel, climate classification models predict a shift in some southern and coastal zones from tropical savanna to arid steppe climates by 2100, reflecting a potential climatic transformation with major implications for agriculture, water supply, and biodiversity (USDA Forest Service, 2011).

The construction of Volta Lake, the world's largest artificial lake by surface area, has also altered local microclimates, though long-term rainfall trends remain difficult to project with high certainty. Nevertheless, rising sea surface temperatures and increasingly erratic rainfall are consistent with broader climate models and regional projections.

2.4.1 Climate Change and Flooding

The recent years have warmed faster than expected and the future is projected to increase with impacts to trigger tipping points, including melting of remaining sheet, sea level rise and inundation of countries and communities close to the sea or not significantly above sea level. Droughts and storms emergence with higher wind and rainfall intensity are here already (Hossen et al, 202

2.5 Flooding

Flooding is one of the most visible and destructive manifestations of climate change. As global temperatures continue to rise, so too does the frequency, intensity, and complexity of flood events.

Recent studies argue that beyond traditional assessments of flood frequency and magnitude, it is now vital to consider the underlying causes, seasonality, and compound conditions triggering floods especially in the context of global warming (Turkington et al., 2016; Gain et al., 2013).

Climate projections indicate that factors such as heavier precipitation, accelerated snowmelt, and extreme weather events will continue to shift the characteristics and timing of flood events. These changes make it increasingly necessary to move beyond simplistic flood classifications and toward a more nuanced, process-based understanding of flood types, particularly as they intersect with socio-economic vulnerabilities and ecological impacts (Garner et al., 2015).

2.5.1 Classifying Floods: Methods and Approaches

Floods can be classified using multiple frameworks. Each classification method provides a different lens through which to understand flood risks, and their relevance depends on the research objective whether understanding local events, assessing climate-driven changes, or informing disaster preparedness strategies.

By Flood Description (Event Type)

This method categorizes floods based on their observable characteristics (Nied et al., 2014; NASA, 2021):

- **Flash floods:** Sudden, high-intensity flooding due to short-duration, heavy rainfall or dam failure.
- **Riverine floods:** Resulting from overflow of riverbanks due to prolonged rainfall or snowmelt.
- **Coastal floods:** Triggered by storm surges, high tides, or tsunamis.
- **Pluvial floods:** Caused by intense rainfall overwhelming drainage in urban areas.

By Meteorological Drivers (Atmospheric Circulation Patterns)

This approach relates flood occurrence to large-scale weather systems:

- **Cyclonic floods:** Linked to low-pressure systems, such as hurricanes or tropical storms.
- **Frontal floods:** Associated with cold or warm fronts.
- **Monsoonal floods:** Tied to seasonal monsoon rains (Nied et al., 2014; Delgado et al., 2014).

By Causal Mechanisms (Hydrological Classification)

Floods are grouped based on the hydrological or physical processes that initiate them (Merz & Blöschl, 2008):

- **Fluvial floods:** In rivers and streams.
- **Pluvial floods:** Surface water floods from rainfall.
- **Rain-on-snow floods:** When rainfall coincides with melting snow.
- **Snowmelt floods:** Seasonal floods caused by thawing snowpack.

Merz and Blöschl (2003) proposed five flood categories based on process-based observation:

Flash floods:

- Short-duration rain floods
- Long-duration rain floods
- Rain-on-snow floods
- Snowmelt floods

Nied et al. (2014) extended this by incorporating antecedent soil moisture and atmospheric circulation patterns, emphasizing the importance of pre-existing environmental conditions in flood generation.

2.5.2 Limitations of Flood Classification Methods

Each classification method has strengths and limitations. Studying single flood events can yield detailed insights (e.g., the 1993 Mississippi flood or 2013 Danube flood), but limits generalisability due to inconsistent data across regions (Blöschl et al., 2013; Dube et al., 2014). Classifying floods by atmospheric conditions helps to link floods to climate change, but this method struggles with small sample sizes, especially at local scales, where flood events are rare relative to the number of non-flood days (Nied et al., 2014; Prudhomme & Genevier, 2011).

To address these challenges, researchers are increasingly combining meteorological, hydrological, and land surface data. This includes the use of antecedent conditions (e.g., soil saturation, snowpack depth) and hydrological models that simulate river flow and flooding under varying inputs (Turkington, 2016). This integrated approach provides a more holistic understanding of flood dynamics, especially as they evolve under a changing climate.

2.5.3 Compound and Coastal Flooding in a Warming Climate

One of the most pressing concerns under climate change is the increase in compound flooding, where multiple drivers (e.g., rainfall + sea-level rise) converge to exacerbate flood impacts. This is particularly relevant in coastal regions, where rising sea levels, storm surges, and riverine overflow can coincide, leading to devastating consequences (NASA, 2021; IPCC, 2023).

Sea level rise, once a slow, geological process, has accelerated significantly in the 20th and 21st centuries, now estimated at 1.2 to 1.7 mm per year and increasing (Griggs, 2021). Projections suggest that sea levels could rise by 34.5 cm by 2080, threatening low-lying coastal cities, deltas, and island nations even if the Paris Agreement's 2°C target is met (IPCC, 2023; Nicholls & Cazenave, 2010).

This risk is further intensified by climate change-driven alterations to:

- Wind patterns
- Wave energy
- Storm frequency and intensity

These factors contribute to more severe coastal erosion and inundation, with effects that vary regionally and seasonally (Allan & Komar, 2006; Barnard et al., 2015; Cooper et al., 2020).

2.5.4 Towards a Climate-Informed Flood Classification Framework

For researchers and policymakers to effectively manage future flood risks, flood classification systems must evolve to incorporate:

- Triggering processes (rainfall, snowmelt, tide, land-use changes)
- Pre-flood conditions (soil moisture, basin saturation)
- Climatic drivers (ENSO, monsoons, Arctic amplification)
- Compound events (e.g., coastal + pluvial + fluvial)

Turkington (2016) argues that the most appropriate method for studying climate change impacts on flooding is classifying floods by their generating mechanisms, as this approach provides a clearer link to how floods may evolve under future climate scenarios. Moreover, such classification should be region-specific, incorporating local geomorphology, climate systems, and hydrological responses.

2.6 Flood Occurrence records in Ghana

Over the past thirty years, there have been more than 2,000 significant disaster occurrences on the

African continent, most of which were a result of extreme weather and climatic factors affecting the sea (Almoradie et al 2020). Ghana's coastline experiences a presence of warm, tropical air, and with an increasing temperature it can lead to a rise in sea levels, which poses a challenge in preventing the ocean from encroaching further inland. For instance, the convergence of the Volta River and the Atlantic Ocean in Ada Foah is marked by a forceful collision of white waves, and the Fuveme fishing community located near the Keta Lagoon in the Gulf of Guinea, was deserted after the sea engulfed it in 2016 (Amuzu and Donkor, 2022).

In Ghana, erosion and flooding caused the loss of almost 37% of the coastal area between 2005 and 2017 (Evers et al, 2021), resulting in about 3,000 people displaced in the Keta Municipal District alone. Ghana has seen catastrophic floods throughout the years with massive storm surges inundating numerous communities in 2021 forcing many people to flee such locations (Evers et al, 2021). There is no particular temporal interval during which floods are more likely to happen, however, floods occur when it rains (Agyemang, 2013). Tidal surges, rapid runoff, heavy rainfall, and dam bursts are some of the causes of the flood disaster in Ghana.

Flooding is a widespread natural disaster that impacts people worldwide. Over the last thirty years, the current condition of flooding reflects the global situation in the frequency of climate and weather-related disasters which has risen by around 35 per cent, and within the last ten years, a staggering 83 per cent of all disasters were a direct result of severe weather and climate-related incidents, which tragically claimed the lives of 410,000 individuals and had a profound impact on the lives of 1.7 billion people (Amponsah et al, 2022).

In recent days in Ghana, the Lower Volta area of Ghana saw unprecedented flooding because of recent intense rainfall. The flooding was a result of an intentional discharge of water from the

Akosombo Dam, which is the largest hydroelectric dam in the country. More than 26,000 individuals were forced to leave their homes. One month following the commencement of the spillage, the surplus water had a significant impact on the settlements situated along the Volta River.

The consequences of this disaster culminated in displacement of local inhabitants, loss of properties, inundation of farmlands, and agricultural produce (Evers et al, 2021). Meanwhile, other areas such as the Ashanti and Western Regions have suffered severe inundation occurred following intense rainfall leading to significant obstruction of roads and considerable disruption of traffic in Greater Accra, and Ga South Municipality specifically (Hossen et al, 2020). Approximately 50 residences in the Ahanta West Municipal District of the Western Region recorded damages due to flooding, while the overflow of the Bonsa River in the Tarkwa-Nsuaem Municipality, Subri River in Daboase, Atafoa, Sepaase, and Tafo also resulted in enormous difficulties for the local inhabitants as they lost food produce, material items, and loss of lives (Amuzu and Donkor, 2022).

2.6 Climate Exchange, Exposure and Vulnerability

The world's coastal regions, which are vulnerable to the effects of erosion, floods, inundation, and seawater intrusion processes, are experiencing both direct and indirect effects of climate change, with devastating repercussions for the natural and socioeconomic resources, (Neumann et al., 2015; Nicholls et al., 2021; Ranasinghe, 2016). Extreme rainfall and weather events, increase in evaporation, the melting of glaciers, and a rise in sea levels are circumstances for flooding incidents.

The challenges associated with coastal flooding influence the accessibility of potable water, decline in water quality, the potential contamination of surface water by untreated sewage carried by storm water, rise in sea level poses a particularly substantial danger to densely populated coastal regions, with the likelihood of floods and erosion along coastal regions, leading to substantial repercussions for the inhabitants, infrastructure, companies, and ecosystems in these places. Climate change impacts exacerbate existing difficulties and increase the risks faced by cultural heritage sites (Alexandrakis et al., 2019).

Sea levels experienced a gradual increase throughout the 20th century, and this trend has intensified in recent years. The projection is that the rise in sea level will diminish the quantity of accessible freshwater, as the intrusion of seawater extends deeper into subterranean aquifers or saltwater intrusion into freshwater bodies, harming agricultural and drinking water supplies, impact on biodiversity in coastal ecosystems, as well as the natural services and goods they supply (Camuffo, 2019).

Coastal systems are distinct habitats, teeming with a wide array of organisms, which exemplify the immense variety found in the central mainland. They serve as habitats for numerous species that live on land and in the surrounding waterways, making them crucial ecosystems for supporting life and maintaining ecological equilibrium (Yang, 2014). Coastal locations see regular fluctuations in temperature, precipitation, water levels, salinity, air currents, and other factors, more often than inland places. This makes studying them challenging, emphasizing the importance of their conservation (Krishnan et al., 2020).

The Large scale Integrated Sea-level and Coastal Assessment Tool (LISCoAsT) developed by the Joint Research Centre of the European Commission, has revealed that a significant portion of the world's sandy coastline is currently experiencing erosion. Furthermore, if no measures are taken to reduce greenhouse gas emissions, nearly half of the world's sandy beaches could be at risk of disappearing by the end of the century. The results of these researches align with prior assessments that have examined the global historical changes in shorelines (Luijendijk et al., 2018; Mentaschi et al., 2018), as well as the identification of locations that are susceptible to flooding.

2.8 Coastal Flooding and Erosion Challenges

Flooding is undeniably the most frequently occurring type of natural disaster. These natural disasters encompass floods that impact over 2.5 billion individuals, resulting in around 500,000 fatalities and an estimated economic loss of US$700 billion (Foresight OST, 2013; World Meteorological Organization, 2023). According to Askew (1999) and cited in Swiss Re Institute. (2023) floods account for approximately one-third of all fatalities, a third of all injuries, and one-third of all damages resulting from natural disasters especially in the coastal communities with high exposures. Also, according to UN-HABITAT (2010), floods are responsible for 50% of the world's disasters and account for 84% of all deaths connected to disasters.

Statistically, the year 2021 was the second-highest recorded floods globally, and in the last thirty years, 2006 stands out as the year with the highest number of recorded flood disasters, totalling 226 (UN-HABITAT, 2010). Consequently, countries with low-income levels in Africa, Asia, such as Bangladesh, Vietnam, and Myanmar, are particularly vulnerable to floods on a global scale. Between 1900 and 2006, floods in African cities resulted in the deaths of around 20,000 individuals and impacted around 40 million people. According to Mulungeta et al. (2007), the estimated cost of the damage was around $4 billion, making floods rank among the most catastrophic natural calamities in Africa. Coastal flood losses account for approximately 1% to 2% of global GDP annually, rising to 2.9% in worst-case scenarios without adequate adaptation (IPCC AR6 Working Group II, 2022; Kirezci et al., 2023; OECD & IMF climate risk assessments). Projected costs are expected to escalate from US$1.7 trillion to US$3.1 trillion per year by 2050 (World Economic Forum, 2023; UN, 2018; Kumar et al., 2021). Since 2000, flooding has incurred an average global cost of US$16 million per hour (Noy & Newman, 2023; UNEP, 2023; Carrington, 2023). Over the past five decades, large-scale flood disasters have resulted in more than 2 million deaths and economic losses exceeding US$3.64 trillion, with a daily global average of 115 deaths and US$202 million in losses (WMO, 2022). In Africa, approximately 77.3% of all disasters are flood-related, causing significant human and economic losses.

The fluctuations in sea levels have impacted human activity in coastal regions, elevating the sea level and causing low-lying wetlands and dry land to become submerged. Which results is the gradual wearing of shorelines, occurrence of flooding in coastal areas, and the influx of salt water into estuaries and surrounding underground water sources. It has been determined that, coastal flood risk increase much faster than previously thought (*Climatechangepost.Com*, n.d.). Out of a total of 10,320 natural disasters that took place globally during the past 30 years (1990–2020), approximately 42% were floods (Institute for Economics and Peace (IEP), (2021).

Coastal floods are amongst the most dangerous natural hazards globally (Haigh et al., 2022). Coastal floods occur due to high total water levels, which result from a combination of factors including relative mean sea level, astronomical tides storm surges and waves, especially setup and run-up particularly the buildup and movement of water towards the shore. These parameters undergo topographic amplification at proximity to the coast, and there are non-linear interactions among the four components. The impact of rainfall and fluvial intake can have a considerable effect on certain estuaries, depending on their size, river flow patterns, and the time it takes for water to travel through them (Harrison et al., 2022; Hendry et al., 2019).

High tide levels are caused by the gravitational impacts of the sun and moon, resulting in elevated sea levels. There is a regular pattern of high and low tides that occurs around twice a day. Additionally, there is a cycle called the spring-neap tide cycle, during which there are extra high and low tides. A surge refers to a rise in sea level beyond the normal tidal level, typically induced by low air pressure. This rise can be further intensified by the wind's effect on the water. Wave action is influenced by factors such as wind speed and direction, local topography, and exposure.

Recent data from the Human Climate Horizons platform, a joint effort by the Climate Impact Lab and UNDP, reveals that the rise in coastal flooding in the coming century will expose more than 70 million individuals to the risk of growing floodplains. Latin America and the Caribbean, East Asia and the Pacific, and Small Island Developing States (SIDS) are expected to experience substantial land loss and damage to essential infrastructure due to chronic flooding (UN, 2023). A significant number of wetlands are at risk of being destroyed, which poses a threat to distinct avian and botanical species, as well as eliminating the inherent Defence mechanism these regions offer against storm surges (UN, 2023).

Flooding can happen when there is an excess of water coming from bodies of water like rivers, lakes, or oceans or it can also happen because of an accumulation of rainwater on soaked land which is termed as geographic flood, and when the amount of water flowing surpasses the river channel's ability (UN, 2023).

Coastal erosion and flooding negatively affects human well-being, economic activities, existing infrastructure and ecosystem services associated with fragile environments. Coastal erosion causes coastline retreat, lowers beaches, threatens homes, roads and activities, strong impact on agriculture, tourism and fisheries sectors as well as increases the risk of flooding (Songsore et al., 2011).Additionally, the most frequent consequences of floods include water point pollution, the outbreak of epidemics, mosquito invasions (rise in waterborne and vector-borne diseases), destruction of infrastructure and cessation of activities, harm to residences and commercial properties located in the natural floodplains of rivers (Duy et al., 2018).

While not all floods cause human damage, the destruction of property causes long-term vulnerability and also affects livelihoods, scientific publications show that all West African countries, from Mauritania to Nigeria, are affected by coastal erosion and/or flooding, at varying levels of severity. Some areas experience a more rapid coastal retreat or suffer more frequent and violent flooding than other areas (Songsore et al., 2011). However, on a regional scale it is the entire West African coastline that should be considered at risk, as coastal areas dominate in the challenges for regional development. The population growth rate of major coastal West African cities is over 4 per cent, and home to a third of the region's population.

The West African coast is also home to large port complexes, strategic places for trade and commerce, and concentrates high productivity activities where more than half of the regional Gross Domestic Product (GDP) is produced (ref). With climate change, West African coastal areas will be more exposed to erosion and flooding in the coming decades, while projections confirm the concentration of the region's demographic and economic growth on the coastal strip, in the immediate vicinity of the ocean, increasing coastal risks (Rodrigues et al, 2022). Climate change will change the patterns of flooding worldwide, impacting ecosystems (Booij, 2005; Gain et al., 2013; Raff et al., 2009).

Resolving coastal flooding and erosion have received a number of proposals. For instance, individuals can prevent damage from river floods by relocating from river banks….. the effort to overcome the consequences of flooding might result in the incidence of maladaptation. Biodiversity and ecosystem resilience to climate change are decreased by maladaptive actions, which also constrain ecosystem services in flooding areas. Examples of these maladaptive actions for ecosystems include fire suppression in naturally fire-adapted ecosystems or hard Defence s against flooding. In Africa, 72% of the people are urban inhabitants and reside in slums or other vulnerable situations, making them more susceptible to flooding and related water disasters (UNDP, 2007).

The escalating devastation of properties and lives caused by floods and the resulting expenses have necessitated the implementation of appropriate adaptation techniques. Unfortunately, not even governments, development partners, NGOs, private organisations, and civil society groups have been very successful in their attempts to make slums and other vulnerable areas less likely to flood disasters in more than 100 communities in Africa (Mulungeta et al., 2007).

According to Nicholls et al. (2007), the tendency for flooding in coastal cities is projected to persist for centuries. This trend has the potential to exacerbate the risks of flooding, as stated by Kebede et al. (2012). The impact of beach morphology will be affected by the existing topography (Jevrejeva et al., 2012). To this end, strategies must be devised to adapt and protect the coastal environment and investments due to the threats posed by sea-level rise, erosion, and floods. The coastal zone is a centre for social and economic activities, and it houses more than half of the world's population (Woodroffe 2003).

Approximately 40% of the population in West Africa resides in central towns, and this number is projected to reach around 50 million by 2020 (Boko et al., 2007). Therefore, the occurrence of disasters related to coastal erosion in coastal towns will have a considerable impact on the economies of coastal nations and influence coastal ecosystems, disruption of the water supply for human and agricultural use through pollution in coastal aquifers, among others.

2.8.1 Sea Level Rise

The rise in sea level caused by climate change, as documented by Rahmstorf et al., (2001), has emerged as a significant obstacle to the sustainable management of coastal areas worldwide. According to the Intergovernmental Panel on Climate Change (IPCC) in 2007, the average worldwide sea level increased by around 1.8 mm per year between 1961 and 2003 and by about 3.1 mm per year between 1993 and 2003. The increase in sea level is primarily attributed to the elevation in global temperature linked to climate change. Accelerated sea-level rise causes a change in the shape and structure of coastal landforms, as observed through the redistribution of these landforms (Crooks, 2004).

Rising sea levels cause an increase in water depth near the beach, leading to stronger waves and tidal movements as energy is absorbed along the coast. Coastal landforms react to the hydrodynamics by moving both perpendicular and parallel to the coast to stay in their location within the energy gradient and try to regain their balance. Sea-level rise will affect coastal towns differently, depending on the local geology and geomorphology that are in place as well as the efficiency of forces like tides and waves that cause erosion. Global development 700,000 individuals in Nigeria are expected to be relocated due to a sea-level rise of 0.2 metres. Similarly, a sea-level rise of 0.4 in the Bay of Bengal would result in around 11% of Bangladesh's coastline land being submerged (Jay et al., 2023; Arias et al., 2021; IPCC, 2021; Crimmins et al., 2023; Easterling et al., 2023)

Flooding belies the issues of sea level rise and according to Nicholls et al. (2007), the tendency for flooding in coastal cities is projected to persist for centuries. This trend has the potential to exacerbate the risks of flooding, as stated by Kebede et al. (2012). The impact of beach morphology will be affected by the existing topography (Jevrejeva et al., 2012). The concern arises primarily from the belief that the hydrological cycle is speeding up and that there will be a worldwide increase in the intensity of rainfall (Huong et al., 2013b) While other components of climate can influence the incidence of floods, research has pinpointed precipitation and temperature as the primary risk factors (IPCC, (2007). An increase in the Earth's average air temperature is predicted to lead to more powerful rainfall since a warmer atmosphere can contain more water (Trenberth, 2011). The escalating strength and length of rainfall caused by global warming could result in higher surface run-off and more frequent occurrences of floods (Seneviratne et al., 2012).

The monsoon season in Bangladesh has been highlighted as the main cause of floods, with very heavy precipitation being a significant factor (Mirza, 2003). Moreover, the 2011 Thailand floods have been associated with climate conditions, as stated by Gale et al. (2013). However, according to Campion & Venzke (2013a) and Douglas et al. (2008), urban floods are not primarily caused by extreme weather events like excessive rainfall but are mostly connected to changes in urban development. The July 2007 floods in West Africa have been characterised as the most devastating in the past thirty years (Owusu-Ansah, 2016). A total of 210 fatalities were documented, and around 785,000 individuals were impacted in different ways. According to Owusu-Ansah (2016), Nigeria, Ghana, Burkina Faso, and Togo were identified as the nations that experienced the most impact.

Observed and projected impacts and risks associated with climate-related hazards, exposure, and vulnerability have expanded. These impacts are now being attributed to climate change, while also identifying key risks. Climate impacts and risks, in terms of their adverse effects and losses, encompass both economic and non-economic aspects. The risks that arise from identifying vulnerabilities and responses to the impacts of climate change are intended to undertake projections and outline risks for different time frames such as the near-term (2021–2040), the mid-term (2041–2060), and the long-term (2081–2100) – considering various global warming scenarios (Jay et al., 2023; Arias et al., 2021; IPCC, 2021; Crimmins et al., 2023; Easterling et al., 2023). Projections take into account trajectories that exceed the 1.5°C global warming threshold over extended periods, which considers the complexity of risks increase due to the simultaneous occurrence of multiple climate hazards and the interaction of different risk factors ((Jay et al., 2023; Arias et al., 2021; IPCC, 2021).

Coastal cities will be submerged; food production risks will rise, possibly increasing the rate of malnutrition; many arid regions will become drier and wetter; heat waves never before seen in many areas, particularly in the tropics; water scarcity will be significantly worsened in many areas; high-intensity tropical cyclones will occur more frequently; and irreversible biodiversity loss, including coral reef systems, will occur. Manifestation of immediate past, current and projected changes are rapid, seemingly intensifying, unprecedented and threatening. Further warming is scientifically to cause more irreversible adverse effects, such as sea level rise and subsequent risks and illumining disasters, if adequate efforts are not put in place for mitigation and adaptation (Jay et al., 2023; Arias et al., 2021; IPCC, 2021; Crimmins et al., 2023; Easterling et al., 2023).

Also, urbanization is recognized as a significant catalyst for floods due to the alterations in land use and land cover that accompany it (Sciences & 2010, 2010). Urbanization is the conversion of natural landscapes into developed areas and the transformation of once porous and cultivable surfaces into concrete surfaces. According to Barasa et al., (2018), this lowers infiltration and raises run-off rates, which are major causes of floods. Climate change has been recognized as a significant factor in the global discussion on flood hazards (Milly et al., 2008). The heightened vulnerability of urban floods is closely linked to local alterations in hydrological and hydrometeorological conditions that enhance the risk of flooding, as well as the concentration of urban areas (Huong et al., 2013a).

The global urban population has experienced a significant increase, rising from 751 million in 1950 to 4.2 billion in 2018 (United Nations, 2018). The current global population residing in urban areas stands at 55%, and it is estimated to increase to 68% by the year 2050, according to the United Nations Department of Economic and Social Affairs/Population Division (United Nations, 2018). Urban growth and other activities related to the construction of the physical environment can heighten the likelihood of flooding in cities. The ocean performs important role in climate activity and impacts regarding GHGs, warming and temperature issues (IPCC, 2021).

According to IPCC AR6, under a low warming scenario, the quantity of ocean heat intake (396 ZJ) observed between 1971 and 2018 will probably double by 2100, and under a high warming scenario, it will grow by 4 to 8 times, with a corresponding rise in sea level. Under the most optimistic scenario for greenhouse gas emissions, the oceans are "locked in" to ongoing warming for at least a century, and for a low warming scenario, the quantity of ocean heat intake (396 ZJ) observed between 1971 and 2018 will probably double by 2100, compared to and a high warming scenario, which will grow by 4 to 8 times, with a corresponding rise in sea level. A number of tools are available to assess salinity and temperature for the ocean (IPCC, 2021; Crimmins et al., 2023; Easterling et al., 2023).

For example, in situ observation systems have been used to assess the salinities and temperatures of the ocean, and these systems range from autonomous profiling floats to ship-based bottle and Conductivity Temperature Depth (CTD) observations. The ethos of these assessment models or measurement coverage has always been limited below 2000m, this contribution has been estimated using the methodology from Zanna et al. (2019). Even in the case of the lowest greenhouse gas emissions, the oceans are "locked in" to sustained warming for a century or longer (Jay et al., 2023; Arias et al., 2021; IPCC, 2021; Crimmins et al., 2023; Easterling et al., 2023).

Several empirical studies conducted in Ghana have established a partial correlation between the issue of urban floods and climate change (Addo & Adeyemi, 2013). However, the continued presence and expansion of the flood into regions that were previously unaffected by floods may raise questions about the influence of climate change.

Although certain prior research has questioned the relationship between climate change and urban flood dynamics in Ghana (Campion & Venzke, 2013b; Owusu-Ansah, 2016) these studies have not thoroughly examined rainfall data on a daily and monthly basis. Nevertheless, these analyses are crucial for showing a strong correlation between climate and the occurrence of floods. Climate change can result in significant precipitation within a relatively short timeframe, leading to the possibility of flooding (Campion & Venzke, 2013b; Owusu-Ansah, 2016).

Various coastal habitats encounter distinct threats due to their specific geology, topography, regional climate conditions, and patterns of development. Coastal areas exhibit a diverse range of terrain formations, such as estuaries, beaches, dunes, low bluffs, high cliffs, and steep mountains. They also demonstrate varying levels of development, ranging from low to high population density. Because of wave action, storms, and big storm waves that coincide with extremely high tides and rise with future sea levels, lower-lying shoreline locations are more susceptible to flooding (Amoako, 2016; Tumawu et al, 2024).

Coastal areas that are located at higher elevations, such as bluffs, cliffs, and coastal mountains, are more susceptible to erosion caused by waves during high tides or when sea levels are rising. However, future sea level rise will result in (1) more frequent and elevated flooding of low-relief shoreline areas, which will be followed by permanent inundation and the loss of beaches and coastal wetlands (Beach & 2005, 2005a); and (2) more frequent wave impact and reach of the base of coastal cliffs, bluffs, and dunes, which will accelerate erosion rates. The economic consequences of coastal risks will also differ depending on the extent and nature of development, as well as whether it is publicly or privately owned. Passive erosion, which refers to the progressive reduction of beaches due to ongoing sea-level rise in areas where the back beach is protected by a barrier, rock revetment, or similar construction, will provide a significant issue in heavily populated and fortified coastal regions (beach & 2005, 2005b; Vitousek et al., 2017).

2.9 Flood Adaptations, Risk Reduction and Management

Addressing Climate change, adequate efforts are required for mitigation and adaptation in addressing flood risks and vulnerability issues of coastal areas. Collectively, countries have committed under the Montreal Protocol, United Nations Framework Conventions on Climate Change (UNFCCC) and its strategies in Kyoto Protocol, Biodiversity and Desertification and now the Paris Agreement to take action (UNFCCC, 2020, IPCC, 2021; IPCC, 2022). Others including commitments under the Disaster Risk Reduction with the Hyogo Protocol, Sendai Framework on Disaster Risk Reduction, Regional Agenda, and National Action Plans are set to genre efforts to address climate change. Another important action is to demystify the existing situation and strategies in managing floods, specifically on flood risks would remain a key driver. The climate action focuses on scientific and other knowledge on climate change, climatic conditions drivers for managing flood risks, coastal flooding and risk governance, adaptation and maladaptation that align to the contemporary needs of the addressing flood risks (UNFCCC, 2020; IPCC, 2021).

2.10 Contemporary Flood management framework

This is a broader concept of flood risk management, which is the process of monitoring, reviewing, communicating, and consulting on flood-related issues in a country as it helps in decision-making (Xu et al, 2021). It provides guidelines and approaches for flood assessment, analysis, evaluation, and implementation of flood risk management. There are several risk techniques and tools used in flood assessment. Researchers, governmental agencies, and international donor organizations come together to create the frameworks (Afornorpe, 2016). Although they differ slightly in their focus and application (Xu et al, 2021), most of the frameworks seem to have been primarily intended to evaluate the resilience of industrialized countries. Nevertheless, assessment frameworks created by professionals from outside the area might not be able to adequately address the extent to which local communities in developing nations can adapt to and withstand the impacts of floods in their respective contexts (Amoako et al, 2016).

Additionally, the frameworks are categorized into four main formats: index, scorecard, model, and toolkit. Indexes are the sum of scores from all indicators in the measurement framework used, with a heavy reliance on quantitative data to get an index value. The value can be a singular value derived from the aggregation of all indicators utilized in the assessment instrument. Choice of strategies must be devised to adapt and protect the coastal environment and investments from threats posed by sea-level rise, erosion, and floods. This is important because the coastal zone is a centre for social and economic activities, and it houses more than half of the world's population

(Woodroffe 2003).

Approximately 40% of the population in West Africa resides in central towns, and this number is projected to reach around 50 million by 2020 (Boko et al., 2007). Therefore, the occurrence of disasters relating to coastal erosion in coastal towns will have a considerable impact on the economies of coastal nations and influence coastal ecosystems. In addition, they will disrupt the water supply for both human consumption and agricultural use by causing pollution in coastal aquifers. The places most susceptible to harm inside the coastal zone include the low-lying coastal towns, coastal Defence buildings, and coastal infrastructure.

Flood management (or flood risk management) is a broader term that includes mitigating and preparing for flooding disasters and providing risk analysis, for example, through the practice of flood risk assessment (Raadgever et al, 2021). In the context of natural hazards, risk management involves "plans, actions, strategies, or policies to reduce the likelihood and/or magnitude of adverse potential consequences, based on assessed or perceived risks (IPCC, 2022). Flood risk management (FRM) has been widely used in the past decade. Conceptual acceptance has frequently led to modifications in decision-making procedures emphasizing risk management as potentially more intricate, yet more efficient and effective in achieving numerous objectives compared to a conventional engineering standards-based approach (Paul Sayers et al., 2013).

Flood risk management encompasses many objectives that pertain to different temporal and spatial scales. Attaining these goals depends on the creation and execution of suitable portfolios. In the process of measurement, one advantage can offset the disadvantages of another, but this is made more complex by the dynamic nature of the flooding system, which is influenced by climate, geomorphology, and socio-economic factors (Paul Sayers et al., 2013; Mehrafarin et al., 2023).

Embracing the uncertainty of the future influences the process of formulating plans and executing decisions.

Flood risk management involves a constant process of adaptation that is different from the traditional strategy of implementing and maintaining flood defences (Paul Sayers et al., 2013; Easterling et al., 2023; Ebbwater Consulting Inc., 2023).

Adopting a broader perspective that considers the entire system over a longer time requires greater effort from both those affected by flooding and those responsible for reducing its impact. It requires cooperative efforts among governments, the public sector, corporations, voluntary organizations, and individuals. This highlights the growing need to effectively communicate the remaining hazards and the necessary steps to be taken. These attributes constitute the fundamental elements of effective Flood Risk Management (FRM) and embody an approach that aims to accommodate water while also promoting the suitable economic utilization of the floodplain (Paul Sayers et al., 2013). Before delving into the specific characteristics of contemporary Flood Risk Management, there are crucial concepts that provide the foundation for comprehending risk. It also elucidates how these concepts are utilized to guide the decision-making process and context of FRM. Risk is a crucial term that has various elements, some of which are subtle and require careful understanding (Paul Sayers et al., 2013).

2.11 Flood Risk Assessment Framework

Extensively Outline the definition, forms of flood risk management framework and those existing in Ghana and gaps. Identify various authors and how they explained variables for the Risk Management (Adelekan and Asiyanbi, 2022).

2.11.1 Flood Risks in Perspective

As indicated earlier, flood risk is a combination of the probability (likelihood or chance) of an event happening and the consequences (impact) if it occurs and more extended, the hazards, exposures and vulnerabilities. There must be a source of flooding, such as a river, a pathway for the flood water to follow, and a recipient of the flood, such as a housing estate. Without a pathway linking the source to the receptor, a flood may be a hazard, but not a risk. This concept is known as the source-pathway-receptor model (Easterling et al., 2023 Amuzu and Donkor, 2022; Sarhadi & Soulis, 2022; Tingsanchali & Karim, 2022).

2.11.2 Climate vulnerability

Vulnerability significantly determines how climate change impacts are being experienced by societies and communities. Vulnerability to climate change is a multi-dimensional, dynamic phenomenon shaped by intersecting historical and contemporary political, economic and cultural processes of marginalization (high confidence). Societies with high levels of inequity are less resilient to climate change (high confidence). About 3.3 billion people are living in countries with high human vulnerability to climate change (high confidence), and approximately 1.8 billion people reside in regions classified as having low vulnerability (Almoradie et al, 2020).

Global concentrations of high vulnerability are emerging in transboundary areas encompassing more than one country as a result of interlinked issues concerning health, poverty, migration, conflict, gender inequality, inequity, education, high debt, weak institutions, lack of governance capacities and infrastructure. Complex human vulnerability patterns are shaped by past developments, such as colonialism and its ongoing legacy (high confidence), are worsened by compounding and cascading risks (high confidence) and are socially differentiated (Xu et al, 2021). For example, low-income, young, poor and female-headed households face greater livelihood risks from climate hazards (high confidence) (IPCC, 2022; IPCC, 2023)

2.11.3 Coastal vulnerability faced by communities.

Vulnerability refers to the degree of harm that can be anticipated in specific circumstances involving exposure, susceptibility, and resilience (Fuchs et al., 2011; Koks et al., 2023; Scheuer et al., 2011). In the context of floods, a system's vulnerability to flooding is determined by its exposure and its ability or inability to be resilient, cope, recover, or adapt to the situation. Coastal locations with a high risk of coastal floods are inhabited by large populations (Small and Nicholls, 2003). The global net migration towards coastal areas is expected to increase the number of affected individuals (Bijlsma et al., 1995). Some populations at risk of floods are safeguarded using a combination of physical and non-physical measures implemented as part of a resilience strategy.

2.11.4 Coastal vulnerability indices

Vulnerability indices have been created as a rapid and uniform way to describe the comparative vulnerability of various regions, while some assessments focus on the physical vulnerability of a place, and others delve into the economic and social risks (Sarhadi and Soulis, 2022; Tingsanchali and Karim, 2022).

The social vulnerability index (SoVI) is calculated using a set of 42 socio-economic variables, which are then reduced to 11 statistically independent elements. These factors include age, race, ethnicity, education, family structure, social reliance, and occupation (Cutter et al., 2012). This methodology is used at the level of individual coastal counties using a principal component analysis (PCA) to generate the comprehensive coastal social vulnerability score (CSoVI).

The coastal social vulnerability score (CSoVI) is a composite measure incorporating various factors relevant to North America and Australia, primarily focusing on beach areas. The factors include dune height, barrier type, beach type, relative sea-level change, coastline erosion and accretion, mean tidal range, and mean wave height (Cutter et al., 2003; Flanagan et al., 2011; Schmidtlein et al., 2008). In 2010, McLaughlin and Cooper created a multi-scale coastal vulnerability index to examine the effects of several spatial scales on representing the risk of coastal hazards and vulnerabilities at national, local authority, and site levels (Cutter et al., 2003; Flanagan et al., 2011; Schmidtlein et al., 2008).

The authors in this index specifically focused on the vulnerability of coastal areas to erosion, rather than exposure to coastal flooding (McLaughlin et al., 2010). The variables used include a coastal characteristics sub-index that focuses on the coast's resilience and susceptibility to erosion, a coastal forcing sub-index that characterizes the variables contributing to wave-induced erosion, and a socio-economic sub-index that assesses the potentially at-risk infrastructure. The socio-economic sub-index, as defined by McLaughlin and Cooper in 2010, consists of six variables: population, roads (essential communication and transportation routes), cultural heritage, railways, land use, and conservation status (Cutter et al., 2003; Flanagan et al., 2011; Schmidtlein et al., 2008).

Sharples, (2006) employs the process of identifying and mapping coastal substrates and landforms (known as geomorphic types) to evaluate the susceptibility of coastal areas to potential impacts of climate change and rising sea levels. These impacts include accelerated erosion, shoreline recession, increased hazards of slumping or rock falls, changes in dune mobility, and other related dangers.

2.11.5 Component of flood risk analysis

Risk has two components, the chance (or probability) of an event occurring and the impact (or consequence) associated with that event. This includes the probability of inundation (Hazard), referred to both likelihood of the initiating event that causes the flood and the likelihood that floodwaters will reach a specific location in the floodplain. This takes into consideration the effectiveness of the wetlands, channels, dams, levees, floodwalls, and other structures that the floodwater must pass through. The other component is the consequences of flooding, which includes the phenomenon demonstrated, both the susceptibility of the receptors and the likelihood, that a particular receptor will be exposed to the flood (Merz et al., 2010; Apel et al., 2009; Klijn & de Bruijn, 2013; Sayers et al., 2002; UNISDR, 2013).

The consequences of flooding manifest through exposure, vulnerability, susceptibility and state of resilience. Exposure quantifies the number of properties or people, areas of habitat, and so on that may be exposed to a given flood event should it occur. Exposure is not as simple as it might seem. Some receptors, such as residential properties, can be considered static, but other receptors, such as people, cars, and wildlife, may be dynamic; that is, they are liable to move, and they may or may not be present in the area at the time of a flood. The degree of exposure will influence the risk. Vulnerability describes the potential for a given receptor to experience harm during a given flood event. To further understand vulnerability, three supporting aspects need to be considered Merz et al., 2010; UNISDR, 2013).

Susceptibility describes the propensity of a particular receptor to experience harm during a given flood event. This includes material destruction (a carpet might be destroyed), loss of or damage to flora or fauna, and human death or injury. Value externalizes the value system used to express the degree of harm to a receptor. Resilience is the ability of the receptor to recover on its own after suffering damage from a specific flood event (Apel et al., 2009; Klijn & de Bruijn, 2013; Sayers et al., 2002).

2.11.6 Meteorological Parameters

Meteorological flooding refers to a situation in an area when there is a predominance of heavy rainfall greater than the average value often observed in the climate. The definition and criteria for floods vary across different regions. In South Asia, a flood is considered moderate when seasonal rainfall exceeds the regular meteorological average, and it is classified as severe when there is an exceptionally high amount of rainfall above the normal mean value. A variety of factors contribute to the occurrence of severe floods, including substantial winter snowfall, elevated summer temperatures, the formation of atypical low-pressure systems, alterations in the track direction, and abnormal rainfall patterns (Jha et al., 2018).

The occurrence of this extreme weather can be attributed to climate change, although confirmation of climate change requires long-term meteorological data rather than individual events. Weather forecasting models have experienced a substantial improvement in quality in recent years. These models can offer crucial data on temperature, wind, and precipitation for the prediction of any meteorological occurrence. Predictive analysis is unable to precisely determine the specific geographic area and magnitude of rainfall. Specifically, there is still a lack of appropriate data regarding the precise location and strength of localized convective heavy rainfall, which hinders the accurate prediction of flash floods (Apel et al., 2009; Klijn & de Bruijn, 2013; Sayers et al., 2002).

2.11.7 Hydrological parameters

Hydrological parameters refer to the measurable characteristics of water systems, such as rivers, lakes, and groundwater. These parameters include variables such as flow rate, water level, temperature, and water quality. The physical features of different physiographic regions within the basins affect how the water moves through them, as shown by the network of stream gauges (Smakhtin, 2001). Monitoring hydrological variables is crucial for assessing flood risks. To conduct this assessment, it is important to examine the alterations in hydrological conditions, particularly the attributes of intense rainfall, at the hydrological scale ranging from regional to local. Hydro-climatological factors play a crucial role in comprehending the relationship between the atmosphere and hydrosphere (Smakhtin, et al., 2001). The hydrological data and analysis of the flood wave have been utilized to enhance the management of water through the implementation of weirs, flood diversion canals, and retentions. This hydrological analysis focuses specifically on mitigating catastrophic floods in various regions of the world. The most destructive floods in rivers are caused by rain-on-snow occurrences, which result in the flooding of settlements.

2.11.8 Socio-economic and physical vulnerability

Socio-economic vulnerability is a term used to describe a shared set of variables that are used to examine variations in social and economic vulnerability across different locations. Vulnerability is sometimes described as a combination of a system's level of exposure and sensitivity to stress, as well as its ability to absorb or deal with the impacts of these stressors (Gunderson and Holling, 2001).

Vulnerability is a useful tool for analysing situations where there is a high risk of harm, powerlessness, and marginalization in both the physical and social systems. It also helps guide the evaluation of actions that can improve well-being by reducing risk (Janssen, et al., 2006). A vulnerability measure that prioritizes human well-being includes both material components and the repercussions of vulnerability (Adger & Winkels, 2006). The capacity of a society in a physically sensitive zone to adapt to flash floods or other disaster risks determines its socioeconomic vulnerability. The level of social and economic development directly affects a population's capacity for adaptation. As a result of population growth, poverty, and limited land availability, communities often establish new settlements near river banks or flash flood debris fans (Sayers et al., 2002; Jha et al., 2018).

This is a clear illustration of our high vulnerability to flash floods. Physical vulnerability refers to the susceptibility of buildings, infrastructure, and agriculture. While the primary emphasis is on tangible resources, this also includes the possible damage or destruction of agricultural produce and other essential infrastructure that supports people's means of living. Vulnerability analysis should assess the level of risk that key facilities, such as hospitals, emergency services, transportation, communication networks, and essential services, face during crises. These facilities are crucial for the running of societies in such circumstances (Rose, 2007; Fox et al., 2024).

Socially vulnerable groups encompass women, those with mental and physical disabilities, children, elderly individuals, individuals living in poverty, refugees, and livestock. Economic vulnerability evaluates the likelihood of potential losses to economic assets and processes caused by hazards. These can be categorized into two groups: The first category includes direct damages to physical and social infrastructure, which involves the expense of repairing or replacing these facilities, as well as crop damage. The second group refers to indirect losses, which encompass losses in production, employment, important services, and income disparities (Cutter, et al., 2001; Fox et al., 2024). The environmental components include indicators that refer to damage to the environment caused by flood events or manmade interferences that could increase the vulnerability of certain areas.

2.11.9 Flash Flood Risk Assessment

Flash floods are sudden and unpredictable floods that occur without any significant warning, and they can surge and recede quickly. Flash floods frequently occur in mountainous areas of the Karakoram, Himalayas, and Hindu Kush regions. Floods typically occur as a result of heavy rainfall, the rapid release of water from a landslide dam or glacier lake, or the failure of man-made hydraulic infrastructure (Bahadurzai and Shrestha, 2008; ICIMOD, 2011; Taherizadeh et al, 2023). Assessing the risk of flash floods is crucial for making informed decisions and effectively managing the risk of flooding.

The process of evaluating the danger of flash floods involves four distinct steps: describing the geographical area, determining the amount and intensity of the hazard, measuring the susceptibility of the area, and finally, evaluating the overall risk. It is crucial to analyse and understand the characteristics of a place that is susceptible to flash floods to estimate the risks and vulnerabilities associated with it. Some key factors to consider include the geography, geology, and geomorphology of the area, as well as its hydrology and hydraulics. Additionally, information about the vegetation, land use, and historical analysis can provide valuable insights (Borga, et al., 2014; Shrestha, 2005; Taherizadeh et al, 2023).

2.11.10 GIS and remote sensing techniques

The Geographic Information System (GIS) is a computerized system that enables the input, management, storage, retrieval, manipulation, analysis, and output of spatial data. It offers a wide array of tools for assessing the extent of flood-affected areas and predicting areas that are prone to flooding. In recent years, remote sensing technology, in conjunction with GIS, has emerged as the primary instrument for monitoring floods. This technology plays a crucial role in addressing hazard and flood-related issues by facilitating surface water modelling and assessing flood hazard exposure.

GIS and remote sensing primarily concentrate on the demarcation of flood zones and the creation of flood hazard and risk maps (Bhatt, et al., 2013; Taherizadeh et al, 2023). Gashaw and Legesse (2011) state that flood hazard mapping is an essential element for mitigating the impact of floods and for planning land use in places that are prone to flooding. The software generates simple, comprehensible, and quickly accessible visual representations, such as charts and maps, that enable administrators and planners to identify regions of potential danger and prioritize their efforts to minimize or respond to these risks.

Remote sensing also plays a significant role in monitoring floods and assessing the extent of damage caused. Satellite data enables efficient flood monitoring, offering rapid and accurate assessments of inundated regions. ArcGIS can utilize high-resolution imagery and digital elevation models (DEMs) to analyze and map flood-prone areas (Jeyaseelan, 2004; Kussul et al., 2008). Digital Elevation Models can visually represent regions with varying susceptibility to flood hazards. Flow accumulation models applied to DEMs classify zones into high-danger, moderate-risk, and low-risk based on elevation intervals (Lillesand et al., 2004; Forkuo, 2008; Forkuo, 2010). Recent advances, such as machine learning-driven DEM and remote-sensing integration, have significantly improved flood hazard mapping by combining SAR-derived water inventories and geospatial factors (Feizbahr et al., 2023). Major breakthroughs in satellite flood detection now include real-time monitoring enabled by AI-enhanced processing of optical and SAR data

(Schumann, 2023). In remote and data-scarce areas, integrating machine learning with GIS and SAR data yields highly accurate flood extent and impact assessments, supporting better-informed risk management (Sampurno et al., 2024).

2.11.11 Modelling processes and uncertainties

The assessment of flood hazards is an intricate procedure that encompasses dynamic systems, such as flood hydrology and hydraulic components, as well as human systems. According to Green et al. (1994), it also incorporates several modelling prerequisites. There are numerous methods for determining the potential damage that upcoming floods might cause. Analysing the assets that are susceptible to damage from floods is a component of deterministic approaches. This method provides specific outcomes regarding the forms of damage and the geographical features of the assets.

Practitioners and scientists regard these strategies as the most realistic ones, and their importance is growing over time. The "unit damage model" (Merz et al., 2010b) is a widely accepted approach for assessing possible flood damage. This approach quantifies the potential financial impact of damage by utilizing damage functions, which are equations that establish a relationship between various factors of hazard and vulnerability. These equations are used to estimate the possible damage that assets at risk may incur. To use this approach, it is essential to have flood inundation maps and data regarding the susceptibility of assets (Merz et al., 2010b).

2.11.12 Flood hazard modelling

Flood hazard maps are generated by a comprehensive procedure that involves the analysis of hydrological, geographical, and hydrodynamic data. An understanding of hydrology is crucial for analysing the risk of floods. They are used to establish a correlation between the flow rate of rivers and their frequency of occurrence.

The second crucial feature of floods is their hydraulic properties, which include flood extent, regional distribution of water depth, spatial distribution of velocity, and factors related to water pollution (Merz et al., 2007). Hydrodynamic modelling procedures are employed to transmit flow rates and ascertain the hydraulic properties of flood events. Uncertainty arises from the many elements and their interactions (Merwade et al., 2008b).

The availability of hydrological data, the Digital Elevation Model's (DEM) resolution, and the type of hydraulic model used, 1D, 1D/2D, or 2D, all have an impact on the accuracy of the results (Stelling and Verwey, 2005). The uncertainty associated with the Digital Elevation Model (DEM) is of utmost importance for ensuring the accuracy (Casas et al., 2006; Werner, 2001; Wechsler, 2007). The study by Xu and Booij (2007), emphasizes the significance of precise flood frequency determination in the outcomes of damage assessment.

2.11.13 Vulnerability assessment

Vulnerability data pertains specifically to information regarding the assets and their susceptibility to floodwater. The procedure for acquiring asset data depends on the goals of the risk analysis. The process involves categorizing assets and assessing their occupational, construction, and human-behavior aspects. Various methodologies, data sets, and theories can be utilized to evaluate the susceptibility of assets to floods (Simpson & Human, 2008; van der Veen & Logtmeijer, 2005; Dutta et al., 2003; D4E, 2007; CEPRI, 2008). Direct damage data typically expresses the susceptibility of assets to potential damage. These functions create the relationship between hazards and vulnerability parameters. Multiple investigations were conducted to generate these damage functions (White, 1964; Penning-Rowsell & Chatterton, 1977; Torterotot, 1993; Nascimento et al., 2007). Recent empirical studies using machine learning and component-level fragility models have significantly improved the accuracy and reliability of flood damage functions, enabling better quantification of direct assets losses (Paulik et al., 2024).

Analyzing indirect vulnerability data becomes challenging due to the intricate nature of understanding the role of networks and their systemic operation (CERTU, 2002; Desgranges, 1999). Vulnerability analysis in complex infrastructure networks highlights the need for topological metrics to assess how flood impacts propagate through interdependent systems (Santos et al., 2023) . The evaluation of susceptibility to floods also relies on several factors and causes of unpredictability. The quality of datasets and field surveys determines the accuracy of data, such as land-use uncertainties (Castilla & Hay, 2007). A large-scale probabilistic assessment in data-scarce regions demonstrated that combining satellite, field, and socioeconomic data can address such uncertainties in vulnerability estimation (Ceresa et al., 2023).

2.11.14 Principles of potential flood damage evaluation.

Vulnerability and hazard datasets are combined at this stage to estimate flood risk and determine the exposure of the assets. The Flood hazard parameters, for example, water depth and flow velocity, for floods with different probabilities of occurrence ***T*** are associated to the assets analysed for determining the probability of individual assets to be flooded. In the third step of the evaluation, flood damage is calculated for different flood probabilities (Sayers et al., 2013).

Direct material damage depends on hazard parameters and vulnerability characteristics of the asset at risk. For each asset at risk ***i*** we express direct damage ***ADDIR*** as a function of hazard parameters ***HPAR***, for example, water depth and flow velocity, and the vulnerability of assets to floods ***AVUL***, Equation (2.1) (Papathoma-Köhle et al., 2019; Sayers et al., 2013).

To avoid the complexity of domino effects and transfer of vulnerability during the propagation of uncertainties, asset's indirect damage ***ADIND*** is estimated by using ratings ***R*** of direct damage, Equation (2.2). Total damage potential for a specific asset ***ADTOT*** is calculated by summing up direct with indirect damage potential, Equation (2.3). Assets expected annual damage ***AEAD*** is calculated by summing up the product of total damage related to floods with their frequency of occurrence ***T***, for all probabilities of occurrence (from 0 to 1), Equation (2.4) (Papathoma-Köhle et al., 2019; Jongman et al., 2012; Vatsa, 2004).

$$AD_{DIR}^{i}(T) = f(H_{PAR}(T), A_{VUL}^{i}) \qquad (2.1)$$

$$AD_{IND}^{i}(T) = R \cdot AD_{DIR}^{i}(T) \qquad (2.2)$$

$$AD_{TOT}^{i}(T) = AD_{DIR}^{i}(T) + AD_{IND}^{i}(T) \qquad (2.3)$$

$$A_{EAD}^{i} = \int_{0}^{1} AD_{TOT}^{i}(T) \times \partial T \qquad (2.4)$$

Figure 2.7: Equation for determining flood evaluation

Source: Adapted (Sayers et al., 2013)

The sum of all the ***n*** assets at risk damage potentials represents the total damage potential caused by one specific flooding event with a certain probability of occurrence ***T*** in the impacted area, Equation (2.5). The total expected annual damage for the area analysed is the sum of the expected annual damage for all the ***n*** assets impacted by the different flood events, Equation (2.6).

$$DAM(T) = \sum_{1}^{n} AD_{TOT}^{i}(T). \tag{2.5}$$

$$EAD = \sum_{1}^{n} A_{EAD}^{i}. \tag{2.6}$$

(Sayers et al., 2013).

Once the different datasets used for analyses have spatial distributions and characteristics, Geographic Information Systems (GIS) are indispensable tools in the evaluation process (D4E, 2007). Contrary to hazard modelling, few models are available to simulate vulnerability and comprehensively assess flood damage (Xu & Booij, 2007).

As the framework in Figure 2.7 relies on multiple estimations of flood damage using varying input datasets to capture output variability, having an appropriate GIS-based tool is essential. Recent developments include the ArcGIS Pro "Flood Impact Analysis" tool (Arc Hydro and flood simulation workflows), which supports detailed damage modelling through DEM-derived hydro information and infrastructure impact mapping (Esri, 2024). Similarly, the RiverCure Portal, an interactive web-GIS and hydrodynamic platform, integrates sensor data, numerical flood simulation, and georeferenced outputs for dynamic vulnerability and damage assessment (Silva et al., 2023). Additionally, GIS-based flood susceptibility modelling, combining bivariate statistical models with remote-sensing factors, enhances spatially explicit vulnerability layers to support flood damage evaluations (Rahman et al., 2023).

2.11.15 Policies, plans, and laws

The United Nations Sustainable Development Goals (UN-SDGs) have developed flood risk management policies and plans as a global framework for managing flood risks. This requires a comprehensive understanding of the threats of extreme floods under regional inequalities, the challenges of flood risk management under future changes, and years of the prospects for sustainable flood management under global cooperation (Yang et al., 2023).

Another tool, the Sendai Framework for Disaster Risk Reduction 2015–2030, delineates seven explicit aims and four key priorities for undertaking measures to avert new and mitigate current disaster risks, namely, understanding disaster risk, strengthening disaster risk governance to manage disaster risk, investing in disaster reduction for resilience, and enhancing disaster preparedness for effective response and "Build Back Better" in recovery, rehabilitation, and reconstruction. Essentially, it aims to achieve a substantial reduction of disaster risk and losses in lives, livelihoods, and health and the economic, physical, social, cultural, and environmental assets of persons, businesses, communities, and countries over the next 15 years (Sendai *Framework for Disaster Risk Reduction 2015-2030 | UNDRR*, n.d.).

Ghana urgently needs flood risk management (FRM) regimes and sustainable adaptation techniques due to the projected increase in the frequency and severity of flood occurrences caused by climate change (IPCC, 2012; World Bank, 2011). To address this issue, the Ghanaian government has implemented several policies aimed at mitigating the impacts of flooding.

These measures principally consist of the National Water Policy of Ghana, (2007), which aims to mitigate floods through the adoption of flood early warnings, the implementation of mitigation techniques in cooperation with affected communities, and the enforcement of buffer zone legislation. The buffer zone legislation, as outlined in Ghana's National Water Policy, has the objective of prohibiting human settlements within a specified proximity to riverbanks. The Blue Agenda, according to Addo & Danso, (2017), is a significant strategy that aims to tackle the issue of flooding and its associated risks. It does so by prioritizing public education and the strict enforcement of building restrictions. There is no singular panacea to prevent the incidence of flood and drought catastrophes.

Several policies, strategies, programmes, and activities have been implemented to manage floods and droughts in the Volta River Basin. Flood and drought policies must take into account the basin's geographical and institutional aspects. The "Integration of Flood and Drought Management for Adaptation in the Volta Basin (VFDM)" project is a collaboration between the World Meteorological Organization (WMO), the Volta Basin Authority (VBA), and the Global Water Partnership in West Africa (GWP-WA). Its purpose is to support the six countries (Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali, and Togo) in implementing coordinated and joint measures to enhance their existing regional, national, and local management plans.

The project aims to draw from past and ongoing initiatives related to disaster risk reduction and climate adaptation (Nana Ama Browne Klutse, 2022).

The World Meteorological Organization (WMO), the Volta Basin Authority (VBA), and the Global Water Partnership in West Africa (GWP-WA) are working together to implement the "Integration of Flood and Drought Management and Early Warning for Adaptation to Climate Change" project within the Volta Basin (VFDM). Initiated in June 2019, the VFDM project is currently in progress, with a scheduled conclusion by the end of June 2023.

One of the tasks of the VFDM project is to conduct thorough research and discussions to identify current or in-progress policies, guidelines, and plans for managing extreme climate events such as floods and droughts. These resources are sourced from regional and national entities in the countries within the Volta basin.

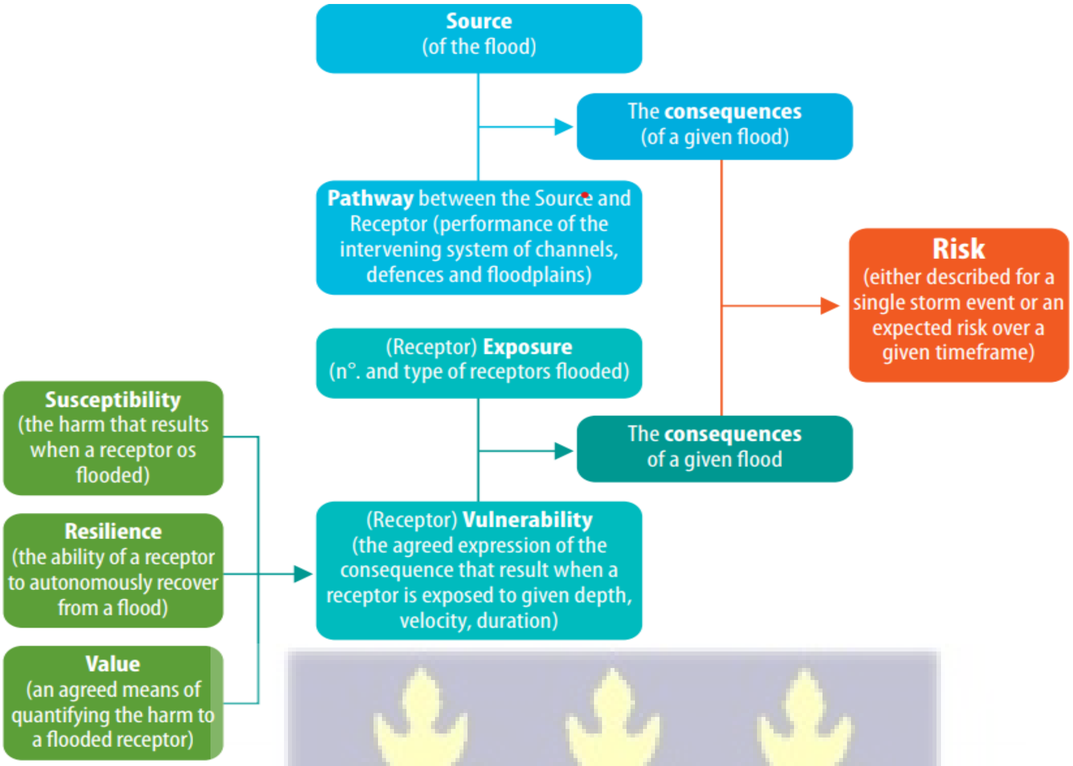


Figure 2.3: Flood Risk assessment framework Source: IPCC, 2023

2.12 Types of Flood Risk Management Practices

Ancient societies employed many techniques for flood control throughout history. Some of the techniques used to manage flooding include the use of vegetation to store excess water, the creation of terraces on hillsides to reduce the speed of downhill flow, and the construction of floodways, which are artificial channels designed to redirect floodwater.

Additional methods involve the establishment of levees, lakes, dams, reservoirs, and retention ponds to store excess water during periods of flooding. Flood control has been classified as structural and non-structural, while the World Bank Compendium for West Africa classifies coastal risk management into three main practices: mainly hard engineering solutions, soft engineering solutions, and coastal planning and risk management techniques.

According to the World Bank (2021), flood risk management could be classified as hard engineering, soft engineering and non-structural practices. It indicates that hard engineering solutions (HES) are employed as coastal management strategies to mitigate erosion and floods, while simultaneously attenuating wave energy. These methods are employed to artificially maintain the stability of the coastline, limiting the interaction between the sea and the land, as well as the subsequent exchange of silt.

As prominent artificial buildings, these strategies impede or interrupt natural processes, leading to harmful consequences for coastal habitats located far away within the same region. Constructing HES structures is a costly endeavour, and ongoing maintenance is necessary to prolong the longevity of these structures. Typically, HES buildings are not enduring, and over time, their effectiveness diminishes, or they sustain significant damage, necessitating further investment. Nevertheless, under many circumstances, HES solutions are indispensable due to societal and economic limitations.

Soft engineering solutions (SES) are commonly suggested as environmentally friendly alternatives that function in harmony with nature, safeguarding the coastline instead of impeding it or disrupting natural processes. While HES focuses solely on structural elements like seawalls and breakwaters (Pontee et al., 2016), SES represents a significant change in coastal protection and risk mitigation strategies. Socioeconomic status (SES) has a positive impact on the effectiveness of sea defence and coastal protection structures, leading to improved service levels. By applying ecological concepts and practices, Sustainable Environmental Systems (SES) minimise the negative effects on the natural environment, prove to be economically efficient in both implementation and maintenance and promote long-term sustainability to a greater extent than traditional engineering projects (Barbier, 2017).

Coastal planning and risk management techniques (CPT) encompass the process of designing the physical arrangement and land utilization in coastal areas (Kay and Alder, 2012)

It is a crucial element in effectively managing and mitigating potential risks. A community's long-term ability to withstand and recover from challenges is crucial (Kay and Alder, 2012). Urban planning encompasses the built and natural environment by strategically determining the locations for development and designating spaces for open space or preservation. The key components include thorough planning, zoning rules, and building codes, where CPT is considered a tool for territorial ordinance and management operations (Kay and Alder, 2012)

Coastal protection methods are typically classified into two distinct categories, namely structural and non-structural, as defined by UNDRR in 2017 (UNDRR, 2017).. Structural measures encompass the implementation of construction and engineering procedures in the field to effectively mitigate the vulnerability to coastal risks (Kernkamp et al, 2022). These approaches are also employed to enhance the durability and adaptability of infrastructure over an entire region. Non-structural measures involve strategies that do not involve physical interventions in the field (UNDRR, 2017). Instead, they rely on increasing their understanding of risks and implementing practices to reduce their impact.

Examples of non-structural measures include urban planning, land-use planning, raising awareness of coastal concerns, and doing research and data gathering (Kernkamp et al, 2022). In a similar dilation, the modern flood risk management approach contends that it is rare to find a single resolution to effectively handle flood-related challenges in the field (UNDRR, 2017). Therefore, the deployment of portfolios consisting of FRM measures and instruments has proven effective. These portfolios were constructed by combining various actions in a manner that effectively and sustainably minimises risk, which includes rigid structural measures such as the construction of dykes, levees, and dams; soft structural measures such as wetland storage; non-structural measures such as improved flood forecasts and warnings; and policy instruments such as land use planning, insurance, and other funding incentives, as happened in Rotterdam in the Netherlands, New Orleans in the United States, and the Huai River region in China (USACE, 2019; UNDRR, 2017).

There is growing acknowledgement that non-structural behaviours play a crucial role in risk management. There are several non-structural options available to address flooding. These include measures to decrease the risk to people, the economy, and ecosystems. One approach is to implement effective planning control in flood-prone areas, as demonstrated in the city of Cape Town, South Africa. Another strategy is to reduce the vulnerability of those at risk by providing safe havens, improving warning and evacuation planning, utilising modern flash flood forecasts, and implementing flood-specific building codes and insurance arrangements, as well as mitigating flood impacts through the implementation of physical measures such as reservoirs, levees, dredging, and diversions, technically referred to as structural flood control fields (UNDRR, 2017; USACE, 2019).

2.12.1 Structural flood control measures

2.12.2 Dams and Reservoirs

Several dams and their accompanying reservoirs are specifically engineered to assist in the prevention and management of floods. Several large dams contain flood-control provisions that require the reservoir level to be maintained below a specific elevation before the start of the rainy/summer melt season (Sánchez-García and Abad, 2022, Hossen et al, 2020). This is done to ensure there is enough capacity to accommodate floodwaters. Additional advantageous uses of reservoirs formed by dams encompass hydroelectric power generation, water preservation, and recreational activities. The construction and design of reservoirs and dams adhere to government-established guidelines (Sánchez-García and Abad, 2022).

2.12.3 Diversion canals

Flood control channels are expansive and vacant reservoirs designed to allow the passage of surface water without retention, except during flood events. Alternatively, they can be subterranean channels situated beneath the street level of certain major cities. In the event of sudden floods, these channels serve as conduits for excess water to drain into nearby rivers or other water bodies. Flood channels are occasionally constructed along the previous paths of natural watercourses to mitigate floods. Excess water can be utilized for replenishing groundwater by redirecting it onto land that can absorb the water. By utilizing the ground as a natural reservoir, this strategy can mitigate the effects of subsequent droughts. In California, this technique is employed to flood orchards and vineyards without causing harm to the crops. Similarly, in certain locations, wilderness areas have been modified to function as floodplains (Avornyo et al, 2023).

2.12.4 River and Sea Defence

Rivers in numerous nations are susceptible to flooding and are frequently subject to meticulous management. Structures such as levees, bunds, reservoirs, and weirs are employed to mitigate the risk of rivers overflowing their banks (Douglas, 2017). Coastal flooding has been mitigated through the implementation of coastal defences, including the construction of sea walls, beach replenishment, and the establishment of barrier islands. Tide gates are employed in combination with dykes and culverts (Zhang and Chen, 2022). They can be positioned at the entrance of streams or small rivers, where an estuary commences, or where tributary streams or drainage ditches intersect with sloughs. Tide gates are closed during the incoming tides to restrict the movement of tidal waters onto higher ground (Zhang and Chen, (2022). They are then opened during outgoing tides to allow the water to drain down the culvert and into the estuary side of the dike. A difference in water elevation on each side of the gate controls how the gates operate (Zhang and Chen, (2022).

2.12.5 Non-structural flood control measures

It encompasses land-use planning, advanced warning systems, and flood insurance, among others. Additional examples of flood control measures include zoning rules and codes, flood forecasting, flood proofing, evacuation and channel clearing, flood battle operations, and upstream land treatment or management aimed at mitigating flood damages without physically limiting flood waters.

2.12.6 Flood mapping

Flood mapping is a method employed by governments and policymakers to demarcate the boundaries of probable flooding incidents, enabling informed decisions to mitigate severe flooding occurrences (Bosman and van der Meulen, 2022). Flood maps serve the purpose of generating documentation that enables policymakers to make well-informed decisions regarding flood threats (Grimaldi et al., 2013). Flood mapping offers conceptual models to both the public and private sectors, providing them with information regarding the risks associated with flooding. The lack of public accessibility, technical writing and data, and easy-to-understand information has led to widespread criticism of flood mapping in various regions globally (Bosman and van der Meulen, 2022). Nevertheless, the increasing focus on flood mapping has sparked interest in improving existing flood mapping techniques for flood risk management (Flood Risk Management in Canada and The Geneva Association, n.d., USACE, 2022).

2.12.7 Flood modelling

Flood modelling is a technique employed to simulate flood risk and its impact on both human beings and their natural surroundings. Flood modelling incorporates the interaction between flood dangers, external and internal processes and components, and the primary causes of floods (Miguez et al., 2017). Flood modelling integrates variables such as terrain, hydrology, and urban topography to simulate the progression of a flood and determine the varying levels of flood hazards associated with each exposed element. The modelling can be conducted using hydraulic models, conceptual models, or geomorphic approaches. Currently, there is an increasing focus on the creation of maps derived from remote sensing techniques. Flood modelling is beneficial for identifying building development strategies and hazard mitigation techniques that minimize the dangers linked to flooding (Abebe et al., 2019).

2.12.8 Stakeholders' Engagement

Stakeholder engagement is an effective strategy for managing flood risks since it facilitates more public involvement to obtain consensus on policy deliberations (Thale & Priest, 2016). Various management concerns can be considered, such as the objectives of disaster risk reduction and emergency management, how land-use planning interacts with the integration of flood risks and the necessary policies (*Flood Risk Management in Canada | The Geneva Association*, n.d.) Stakeholder engagement is considered a crucial approach in flood management to foster increased unity and agreement (Thaler & Levin-Keitel, 2016) Incorporating stakeholder participation into flood management frequently leads to a more intricate examination of the situation, which typically necessitates a greater effort in identifying collaborative solutions and prolongs the time required to reach conclusions. (Thale & Priest, 2016).

2.12.9 Early warning systems

Early warning systems play a crucial role in plans for managing and mitigating the risks associated with disasters. Unlike flood forecasting systems that evaluate flood risk, early warning systems primarily aim to send alerts when a flood is about to happen or is already happening (Appeaning Addo and Awotwi, 2022).

Flood early warning systems consist of four interconnected components: The key components include: 1) evaluations and understanding of flood vulnerabilities in the region, 2) localized surveillance of potential hazards (predictions) and alert systems, 3) distribution of flood risk information and communication services; and 4) the ability of the community to respond effectively. This versatile system enhances community readiness for severe weather occurrences like floods, by providing effective alerts and enhancing comprehension of hazards and suitable flood reactions. This reduces the risks associated with safety and infrastructure (Ofori and Anornu, 2022; Appeaning Addo and Awotwi, 2022). The system issues a warning that includes a forecast of the magnitude, timing, location, and probable consequences of the upcoming flood. The system utilizes sensor data to quantify water levels at important locations within local water basins (such as rivers and lakes) or flood control structures (such as dikes, dams, and embankments) to predict the likelihood of a flood occurrence. The escalating frequency and intensity of extreme weather phenomena, such as floods, underscore the significance of this technology in adapting to climate change (Ofori and Anornu, 2022; Appeaning Addo and Awotwi, 2022).

2.12.10 Resilient infrastructure development

The concept of resilience has been extensively studied in various academic disciplines, as evidenced by the works of Dancy et al. (2018) and DE Alexander (2013). Additionally, resilience has also been influenced by non-academic factors, particularly in the areas of community resilience, institutional resilience, and political resilience, as highlighted by (Edwards, 2009).

In the context of flood resilience, the development of resilience follows a similar path in many countries. This path is based on a social-ecological systems approach, which originated in ecology and is reflected in conceptual frameworks within sustainability research (Turner et al., 2003). In this approach, floods are seen as hazards that impact various compartments or systems, which interact with each other.

These compartments include hazards, susceptibility/vulnerability, and resilience, and they are nested within different micro- and macro-scales (Turner et al., 2003). he concept of a place-based system approach is also emphasized in frameworks like the one derived from geography (Cutter et al., 2014). Nevertheless, there are significant similarities between the current framework and previous frameworks that focus on coping or recovery capacities rather than resilience (Norris et al, 2008). Flood resilience must incorporate elements of vulnerability and exposure to traditional risk techniques. This applies to many stakeholders and property types that are interconnected with the locations of critical infrastructure assets. One hard component is identifying distinct resilience features that are distinct from existing vulnerability and risk techniques (Cutter et al., 2008).

Climate-resilient infrastructure is characterized by its proactive approach to planning, designing, constructing, and operating to anticipate, prepare for, and adapt to climate-related challenges. In response to fluctuating environmental conditions, it can also withstand, adapt to, and swiftly recover from disturbances brought forth by various weather patterns (Paton and Johnston, 2017). Maintaining climate resilience is an ongoing task over the whole lifespan of the asset. attempts to enhance climate resilience can synergistically support attempts to bolster resilience to disasters

(Paton and Johnston, 2017).

The interaction between growing climate hazards, asset location (exposure), and susceptibility to unfavourable effects (vulnerability) determines the impact of climate change on infrastructure risks (Agard & Schipper, 2014). The interplay between increasing climate hazards, asset location (exposure), and susceptibility to unfavourable effects (vulnerability) (Agard & Schipper., 2014). Infrastructure's vulnerability to climate risks can be mitigated by strategically placing assets in regions with lower exposure to climate hazards, such as by avoiding constructing new infrastructure in flood (Manyena, 2006). By strategically placing assets in areas with lower

exposure to climate hazards, such as avoiding building new infrastructure in flood plains, one can

reduce the vulnerability of infrastructure to climate risks in other areas, such as the possible exacerbation of flood risk due to the expansion of paved surfaces (Tumawu et al, 2024).

Climate resilience refers to the evaluation of whether climate change implications have been accounted for and, if needed, addressed by examining the methods employed and the results obtained. The strategies employed to achieve this goal will exhibit significant variation due to the context-specific nature of climate adaptation. Occasionally, no alterations to the structure are required: the climate-resilient fibre optic cable could be indistinguishable from the line that would have been put otherwise. Nevertheless, when modifications are necessary, they can be classified into two distinct groups according to EUFIWACC (2016).

Structural adaptation measures involve modifying road surfaces to prevent deformation in high temperatures, constructing seawalls, or employing permeable paving surfaces to minimise runoff during heavy rainfalls. Ecosystem-based techniques, which utilise natural infrastructure for the development of adaptation measures, are important options that should be considered in addition to structural adaptation measures.

Management adaptation methods, also known as non-structural adaptation measures, involve making changes to address the effects of climate change. Examples of these approaches include adjusting the timing of maintenance activities to align with changing patterns of energy demand and supply, investing in early warning systems, and acquiring insurance to mitigate the financial impacts of climatic variability. These strategies can also involve intensifying surveillance of current resources to mitigate the risk of malfunction as climate circumstances evolve. Adaptive management techniques incorporate provisions for flexibility from the beginning. Allowing for monitoring and adjustment to changing circumstances throughout the lifespan of the assets (OECD, 2014).

Observed mortality and losses due to floods and droughts are much greater in regions with high vulnerability and vulnerable populations, such as the poor, women, children, Indigenous Peoples and the elderly, due to historical, political and socioeconomic inequities (high confidence).

2.12.11 Adaptive capacity

Climate change is impacting Indigenous Peoples' ways of life (very high confidence), cultural and linguistic diversity (medium confidence), food security (high confidence) and health and well-being (very high confidence). Indigenous knowledge and local knowledge can contribute to reducing the vulnerability of communities to climate change (medium to high confidence). Supporting Indigenous self-determination, recognising Indigenous Peoples' rights and supporting Indigenous knowledge-based adaptation are critical to reducing climate change risks and effective adaptation (IPCC, 2023; UNFCCC, 2011).

2.12.12 Spatial Planning

In the first place, *"Not planning well is to fail*" by Benjamin Franklin; in this context, it implies effort must first and foremost be geared towards planning for the development of the coastal regions. Spatial, land use and long-term development planning are difficult to arrive at in many communities and coastal areas, particularly in developing nations. Ghana is one of the countries faced with these challenges (Land Use and Spatial Planning Authority, 2016). Some argued that, Ghana has far performed in planning since the days of Guggisberg's 10-Year Development Plan, to President Kwame Nkrumah's Seven-Year Plan, President Rawlings' Vision 2020, and Four-Year

Plans Concept from President Kufours, President Mills, President Mahama and President Akufo Addo led governments. Largely, implementation challenges are faced in Ghana's planning, and if no adequate commitment is made, the current Vision 2057: Long-Term National Development Perspective Framework may also fail (Ghana National Development Planning Commission, 2023).

As a result of a lack of adequate implementation, people settle anywhere accessible and affordable to them. The worst situation is that spatial and land use planning were not significantly done to accompany development plans. The location of functions over proper land use and layout system is scanty. There is no adequate sustainable plan for the resettlement, management, and allocation of land to the people affected by coastal challenges (Land Use and Spatial Planning Authority, 2016).

The Land Use and Spatial Planning Act 2016 (Act 925) was formulated to promote spatial and land use planning in the country. This is expected to promote a broad national and regional spatial framework to guide planning in metropolitan, municipal, and district assemblies. The National

Spatial Framework was done, and interestingly, the Regional Spatial Framework for Greater Accra and the Western and Central Regions was also completed. Another concept of the Integrated Plan is to promote inter-border or international coastal projects; for example, a four-year project going through the feasibility stage, supported by UN-Habitat, is to be implemented by Ghana and Cote D'Ivoire (UN-Habitat, 2020).

Aside from spatial planning, development planning in the long term could be considered essential so that every government in office would be compelled to continue the implementation of the plans. Four-year District Medium-Term Plans are done by Metropolitan, Municipal and District Assemblies (MMDAs) in Ghana are known to outline so many activities which coastal improvement on the sea defence, protection of mangroves and improving the lives of the communities through farming and fishing are indicated but in the short term.

As a result of the increased sensitivity to coastal challenges, amidst inadequate planning, is important that actions are taken to develop broad planning schemes with long term forecast and master plans. A Master Plan of both development and spatial content are needed to guide future development. Development of Integrated Coastal management plan and programmes are also needed to include major policies such as Transport, Tourism, Industries, Utilities and Capacity Building. There is the need to formulate or review a more strategic a National Coastal Management Policy and Action plan to guide the planning and implementation of the coastal management and development in Ghana.

2.12.13 Coastal agriculture, livelihoods and small-scale businesses

Coastal areas serve as space for agricultural activities including fishing and farming. Large low-lying natural coastal lands are arable to rice farming, market gardening and other agricultural uses to meet food security needs (Clark, 1994). Coastal lowlands and wetlands farmed with unregulated practices such as excessive use of chemicals can cause acid-sulphate soils. Ecosystem could be affected from pollution from the release of agricultural chemicals into riverine and coastal waters, pre-emption of mangrove forests and other critical wetland habitats. It is proper that stronger development control is exercised to avoid practices that endanger the ecosystem (Singh, 2020). Global estimated fish of 100 million tonnes fish per year are consumed far larger than consumption of both beef and mutton combined (Roy et al, 2016).

Along the value chain, fisheries industries serve as a major livelihood source to fishermen, boat builders, trap and net makers, packers, distributors, and retailers. It is needful to manage the fisheries industry for posterity. The uses of illegal methods, light and pair-trolling are destruction that must be curtailed to ensure a more reliable fisheries industry. There is the need to maintain or enhance the present seafood production through improved fishing or aquaculture. Again, a more controlled aquaculture will prevent pollution of and degradation to the coastal waters such lagoons, estuaries and mangroves.

2.12.14 Infrastructure

The removal of forest cover in watersheds, among other effects, increases sediment loadings of rivers and direct fresh water runoff to coastal seas, and this has particular effects on riverine fisheries, and on some valuable anadromous species (e.g., salmonids) (Carandang et al, 2013). It also leads to smothering of estuary organisms such as oysters, coral reefs and submerged vegetation (seagrasses and seaweed beds) of key importance as fish habitat (Liang L et al,2017). Regulatory measures and conservation guidelines are therefore needed to ensure the mangrove forests are not depleted. The World Heritage recognition of wetlands and mangrove are very critical and must be enhanced.

Integrated and sustainable solutions are required, not just hard engineering. Integrated river sediment management aims to maintain sediment balance across the entire watershed and assess impacts for each river development project. However, this demands advanced scientific expertise and inter-institutional cooperation. Despite obstacles, such management is crucial in large estuaries like the Senegal River, where socioeconomic stakes are high (Mendoza et al., 2025; Ndiaye et al., 2024). Alongside engineering measures, disaster prevention and management, such as early warning systems (EWS) and flood risk mapping, are essential to build knowledge and apply hazard mitigation practices. EWS are being deployed in coastal cities like Dakar and Cotonou to enhance preparedness (Fofana et al., 2023). While flood risk mapping is increasingly common across West Africa, many areas remain unmonitored, highlighting the need to identify high-risk zones for informed urban and coastal planning (Nwogu et al., 2025). Planning frameworks can specify minimum construction distances from the sea, like in Grand Bassam, Côte d'Ivoire. In highly exposed locations, relocations have occurred (e.g., Grand-Lahou, near Abidjan) and continue (e.g., Guet N'Dar, Saint-Louis) (Okeke & Kouame, 2023). However, successful resettlement requires strong technical capacity, institutional enforcement, and meaningful dialogue with local communities (Rodrigues et al., 2022; Silva et al., 2023).

2.12.15 Global Policy on Climate Change and flood/coastal issues

The new data from UNDP and CIL indicates that the impact of climate change on coastal flooding is projected to rise by a factor of five throughout this century. This would result in over 70 million individuals being exposed to the expanding floodplains. Projections indicate that by 2050, numerous densely populated coastal cities will face a higher likelihood of flooding. This includes areas that are home to around 5 percent of the population in coastal cities such as Santos, Brazil, Cotonou, Benin, and Kolkata, India. According to our present emissions trajectory, by 2100, that exposure will have doubled to territory where 10% of the people living in these densely populated coastal areas reside. The potential consequences for coastal regions, which frequently serve as significant centres for social and economic activities, have the capacity to initiate global setbacks in human development.

2.12 Mainstreaming and Institutionalization of Disaster Risk Reduction and Climate Change adaptation in Ghana

Ghana has demonstrated a strong commitment to disaster risk reduction (DRR) and climate change adaptation (CCA) since becoming a party to the United Nations Framework Convention on Climate Change (UNFCCC) in 1995. Following the Hyogo Framework for Action (2005– 2015), the country transitioned to the Sendai Framework (2015–2030), reflecting its dedication to integrating DRR and CCA into environmental management plans and strategic policies (Forino et al., 2015). These frameworks have been foundational in shaping national policies.

2.13.1 Governance Structures

The governance for DRR and CCA in Ghana involves multi-level coordination among ministries, departments, and agencies. The National Development Planning Commission (NDPC), established under Acts 479 and 480 (1994), serves as the coordinating body. At the district level, District Planning Authorities implement these plans, while Regional Coordinating Councils facilitate coordination between districts and national-level ministries (NDPC, 1994).

Specific tasks are implemented by ministries and agencies, such as the National Disaster

Management Organization (NADMO) under the Ministry of Interior. NADMO, established in 1996 under Act 517, oversees disaster management and aims to enhance capacity and link DRR with medium-term plans through effective social mobilization (Kranjac-Berisavljevic et al., 2019).

2.13.2 Policy, Laws and Projects

Over the years, Ghana has integrated DRR and CCA into various development plans. The Ghana Poverty Reduction Strategy Paper (2003–2005) emphasized rapid response units and early warning systems (DARA, 2013). Subsequent plans, such as the Ghana Growth and Poverty Reduction Strategy (2006–2009) and the Ghana Shared Growth and Development Agenda (2010–2013, 2014–2017), addressed environmental degradation, hazards, and vulnerabilities (NDPC, 2006; NDPC, 2014). National Medium-term Vision, the "Agenda for Jobs II: Creating Prosperity and Equal Opportunity for All (2022 – 2025)" (Armah et al., 2023; Boadi et al., 2023)

Ghana has undertaken a comprehensive approach to mainstream DRR and CCA through a series of policies and strategies that align with international frameworks while addressing local vulnerabilities. These policies and strategies demonstrate Ghana's commitment to sustainable development, climate resilience, and effective disaster management (Agyeman et al., 2023; Kumi et al., 2023).

National Climate Change Adaptation Strategy (NCCAS): The NCCAS, spanning 2010–2020, was developed to reduce the adverse impacts of climate change on Ghana's socio-economic and developmental sectors. This strategy emphasised the integration of climate adaptation into national planning frameworks. Three primary considerations guided its formulation:

- **Alignment with International Commitments**: NCCAS was crafted to meet global goals, such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Hyogo Framework for Action (HFA) 2005–2015.

- **Sectoral Climate Vulnerability**: Recognizing Ghana's reliance on climate-sensitive sectors, such as agriculture (employing 70% of the population), fisheries, forestry, and energy, the strategy highlighted the urgency of integrating adaptation measures into these critical areas.
- **Emerging Climate Risks**: The strategy acknowledged the increasing frequency and severity of droughts and floods, necessitating robust planning for climate resilience.

The NCCAS aimed to:

- Enhance climate resilience while reducing vulnerability.
- Increase public awareness of the role of adaptation in national development.
- Attract international funding for adaptation projects.
- Mainstream climate adaptation into local-level planning and development.

Despite its significance, the NCCAS faced challenges in financing and inclusive participation, as local communities were often excluded from decision-making processes (Arhin, 2022; Awuni et al., 2023).

National Climate Change Policy (NCCP): The NCCP serves as Ghana's primary policy framework for addressing climate change. It is designed to ensure climate change considerations are integrated into national planning, budgeting, and development processes. Implemented from 2015 to 2020, the policy's key features include:

- **Cross-Sectoral Collaboration**: The National Climate Change Committee (NCCC), comprising representatives from ministries, departments, and civil society, oversaw its development and implementation.

- **Local Government Integration**: Metropolitan, Municipal, and District Assemblies (MMDAs) were required to incorporate climate policy statements into their medium-term plans to secure budget allocations.

- **Policy Priorities**: The NCCP focused on areas such as agriculture, water management, natural resources, energy, and health to enhance resilience and sustainable development.

The NCCP has played a crucial role in positioning Ghana as a regional leader in climate policy integration. However, limited financial resources and technical capacity have hindered their full implementation (OECD, 2020).

National Disaster Management Plan: Developed by the National Disaster Management Organization (NADMO) under the Ministry of Interior, this plan provided a structured approach to disaster management from 2011 to 2015. The plan's objectives included:

- Strengthening disaster prevention and response mechanisms.
- Linking disaster management programs with broader reforestation and poverty reduction initiatives.
- Enhancing institutional capacity and stakeholder coordination through regional and national platforms.

NADMO has played a pivotal role in managing disaster risks through a decentralized structure, with over 170 district secretariats and 900 zonal offices across the country. The organization collaborates with agencies such as the Ghana Police Service, Ghana Armed Forces, and international bodies like UNDP for technical and financial support (Kranjac-Berisavljevic et al., 2019).

Nationally Determined Contributions (NDCs): Ghana's updated NDCs, submitted under the Paris Agreement, outline commitments to reduce greenhouse gas emissions and enhance adaptation actions. These include:

- Scaling up renewable energy solutions.
- Promoting sustainable land management practices.
- Developing resilient infrastructure to mitigate climate-induced risks.

The implementation of NDCs requires an estimated investment of $9.3–$15.5 billion from 2020 to 2030, posing significant financing challenges (EPA & MESTI, 2021).

Strategic Plans for Agricultural Resilience: Recognizing agriculture's vulnerability to climate impacts, the Ministry of Food and Agriculture developed the Medium-Term Agricultural Plan. This plan integrates climate adaptation strategies, such as:

- Promoting drought-resistant crops and sustainable irrigation.
- Enhancing weather forecasting services for farmers.
- Implementing community-based reforestation programs to mitigate soil degradation.

Disaster Risk Reduction Initiatives: To align with the Sendai Framework for DRR (2015–2030), Ghana has implemented several initiatives:

- Establishing rapid response units for disaster management.
- Developing community-based disaster risk reduction programs.
- Strengthening early warning systems to reduce the impact of floods and droughts.

The National Adaption Plan (NAP). The National Adaptation Plan (NAP) process, initiated under the United Nations Framework Convention on Climate Change (UNFCCC) in 2010, aims to address medium- and long-term climate adaptation needs in developing countries. This iterative, country-owned planning approach enables nations to identify, address, and review their evolving adaptation requirements. In Ghana, the NAP process aims to provide a framework for implementing adaptation actions as outlined in national policies and strategies, within the broader context of sustainable development. By enhancing adaptation planning, the NAP process helps build local adaptive capacity to address climate change, reduce poverty, improve livelihood opportunities, and enhance gender equality.

The primary goals of the NAP process are to reduce vulnerability to the adverse impacts of climate change by building adaptive capacity and resilience and to integrate climate change adaptation into fiscal, regulatory, and development policies, programmes, and activities. The process also supports the coordination of climate change adaptation efforts at the national level, fostering collaboration among ministries and between the government and its development partners, and accelerating strategic investments in climate-resilient development.

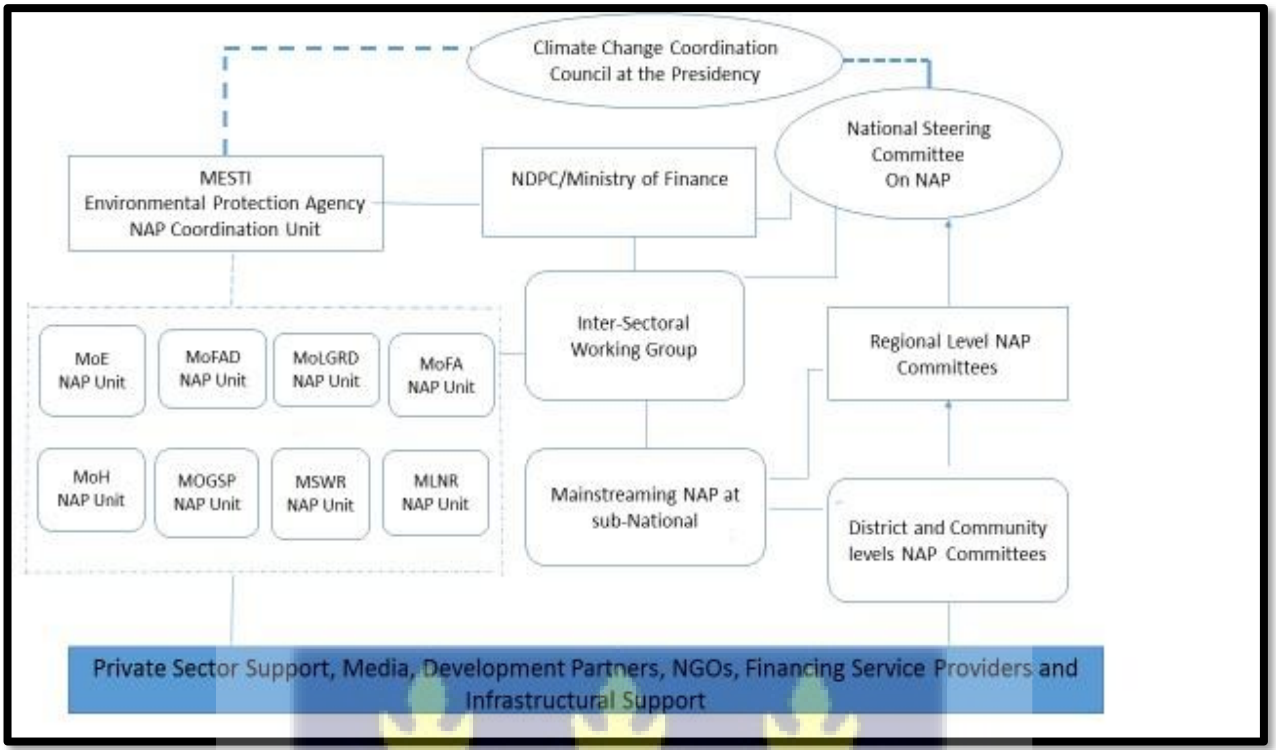


Figure 2.4: Proposed Framework for NAP Planning and Implementation Source: EPA, 2022

2.13 Thesis Framework

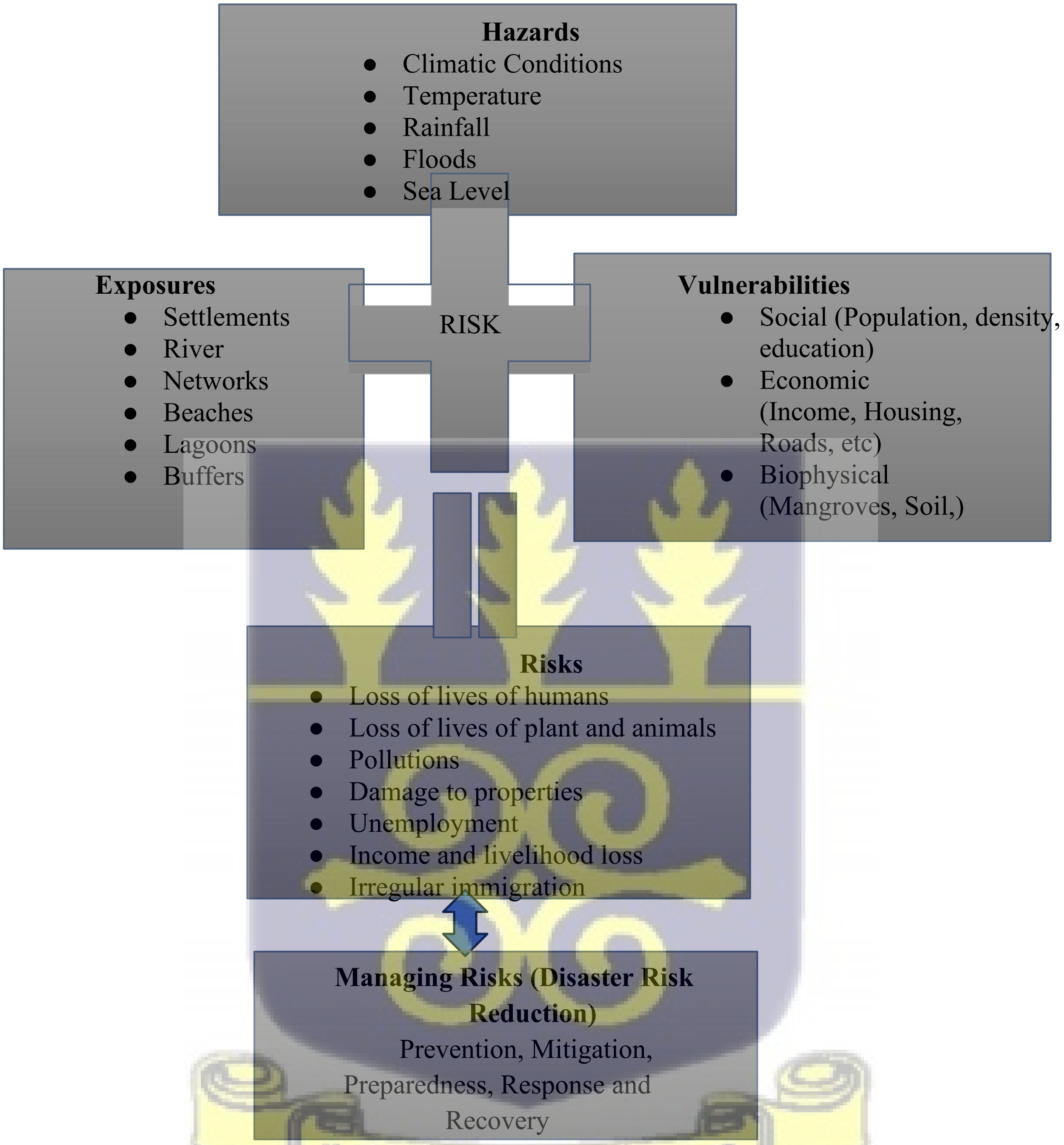


Figure 2.5: Framework on Climate Change and Flood Risk Management

Source: Author's Work, 2024

The framework illustrates the complex interplay of factors contributing to flood risk. It begins by identifying the *hazards*, which are the underlying environmental stressors. These include variations in climatic conditions (e.g., changes in weather patterns and increased frequency of extreme weather events), temperature fluctuations (affecting precipitation and evaporation), rainfall (both intensity and duration of rainfall events), the occurrence of floods themselves (their frequency and severity), and the ongoing rise in sea level due to climate change. These hazards do not operate in isolation; they interact with *exposures*, the elements susceptible to damage from flooding. These exposures include human settlements (and their population densities), river systems, infrastructure networks (roads and communication lines vital for response and evacuation), beaches (facing coastal erosion), lagoons (prone to inundation), and naturally occurring or man-made buffers.

The susceptibility of these exposures to the hazards is further influenced by *vulnerabilities*. These vulnerabilities are pre-existing conditions that amplify the negative impact of the hazards. They can be categorised as social (population density, levels of education, access to information and communication technologies, social cohesion within the community), economic (income levels, quality of housing, economic dependence on flood-prone sectors), and biophysical (the health and extent of mangrove ecosystems, soil types, and the quality of existing infrastructure, land use patterns). The combined influence of hazards, exposures, and vulnerabilities determines the level of *risk*, representing the likelihood and potential severity of flooding events. The central position of "RISK" in the diagram emphasises this crucial intersection.

The framework's second aspect focuses on the consequences of flood risk and the strategies needed to manage it. The *risks*, which represent the consequences of flooding, are categorized as follows: loss of human and animal life, damage to property, water and land pollution from contaminated floodwaters, unemployment stemming from the damage to livelihoods and infrastructure, income and livelihood loss from damage to homes, businesses, and agriculture, and irregular migration resulting from displacement.

Effective flood risk management requires a multifaceted approach encompassing several core strategies. *Disaster risk reduction*, as depicted in the framework, involves: *Prevention*, focusing on proactive measures such as land-use planning that minimizes development in high-risk areas, protecting and restoring environmental buffers such as mangrove forests, and upgrading infrastructure to enhance resilience. *Mitigation* aims to reduce the severity of flooding through measures such as enforcing building codes and implementing early warning systems. *Preparedness* involves community education and awareness campaigns to build knowledge of flood risks and appropriate responses, effective emergency planning, and securing necessary resources beforehand. *Response* focuses on immediate actions during a flood event, including organized evacuation strategies, search and rescue operations, and damage assessments. Finally, *Recovery* addresses the long-term consequences by supporting the rebuilding of damaged infrastructure, economic recovery efforts, and provision of essential psychosocial support to affected communities. This comprehensive approach, drawing on Das et al. (2020), is essential for minimizing the devastating impacts of floods and building more resilient communities.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

This chapter addresses major issues including the profile of the study area and study design. The chapter is divided into four sections. They included the geographical and demographic characteristics of the study area, socio-economic conditions of the study areas as well as the physical background, demographic characteristics, climate conditions, poverty, drainage patterns and the economy of the areas. The chapter provides detailed methodology involving the study design, study population, types and sources of data, sample and sampling approach, as well as data analysis.

3.1 Profile of the study arear

The profile of the study area described the Region, District and communities selected. The Basin is broad, and the lower part of the Basin is also large. There is sometimes distinction between the Lower Basin and Delta. Some studies indicated that the Delta is part of the Lower Volta River Basin, especially areas close the estuary. Sometimes the two are used synonymously as in the work of Hossen et al (2020).

3.2 Description of Study Area

The study focuses on Four Districts (generic) in the Lower Volta Basin or the River Volta Delta which comprises ten (10) Districts (Central Tongu, North Tongu, South Tongu, Ningo Prampram, Ada East, Ada West, Ketu North, Ketu South, Akatsi South, Anloga and Keta). Out of the ten

Districts, Ada East, Anloga, Keta and Ketu Municipal Assemblies were selected for the study. Again, 2 communities each from the four districts made up a total of 8 Communities selected for the study and they include Totope and Ada Foe (Ada East), Nyanyui and Dzita (Anloga) Keta and Kedzi (Keta Municipal) as well as Adafianu and Brekuso (Ketu South). The Districts (generic term) are all located along the coast.

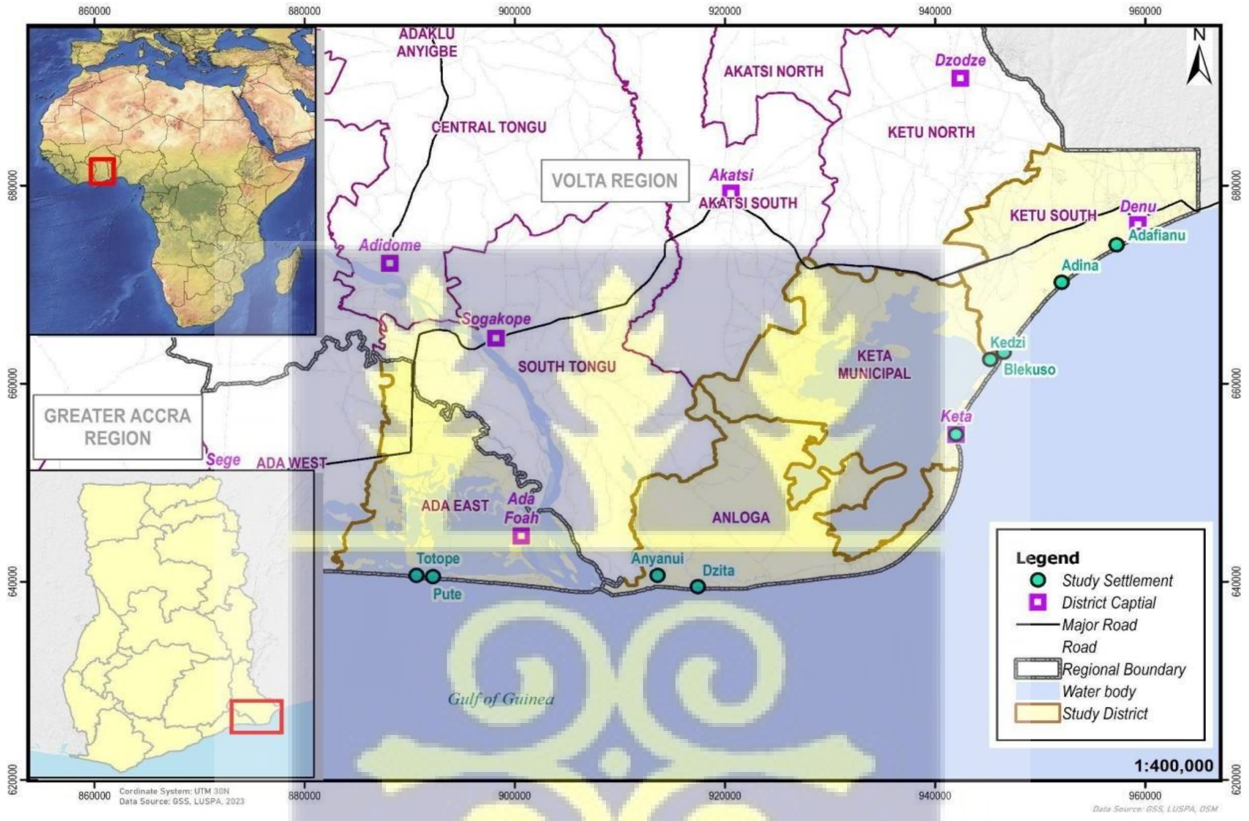


Figure 3.1: Map of study areas
Source: Adopted and modified from Hossen et al, 2019.

3.3 Location and Size of Study Area

The Volta River basin covers about 400,000 km^2 (Van de Giesen et al. 2010). The river basin is a trans-national catchment shared by six riparian countries. The watershed is 40% in Ghana, 42% in Burkina Faso, 6% in Togo, 5% in Mali, 4% in Benin and 3% in Côte d'Ivoire (Oguntunde et al.

2006). The Volta River has three main tributaries namely the White Volta, the Black Volta and the Oti River (Ibrahim et al. 2016). It is one of the main sources of sediment supply to the Gulf of Guinea (Goussard and Ducrocq, 2014). The river drains a predominantly sandstone catchment that also includes a wide variety of lithologic terranes covering an area of about 390,000km2 (Anthony, 2015). The Volta River presently has a single outlet channel to the sea at Ada, which is associated with a relatively large spit. The large spit is as result of a direct outgrowth of a natural change in the location of the mouth of the river (Anthony et al. 2016). Located at the lower portion of the basin is the Volta delta, which is defined as the 5m contour within the Accra-Ho-Keta Plains (Appeaning Addo et al. 2018).

The Volta River Delta Basin constitutes the biggest delta in Ghana, covering a total area of 4562 sq.km, which is within the lower part of the Volta River basin, a transnational catchment shared by six countries. The delta has a diverse economy including agriculture, fisheries, salt harvesting and sand mining as well as tourism, with the agricultural and fishing sectors providing significant employment. The Ada East District, which is one of the areas in the lower Volta Basin is located within Latitudes 5°45 and 6°00 (North) and Longitudes 0°20 to 0°35 (East) respectively. The district is bordered to the north and east by North Tongu District (in the Volta Region), to the south by the Gulf of Guinea, and to the west by Ada West District. The total area of the district is 289.783 square kilometres.

Similarly, Anloga District is located east of the Volta estuary, about 160km to the east of Accra, off the Accra-Aflao main road and lies within Longitudes 0.53E and 0.89W and Latitudes 5.47N and 5.79S. It shares common borders with Keta Municipality to the East, South Tongu District to the West, Akatsi South District to the North and the Gulf of Guinea to the South. The total land area for the district is 90,624.9 acres comprising 36, 855.4 acres of Lagoon and Volta River, 18, 986.4 acres of wetlands and 34,801.1 acres of arable land. Also, the Keta Municipal, with Keta as the capital is one of the 18 Administrative Municipal/Districts of the Volta Region. The Municipality lies within Longitudes 0.30E and 1.05W and Latitudes 5.45N and 6.005S. It is located east of the Volta estuary, about 160km to the east of Accra, off the Accra-Aflao main road. It shares common borders with Akatsi South District to the north, Ketu North and Ketu South Districts to the east, South Tongu District to the west and the Gulf of Guinea to the south.

Out of the total surface area of 446km^2, approximately 132km^2 (about 29.6 per cent) is covered by water bodies. The largest of these is Keta Lagoon, which is about 12 km at its widest section and 32km long. Many contemporary problems are recognized in the Volta delta, especially the erosion and flooding of the open coast fringe, such as at the town of Keta. Flooding was a bigger problem in earlier times; however, since the construction of dams, starting with the Akosombo Dam in 1964, flow from upstream has been controlled, but sediment supply has been considerably reduced, leading to significant shoreline recession (Addo et al, 2016).

Additionally, the Ketu South Municipality is in the southeastern most region of Ghana, and it is bordered by the Republic of Togo to the East, Keta Municipality to the West, Ketu North Municipality to the North, and the Gulf of Guinea to the South. The Municipality is located between latitudes 6º 3″N and 6º 10″ N, and longitudes 1º 6″ E and 1º 11″ E. It has a coastline that measures 23.81km. The municipality covers a land area of 261 km², which accounts for 2.8 percent of the total regional land area, and it is the second smallest in terms of land size and serves as Ghana's primary eastern boundary with Togo. Generally, the Volta Delta portends a high level of vulnerability expressed in the form of erosion and flooding of the open coast fringes, some which is attributable to the construction of dams, starting with the Akosombo Dam in 1964 (Addo et al, 2016).

3.3.1 Geology and Water Resources

The geology of the Volta River Delta is generally Quaternary which is made up of alluvial sand, silt and clay (Jayson-Quashigah et al. 2013). The delta coast is bounded by a narrow shelf 15–33km width, and characterised by a uniform, moderately steep shore face with a gradient of between 1:120 and 1:150 down to 15 m, which is considered as the close-out depth for significant wave-induced sediment movement on this coast (Rossi 1989; Anthony 2015). The Volta River historically carried large quantities of sediment, including coarse-grained sand, to the sea and this sediment was deposited at the river mouth, forming the modern delta (Nairn et al., 1999).

3.3.2 Climate and Vegetation

Climate variability has caused a shift in the start of the rainy season. The delta lies in the Coastal Savannah climatic zone with two rainy seasons (Ofori-Sarpong and Annor, 2001). The first rainy season begins in May and ends in the mid-July and (second season begins in mid-August and ends in October. The average annual rainfall is about 780mm, which falls primarily during the two rainy seasons (EPA UNDP, 2012). Nevertheless, the heightened precipitation intensity during the rainy season leads to regular occurrences of flooding in the Volta Delta. Coastal flooding is facilitated by energetic swell waves, rising sea levels, and storm surge, which are further encouraged by the relatively low topography. The delta coast is characterized by its dynamic nature, with elevated ridges composed of soft rocks.

This natural composition makes the coast vulnerable to flooding, erosion, and the gradual retreat of the shoreline from Prampram to Aflao (Ly, 1980). The areas have a relative humidity with high average of 65% at mid-afternoon to 95% at night. Data available shows that there is very little variation in temperature throughout the year (Ghana Meteorological Agency, 2013). The mean monthly temperature ranges from 24.7°c in August (the coolest) to 28°c in March (the hottest) with a relatively high annual average of 26.8°c (EPA and UNDP, 2012). The Volta basin zone comprises two vegetation types: wetlands and dunes. The wetlands consist of mangroves with estuaries and lagoons. Their protection as coastal wetland is very important to the long-term sustainability of fish, and which are poached by people.

3.4 Demographic Characteristics

3.4.1 Study Population

The 2021 Ghana Statistical Service Census shows a population of 253,122, with 52.1% females and 47.9% males, in the Ketu South Municipality, which accounts for 15.3% of the Volta Region due to the significant growth in immigrants. The sex ratio is 88.9 men per 100 females, with a higher number of females. The population of Keta Municipality is 78,862, with 46.9% males and 53.1% females. The Anloga district's total population is 94,895, with 59.9% females and 47.1% males.

Table 3.1: Population for the selected district from 2010 to 2020

Districts	YEAR	TOTAL	MALE	FEMALE
Anloga	2010	160,756	75,648	85,108
	2020	94,895	44,709	50, 189
Ketu South	2010	253,122	121,277	131,845
	2020	259,270	124,223	135,047
Keta Municipal	2010	147,618	68,556	79,062
	2020	78,862	36,986	41,8796
Ada East	2010	71, 671	34,012	37,659
	2020	76,411	37,034	39,377

Source: Ghana Statistical Service PHC, (2010 and 2021)

Anloga district is highly urbanized, with over half of its population residing in urban areas (GSS, 2021). The population density in the Volta Delta is 151 individuals per square kilometre, whereas, across Ghana, it is 103 individuals per square kilometre. In the Volta Delta, both the Total fertility rate (3.6) and the yearly population growth rate (1.6%) are lower than the national norms of 4.0 and 2.1% respectively. Approximately 66% of the delta population currently resides in rural areas. However, it is anticipated that by 2035, over 50% of the population in the Volta Delta will have migrated to urban areas (Codjo et al., 2019; Osei-Wusu Adjei et al., 2018).

3.4.2 Migration and resettlement

The Ga-Dangme and Ewe ethnic groups were the first to migrate into the Volta Delta, as reported in the sixteenth century. Migration to and from the delta has occurred since this period, with out-migration being the primary trend. In the Anthropocene, the Volta Delta is primarily a region that sends out more migrants than received. However, there are few districts within the region, like

South Tongu, Ketu South, Akatsi South, Ada East, Ada West, and Prampram, that receive more migrants than they send out. People from migrate from the delta areas citing economic opportunities, such as work, education, and to re-unite with family (Codjoe et al., 2017b).

3.4.3 Ethnic group (Ada or Damgbe and Ewe)

There are two main ethnic groups in the Volta Delta Ewe and Ga-Dangme and both are patrilineal. The dominant religion in the Volta Delta areas is Christianity (72%), followed by Traditional African Religion (22%) and Islam (3%). The illiteracy rate for the population aged 15 years and above is about 30%, with higher illiteracy rates for females compared to males Infrastructure, housing and Roads

The primary types of housing are compound houses and separate structures, with slightly more than 60% of households owning their dwelling units (Ghana Statistical Service, 2013). The primary materials used for the outer walls of buildings are predominantly concrete or cement blocks, while the primary source of illumination is the kerosene lamp. Immediately after that, there is the presence of electricity that is linked to the national power network. Biomass, including wood, charcoal, and sawdust, is the primary fuel source for cooking in households. Although pipe-borne water is the primary source for drinking and household use, it is not uncommon to find other unimproved sources such as groundwater from wells and open water sources in the delta area.

3.4.4 Tourism and Hospitality

The Volta Delta boasts significant tourist attractions, including marine turtle breeding sites situated in the estuary at Totope, Lolonya, Akplabanya, and Kewuse. Additionally, visitors can engage in bird watching at the Songhor and Keta Lagoons, which are designated wetlands and Ramsar sites that serve as a sanctuary for approximately 80% of migratory birds passing through Ghana. Other noteworthy attractions include fetish shrines, sacred groves, and traditional festivals. Resorts situated along the Volta River offer water-based recreational activities and serve as a magnet for migrants seeking employment in the tourist sector (Codjoe et al., 2017).

3.5 Study Design and approaches

The study design was largely descriptive both qualitatively and quantitatively. It was to describe the current and future occurrence of climate change risks, the hazards, exposures and vulnerability. It was longitudinal with space and time demonstration of historical data of temperature and rainfall for at least 30 years, and the projection of floods, sea level rise and risk. The study also was based on exploratory design mainly in exploring the risk reduction strategies and measures.

A mixed-method approach was adopted for the research, combining both quantitative and qualitative methods was used, and this ensures robustness, validity (Creswell et al., 2003), as well as triangulation between each mixed methods (Denzin, 2006). Data was gathered through participatory methods to test the theory underlying the research (Saunders et al, 2012). The participatory action research method paved the way to give each participant the opportunity to describe their awareness of the flood risk and governance method implemented in the areas and whether they are effectiveness in addressing flooding issues confronting them (Vaessen, 2010). For the quantitative data, questionnaires were used to collect primary data on knowledge and perceptions regarding changes in climate, effects, and vulnerability and residents. Also, in-depth interviews, key focus group discussions and observations were the key data collection instruments appropriate for collecting qualitative data suitable for qualitative research (Crouch and McKenzie, 2006).

3.6 Types and Source of Data

3.6.1 Primary Data (quantitative and qualitative)

Primary data based on knowledge and perceptions of changes in climate conditions of the area including rainfall, temperature seasonal variation or fluctuations, flood disasters, vulnerable conditions of the people and adaptation measures were gathered. Concerning the background information of the respondents, data was gathered on age, marital and educational status of the respondents. Others included income levels and occupancy ratios to determine people's vulnerability due to housing conditions. The perception and experience of flood disaster was interesting, as respondents expressed their views on the flooding situation in the city. At the same time, data on how communities adapt to the disaster situations was also gathered. Secondary Data.

The secondary data was gathered from books, book-chapters, journals, articles, working papers, newspapers, published and unpublished conference papers. These were pre-existing literature, which serve as secondary sources of information to the study. As part of the secondary data, climate data was gathered from Ghana Meteorological Agency (GMet), specifically from Kotoka International Airport Station. Data included monthly and annual average rainfall and temperature records. The data covered 1990-2020 and was used to complement knowledge and perceptions expressed by people on variabilities and changes experienced in climate conditions.

In addition, socio–economic and physical demographic characteristics data was gathered from the Four District Assemblies in the Lower Volta Basin. This included the profile of the Basin and other available documents from the district. The flood record was gathered on and the Four (4) District Assemblies, NADMO and Ghana Hydrological Department. These included the recent flood records, risks areas and communities, as well as digital elevation model (DEM) data to assess the impact of climate change on the surface area of the basin.

3.7 Data Collection Methods, Instruments and Techniques

3.7.1 Survey Questionnaires

Quantitative Data were gathered from the field using questionnaires. The Questionnaires were designed with closed ended and a few open-ended questions. It questionnaires initiation collected data on respondents' personal profile including age, sex, educational background, income, location and number of years living in the communities. It collected data on respondent's knowledge on flood risks, including, temperature and rainfall, flooding, socio-economic conditions. It was used together the primary data on knowledge of the respondents on flood reduction and management practices.

3.7.1.1 Sample Size and Sampling Design Survey Questionnaires

A sampling for the Survey Questionnaires was done to select the sample size and demonstrate the sampling design for the data collection. While the sample size was done using Solvin Formula (Yamane, 1967) (cited in Oribhabor, 2019). (Refer to Table 3.3).

A multi-stage sampling design was done as referenced to Ghana Statistical Service (GSS) (1999; 2022 and Kofi et al (2020) using probability and non-probability sampling techniques while ensuring that the right forms of the random and purposive sampling are done accurately. Multi-stage Sampling Method was used and purposive sampling and simple random sampling were used (Etikan et al., 2016; Kofi et al, 2020).

Purposive Sampling was used to first select the Administrative Regions that shared the Lower Volta Basin (Delta) including Greater Accra and Volta Regions. Again, the Purposive Sampling was used to select the districts, including the Ada East in Greater Accra Region and the rest (Anloga, Keta and Ketu South) and communities, including Totope, Ada Foah, Nyanyui, Dzita, Kedzi, Keta, Blekusu and Adina located in the Basin, near coast and close or within the Delta. Also, the purposive sampling method serves as the need to analyse the flooding not only for the flash and fluvial, but also due to sea level rise and inundation. Also was to calculate their Shorelines based on erosions.

The two regional, four (4) Municipalities and Districts and the eight (8) communities were also clustered in terms of population. The communities' populations were respective total population and not households. Systematic sampling was adopted and every

The sampling approach used to select households for interview in the selected coastal communities. The design follows standard survey methods employed by national statistics offices and international household surveys, specifically was in reference to the GLSS (Ghana Living Standards Survey) and GDHS (Ghana Demographic and Health Survey)

Sample Size

The study used Yamane's (1967) finite-population formula to determine the minimum required number of households for interview at a 5% margin of error and 95% confidence level:

$$n = N/((1 + N * e^2))$$

Where N = 84681 (total population across all listed communities) and e = 0.05. Substituting gives:

n = 84681 / (1 + 84681 * 0.05^2) ≈ 400. The final target sample was therefore set to 400 households.

Sampling procedure

Sample sizes were allocated to communities in proportion to their population shares using:

$$n_i = \left(\frac{Population\ of\ the\ Community}{Total\ Population}\right) x\ Overall\ Sample$$

The resulting allocation and the implied systematic sampling interval (k_i) are shown in Table 3.2.

Table 3.2: Resulting allocation and the implied systematic sampling interval (k_i)

District	**Community**	**Population**	**Sample Size**	**Sampling Interval**
Ada East District	Ada Foah	7,095	34	209
Ada East District	Totope	1,031	5	206
Anloga District	Anloga	29,813	141	211
Anloga District	Nyanui	3,619	17	213
Keta Municipal	Keta	23,207	110	211
Keta Municipal	Kedzi	8,355	39	214
Ketu South Municipal	Blekusu	6,514	31	210
Ketu South Municipal	Adina	5,047	24	210

Systematic Household Sampling Procedure

Within each community, all households were listed to form the sampling frame. Systematic sampling was then applied as follows:

(i) Compute the sampling interval: $k\_i = H\_i/\ n\_i,$ where H_i is the total number of listed households and n_i is the allocated sample size for community i.

(ii) Select a random start r_i uniformly from 1 to k_i.

(iii) Select households numbered $r_i,\ r_i + k_i, r_i + 2k_i$, ... until n_i households are obtained.

Within each selected household, only members aged 18 years and above were eligible for interview.

3.8 Focus Group Discussion

FGDs was organised to include a cross section of diverse community members who have direct experiences and linked to the issues understudy. The FGDs offered participants the opportunity to contribute to the various concerns that bothers on climate change perception, flood risks, flood management practices in their communities and its impact on their wellbeing. (Vaessen, 2010; Larson, 2013; Roncoli et al., 2009).

Plate 3.1: FGD In Nyanyui (incl.Titeti and Fuveme), Anloga, Totope, Blekusu

Source: Field Work, 2024

FGDs were regarded as beneficial for allowing group interaction that might be absent in one-on-one interviews and for exploring varied understandings of climate change or variability in the areas. A total of FGDs were conducted, with each community having 2 sets of discussions composed of 2 distinct groups: female and male. Participants for the FGDs were purposively selected with the help of local people, ensuring fair representation of various age brackets.

The discussions were recorded using audio-visual methods and subsequently transcribed for analysis. Five focus group discussions (FCommunities) were conducted across 13 communities regrouped into five and hosted by the Study Area Communities with more priority on women. Field notes were taken, and the discussions were both recorded and transcribed. The communities involved in the FGDs included the Fuveme, Atiteti and Nyanui Group; Dzita, Srogboe and Anloga Group, Azizanya, Ada Foah and Totope Group, Keta, Kedzi and Gavedzi Group, and Brekusu, Adina and Adafianu Group. These were selected based on their geographical proximity and similar characteristics. The host locations for the discussions were Fuveme, Anloga, Totope, Kedzi, and Brekusu. The researcher facilitated the discussions, with assistance from a NADMO official for translation when necessary.

A focus group discussion guide was developed to steer the conversation, divided into four sections for data collection: (1) Hazards, (2) Exposure, (3) Vulnerability, and (4) Management (Adaptive capacity/Resilience). This structure aimed to identify indicator variables to formulate household survey questions and assess community vulnerability. Table 12 lists the participants in each community for the FGDs, and Figure 12 provides a cross-section of the discussions.

Key topics discussed included:

- **Climate Change Hazards**: Participants were asked about climate change conditions, rainfall patterns, the nature and types of floods, the timing and frequency of floods, sea level rise, river and lagoon floods, and flash floods.
- **Community Exposure**: This section aimed to determine the community's vulnerability to natural or climate change-induced hazards and their environmental awareness. Questions focused on environmental threats, their consistency over the past five years, and their impact

on the community's physical, economic, and social life.

- **Community Vulnerability, Susceptibility**: Discussions centered on factors influencing their exposure to hazards and disaster risk. Participants were asked what made their buildings susceptible to environmental threats, which social, physical, and financial categories of people were most vulnerable, and how many community facilities (such as schools, markets, health facilities, etc.) had been affected by these threats.

- **Management, Adaptive Capacity, and Resilience**: This section explored the community's resilience strategies. Questions included how the community prepares for floods, the measures they take to reduce vulnerability, the infrastructure in place to withstand flooding, available livelihoods and alternative livelihoods, and the community's priority options for flood management. Probing was conducted to gather comprehensive information on each question

3.9 In-depth Interview

The methodology employed in-depth interviews to collect detailed, personal, and contextual information from key informants, experts, and organizational representatives. These interviews were intensive, one-on-one sessions with a small number of participants to delve deeply into their thoughts, feelings, and experiences regarding flood risk components (hazards, exposure, and vulnerability) and flood risk management, as highlighted by Kvale (2007) and Patton (2015).

Representatives from various institutions at the national, regional, and district levels participated, including the Keta Municipal Assembly, Anloga District Assembly, Ada East District, Ghana Meteorological Agency, Environmental Protection Agency, National Disaster Management Organization, Assembly members, Ministry of Food and Agriculture, Ministry of Fisheries and

Aquaculture Development, Ministry of Local Government, Decentralisation and Rural Development, Volta Regional Coordinating Council, Greater Accra Regional Coordinating Council, Ministry of Sanitation and Water Resources, Ghana Tourism Development Authority, Ghana Health Services, Coastal Development Authority, and Volta River Authority. Additionally, representatives from the Association of Peasant Farmers, Association of Fishers and Fishmongers, Market Women, and Traditional Council were engaged.

The key informants were purposively selected as they were stakeholders critical to flood management in the basin. This purposive sampling was chosen for its efficacy in selecting individuals based on their expert knowledge of the issues under investigation, as per Abrams (2010). Participants from their respective organizations, groups, communities, or associations were chosen based on their position and experience related to the study topics. The interviews, conducted in English and Ewe using a structured guide, were digitally recorded with consent and transcribed for analysis, following the methodology of Tongco (2007).

3.10 Data Analysis Methods

3.10.1 Qualitative Data Analysis

Data were analyzed using a thematic analysis approach, focusing on the identification, analysis, and interpretation of patterns or themes within transcripts according to Byrne (2022) using the NVivo software. Data collected from the notes and audio tapes were transcribed verbatim by the researcher. Descriptive coding was used to code the transcripts, which were then grouped to generate themes.

Preparation of Data:

- **Transcription:** All audio recordings from the interviews were transcribed verbatim.

- **Management of Data:** All transcribed data were uploaded into NVivo, facilitating effective management and analysis of data, thereby enabling data storage, retrieval, and organization of results (Bitencourt & Santos, 2016).

Familiarization with Data:

- **Data Familiarization:** Through the process of transcribing, conducting interviews, and collecting observation notes, the researcher became familiar with the content and intricacies of the data (Chan, 2013).

Coding:

- **Coding:** Using NVivo software, codes were generated. Descriptive coding was applied as findings from transcripts were coded as they were, without interpretation, based on the research objectives. These codes were then grouped to form themes.

3.10.2 Analysis of Climatic Conditions

The data for Ada was collected from a coastal Gauge station at 05°47'N latitude and 00°38'E longitude, covering the period between 1960 and 2023. Similarly, the data for Keta was obtained from another coastal Guage station situated at 06°00'N latitude and 00°36'E longitude, covering the same period. The data was analysed along the following variables:

- *Average Annual Rainfall trends in the Ada*
- *Rainfall Anomalies for Ada*
- *Maximum Temperature trend (Ada)*

- *Minimum Temperature trend (Ada)*
- *Keta Rainfall Trends*
- *Rainfall anomaly in Keta*
- *Maximum Temperature Trend (Keta)*
- *Minimum Temperature trend (Keta)*
- *Average Yearly Rainfall of Ada and Keta*
- *Total Yearly Rainfall and Adjust Prediction of Ada and Keta*
- *Monthly Average Temperature Across All Years for Ada and Keta (Monthly Temperature)*
- *Yearly Average Temperature Trend for Ada and Keta (Annual Temperature)*
- *Yearly Average Temperature Trend with Trend Line for Ada and Keta (Annual Temperature with Trendline)*

Descriptive Statistics: Calculated temperature and rainfall mean, median, variance, and standard deviation for monthly data.

Trend Analysis: Conducted using linear regression models to identify and quantify trends. As well as Observed changes and patterns over time.

Future Projections: Forecasted future temperature and rainfall patterns based on established trends.

Rainfall Distribution: Divided into four distinct seasons: Dry (Dec-Feb), Major Wet (Mar-Jun), Seasonal Break (Jul-Aug), Minor Wet (Sep-Nov). In application of the Geographical Information (GIS):

Data Preprocessing: Data was cleaned and converted for compatibility with GIS software.

Data Integration: Rainfall and temperature data were integrated with spatial data in GIS.

Spatial Analysis: GIS tools overlaid rainfall and temperature data on spatial maps and Thematic maps visualized spatial distribution of these variables.

Spatial Interpolation: Techniques like Kriging and Inverse Distance Weighting (IDW) filled gaps in data as well as Interpolated surfaces provided a comprehensive understanding of data distribution.

Zonal Statistics: Calculated for zones like Ada East and Keta. Compared average rainfall and temperature values to identify spatial variations.

Spatial Correlation Analysis: Explored relationships between rainfall and temperature patterns.

Spatial Modelling: Developed to predict future patterns based on historical data and Models validated using statistical techniques and spatial validation methods.

Visualization and Interpretation: Results were visualized through maps, charts, and graphs to aid in understanding spatial patterns and relationships.

3.10.3 Flood Hazards and Extreme, including Sea Level Rise

Bathtub Model in ARCGIS was employed. The Bathymetric TIN (Triangulated Irregular Network) or Bathtub Model in ArcGIS is a 3D representation of a waterbody's depth, used for hydrological analysis and visualization. It was applied based on ArcGIS (ArcMap or ArcScene), Bathymetric data (depth measurements or contours) and DEM (Digital Elevation Model) or TIN data

The first major action was on Data Collection and as part of this, Digital Surface Model (DSM) was employed. A 12m DSM from L3HARRIS was used for the study area. The DSM captures surface features such as buildings, vegetation, and other structures, which could influence the accuracy of flood extent projections. *Consideration*: Since DSM data includes surface features, it may overestimate flooding in areas with tall buildings or vegetation. This will be addressed during the preprocessing stage.

In terms of the Sea Level Rise/ Projection (SR/P), the model used the Shared Socioeconomic Pathways (SSPs) from the latest IPCC assessment report, instead of the older Representative Concentration Pathways (RCPs). Projections were made for two SSPs: SSP2-4.5 (moderate emissions) and SSP5-8.5 (high emissions). Sea-level rise thresholds for the 17th percentile (lower bound) and 83rd percentile (upper bound) was used to capture uncertainty in the projections.

In terms of timeframes, the IPCC timelines, including short term (i.e., 2020-2040 years); Midterm (i.e., 2040-2060 years period); Long term (i.e., 2080-2100 years period) were defined. A Hydrographic Data, a specific data on water bodies and drainage networks in the area was used and thus, to help refine the simulation of connected flooding regions.

Secondly, data processing was done employing the DSM Preparation including smooth or filtering out surface features to provide a better representation of the ground elevation. This step ensured that the flooding was not overestimated in areas with tall buildings or vegetation. The DSM Preparation also aided the use of the *Focal Statistics* tool in ArcGIS to reduce the effect of outliers caused by high-rise buildings or dense tree canopies.

As part of the data processing DEM Transformation approach was deployed, where the DSM to a Digital Elevation Model (DEM) were converted to enable better represent the bare earth surface by subtracting surface features. Data processing on the Sea-Level Rise Thresholds was done for each timeframe (2020-2040, 2040- 2060, and 2080-2100), and by doing so created SLR thresholds based on SSP projections for the 17th and 83rd percentiles. These thresholds were applied to the DSM to simulate flooding.

By the third major step, running the Bathtub Model was deployed, including the flooding simulation, using *Raster Calculator* in ArcGIS, simulate flooding by comparing the DSM values to the defined sea-level rise thresholds. For each year range, the conditional expression appeared as:

Con(DSM < SLR_threshold, 1, 0)

This produced a binary raster where areas below the SLR/P threshold are flagged as flooded (1), and areas above are marked as not flooded (0).

Data processing on the Hydrological Connectivity used the *Region Group* tool to identify hydrologically connected areas, while ensuring that the modelled flooding areas are connected to water bodies and remove any isolated depressions that are not likely to be flooded using the *Set Null* tool.

In terms of the Post-Processing and Analysis marking the fourth stages, Flood Depth Calculation was done. It calculated the depth of inundation by subtracting the DSM from the sea-level rise threshold using the Raster Calculator:

i.e., SLR_threshold - DSM

This step provides a raster that shows the depth of flooding for each scenario, helping to analyze the severity of potential inundation.

Flood Extent Mapping was done to visualize the flooded areas using *Reclassify* to assign different symbologist or colours based on flooding scenarios (short-term, midterm, and long-term).

Land Use and Population Impact was done to overlay land use maps, population density layers, and critical infrastructure to analyse the impact of flooding on various sectors. Similarly, *Zonal Statistics was used* to calculate the percentage of land use types (residential, commercial, agricultural) and population affected by flooding in each timeframe and SSP scenario.

As part of the Step 5, including Validation and Sensitivity Analysis, a validation was done to compare the modelled flood extents to historical flood events or observed tide gauge data in the region. This comparison helps to validate the accuracy of the projections. Sensitivity Analysis aided efforts to evaluate the sensitivity of the model by adjusting SLR thresholds and DSM resolution to explore different scenarios and their effects on flooding extent.

It was necessary to do Scenario Analysis as part of Step 6, including Multiple Scenarios Uncertainty Boundaries as follows:

- Multiple Scenarios: Run the model for each combination of SSPs (SSP2-4.5, SSP5-8.5) and IPCC timeframes (short-term, midterm, long-term).
- Uncertainty Boundaries: Perform scenario analysis using both the 17th percentile (lower bound) and 83rd percentile (upper bound) sea-level rise projections to account for uncertainty and provide a range of possible outcomes.

Visualization and Reporting were done to eventually Map Layout, i.e., create clear and informative map layouts for each scenario, including the flooded areas under both the lower and upper bounds for each timeframe. Use legends, labels, and annotations to indicate the severity of flooding in each case. Charts and Graphs were generated to illustrate the proportion of land and population affected by different scenarios, and the use of the visualizations to highlight key findings.

Reporting: Summarize the results and include recommendations based on the differences between scenarios, emphasizing the importance of mitigation and adaptation measures for long-term planning.

3.10.4 Coastal Sea Erosion and Shoreline Analysis

This study investigates shoreline change using satellite imagery and the Digital Shoreline Analysis System (DSAS). The methodology is robust, employing a high-water mark as a proxy for shoreline position, converting raster data to vector format for analysis in ArcMap, and utilizing DSAS v5 for rate-of-change computation. The use of DSAS is advantageous due to its flexibility in applying various statistical methods, providing options for tailored analysis depending on data characteristics. The establishment of a baseline, 750m inland, and the use of regularly spaced transects (50m) ensures consistent measurement and avoids biases introduced by arbitrary transect placement. The employment of linear regression, especially when more than two shoreline positions are available, allows for a robust quantification of the rate of change and associated uncertainties, a crucial step in minimizing error propagation.

Extraction of shoreline: Shorelines were identified as the water-land boundary from the satellite images and the high-water mark was used as proxy. The water-land interface was then converted from raster to vector and exported as shapefiles for overlay in ArcMap.

Shoreline preparation and change analysis: The Digital Shoreline Analysis System (DSAS v5) which is an extension of ArcGIS, was used for the rate of shoreline change computation. DSAS was chosen due to the various statistical methods available for rate of change estimation. DSAS helped compute rate of change at user specified interval along the shoreline using different methods.

The shorelines were analysed in ArcMap using DSAS. The software is based on three components; shorelines, baseline and transects. In order to calculate rate-of-change statistics for a time series of shoreline a baseline is needed. The DSAS uses measurement baseline method to calculate rate of change statistics. The baseline is constructed to serve as the starting point for all transects cast by the DSAS application (Himmelstoss & E. Robert Thieler., 2009). The baseline was constructed by manually digitizing the shoreline about 750m onshore away from the closest shoreline. A transect was then constructed when all the inputs were ready in the database. The transects were cast at simple perpendicular to the baseline with a spacing of 50m to ensure it intercepts the shoreline positions.

Linear regression rate-of-change statistic was determined by fitting a least-squares regression line to all shoreline points for a particular transects. This rate of change was used since there were more than two shoreline positions and uncertainties were also quantified.

3.10.5 Flood Risk Mapping Method

Mann-Kendall Test for Trend Analysis: To assess the long-term trends in rainfall and temperature data for the selected weather stations, the Mann-Kendall (MK) test was applied. It is a widely used non- parametric statistical test. The MK test is particularly suited for detecting trends in time series data and is effective in analysing both linear and non-linear trends without requiring the data to follow a normal distribution. This method was chosen to analyse the trends in rainfall and temperature over the study period, as it allows for the identification of monotonic trends in the data.

Before applying the MK test, the data was organized by year and weather station. The cumulative annual rainfall and average annual temperature were calculated for each station. This ensured that the analysis captured the yearly trends across the long-term dataset. For each station and each variable (rainfall, maximum temperature, and minimum temperature), the MK test was applied separately.

Mann-Kendall Test Statistic (S):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sign}(x_j - x_i)$$

Where:

- S is the Mann-Kendall test statistic,
- x_j and x_i are values at different time points,
- $\operatorname{sign}(x_j - x_i)$ = 1 if $x_j > x_i$, 0 if $x_j = x_i$, and -1 if $x_j < x_i$.

Sen's Slope Estimator: To quantify the magnitude of the trend, the Sen's slope estimator was applied in conjunction with the MK test. Sen's slope provides an estimate of the median rate of change over time. It is calculated as:

$$\beta = \operatorname{median}\left(\frac{x_j - x_i}{j - i}\right)$$

Where:

Xj and **X**i are the values at times j and i, respectively, and j > i.

The Sen's slope gives an estimate of the annual rate of change (e.g., °C per year for temperature, mm per year for rainfall). A positive slope indicates an increasing trend, while a negative slope indicates a decreasing trend.

Analytic Hierarchy Process (AHP): The Analytic Hierarchy Process (AHP), was employed as the basis to assign weights to various flood-influencing factors. which was subsequently used to generate a flood-prone map. AHP is a structured decision-making process that enables the quantification of subjective judgements by comparing the relative importance of each factor to flood susceptibility.

Seven key factors influencing flood susceptibility were identified based on literature review, expert consultation, and the availability of data.

1) Rainfall: Represents the volume and intensity of precipitation, which is a direct contributor to flooding.

2) Slope: Reflects the steepness of terrain, affecting water runoff and accumulation.

3) Digital Elevation Model (DEM): Indicates the topography, with lower elevation areas being more prone to flooding.

4) Land Use: Identifies how land cover types influence water infiltration and runoff.

5) River Buffer: Proximity to rivers, which influences the risk of flooding due to overflow.

6) Road Buffer: Proximity to roads, which may have drainage systems or alter natural water flow.A pairwise comparison matrix was constructed by comparing the relative importance of each factor to flooding. Each factor was rated against the others using a scale ranging from 1 to 9. Intermediate values of 2, 4, 6, and 8 were used for comparisons where the importance lies between the defined points.

Table 3.3 Saaty's Fundamental Scale for Pairwise Comparison

Scale	**Description**
1	Factors are equally important
3	One factor is moderately more important than the other
5	One factor is strongly more important
7	One factor is very strongly more important
9	One factor is extremely more important

After constructing the pairwise comparison matrix, each value was normalized. This was done by dividing each entry in a column by the sum of the values in that column. The normalized matrix represents the relative importance of each factor.

The eigenvalue for each factor was also calculated by averaging the normalized values across each row. These averages provide the relative weight (priority) for each criterion. These weights reflect the overall importance of each factor in determining flood susceptibility.

Table 3.4 Pairwise Comparison Matrix for Flood Risk Criteria

	Rainfall	**Slope**	**DEM**	**Land Use**	**River Buffer**	**Road Buffer**
Rainfall	1	3	5	7	3	7
Slope	1/3	1	3	5	3	5
DEM	1/5	1/3	1	3	5	3
Land Use	1/7	1/5	1/3	1	3	3
River Buffer	1/3	1/3	1/5	1/3	1	3
Road Buffer	1/7	1/5	1/3	1/3	1/3	1

To ensure the consistency and reliability of the pairwise comparisons, a Consistency Ratio (CR) was calculated. The CR assesses how consistently the judgments were made in the pairwise comparison matrix. It is calculated using the following steps:

Consistency Ratio Formula:

$$\mathrm{CR} = CI/RI$$

Where:

CR = Consistency ratio CI = Consistency Index

RI = Random consistency index

The RI is a standard value based on the number of factors which is 1.32.

If the CR is less than 0.1, the consistency is acceptable. In this study, the calculated CR was below the threshold, indicating acceptable consistency in the comparisons.

Consistency Index:

CI = $(\lambda max - n)/(n - 1)$ere:

λ max =the principal eigenvalue and n is the number of factors.

Weighted Overlay Analysis in ArcGIS: The weights generated from the AHP were incorporated into a weighted overlay analysis in ArcGIS. Each factor was reclassified on a scale from 1 to 5, representing flood susceptibility, with 1 being least susceptible and 5 being most susceptible.

The calculated weights for this study were:

1) Rainfall: 0.35
2) Slope: 0.25
3) DEM: 0.15
4) Land Use: 0.10
5) River Buffer: 0.10
6) Road Buffer: 0.05

The weighted overlay tool was used to combine the reclassified raster layers. Each layer was input with its assigned weight, and the tool summed the weighted values across all layers to produce a final flood-prone map.

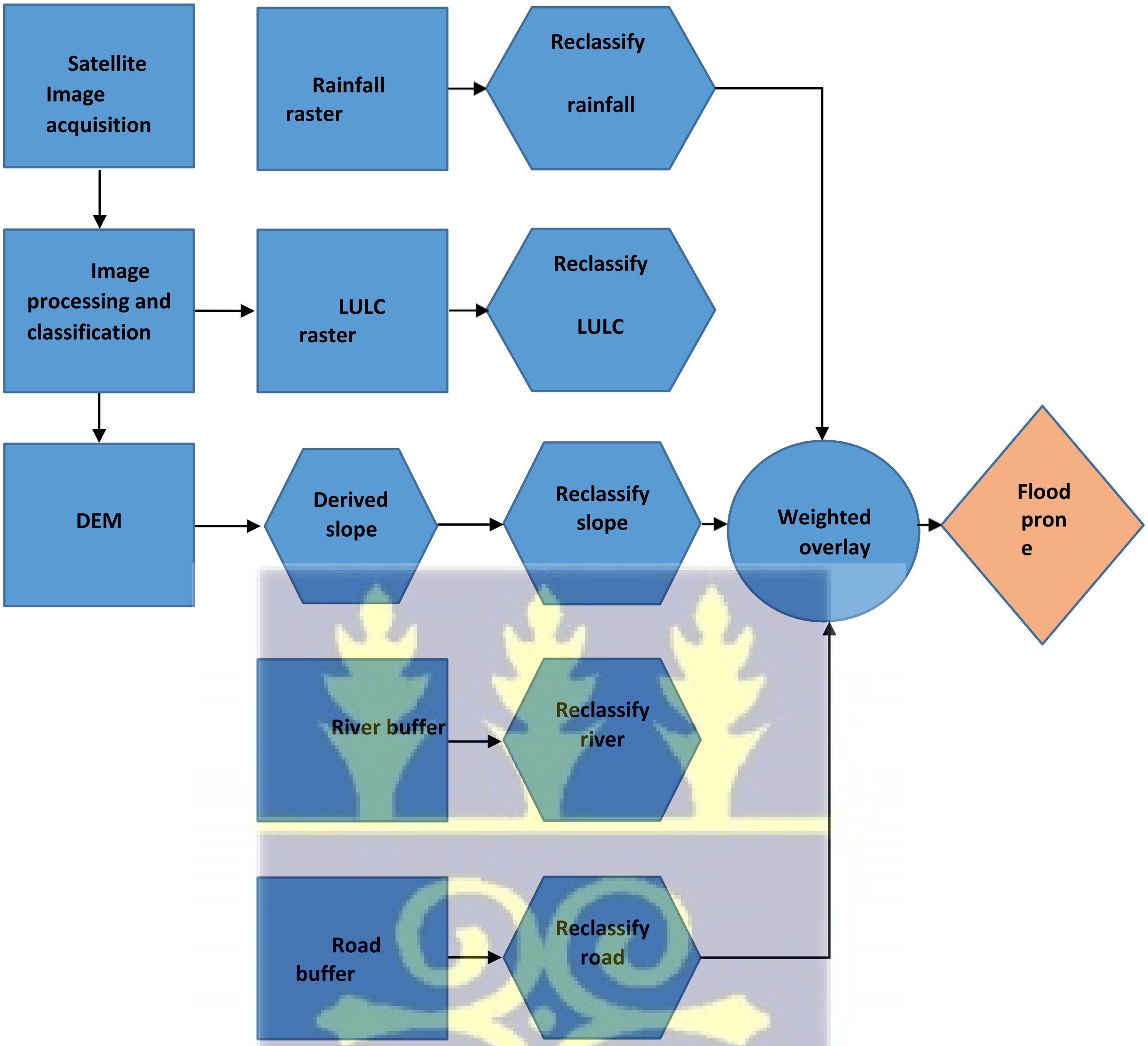


Figure 3.2: Schematic diagram for the Weighted Analysis

3.10.6 Application of Principal Component Analysis

This study **identifies 22** key bio-physical and socio-economic indicators, categorized into ten thematic areas, through a thorough examination of existing literature and secondary data sources. These thematic areas encompass climate variability, natural hazard exposure, demographic characteristics, socioeconomic conditions, livelihood patterns, human capital, economic stability, infrastructure, basic services, and agricultural livelihood strategies.

Table 3.5: Variable for the PCA

Concepts	**Variables**	**Explanation of variables**
Climate variability	Maximum temperature	- Average standard deviation of the daily maximum temperature by month over the past 30 years (Suhr **& Steinert, 2022**)
	Minimum temperature	- Average standard deviation of the daily minimum temperature by month over the past 30 years (IPCC, **2022**)
	Average precipitation	- Average standard deviation of the monthly precipitation over the past 30 years(Author's **Work, 2023**)
Natural hazards	Flood	- Proportion of area affected by high return period floods in the past 10 years (IPCC, **2023)**
	Coastal erosion	- Rate of coastal erosion in square kilometers per year(Author's **Work, 2024**)
Demographic profile	Population density	- Population density (number of people per square kilometer) (Suhr **& Steinert, 2022**)
	Average household size	- Average household size (number of people per household) (IPCC, **2022**)
	Female population	Female population as a percentage of total population(Author's **Work, 2023**)
	Child population	Population of children under 7 years as a percentage of total population(IPCC, **2023**)
Socio-economic status	Socially disadvantaged people	Scheduled caste and scheduled tribe population as a percentage of total population(Author's **Work, 2024**)
	Poverty	Population living below the poverty line (BPL) as a percentage of total population (Suhr **& Steinert, 2022)**
	Rural population	Rural population as a percentage of total population(IPCC, **2022**)
Livelihood activity	Agricultural dependency	Percentage of total working population employed in agriculture as cultivators and laborers(Author's **Work, 2023**)

		- Percentage of non-workers (not engaged in economically productive activities) (IPCC**, 2023)**
	Unemployment	Literacy rate (percentage of literates among those aged 7 years and above) (Author's **Work, 2024**)
Human resource capacity	Literacy rate	Total worker participation rate (main and marginal workers as a percentage of total population) (Suhr **& Steinert, 2022**)
	Work participation rate	Percentage of households owning their own homes(IPCC**, 2022**)
	Home ownership	Number of healthcare centres (Author's **Work, 2023**)
	Health care centres	Number of educational institutions(IPCC**, 2023**)
	Educational institutes	Road length (in kilometers) per square kilometer(Author's **Work, 2024**)
	Road density	Percentage of households with sanitation facilities within premises(Suhr **& Steinert, 2022**)
Basic facilities	Sanitation	Average standard deviation of the daily maximum temperature by month over the past 30 years (Suhr **& Steinert, 2022**)

Author's Work, 2024

The correlation matrix served as the input for Principal Component Analysis (PCA) to extract the principal components, as the variables were not standardized (cite). Following Kaiser's "eigenvalue-greater-than-one" criterion, only components with eigenvalues greater than 1.0 (representing the variances explained by the components) were retained (cite).

To enhance the interpretability of the components, the varimax orthogonal rotation method was applied (cite). The varimax orthogonal rotation method enhances the interpretability of principal components in Principal Component Analysis (PCA). It adjusts the loadings, or correlations between variables and components, to simplify the component structure. This process ensures that each variable strongly associates with only one component while having weaker associations with others. As a result, it becomes easier to understand and interpret the specific contributions of each variable, offering more straightforward insights into the data's underlying patterns. Component score coefficients were calculated to compute a composite index, with these scores representing the values of each case on each principal component.

Table 3.6: Variable for the PCA

Ada East District	**Anloga District**	**Keta Municipal**	**Ketu South**
Ada Foah	Anloga	Keta	Denu
Big Ada	Dabala	Abutiakope	Aflao
Toflokpo	Vodza	Kedzi	Agbozume
Kablevu	Afiadenyigba	Vui	Klikor
Koluedor	Atsito	Havedzi	Tadzewu
Azizakope	Devego	Atiteti	Tokor
Akrokor	Kpomkpo	Dzita	Akame
Totimekope	Konu	Fiaxor	Gbodome
Goi	Mepe	Wuti	Kpoviadzi
Tekporga	Tefle	Suipe	Tegbi
Anyakpor	Sogakope	Tsiame	Adafienu
Kpetsaku	Tordzin	Adzato	Aveyime
Salom	Woe	Anyanui	Hlorveme
Toku	Alakple	Kpodzi	Kpedze
Bedeku	Kpoglu	Blekusu	Tsavanya
	Zongo	Atorkor	Weta
		Dzelukope	Zioveme

Author’s Work, 2024

To enhance the interpretability of the components, the varimax orthogonal rotation method was applied (cite). The varimax orthogonal rotation method enhances the interpretability of principal components in Principal Component Analysis (PCA). It adjusts the loadings, or correlations between variables and components, to simplify the component structure. This process ensures that each variable strongly associates with only one component while having weaker associations with others. As a result, it becomes easier to understand and interpret the specific contributions of each variable, offering more straightforward insights into the data's underlying patterns. Component score coefficients were calculated to compute a composite index, with these scores representing the values of each case on each principal component.

To calculate the value of the contributing factors indicated in the IPCC for all the communities in the Volta Basin, component score coefficients are multiplied by the proportion of the corresponding component's variance and summed these products in SPSS software (Krishnan, 2010). The value of contributing factors has been calculated using the formula:

$$CF = \sum \left(\frac{F_i}{TV}\right) \times FS_i \tag{1}$$

Where CF represents a contributing factor (hazard, exposure, sensitivity, or adaptive capacity), *F_i*

denotes the percentage of variance explained by each component (*i*), TV refers to the total variance accounted for by all retained components, and 〖*FS*〗_*i* signifies the component score coefficients for each component (*i*). The value of CF can be either positive or negative, which complicates its use in final calculations. To address this, all CFs need to be normalized to ensure comparability. This normalization process follows the methodology developed for calculating the Human Development Index (HDI) (UNDP (2006). The equation is expressed as:

$$X'_{ij} = (X_{ij} - Min(X_j)) / (Max(X_j) - Min(X_j)) \tag{2}$$

Where *X_ij* represents the normalized value of CF (*j*) for community (*i*), *X_i* is the actual value for community (*i*), and *Max X_j* and *Min X_j* are the minimum and maximum values of CF (*j*) across all communities. The normalized values range from 0 to 1. Following normalization, the next step is to aggregate all the normalized CFs into a single composite index.

Potential Impact and Risk: As outlined in the framework proposed by Fussel and Klein (2006), potential impact (PI) is determined by the combination of exposure (E) and sensitivity (S), whereas adaptive capacity (AC) represents a system's ability to manage and respond to these impacts.

$$PI = E \times S \qquad (3)$$

Individuals residing in areas prone to climate change impacts and exhibiting high sensitivity to these impacts are likely to form a "potentially vulnerable group." This group can be further categorized into two subgroups: those with adaptive capacity and those without it. The latter subgroup, lacking the ability to adapt, constitutes an "immediately vulnerable group" as they are unable to cope with the effects of climate change (Das et al., 2020; Fssel & Klein, 2006). In essence, a system's vulnerability increases when it is both exposed and sensitive to climate change impacts while possessing limited or no adaptive capacity.

Vulnerability (V) under changing climate conditions can, therefore, be represented using the following mathematical equation:

$$V = PI - PI \times AC \qquad (4)$$

$$V = PI(1 - AC) \qquad (5)$$

$$V = E \times S(1 - AC) \qquad (6)$$

$$R = H \times V \qquad (7)$$

$$R = H \times E \times S(1 - AC) \qquad (8)$$

$$R = H \times E \times V \qquad (9)$$

The ‘potential impact’ in the risk equation is the combination of hazard, exposure, and sensitivity. The vulnerability and risk indices range from 0 to 1, with higher values signifying a greater level of vulnerability and risk.

3.10.7 Risk Reduction Components and Variables

The researcher made use of the Disaster Risk Reduction Framework (prevention, mitigation, preparedness, response, and recovery) to extract data and analysed them. These indicators background was linked to the 1994 Yokohama Strategy and Plan of Action for a Safer World marked the first significant international framework for Disaster Risk Reduction (DRR), highlighting the connections between sustainable development and DRR.

It set forth guidelines for disaster prevention, preparedness, and mitigation. In 1999, the UN established the International Strategy for Disaster Reduction (UNISDR), which was later renamed the UN Office for Disaster Risk Reduction (UNDRR) to better coordinate the UN's disaster reduction initiatives and emphasize risk.

Questions were set along the five (5) Disaster Risk Reduction Framework:

The five indicators and the refined properties were linked to subsequent agreements with the perspective on DRR. The 2002 Johannesburg Plan of Implementation emphasized a comprehensive, multi-hazard, inclusive approach to addressing vulnerability, risk assessment, and disaster management, covering aspects such as prevention, mitigation, preparedness, response, and recovery.

Table 3.7: Five (5) Disaster Risk Reduction Framework

Flood Disaster Prevention ➢ Construction of dams and reservoirs ➢ Creation of levees, dikes, and flood embankments ➢ Implementation of catchment management practices ➢ Channel improvements and dredging ➢ Zoning and land-use regulations to restrict development in flood-prone areas ➢ Development of green infrastructure (e.g., wetlands, parks)	**Flood Disaster Preparedness** ➢ Development of flood forecasting and early warning systems ➢ Emergency planning and evacuation drills ➢ Creation of disaster preparedness kits ➢ Public awareness campaigns on flood safety measures ➢ Coordination among local, regional, and national authorities ➢ Training of emergency response teams and volunteers
Flood Disaster Mitigation ➢ Floodplain regulation and management ➢ Installation of flood Defence s and barriers ➢ Improvement of drainage systems and infrastructure ➢ Implementation of flood-proof building designs and materials ➢ Retrofitting existing structures to withstand flooding ➢ Community awareness and education programs on flood risks	**Flood Disaster Response** ➢ Activation of emergency response plans ➢ Evacuation and sheltering of affected populations ➢ Search and rescue operations ➢ Provision of emergency medical care ➢ Distribution of food, water, and other essential supplies ➢ Communication and information dissemination to the public
Flood Disaster Recovery ➢ Damage assessment and documentation ➢ Restoration and reconstruction of infrastructure and homes ➢ Financial assistance and insurance claims processing	

3.9 Ethical Approval

The study received ethical approval from the College of Basic and Applied Sciences at the University of Ghana (see Appendix J). Prior to each interview or focus group discussion (FGD), participants were asked for verbal consent. All information provided by participants was kept confidential and used exclusively for the purposes of this research. To ensure anonymity, participants' real names were replaced with codes during the data collection process.

CHAPTER FOUR

RESULT, ANALYSIS AND PRESENTATION

4.0 Introduction

This chapter presents detailed analysis of the quantitative and qualitative data collected using surveys, interviews, focus group discussions as well as data on hazards, with focus on temperature and rainfall analysis. Additionally, exposures and vulnerabilities data were analysed to determine the socio-economic characteristics of the study area, mainly, incomes, livelihoods, employment, property, and access to other social amenities. Also, the analysis applied flood risk models, which focused mostly on risk analysis. Finally, the analysis also looked at the risk reduction and management practices, with emphasis placed on community resilient approaches.

4.1 General Background/Personal Information

The general background and personal information of the study relative to respondents was characterized according to their gender, age, education and length of stay in the community.

4.1.2 Gender/Sex

For the purpose of this study, the gender analysis of respondents was categorized into male, female and those who did not want to disclose. Majority of them, 66% were male and 23.7% were also female. The least number, 1.2% of the respondents preferred not to disclose a particular gender they belong (Table 4.1).

4.1.3 Age

The age range of respondents from all the communities was determined to provide an appropriate measure of relatability of the persons to the issues under consideration. As many as 48.8% of the respondents were within the age range of 31-45 years, while 27.2% of them were between 46 and

60 years. Others, 14.8% were 61 years old and above, as the age bracket of 18-30 years constitutes 9.3% of the respondents with least number (Table 4.1).

Table 4.1: Personal Information of the Respondent

	Variables	**Frequency**	**Percentage**
1)	**Gender**		
	Female	106	32.7
	Male	214	66
	Prefer not to say	4	1.2
2)	**Age**		
	18-30	30	9.3
	31-45	158	48.8
	46-60	88	27.2
	61 and Above	48	14.8
3)	**Education**		
	Dropout	4	1.2
	Middle School Certificate	4	1.2
	No Formal Education	40	12.3
	Primary	106	32.7
	Secondary	80	24.7
	Tertiary	85	26.2
4)	**Existing in Community**		
	1-5 years	26	8
	6-10 years	42	13
	Less than 1 year	38	11.7
	More than 10 years	218	67.3

Source: Field Work, 2024

4.1.4 Length of Stay in Community

Instructively, 67.3% of the respondents indicated that they have lived in their respective communities more than 10 years, and this was followed by 11.7% who have spent less than 1 year in the communities. For respondents who have lived between 6 and 10 years in these communities, 13% of them fell within this category, with the remaining 8% haven lived there for 1-5 years (Table 4.1).

4.1.5 Education

Majority of the respondents, 32.7% made up of the single highest category in terms of their levels of education, have had primary education. Some (26.2%) received tertiary level education and 24.7% of them said they obtained secondary level education. Also, 12.3% have never had any formal education and those who received middle school education and school drop were at par with 1.2% each (Table 4.1).

4.2 Climate Change Extremes and Flood Hazards

4.2.1 Average Annual Rainfall trends in the Ada

The annual rainfall data for Ada between 1960 and 2023 shows significant year-to-year variability, with considerable fluctuations in total rainfall across the decades. The total annual rainfall for this 63-year period ranged from a low of 359.2 mm in 1992 to a high of 1696.4 mm in 1968. Such wide fluctuations are characteristic of rainfall patterns in the region, which can be influenced by both local and global climatic factors. Rainfall during the 1960s showed moderate variation, with the highest rainfall recorded in 1968 (1696.4 mm). However, the 1970s experienced a marked decline in total rainfall, particularly during 1976 (534.7 mm) and 1977 (373.1 mm), which represent some of the lowest values for the entire data set. This suggests a dry period or drought condition during these years **(Figure 4.1)**

The rainfall levels were relatively lower in the 1980s compared to earlier decades, with notable lows in 1983 (539.7 mm) and 1986 (495.8 mm). The 1990s saw a significant decrease, especially in 1992, when the lowest recorded rainfall occurred (359.2 mm). However, in 1991 rainfall reached 1,298.1 mm, which was a year of high rainfall in this period (2000s to 2020s): In the early 2000s, the rainfall amounts showed a steady recovery, with years like 2003 (1,061.9 mm) and 2009 (1,070.0 mm) standing out as high-rainfall years. The most recent decade, from 2010 to 2023, shows a more consistent pattern with annual rainfall averaging between 600 mm and 900 mm, with relatively fewer extreme highs and lows. For instance, 2015 had 852.5 mm and 2023 recorded 849.9 mm of rainfall (Figure 4.1).

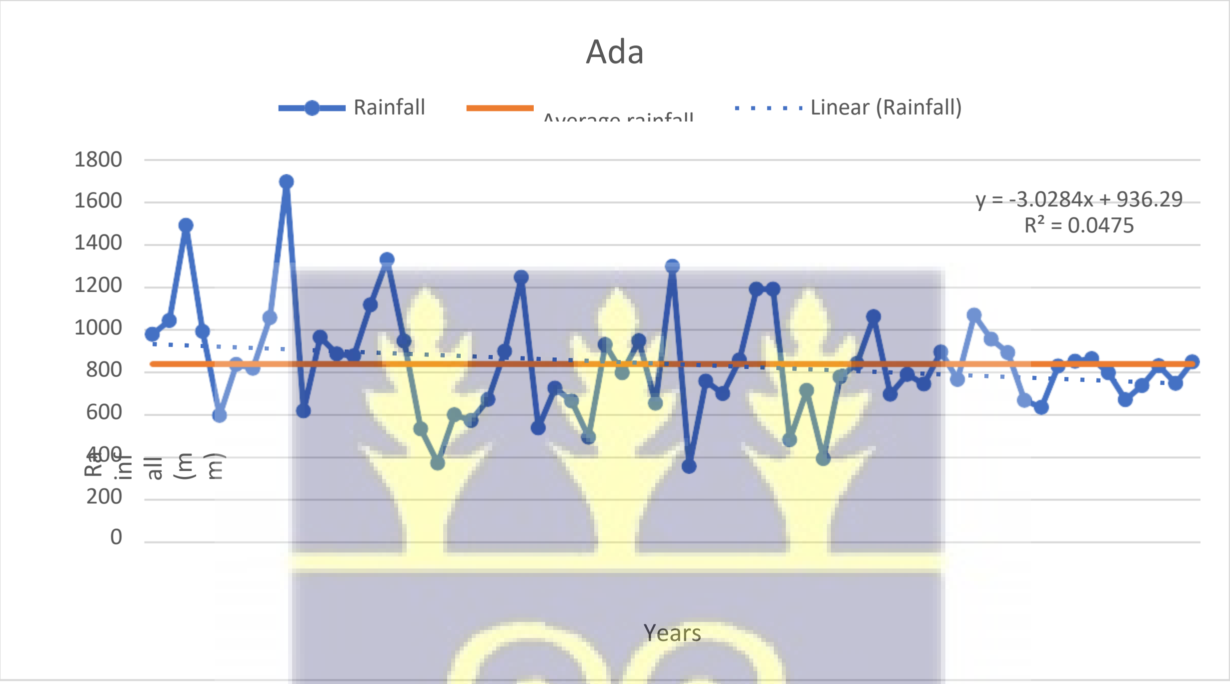


Figure 4.1: Annual Rainfall trends in the Ada area Source: Field work, 2024

A coefficient of variation (CV) of 29.9% was calculated for the annual rainfall data. This indicates moderate variability in rainfall patterns across the observed period. This highlights a consistent though fluctuating rainfall pattern, which aligns with the region's susceptibility to both dry and wet conditions (Figure 4.1). A linear trend analysis revealed a slight negative trend in annual rainfall, with a decline of approximately 3.03mm per year. Over the 63-year period, this would amount to a total decrease of about 190 mm. However, the R^2 value of 0.0475 indicates that only 4.75% of the variation in annual rainfall can be explained by this linear trend. This low R^2 suggests that the overall trend is weak, with most of the variation in rainfall being attributed to other factors such as climatic variability, regional weather patterns, and potentially, larger global climatic events such as El Niño or La Niña Circulation (Figure 4.1).

While the rainfall data for Ada between 1960 and 2023 shows substantial inter-annual variability, there is a weak overall negative trend in total annual rainfall (Figure 4.1).

4.2.2 Rainfall Anomalies for Ada

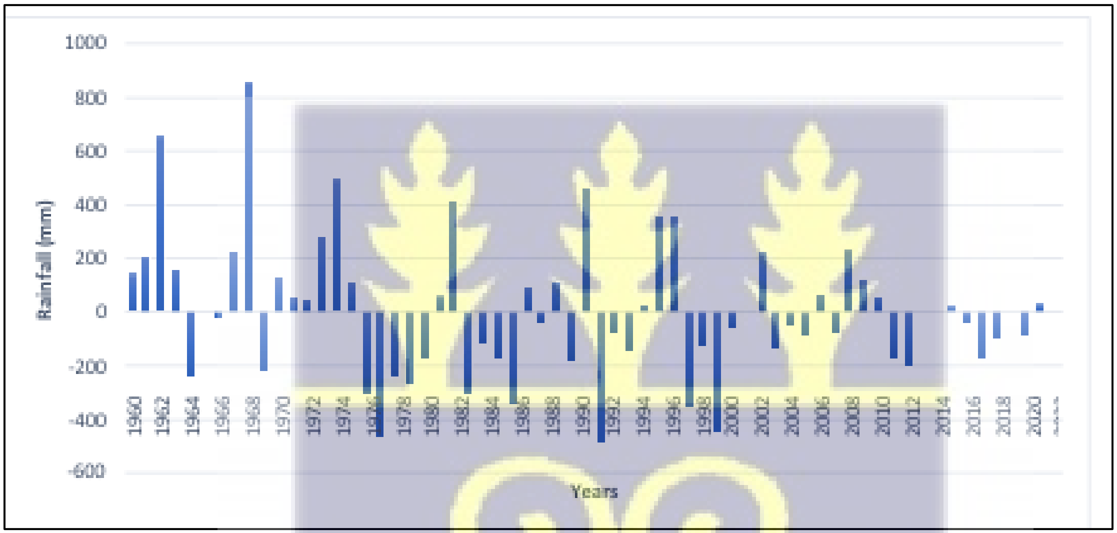


Figure 4.2: Annual Rainfall anomaly in Ada

Source: Field work, (2024)

The rainfall anomaly graph (Figure 4.2) depicts the deviation of annual rainfall from the long-term mean over the period from 1960 to 2023. Positive values indicate years where rainfall exceeded the long-term average, while negative values represent years with below-average rainfall. This analysis provides insight into periods of excess rainfall as well as drought conditions in the Ada region of the Lower Volta Basin.

4.2.3 Maximum Temperature trend (Ada)

The maximum temperature for Ada from 1960 to 2023 shows a generally consistent trend with some fluctuations and notable periods of variation. The maximum temperatures range from a low of 29.8°C in 1960 to a high of 32.2°C in 1998. During the first two decades, temperatures remained relatively stable, oscillating between 29.8°C and 31.6°C. The lowest recorded temperature in the entire dataset occurred in 1960 (29.8°C). This period shows a gradual increase over time, peaking in 1973 at 31.8°C (Figure 4.3).

The temperature between 1981 and 1997 exhibits moderate fluctuations. During this period, the temperatures remained between 30.3°C and 31.8°C, with minor peaks, such as 31.7°C in 1993 and 1996. Notably, 1998 saw the highest maximum temperature at 32.2°C. From 1998 onwards, the temperatures remained consistently within the 31°C range. The most recent years (2021) recorded a peak of 32.0°C, while in 2022, the maximum dropped slightly to 31.1°C. In 2023, the maximum temperature reached 31.3°C, reflecting a stable pattern (Figure 4.3).

A linear trend analysis was performed to determine the overall pattern of maximum temperatures in Ada over the 63-year period. The slope of 0.0066 suggests a very modest upward trend in maximum temperatures over time. This indicates that on average, the maximum temperature in Ada has been increasing by approximately 0.0066°C per year over the period studied. The coefficient of determination (R^2) is 0.0578, indicating a weak correlation between the years and maximum temperature values. This weak correlation suggests that while there is a general increase, it is not highly linear, and other factors may be contributing to the variability observed in the temperature data (Figure 4.3).

The positive slope in the linear regression suggests a slight warming trend in Ada's maximum temperatures, with a modest increase of about 0.0066°C per year over the 63 years. While the trend is upward, it is not significant enough to indicate rapid warming. The peak in maximum temperature occurred in 1998 with 32.2°C, followed by 32.0°C in 2021. These are notable deviations from the otherwise stable temperatures observed in most other years. Moreover, from the early 2000s to 2023, the temperatures have generally remained stable around 31°C, with small fluctuations. The most recent data shows a maximum temperature of 31.3°C in 2023.

Overall, while Aada exhibits a slight warming trend over the study period, the increase is minimal and the data shows considerable year-to-year variability (Figure 4.3).

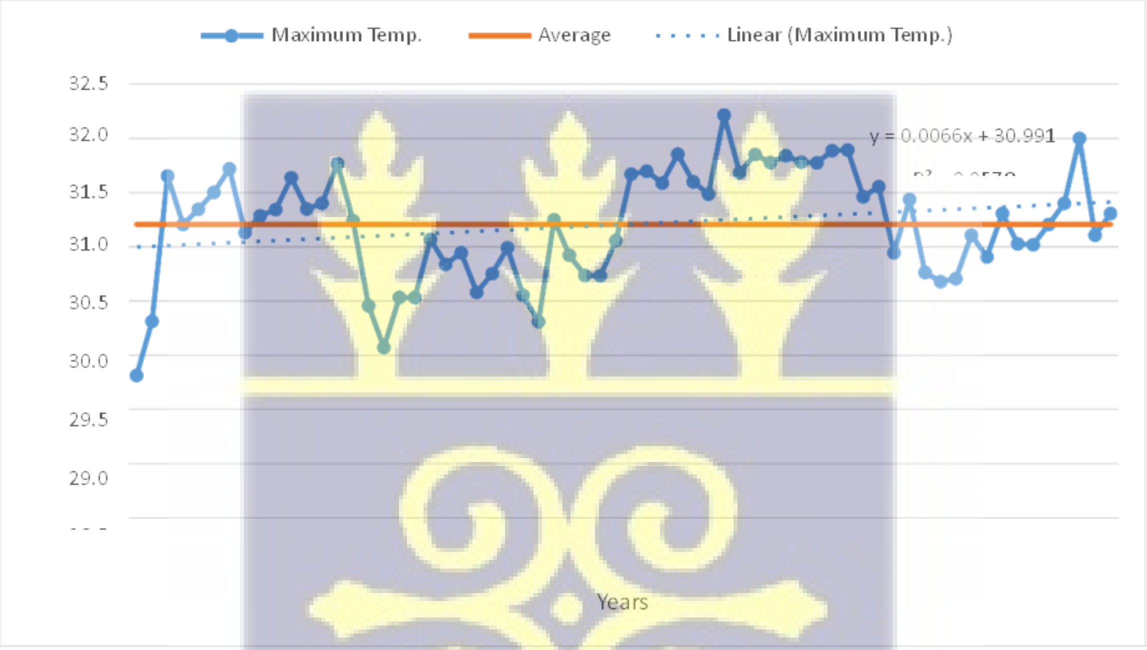


Figure 4.3: Maximum temperature trends in Ada area Source: Field work, (2024)

Minimum Temperature trend (Ada)

The minimum temperature data for Ada from 1960 to 2023 shows a clear increasing trend with significant warming over the entire 63-year period. The minimum temperatures range from 24.0°C to 27.5°C. The minimum temperatures remained relatively stable from 1960 to 1980, fluctuating between 24.0°C and 25.1°C. This decade shows minor variability, with the highest minimum temperature during this time being 25.1°C in 1969 and 1979. The overall trend during this period was relatively flat (Figure 4.4)

The data begins to show a gradual increase in minimum temperatures from 1981. The temperatures mostly fluctuated between 24.5°C and 25.5°C, with a peak of 25.5°C in 2003. The upward trend in this period was slow but consistent, showing the onset of more warming conditions compared to the previous decades (Figure 4.4)

The period from 2000 to 2023 shows a more pronounced increase in minimum temperatures. The highest minimum temperature was recorded in 2021 at 27.5°C. This significant jump marks the most notable change. The minimum temperatures regularly exceeded 25.0°C during this period, with peaks occurring in 2017 (26.2°C), 2018 (26.3°C), and 2022 (26.6°C). This represents a substantial rise from the earlier decades, where the minimum temperatures hovered around 24.0°C to 25.0°C (Figure 4.4)

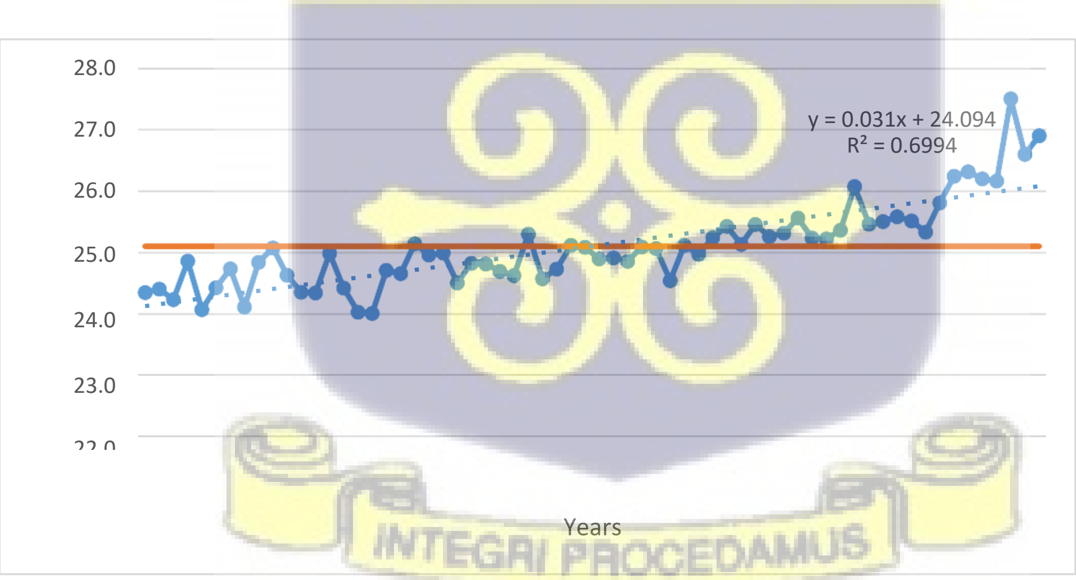


Figure 4.4: Minimum temperature trend in Ada area Source: Field work, (2024)

A linear trend analysis was conducted to examine the overall trend of minimum temperatures. The slope of the trend line (0.031) suggests that the minimum temperature in Ada has been increasing by approximately 0.031°C per year over the past 63 years. This upward trend reflects the warming effect observed in the regions. The coefficient of determination (R^2) is 0.6994, indicating a moderate to strong correlation between time and the increase in minimum temperatures. This suggests that the linear trend explains about 69.94% of the variability in the data, making it a good fit for the observed trend (Figure 4.4)

Compared to Ada's maximum temperature trend (which had a weaker upward trend), the minimum temperatures show a more consistent and pronounced increase. This could suggest that the region is experiencing more warming at night than during the daytime. The minimum temperature data for Ada clearly shows a warming trend over the 63-year period, with a more pronounced increase in the last two decades. This trend is consistent with broader global and regional patterns of climate change (Figure 4.4)

4.2.4 Keta Rainfall Trends

The annual rainfall data for the period from 1960 to 2023 presents substantial variability, with notable fluctuations in the total amount of rainfall received each year. Over this 63-year period, rainfall ranged from as high as 1681.4 mm in 1968 to as low as 220.9 mm in 1983. The general pattern of rainfall does not display a consistent upward or downward trajectory, indicating considerable inter-annual variability. From the 1960s to 1970s the rainfall levels fluctuated widely, with years like 1968 experiencing extremely high rainfall (1681.4 mm), followed by a significant drop in 1972 (469.5 mm) (Figure 4.5).

The overall variability during this period is reflected in the sporadic changes year on year. 1980s:

The 1980s marked a period of lower rainfall, especially in 1983, where the lowest value (220.9 mm) was recorded. This may suggest a period of drought or other meteorological anomalies during this decade. Rainfall levels started increasing again in the early 1990s, with years such as 1991 (1404.3 mm) and 1997 (1327.8 mm) standing out. However, the rainfall levels continued to display variability, with some years falling back to lower totals such as 1992 (385.0 mm). Rainfall during the last decade has generally been more moderate, with some peaks such as 412.9 mm in 2016 and 857.9 mm in 2023 (Figure 4.5).

The data shows sustained variability even in recent years, with annual totals fluctuating between around 500 mm and 900 mm. A coefficient of variation (CV) of 36.7% was calculated for Keta which indicates moderate to high variability in the annual rainfall totals. This means the region experiences considerable shifts in rainfall year to year (Figure 4.5).

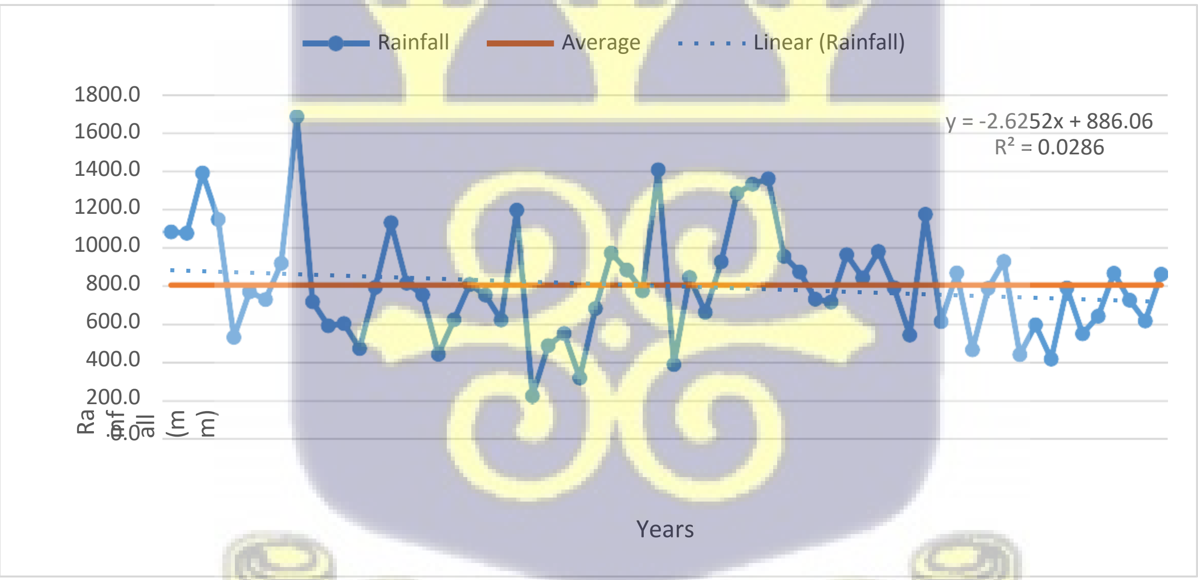


Figure 4.5: Keta Annual Average Rainfall Analysis Source: Field work, (2024)

To further understand the long-term pattern in rainfall over the 63-year period, a linear trend analysis was conducted. The equation in the graph (Figure 4.5) shows a slight negative slope (-

2.6252), which suggests a minor decrease in annual rainfall over time.

However, the R² value of 0.0286 indicates that this trend explains only about 2.86% of the variation in the data, meaning that the overall linear trend is weak and the data is dominated by large inter-annual variations. This weak correlation suggests that other factors, such as periodic climate variations or local meteorological conditions, are more likely responsible for the observed changes in annual rainfall totals over time, rather than a consistent decline or increase. While there is a slight downward trendin rainfall based on the linear regression, the variability of annual rainfall is substantial, and the trend is not statistically significant given the low R² value (Figure 4.5).

4.2.5 Rainfall anomaly in Keta

The analysis of rainfall anomaly for Keta from 1960 to 2023 highlights significant inter-annual variability, with notable fluctuations in annual rainfall deviations from the long-term average (800.7mm). Over the 63-year period, positive and negative anomalies were observed, indicating years of above-average rainfall interspersed with periods of drought or below-average conditions. (Figure 4.6)

Figure 4.6: Rainfall anomaly in Keta Source: Field work, (2024)

4.2.6 Maximum Temperature Trend (Keta)

The maximum temperature analysis for Keta from 1960 to 2023 reveals significant variations over the years. The recorded maximum temperatures range from a low of 30.1°C in 1976 to a high of 34.1°C in 2011. The following trends and observations can be made from the data: During the early decades, maximum temperatures hovered mostly between 30.1°C and 31.6°C, with a few outliers. The year 1965 had a relatively low temperature of 30.2°C, while the highest value of this period was recorded in 1963 at 31.6°C. From the 1980s onwards, the maximum temperatures began showing a gradual increase. By 1986, the temperatures exceeded 32°C, peaking at 32.5°C. The year 1997 marks a significant increase, reaching 33.1°C, and temperatures remained above 32°C for most years after this. Maximum temperatures continued to rise, with 2011 recording the highest value of 34.1°C. While fluctuations occurred, maximum temperatures remained above 33°C in almost every year after 2012, indicating a warming trend. The most recent years, such as 2020, saw temperatures reaching 34.0°C (Figure 4.7).

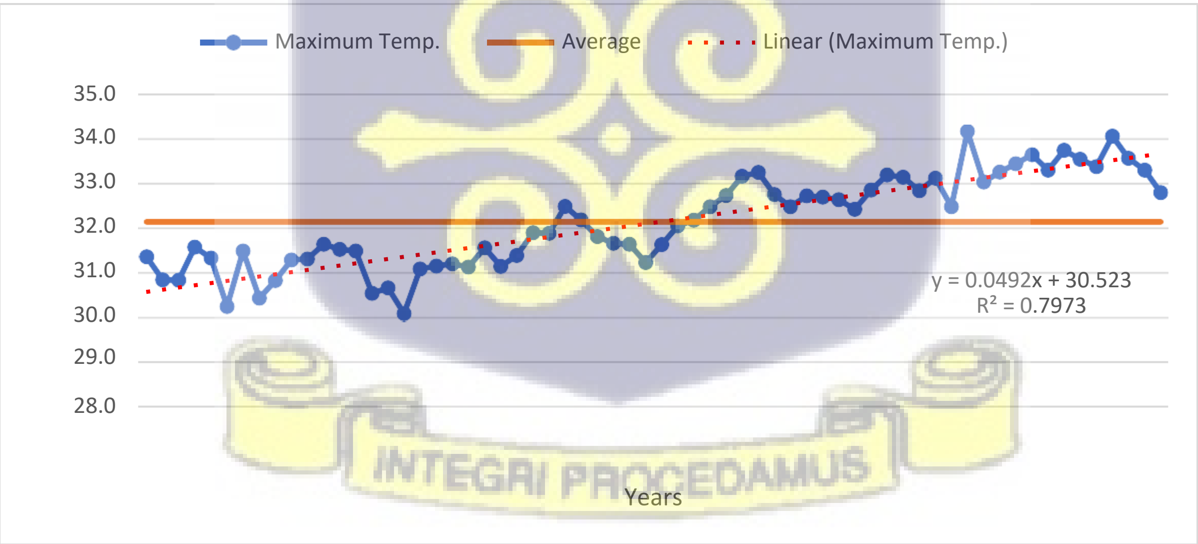


Figure 4.7: Maximum Temperature trend (Keta) Source: Field work, (2024)

A linear trend analysis with a positive slope of 0.0492 indicates a rising trend in maximum temperatures over time. This means that, on average, the maximum temperature has increased by approximately 0.049°C per year. The coefficient of determination (R^2) for the trend line is 0.7973, suggesting a strong correlation between the year and the maximum temperature, with nearly 80% of the variability in maximum temperature explained by the progression of years. This indicates that there is a clear upward trend in maximum temperatures, consistent with global and regional warming patterns. There is a clear increase in maximum temperatures over the 63 year period.

Significant temperature peaks were observed in 2011 (34.1°C) and 2020 (34.0°C). To emphasize, the increasing trend in maximum temperatures may reflect broader regional or global climate change patterns, particularly the intensification of heat waves and warming conditions in the coastal region of Ghana (Figure 4.7).

Minimum Temperature trend (Keta)

The minimum temperature analysis for Keta from 1960 to 2023 shows variability across the years. The minimum temperatures range from a low of 20.9°C in 1988 to a high of 25.3°C, which occurred in both 1970 and 1981. Between 1960 and 1980, minimum temperatures remained consistent, fluctuating between 23.7°C and 25.3°C. In 1970, the highest minimum temperature of 25.3°C was recorded, marking a notable peak during this period (Figure 4.8).

A significant shift in temperatures can be observed from 1987 to 1990, where minimum temperatures dropped sharply, reaching as low as 20.9°C in 1988 and 21.3°C in both 1987 and 1989. This period represents an anomaly of cooler conditions compared to the overall trend. After the cooler spell, the minimum temperatures gradually returned to the 23°C–24°C range, with temperatures generally stabilizing around these values from the 1990's onward. In recent years, 2020 recorded a minimum of 25.0°C, and from 2021 to 2023, the values fluctuated slightly around the 24°C mark (Figure 4.8)

A linear trend analysis was conducted to assess the overall pattern in minimum temperatures across the years. The slope of -0.0096 suggests a very slight overall decrease in minimum temperatures over the 63-year period, albeit minimal. The negative slope indicates that, on average, minimum temperatures have been decreasing by approximately 0.0096°C per year (Figure 4.8)

However, the coefficient of determination (R^2) is 0.0409, which indicates a very weak correlation between the year and the minimum temperature values. This implies that the trend is not strongly linear. Despite occasional peaks, such as 25.3°C in 1970 and 1981, the overall trend shows a slight cooling, as evidenced by the negative slope in the linear regression analysis. (Figure 4.8) The years between 1987 and 1990 exhibit a dramatic dip in minimum temperatures, especially in 1988, which recorded the lowest value of 20.9°C. This period deviates significantly from the surrounding data and could be linked to broader regional or global climate phenomena. From 1991 onwards, the minimum temperatures have mostly stabilized in the 23°C–24°C range, with some fluctuations. The highest recent value was 25.0°C in 2020, followed by slightly lower values in subsequent years. The observed cooling trend, particularly in the 1980s, could have implications for local climate adaptation strategies (Figure 4.8)

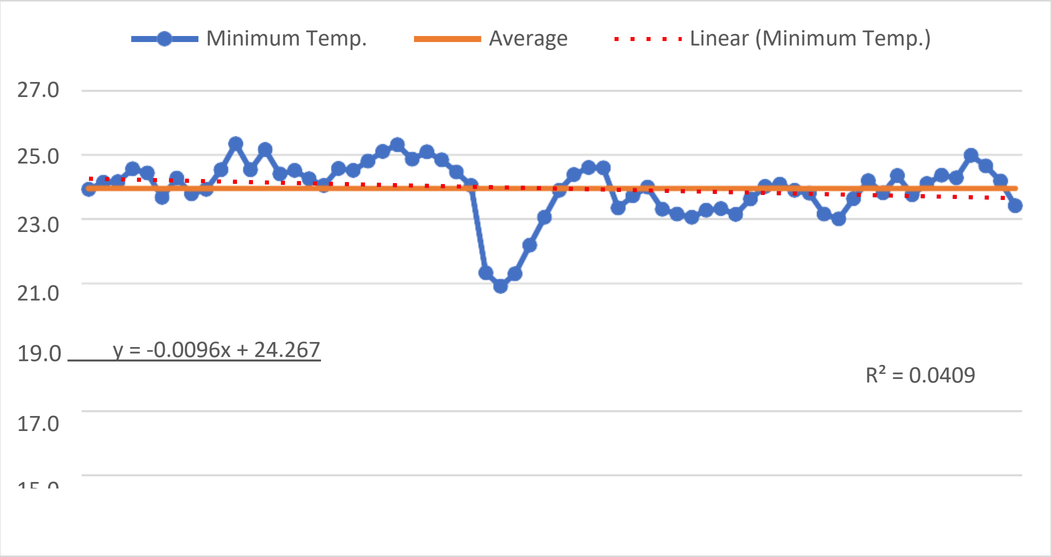


Figure 4.8: Minimum Temperature trend (Keta) Source: Field work, (2024)

4.2.7 Synthesized Rainfall Trends in Ada and Keta

4.2.7.1 Average Yearly Rainfall of Ada and Keta

This graph displays the average monthly rainfall from approximately 1970 to 2025 projection. The rainfall is highly variable throughout the year. The graph presents a clear picture of the monthly rainfall distribution in Ada and Keta, showcasing a strong seasonality. A distinct peak in rainfall is observable during certain months (June-July), signifying a well-defined rainy season. The duration and intensity of this rainy season appear consistent across the years depicted. However, considerable intra-seasonal variability is evident, with significant fluctuations in rainfall even within the months typically classified as part of the rainy season. The drier months exhibit consistently low rainfall amounts, indicating a pronounced dry season. The overall pattern suggests a tropical climate characterized by distinct wet and dry periods (Figure 4.9)

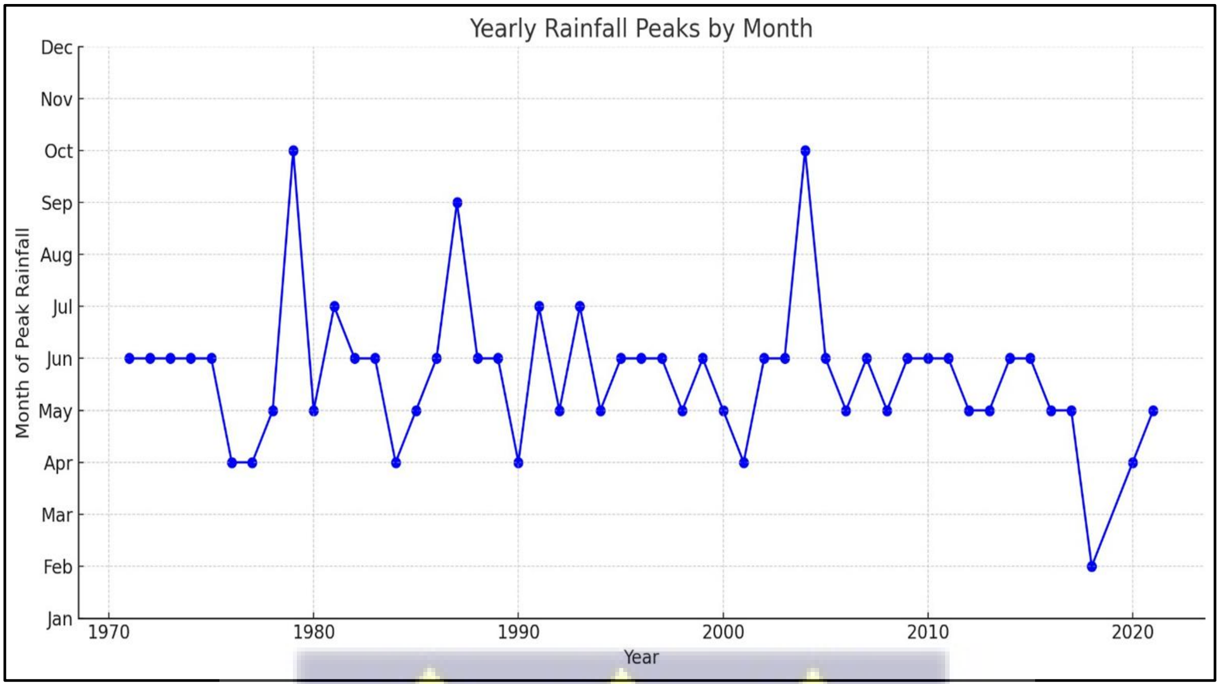


Figure 4.9: Average Yearly Rainfall of Ada and Keta Source: Field work, (2024)

4.2.7.2 Total Yearly Rainfall and Adjust Prediction of Ada and Keta

This figure illustrates the total annual rainfall over a considerable time span, revealing a considerable degree of year-to-year variability. A trend line is overlaid, suggesting a possible long-term decreasing trend in total annual rainfall. The scatter of data points around the trend line highlights the influence of factors that lead to year-to-year fluctuations, making the overall trend less pronounced than it may initially appear. The model's predicted rainfall for a future year indicates an attempt at forecasting but shows the inherent uncertainties associated with predicting long-term rainfall patterns. The discrepancy might be due to limitations of the model or the influence of unpredictable weather patterns (Figure 4.10).

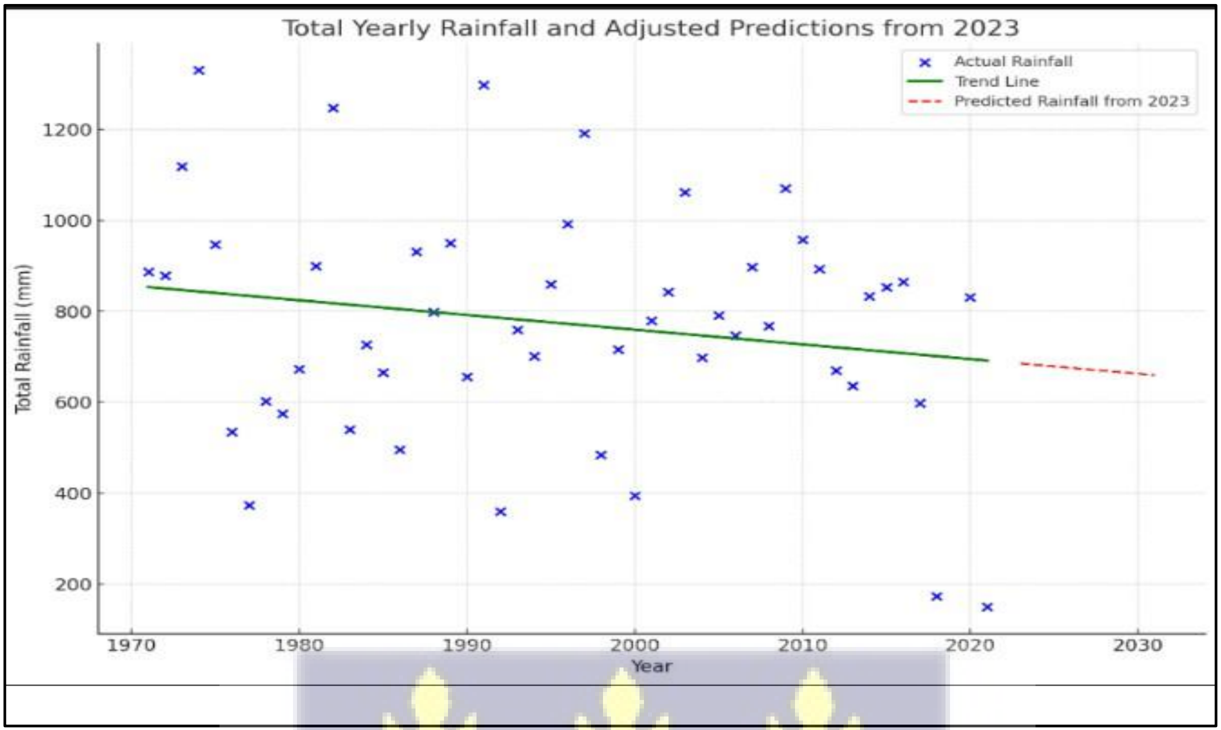


Figure 4.10: Total Yearly Rainfall and Adjust Prediction of Ada and Keta Source: Field work, (2024)

4.2.7.3 Monthly Average Temperature Across All Years for Ada and Keta (Monthly Temperature)

The graph displays the average monthly temperature across many years. The data illustrates a strong seasonal temperature cycle. The highest average temperatures occur during specific months, consistent with the warmest period of the year, while the lowest average temperatures occur during months indicative of the coolest period (Figure 4.11).

The peak temperature months appear to be around June/July, while the low temperature months appear to be around December/January. Again, the precise temperature values are not shown. The average monthly temperature across the year shows significant variation. The smooth curve suggests a relatively stable and predictable temperature pattern across the years, with minimal deviations from the average monthly temperatures over the years examined. The pattern shown is typical of locations with tropical climates.

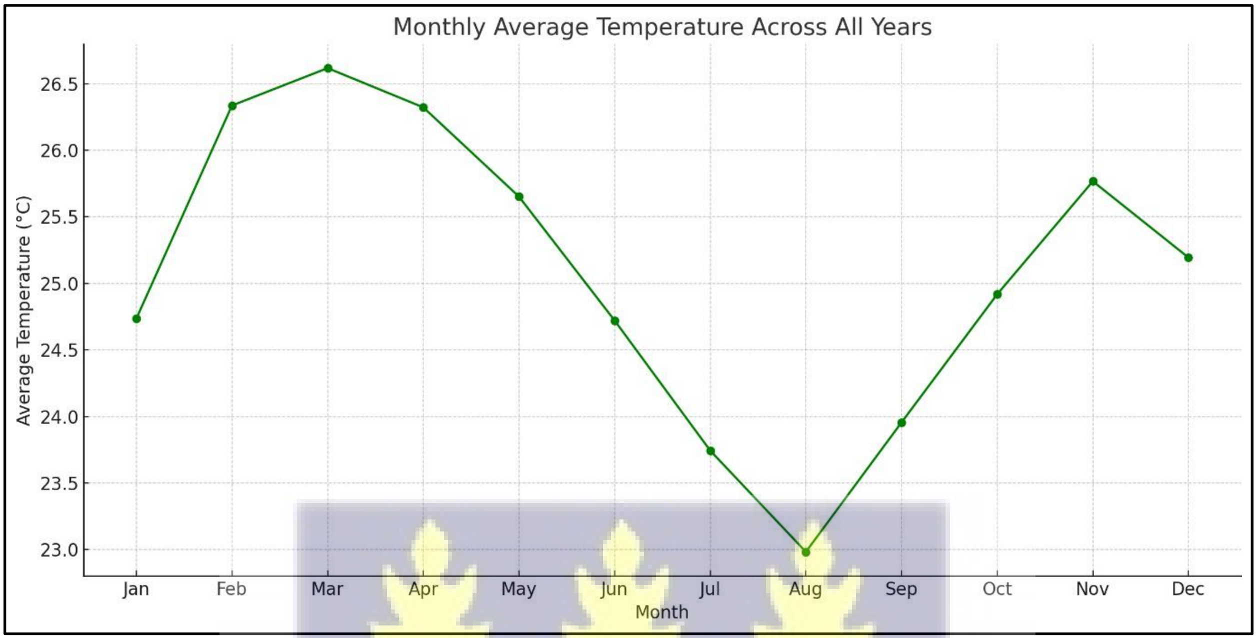


Figure 4.11: Total Yearly Rainfall and Adjust Prediction of Ada and Keta Source: Field work, (2024)

4.2.7.4 Yearly Average Temperature Trend for Ada and Keta (Annual Temperature)

This figure tracks the yearly average temperature trend from approximately 1970 to 2020. The data show substantial variability in yearly average temperatures, with significant fluctuations from year to year. There is no clear, consistent upward or downward trend apparent across the entire timespan. The pattern highlights the considerable influence of short-term climate variations. The absence of a dominant trend doesn't preclude the existence of subtle underlying patterns that might only become apparent with more refined analysis and a longer observation period (Figure 4.12). There may be some short-term periods of slight increases or decreases but no clear, long-term trend is immediately apparent. There are some notably higher temperature points, potentially representing unusual weather events or anomalies (Figure 4.12).

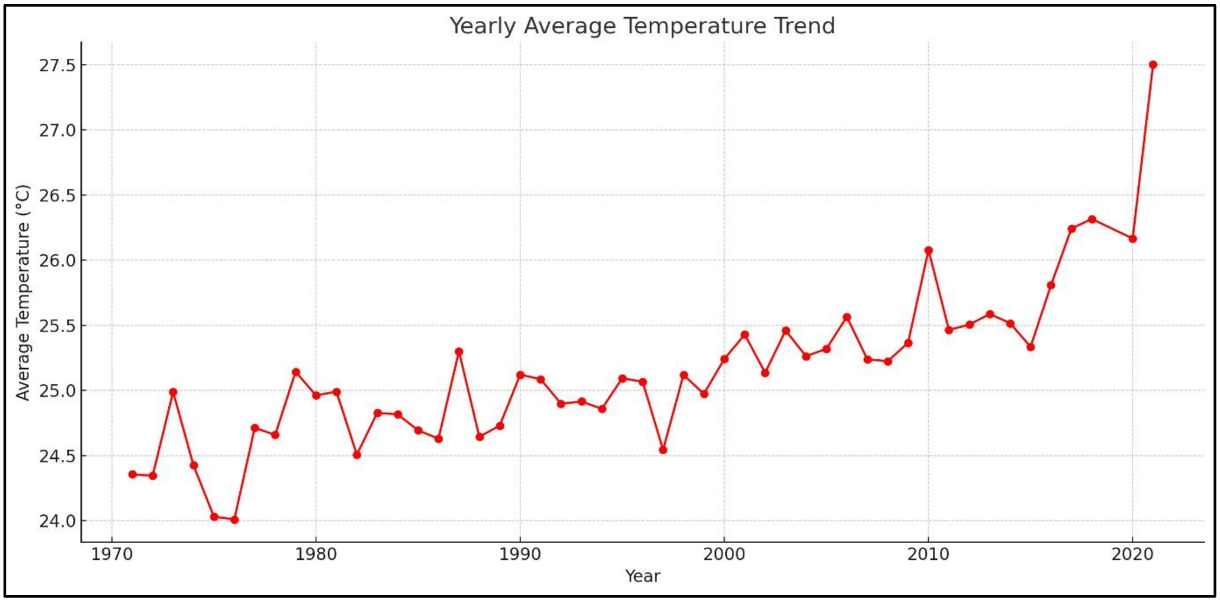


Figure 4.12: Yearly Average Temperature Trend for Ada and Keta Source: Field work, (2024)

4.2.7.5 Yearly Average Temperature Trend with Trend Line for Ada and Keta (Annual Temperature with Trendline)

This graph adds a trend line to the yearly average temperature data from (Figure 4.13). The trend line suggests a slight upward trend in average yearly temperature. However, the considerable spread of the data points around this trend line indicates that the upward trend, while present in the model, is not clearly overwhelming the variability inherent in the yearly temperature data. This graph is similar to Figure 4.12 but includes a trend line. The trend line shows a very slight upward trend in the yearly average temperature over the period of time shown. However, the variability in the yearly average temperature is substantial, suggesting that the slight upward trend may not be statistically significant. The noticeable discrepancies between individual data points and the trend line highlight the importance of considering that considerable yearly variations exist even when a slight long-term trend is detectable.

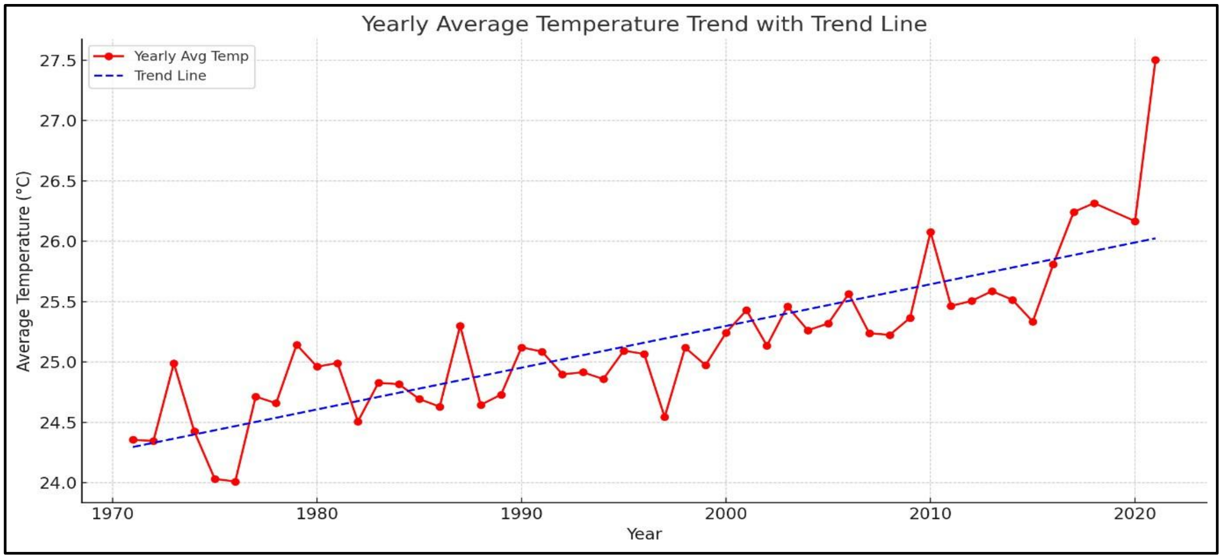


Figure 4.13: Yearly Average Temperature Trend for Ada and Keta Source: Field work, (2024)

Presentation of moving average for temperature

Presentation of moving average for temperature trend analysis is a common technique to smooth out short-term fluctuations and highlight long-term trends. Here's an example comparing linear regression versus moving. Annual mean temperatures were derived from daily minimum (Tn) and maximum (Tx) records. Where either Tn or Tx was missing, the available value served as a proxy for the daily mean; implausible values (≤ 5 °C) were treated as missing. Annual gaps were imputed via linear interpolation to permit continuous trend estimation. A centered 5-year moving average (MA) was computed to smooth inter-annual variability, and a least-squares linear regression (LR) was fitted to quantify long-term trends (°C per decade).

Ada Station Temperature 5 Yr Moving Average

Linear regression slope: -0.02 °C per decade. The moving average reveals multi-year fluctuations superimposed on a near-flat long-term trajectory. The small negative slope suggests no strong warming signal in the processed series for Ada; however, this outcome is sensitive to data completeness, proxy rules (Tn/Tx availability), and potential non-climatic influences (e.g., instrumentation or siting changes).

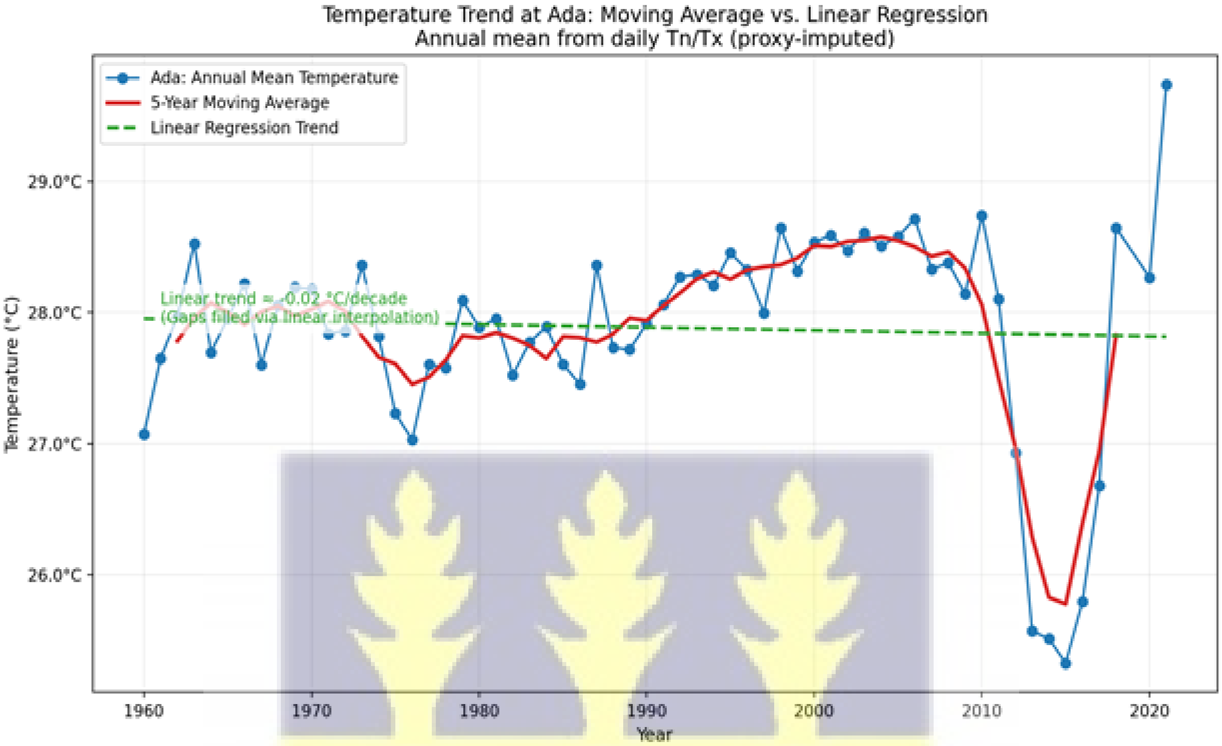
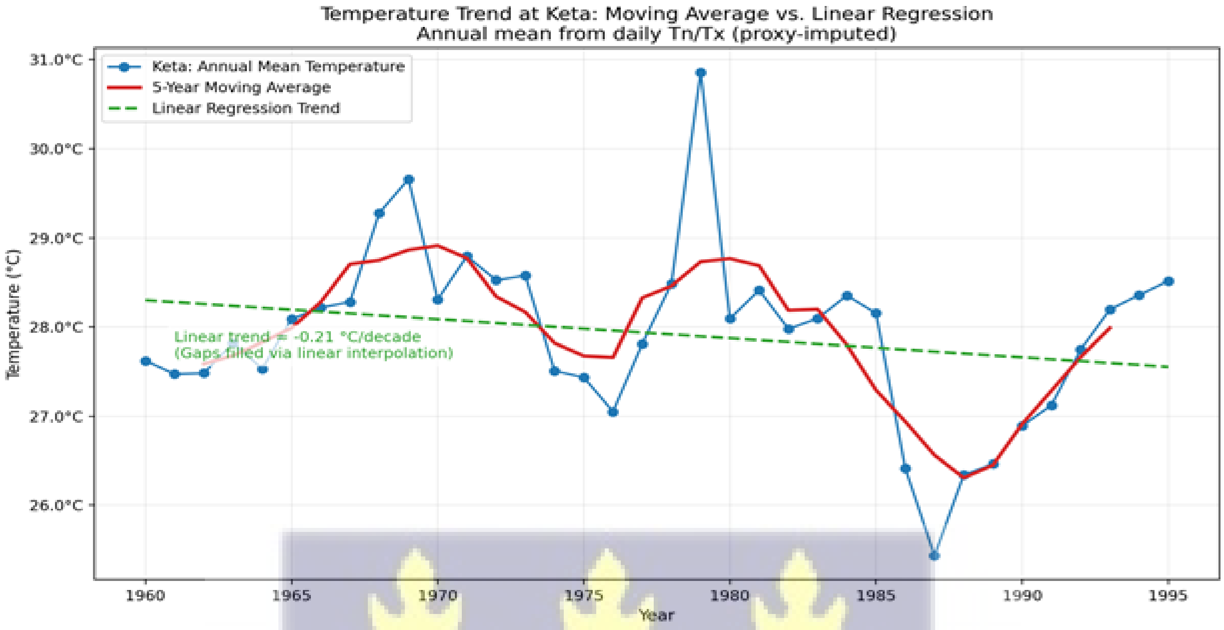


Figure 4.14: Ada: Annual Mean Temperature (blue), 5-year Moving Average (red), and Linear Regression Trend (green dashed).

Keta Station Temperature 5 Yr Moving Average

Figure 4.15: Keta: Annual Mean Temperature (blue), 5-year Moving Average (red), and Linear Regression Trend (green dashed).

Linear regression slope: -0.21 °C per decade. The 5-year moving average highlights pronounced multi-decadal variability. The net cooling indicated by the linear fit is counter-intuitive given broader regional warming expectations; this underscores the role of data gaps, proxy usage, and station metadata (instrument changes, relocation, urbanization) in shaping apparent trends.



4.2.8 Analysis of Residents' Knowledge on Flood Hazards

Overwhelmingly indicates a widespread flooding problem. Of 324 respondents, a mere 1.2% (4 individuals) reported no flood occurrence, while the vast majority (98.8%, or 320 respondents) confirmed experiencing floods.

The frequency of flooding varied considerably, with 22.2% (72 respondents) experiencing floods 2-3 times per year, 2.5% (8 respondents) annually, and a smaller percentage (3.7%, or 12 respondents) experiencing even more frequent flooding. A small percentage (1.2%, or 4 respondents) reported infrequent flooding, while an additional 2.5% (8 respondents) specifically linked their flooding experiences to Bagre Dam spillage. A substantial portion (51.9%, or 168 respondents) reported annual flooding, and a considerable number (9.3%, or 30 respondents) stated that flooding frequently occurs during the rainy season.

Additional analysis of responses provided in the survey focused on flooding in these communities by way of their knowledge and experiences expressed. The context was to recount flood records, years of such floods, and the types of floods (i.e., flush, sea, lagoon, river) through the lenses of respondents. The most frequent flood years mentioned were 2015 (26%, 79 respondents) and 2011 (16.1%, 49 respondents).

Variables	**Freq.**	**%**	**Variables**	**Freq.**	**%**	**Variables**	**Freq**	**%**
Affirmed Flood Occurrence			Evidence of Intense Rains			Regular flooding areas		
Indifferent	*4*	*1.2*	*Akosombo Dam Spillage*	*16*	*4.9*	*Ada Foah Coastal Area*	*4*	*1.2*
Yes	*320*	*98.8*	*Coastal Flood*	*204*	*63*	*Adafianu*	*8*	*2.5*
Flood occurrence moments			*Flash Flood*	*18*	*5.5*	*Adina*	*6*	*1.9*
2-3 times a year	*72*	*22.2*	*High Tide*	*5*	*1.5*	*Aflive*	*4*	*1.2*
Annually	*8*	*2.5*	*Lagoon Flood*	*13*	*4*	*Anloga And Its Environs*	*4*	*1.2*
More than 3 times a year	*12*	*3.7*	*River Flood*	*9*	*2.8*	*Anyanui*	*4*	*1.2*
Not always	*4*	*1.2*	Tendency of flood in Dry Season			*Baitrenya*	*4*	*1.2*
Often during Bagre Dam Spillage	*8*	*2.5*	*Indifferent*	*18*	*5.6*	*Blekusu*	*4*	*1.2*
Often Rainy Season	*30*	*9.3*	*No*	*70*	*21.6*	*Gavedzi*	*4*	*1.2*
Once a Year	*168*	*51.9*	*Yes*	*236*	*72.8*	*Kedzi*	*12*	*3.7*
Sometimes	*22*	*6.8*	Affirmed Rainfall Intensity			*Keta*	*4*	*1.2*
Flood occurred mentioned years			*Indifferent*	*8*	*2.5*	*Kopega At The Farm Area*	*14*	*4.3*
1996	*4*	*1.3*	*No*	*58*	*17.9*	*Seva*	*4*	*1.2*
2007	*11*	*3.6*	*Yes*	*258*	*79.6*	*Tahe Kpota*	*8*	*2.5*
2010	*4*	*1.3*	Indication of more rains			*Totope*	*6*	*1.9*
2011	*49*	*16.1*	*Coastal Erosion*	*4*	*1.2*	*Totope*	*6*	*1.9*
2015	*79*	*26*	*Flash Floods*	*196*	*60.5*	*Woe Afedome*	*26*	*8*
2016	*4*	*1.3*	*Heavy Storms*	*42*	*13*	*Woe Coast*	*4*	*1.2*
2017	*5*	*1.6*	*Increasing River Level*	*4*	*1.2*			
2019	*19*	*6.3*	*No Rains Observed*	*18*	*5.6*			
2020	*8*	*2.6*	*Affirmed sea level rise*					
2021	*22*	*7.2*	*Indifferent*	*4*	*1.2*			
2022	*60*	*19.7*	*No*	*16*	*4.9*			
2023	*31*	*10.2*	*Yes*	*304*	*93.8*			
2024	*8*	*2.6*						

Source: Field Work, 2024

Table 4.2: Analysis of Knowledge on Flood Hazard

Other notable years include 2022 (19.7%, 60 respondents), 2023 (10.2%, 31 respondents), and 2007 (3.6%, 11 respondents). The remaining years on kindred responses also recorded floods with the exception of the period between 1997 and 2006 (Table 4.2).

The data reflects the community's strong consensus on the occurrence of floods, with 98.8% of respondents affirming that flooding happens. The frequency of floods varies, with the majority (51.9%) experiencing it once a year. Additionally, significant portions report floods occurring two to three times a year (22.2%), sometimes (6.8%), or more than three times a year (3.7%). Floods are often linked to the rainy season (9.3%) and the Bagre Dam spillage (2.5%) (Table 4.2).

The types of floods experienced in Ada, Keta, Adina, Afloa, Alakple, Alorkplem, Azizanya, Baitrenya, Gavedzi, Havedzi, Kasea, Kedzi, Kpozi, Netsime, Totope, Woe, among others, according to the respondents were mainly coastal floods, lagoon floods, river floods, flash flood, high tide, and spillage from the Akosombo dam. Respondents overwhelmingly linked flooding to intense rainfall, with a vast majority (79.6%, or 258 out of 324 respondents) confirming increased rainfall intensity. The most frequently cited evidence was coastal flooding (63%, or 204 respondents), indicating significant vulnerability in coastal areas. Flash floods also contributed significantly (5.5%, or 18 respondents), highlighting the intensity and rapid onset of rainfall in certain events. Akosombo Dam spillage and river flooding were also mentioned, albeit less frequently, suggesting a possible role of these factors as contributing elements. The overwhelming majority (93.8%, or 304 of 324 respondents) also reported observing a rise in sea levels, suggesting that sea-level rise contributes significantly to increased flood risk (Table 4.2).

> ***Respondent in Nyanui****: The rains have been short in duration but intense with a lot of wind. Sometimes this happen in June/July. Sometimes at the beginning of the rainy season. When it happens like that, flood happen but not as the one that happen from the sea and lagoon.*

The survey demonstrates a near-universal awareness of flooding within the community, with an overwhelming 98.8% of respondents confirming flood experiences. This high percentage underscores the significance of flooding as a recurring hazard within the area. The frequency of flooding, as perceived by respondents, is quite varied, highlighting the variability of flood events. "Once a year" (51.9%) is the most frequent response, indicating the annual nature of flooding for a significant portion of the community. However, responses such as "Sometimes" (6.8%), "2-3 times a year" (22.2%), and even "Annually" (2.5%), "Often during Bagre Dam Spillage"(2.5%), "Often Rainy Season" (9.3%) reveal a complex picture of flood events, ranging from regular inundation to more sporadic occurrences linked to specific events such as dam spillage or seasonal rainfall patterns (Table 4.2).

Flood Tendency in the Dry Season: The table addresses whether flooding occurs outside the typical rainy season. The majority (72.8%, or 236 respondents) reported that flooding does not typically occur during the dry season. However, a significant minority (21.6%, or 70 respondents) indicated that flooding can occur even during the dry season, while a small portion (5.6%, or 18 respondents) expressed indifference. This suggests some level of year-round flood risk, indicating vulnerabilities outside of the usual rainy season (Table 4.2). Rainfall Intensity: The table focuses on respondent perceptions of rainfall intensity. A significant majority (79.6%, or 258 respondents) affirmed experiencing increased rainfall intensity, with only a small percentage (2.5%, or 8 respondents) indicating indifference, and another 17.9% (58 respondents) stating they had not observed an increase. The data strongly points to an increase in rainfall intensity as a significant contributor to flooding (Table 4.2). Table 6: Indications of More Rains: This table examines specific indicators of increased rainfall, with coastal erosion identified as a leading indicator (60.5%, or 196 respondents). Heavy storms (13%, or 42 respondents) were also frequently cited, supporting the findings from previous tables regarding intense rainfall events. Increases in river levels (1.2%, or 4 respondents) were mentioned less frequently and few indicated no observed increases in rainfall (5.6%, or 18 respondents). This confirms the link between heavy rainfall and flooding in the region (Table 4.2). The (Table 4.2) assesses respondent perceptions of sea level rise. An overwhelming majority (93.8%, or 304 respondents) confirmed observing a rise in sea levels, indicating a significant contribution to flood vulnerability. This highlights the potential impact of climate change on coastal flooding. Regularly Flooded Areas: This table lists specific areas frequently impacted by floods, with Woe Afedome cited most often (8%, or 26 respondents). Several other coastal communities and farming areas also report regular flooding, demonstrating the widespread nature of the problem. This information is crucial for prioritizing mitigation efforts and targeted interventions (Table 4.2).

Box: FGD (Atiteti Venue for Nyanui, Fuveme and Atiteti)

> *For many people engaged through focus group discussion, there were extensive hydrological process where the flow from the River Volta, run-off during rainfall and overflow of lagoon go into the sea and the sea turn to spill back these waters back to inland causing the more extensive flooding. At the same time, the various sources, such as the River, Lagoon, Sea and Flash floods have their own respective floods in various sections. The temporal aspect of the study offers valuable insights into the community's lived experience with flooding. The high frequencies associated with the years 2011, 2015, and 2022 strongly suggest these were years of particularly impactful flood events, shaping community memory and understanding of flood risks. The inclusion of more recent years, such as 2024, in the dataset provides a valuable link between the community's historical knowledge and contemporary concerns. Further analysis, particularly investigations into the reasons for the disparity of opinions regarding rainfall intensity and incorporating quantitative hydrological data, would strengthen the insights derived from this valuable community survey.*

Box 4.1: FGD (Atiteti Venue for Nyanui, Fuveme and Atiteti)

Plate 4.1: November 2021 Flood at Kedzikope

4.2.9 Scenarios for Flood Projections (IPCC Intermediate and High Scenarios)

Major scenarios for flood projection were included in the analysis drawing the IPCC approach of climate risk assessment. Three scenario model outcomes were plagued in and achieved. In essence, the projection involved the modelling of the Ada-Keta coast relative to flooding, sea level rise and erosion. The process further includes the showing of the topography of the areas, and the elevation variants using the digital elevation model (DEM). Sea level rise values or projections for different timelines were obtained (meta data) and applied the IPCC's definition of the three timelines as; short-term (2040), mid-term (2060), and long term (2100).

Intermediate Scenario (SSP 2-4.5) (2040):

The map present a sea-level rise (SLR) projection for the year 2040 under two Shared Socioeconomic Pathways (SSPs): SSP2-4.5 and SSP5-8.5. The map visually represents the projected areas inundated by sea level rise under the intermediate SSP2-4.5 scenario. Based on the aforementioned, emission scenarios for Intermediate Scenario-1 and applying the SSP 2-4.5 for sea level rise (SLR) in 2040 projections, the outcome shows that, at a Minimum (showing blue), 3.43% of the area will fall below LMSL, and at a Maximum (showing red), 5.21% of the area will be covered below LMSL (Figure 4.16).

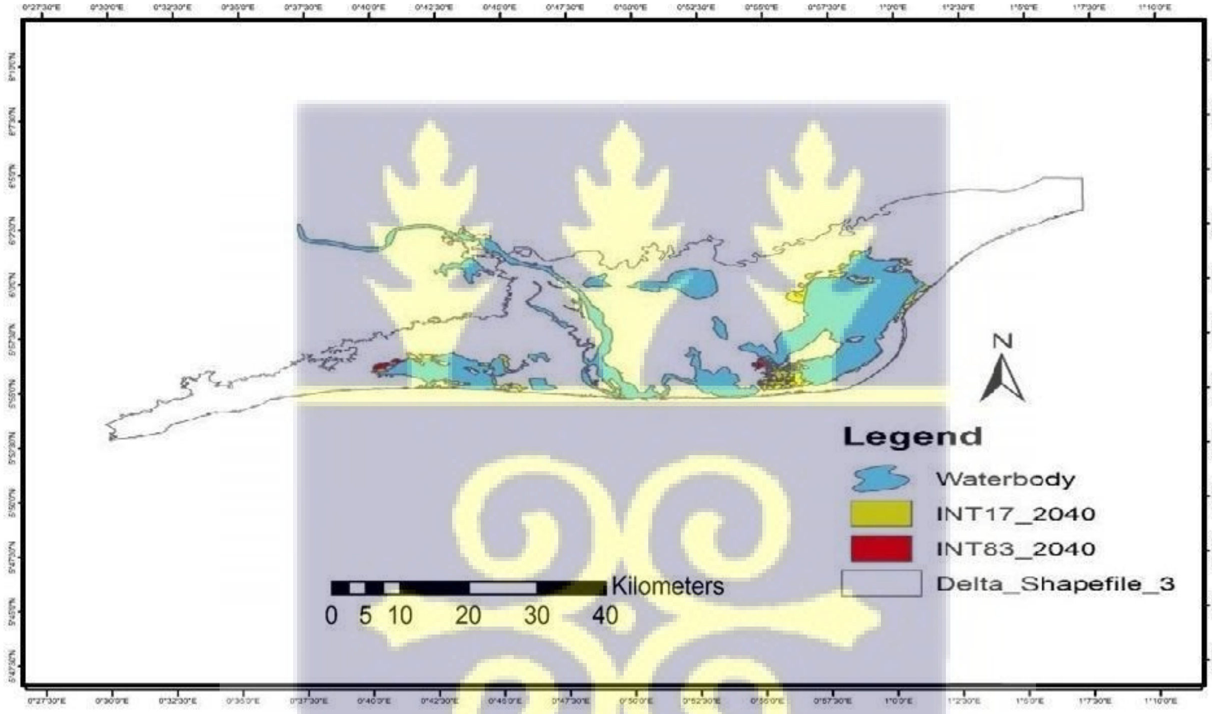


Figure 4.16: A graph showing SLR projections for SSP2-4.5 scenario for 2040 Source: Field work, (2024)

The relatively small difference between the minimum and maximum projections suggests a lower degree of uncertainty in the prediction under this scenario. This reduced uncertainty is attributed to the lower greenhouse gas emissions associated with the SSP2-4.5 pathway, resulting in a more moderate and controlled sea-level rise (Figure 4.16).

The map visually supports the text. It shows the areas projected to be inundated in 2040 under the SSP2-4.5 scenario. The legend distinguishes water bodies, areas inundated under different projections (INT17_2040 and INT83_2040, potentially representing different aspects of the projection), and the coastline shapefile. The visualization makes it easy to see the spatial extent of the projected inundation and its location within the study area. The map provides a clear spatial context for the numerical projections given in the text (Figure 4.16).

Intermediate Scenario (SSP 2-4.5) (2060):

The map that likely displays the spatial distribution of the projected inundation under the SSP2-4.5 scenario for 2060. Different colours likely represent the water bodies, areas projected to be below LMSL under different model parameters (INT17_2060 and INT83_2060) (Figure 4.16). The map allows for a visualization of the geographic areas most vulnerable to sea-level rise based on these projections.

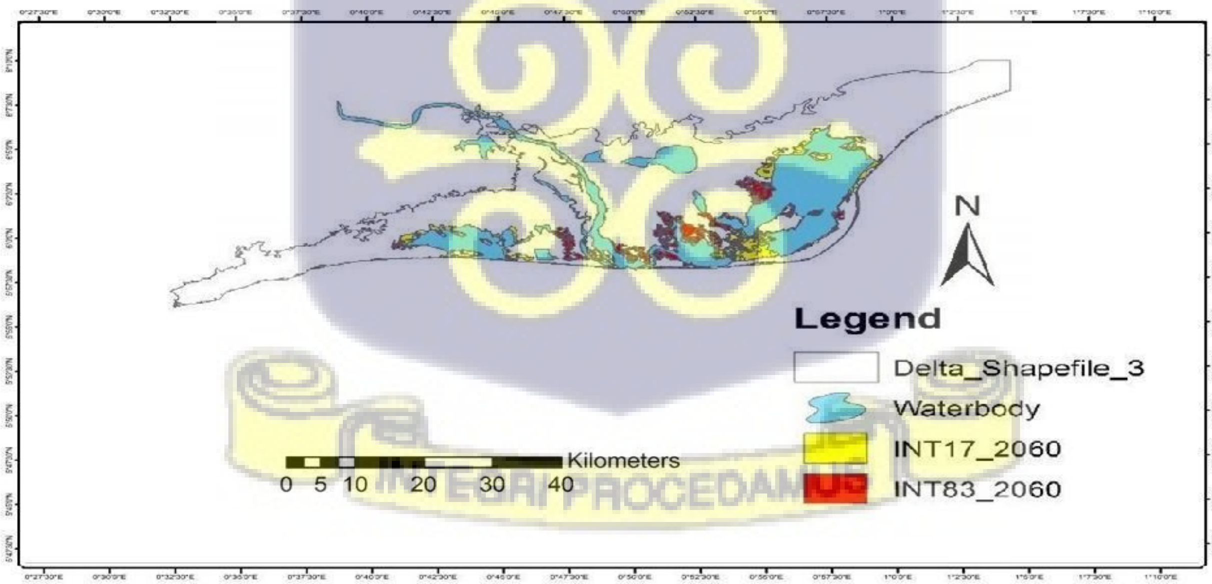


Figure 4.17: A graph showing SLR projections for SSP2-4.5 scenario for 2060 Source: Field work, (2024)

It presents a sea-level rise (SLR) projection for 2060, focusing on the percentage of land area projected to fall below the local mean sea level (LMSL) under two distinct Shared Socioeconomic Pathways (SSPs): SSP2-4.5 and SSP5-8.5. The analysis highlights the impact of differing greenhouse gas emission scenarios on future flood risk (Figure 4.16)

Under the SSP2-4.5 scenario (representing a pathway with relatively moderate greenhouse gas emissions), the projection shows a minimum of 6.11% and a maximum of 15.67% of the area 'projections under the SSP5-8.5 scenario (which represents a high emissions pathway). The comparatively smaller range between the minimum and maximum projections under SSP2-4.5 indicates a lower degree of uncertainty in the prediction, suggesting more confidence in the model's output under this less extreme emission scenario. The lower percentage of area at risk under SSP2-4.5 underlines the potential effectiveness of climate mitigation strategies in reducing future flooding threats. However, the considerable range (almost 10 percentage points) between the minimum and maximum projections under SSP2-4.5 still necessitates preparing for a wide range of possible flooding outcomes

Intermediate Scenario (SSP 2-4.5) (2100):

A map accompanies the text and likely displays the spatial distribution of projected inundation under the SSP2-4.5 scenario for 2100. Different colours on this map probably represent water bodies, areas projected to be below LMSL under different model parameters (INT17_2100 and INT83_2100, requiring further explanation), and the coastline's shapefile. This map offers a visual representation of the geographic areas most vulnerable to sea-level rise in the future based on the provided model and scenario. Without the map's scale, precise area estimations cannot be made. The reference to a separate graph showing SLR projections for SSP 2-4.5 for 2100 suggests additional data is available, but its contents are unknown (Figure 4.18).

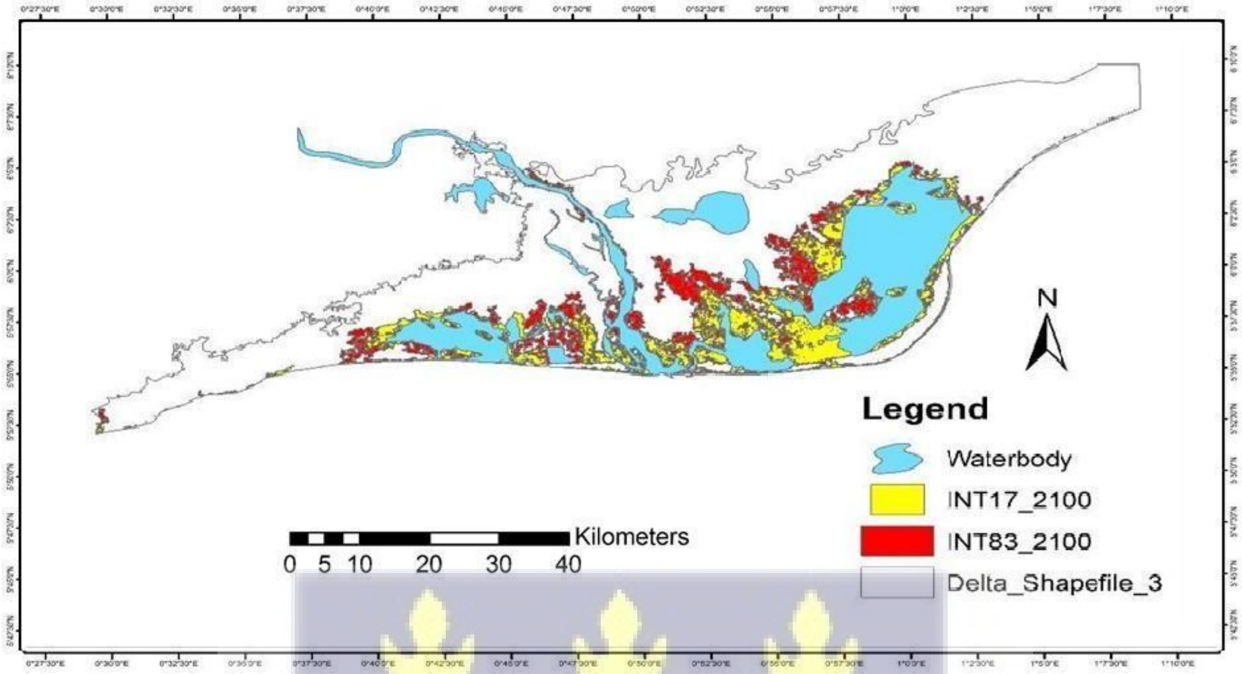


Figure 4.18: A graph showing SLR projections for SSP2-4.5 scenario for 2100 Source: Field work, (2024)

The provided text presents a sea-level rise (SLR) projection for the year 2100, focusing on the percentage of land area anticipated to fall below the local mean sea level (LMSL) under the SSP2-4.5 scenario. The analysis compares this projection to that of a high-emissions scenario (SSP5-8.5), emphasizing the impact of greenhouse gas emissions on the extent of coastal inundation (Figure 4.18).

Modelling the Intermediate Scenario-3 of the sea level rise (SLR), using the 2100 year, the minimum value for the area to go under water constitutes 18.52% (LMSL), and the maximum value was 26.32% of the area below LMSL (figure 4.16). This means that, by 2100, even under SSP2-4.5, a significant portion of land will be below sea level. However, the upper bound (26.32%) remains well below the 39.31% value as seen in SSP5-8.5 scenarios.

Intermediate Scenario (SSP5-8.5) (2040):

The Figure 4.19 presents a sea-level rise (SLR) projection for 2040, specifically focusing on the percentage of land area expected to fall below the local mean sea level (LMSL) under the SSP5-8.5 scenario (a high greenhouse gas emissions pathway). The analysis highlights the projected range of inundation and emphasizes the uncertainty inherent in such predictions (Figure 4.19).

The map visualizes the spatial distribution of projected inundation under the SSP5-8.5 scenario. Different colours represent the existing water bodies, areas likely to be submerged according to two different modelling approaches (HIGH17_2040 and HIGH83_2040). The map provides a spatial context to the numerical projections, allowing for the identification of specific areas with high vulnerability. However, without a map scale, precise area measurements cannot be determined. The inclusion of multiple inundation projections (HIGH17_2040 and HIGH83_2040) suggests that multiple modelling approaches or parameters have been used, resulting in a range of potential outcomes (Figure 4.19).

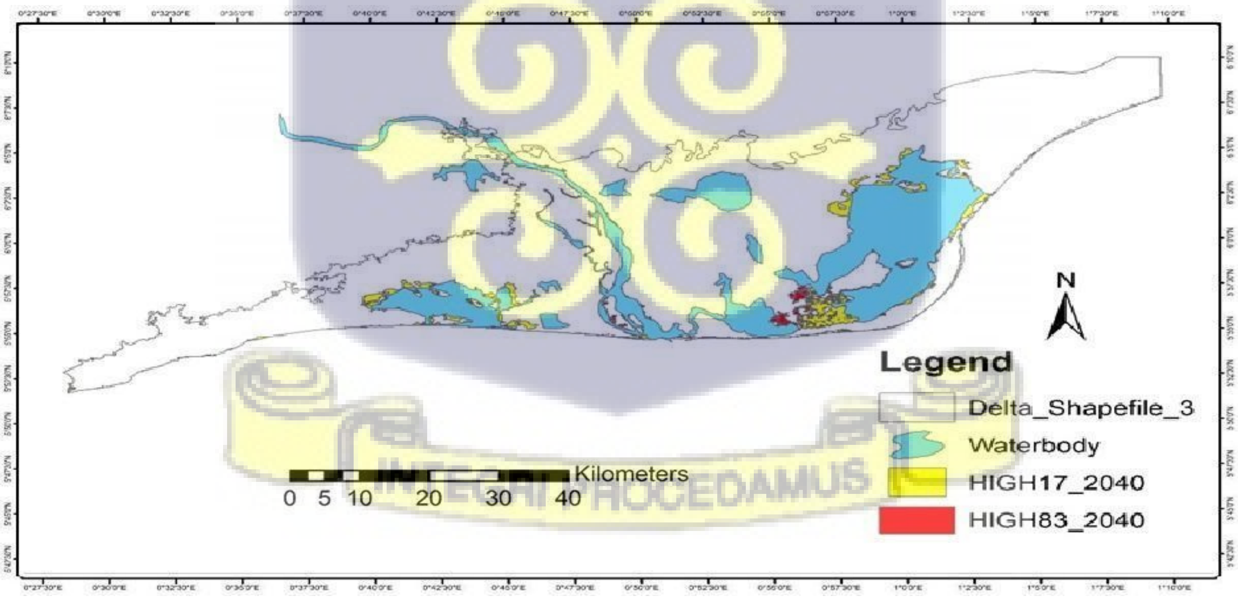


Figure 4.19: A graph showing SLR projections for SSP 5-8.5 for 2040 Source: Field work, (2024)

For SLR 2040, it was observed that, at the Minimum (i.e., showing in blue colour) was 4.51% of the area below local mean sea level (LMSL), and at a Maximum (i.e., showing in red) was 6.42% of the area below LMSL (Figure 4.17). Although this range represents a relatively small percentage of the total area compared to later projections, the difference between the minimum and maximum projections points to a degree of uncertainty that necessitates planning to protect vulnerable areas. This uncertainty highlights the inherent challenges in precisely predicting the impacts of climate change. (Figure 4.17).

Intermediate Scenario (SSP5-8.5) (2060):

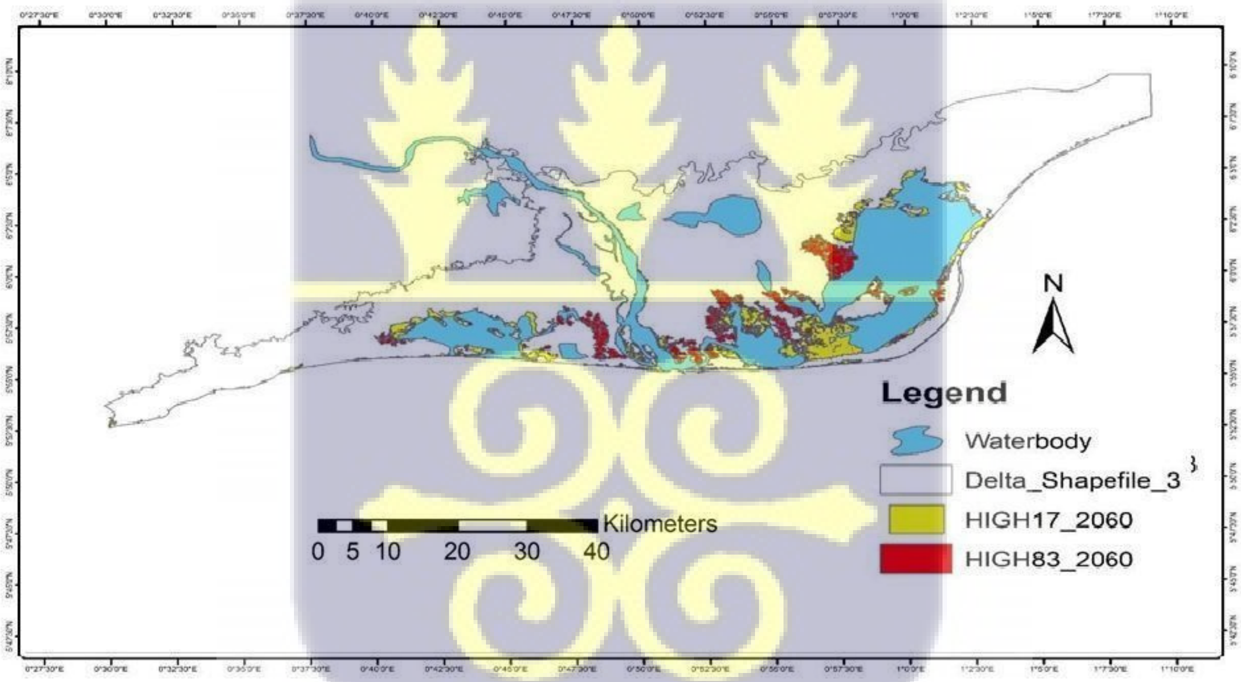


Figure 4.20: A graph showing SLR projections for SSP 5-8.5 for 2060 Source: Field work, (2024)

The map shows the spatial distribution of the projected inundation. Different colors represent the existing water bodies, areas projected to fall below LMSL according to different model parameters

(HIGH17_2060 and HIGH83_2060, requiring further explanation for precise interpretation), and the boundary of the area (Figure 4.20).

The provided Map presents a sea-level rise (SLR) projection for 2060 under the SSP5-8.5 scenario (a high greenhouse gas emissions pathway). The analysis focuses on the projected percentage of land area expected to fall below the local mean sea level (LMSL) and highlights the increased uncertainty and the need for robust adaptation strategies (Figure 4.20).

Similarly, for SLR 2060, at a Minimum, there is 12.8% of the area below LMSL as observed and compared to the Maximum at a value of 18.99% of the area below LMSL (Figure 4.20). By 2060, the range of sea-level rise increases significantly. The min-max gap suggests that under the SSP5-8.5 scenario, considerable portions of land will be below LMSL, necessitating more robust flood Defence mechanisms. The substantial difference between the minimum and maximum projections indicates a higher degree of uncertainty compared to lower emission scenarios. This uncertainty necessitates a more flexible and adaptable approach to flood risk management (Figure 4.20).

Intermediate Scenario (SSP5-8.5) (2100):

The map visualized the projected inundation spatially. The different colors probably represent existing water bodies, the areas projected to fall below LMSL (according to different model parameters, HIGH17_2100 and HIGH83_2100.

The presentation of two inundation projections (HIGH17_2100 and HIGH83_2100) capture the uncertainty inherent in long-term projections under a high emissions scenario.

It presents a sea- level rise (SLR) projection for the year 2100, specifically focusing on the percentage of land area anticipated to fall below the local mean sea level (LMSL) under the SSP5-8.5 scenario (representing a high greenhouse gas emissions pathway) (Figure 4.21).

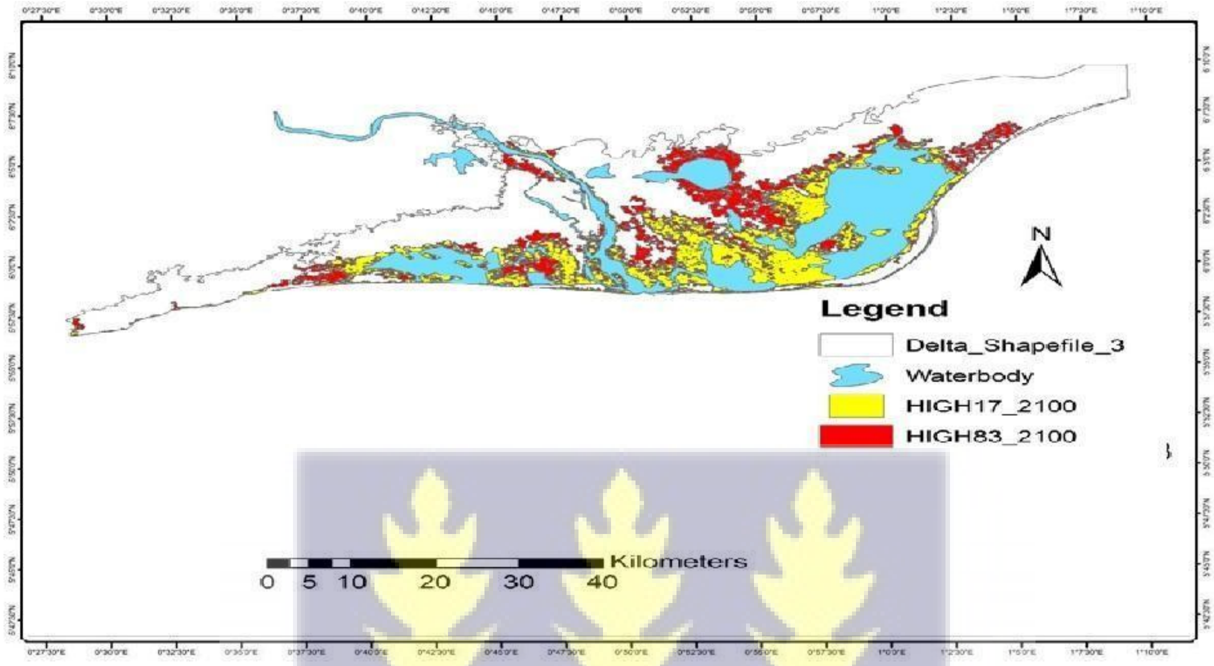


Figure 4.21: A graph showing SLR projections for SSP 5-8.5 for 2100 Source: Field work, (2024)

Comparison Between SSP2-4.5 and SSP5-8.5:

Box 2: Comparison Between SSP2-4.5 and SSP5-8

2040:

- **SSP5-8.5**: Min = 4.51%, Max = 6.42% of the area below the LMSL.
- **SSP2-4.5**: Min = 3.43%, Max = 5.21% of the area below the LMSL.
- **Comparison**: In 2040, the SSP5-8.5 scenario projects a slightly higher percentage of land below sea level compared to SSP2-4.5. While the difference is not drastic, it suggests that even early on, emissions choices affect flood risk. The max projection under SSP5-8.5 is about 1.2% higher than SSP2-4.5.

2060:

- **SSP5-8.5**: Min = 12.8%, Max = 18.99%.
- **SSP2-4.5**: Min = 6.11%, Max = 15.67%.
- **Comparison**: By 2060, the difference between the two scenarios becomes more pronounced. Under SSP5-8.5, the area below LMSL increases significantly, nearly doubling the lower bound of SSP2-4.5 and having a higher max value. This evidence suggests that the more aggressive emissions in SSP5-8.5 lead to a much higher risk of

flooding.

2100:

- **SSP5-8.5**: Min = 25.43%, Max = 39.31%.
- **SSP2-4.5**: Min = 18.52%, Max = 26.32%.
- **Comparison**: By 2100, the gap between SSP5-8.5 and SSP2-4.5 becomes enormous. SSP5-8.5 shows a maximum area below sea level nearly 13% higher than SSP2-4.5. This difference demonstrates the long-term consequences of failing to control greenhouse gas emissions, with the SSP5-8.5 scenario projecting much more widespread coastal inundation.

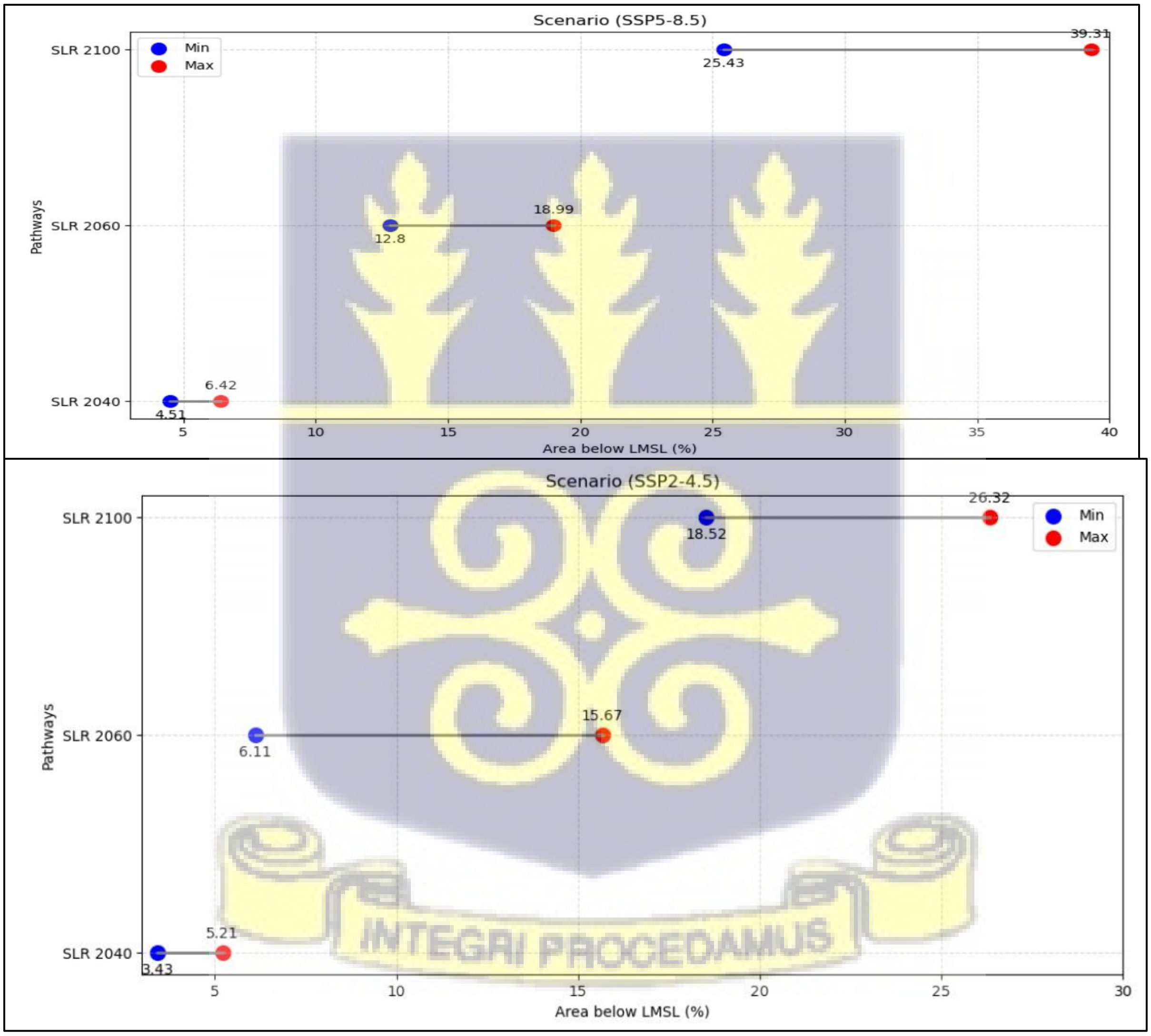


Figure 4.22: Comparison Between SSP2-4.5 and SSP5-8 Author's Work, 2014

The comparison between the SSP5-8.5 and SSP2-4.5 scenarios reveals significant differences in projected sea-level rise (SLR), uncertainty ranges, and the severity of impact over time.

Overall Projected Sea Level Rise (SLR) by Year: In 2040, the SSP5-8.5 scenario projects a slightly higher percentage of land below the local mean sea level (LMSL) compared to SSP2-4.5, with 4.51% to 6.42% of the area below LMSL for SSP5-8.5 and 3.43% to 5.21% for SSP2-4.5. This early difference, though not drastic, suggests that emissions pathways already influence flood risk, with the maximum projection under SSP5-8.5 being about 1.2% higher than SSP2-4.5.

By 2060, the disparity between the two scenarios becomes more pronounced. Under SSP5-8.5, the area below LMSL increases significantly, ranging from 12.8% to 18.99%, while SSP2-4.5 projects 6.11% to 15.67% of the area below LMSL. This nearly doubling of the lower bound in SSP5-8.5 suggests that more aggressive emissions lead to a much higher risk of flooding.

By 2100, the gap between the scenarios is substantial. SSP5-8.5 shows that 25.43% to 39.31% of the area could be below sea level, compared to 18.52% to 26.32% under SSP2-4.5. This stark difference illustrates the long-term consequences of failing to control greenhouse gas emissions, with SSP5-8.5 projecting much more widespread coastal inundation.

Overall Uncertainty Ranges (Min-Max Gap):The uncertainty ranges also vary significantly between the scenarios. In 2040, both show a relatively small range of uncertainty, with 1.91% for SSP5-8.5 and 1.78% for SSP2-4.5, indicating a more predictable sea-level rise in the short term. However, by 2060, SSP5-8.5 shows a 6.19% difference between the minimum and maximum values, while SSP2-4.5 exhibits a larger 9.56% range. By 2100, SSP5-8.5's uncertainty range expands to 13.88%, reflecting the greater unpredictability of high-emission pathways, compared to a 7.80% range in SSP2-4.5, which suggests a more constrained but still considerable range of outcomes.

Overall Severity of Impact: In terms of the severity of impact, SSP5-8.5 consistently projects a larger area below sea level at each time interval, with up to 39.31% of the area potentially submerged by 2100, posing significant risks to urban coastal centers. The impacts are more severe in both mid-term and long-term projections. SSP2-4.5, being a moderate-emission scenario, shows significantly lower percentages of land below LMSL across all years, suggesting that mitigating emissions through international cooperation and policies can limit sea-level rise and its associated risks. However, even under SSP2-4.5, the impacts remain considerable, especially by 2100 when up to 26.32% of the area could be submerged.

Overall Rate of Increase Over Time: The rate of increase over time also differs between the scenarios. SSP5-8.5 sees a sharp acceleration in the area below LMSL between 2060 and 2100, indicating much larger impacts towards the end of the century. In contrast, SSP2-4.5 exhibits a more gradual rise, with less acceleration between 2060 and 2100, reflecting a slower rate of sea-level rise that allows for more time to adapt and implement protective measures.

4.3 Analysis of Exposures and Vulnerabilities

4.3.1 Erosion and Shoreline Analysis

The coast of the Lower Volta has been identified in the literature to be facing a lot of erosion and has played and significant role on the sea erosion. Using the Shoreline analysis the results presented in Table 4.3 and Table 4.4 and Figure 23, reveal a complex pattern of shoreline change, highlighting both spatial and temporal variability.

Table 4.3 (**Overall Shoreline Change (2016-2024)** provides a holistic view of shoreline change across the entire study area from 2016-2024. The result of -3.07 m/yr for erosion indicates an overall landward retreat of the shoreline. The co-occurrence of a positive accretion rate of 1.47 m/yr, however, suggests the presence of areas experiencing shoreline progradation (sea-ward advancement). This highlights inherent spatial heterogeneity, where erosion and accretion occur simultaneously within the study area. The error of ±0.25 m/yr, while relatively small, underscores the importance of acknowledging inherent uncertainties in any shoreline change analysis based on remotely sensed data. Factors like image resolution, tidal variations during image acquisition, and accuracy of shoreline delineation contributes to this uncertainty. The reported values represent average rates and don't fully capture localised, short-term events such as storms or specific human interventions that can influence shoreline positioning.

Table 4.3: Estimated accretion and erosion rates using the method for the years 2016, 2020 and 2024

Shoreline Change Results		
Period	**Rate of Erosion (m/yr.)**	**Rate of Accretion (m/yr.)**
2016–2024 (LRR)	-3.07	1.47 Error = ±0.25

Source: Author's Work, 2024

Table 4.4 (**Shoreline Change by Major Town (2016-2024)**) offers a more localised perspective, presenting results specifically for three major towns: Ada, Fuveme, and Keta. While all three locations show net erosion (-2.40 m/yr, -4.56 m/yr, and -2.24 m/yr, respectively), the magnitudes vary, underscoring the influence of local factors on erosion patterns. These factors could include differences in sediment supply, coastal morphology (e.g., presence of cliffs, beaches, or estuaries), wave energy, and human activities. Furthermore, the presence of simultaneous accretion in each town (ranging from 1.12 m/yr to 2.05 m/yr) reinforces the spatial variability observed in Table 4.3.

The consistent error of ±0.25 m/yr emphasises that these are average rates over the study period, and short-term fluctuations might significantly differ.

Table 4.4: Estimated accretion and erosion rates using the linear regression rate method for the major towns

Major Towns	**Rate of Erosion (m/yr.)**	**Rate of Accretion (m/yr.)**
Ada	-2.40	1.12
Fuvume	-4.56	1.24
Keta	-2.24	2.05

Figure 23 (**Linear Regression Rates of Change, (2016-2024))**

Figure 23 (Linear Regression Rates of Change, (2016-2024)) offers a visual representation of the spatial variability of shoreline change. The figure plots the LRR for each transect along the coastline.

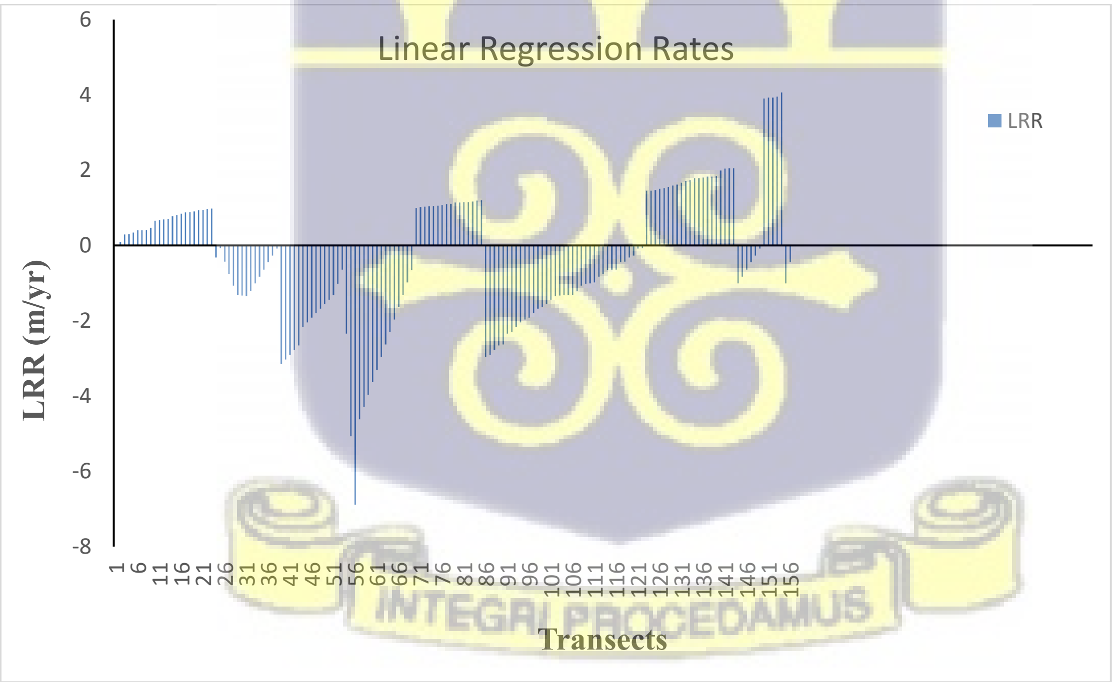


Figure 4.23: Linear Regression Rate of Change for 2016, 2020 and 2024.
Source: Author, 2024

The combined results from the tables and figure strongly support the conclusion that shoreline change in the study area is highly heterogeneous. While a net erosional trend exists, specific locations experience differing degrees of erosion and even accretion. This complexity underscores the necessity of employing high-resolution data and sophisticated analysis techniques like those used here. Future studies could incorporate additional data (e.g., bathymetry, sediment transport data, historical shoreline positions) to improve understanding of the underlying drivers of this spatially variable shoreline change.

Furthermore, investigating the influence of sea-level rise, storm events, and human interventions on shoreline position would add valuable context to the observed patterns. The inclusion of error margins and the clear presentation of both overall and site-specific rates enhance the reliability and informativeness of this coastal change assessment.

> *According to residents, the primary factor contributing to coastal erosion in Fuveme is the poorly constructed sea defence structure at Ada. Prior to its construction, the impact of erosion was not as severe as it is today.*
>
> *The District Planning Officer said, 'Historical accounts from the community suggest that coastal erosion has been a persistent issue, but its severity has intensified over time.' Many believe that the inadequate construction of the sea defence structure at Ada has exacerbated the problem. Specifically, the structure should have been built on the eastern side to mitigate the pressure of tidal waves from the west* (Ada District Planning Officer, 2024).

> *The destruction of homes in the area is not attributed to poor building materials or location, but rather the intense tidal waves that cause erosion.*
>
> *The waves wash away the sand beneath the houses, leading to their eventual collapse* (Resident, Ada Foah, 2024).

> *The construction of the sea defence structure was done without our input, resulting in a poorly built project. Despite the authorities' awareness of the contractors' mistakes, they failed to address the issue, leaving us to suffer the consequences of sea erosion* (Resident, Blekusu, 2024).

Pictures of Exposures, vulnerabilities, and Impacts:

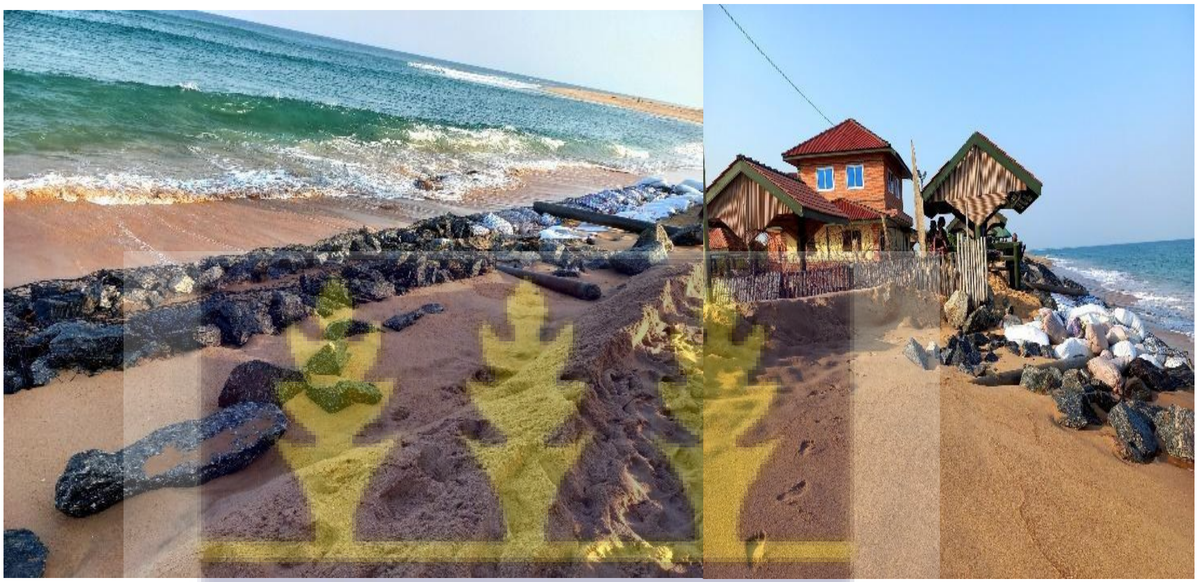


Plate 4.3: Erosion at Aborigin Hotel, Keta Source: Author’s Work, 2023

Pictures of Exposures, Vulnerability and Impacts:

Plate 4.4: Flooded Farms in Anloga Source: Author’s Work, 202

Pictures of Exposures, Vulnerability and Impacts:

Plate 4.5: Flooded Homes and other properties in Nyanui Source: Author's Work, 2023

Pictures of Exposures, Vulnerability and Impacts:

Plate 4.6: Flooded Homes in Fuveme and Atiteti Source: Author’s Work, 2023

4.4 Flood Risk Analysis (Models)/Multiple Regression Analysis (Flood Risk Analysis)

4.4.1 : Mann-Kendall Test

Table 4.5: Mann-Kendall Test (Rainfall (Keta)

Rainfall (Keta)	
Alpha	0.05
MK-stat	-161
s.e.	180.6977
z-stat	-0.88546
p-value	0.37591
Trend	No
Sen's Slope	
Alpha	0.05
Slope	-1.63208
Lower	-5.39048
Upper	1.852941

Source: Author's Field Work, 2024

The results of the Mann-Kendall test (Table 4.5) show that the Mann-Kendall statistic (MK-stat) is -161, which indicates a potential decreasing trend in rainfall. However, this alone does not determine statistical significance. The calculated z-statistic is -0.89, and the corresponding p-value is 0.376. Given that the p-value is greater than the significance level ($\alpha = 0.05$), we fail to reject the null hypothesis that there is no trend. This implies that there is no statistically significant trend in the rainfall data over the period analyzed. The calculated standard error (s.e.) of the MK-statistic is 180.70, which further supports that the observed value of the MK-statistic lies within a range of expected variations due to random fluctuations in rainfall patterns. Hence, the test results suggest that the fluctuations in rainfall over the 63-year period are likely due to natural variability rather than a systematic increase or decrease(Table 4.5).

To quantify the direction and magnitude of the potential trend, Sen's slope estimator was calculated. The Sen's slope was estimated to be -1.63 mm/year, which suggests a slight decreasein annual rainfall. However, the 95% confidence interval for the slope ranges from -5.39 mm/year to

1.85 mm/year. Since the confidence interval includes zero, the slope is not statistically significant. This means that the actual rate of change in rainfall could be anywhere between a decrease of 5.39 mm/year and an increase of 1.85 mm/year, indicating no conclusive evidence of a consistent upward or downward trend (Table 4.5).

The analysis using the Mann-Kendall test and Sen's slope estimation does not provide sufficient evidence to support the existence of a significant trend in rainfall in Keta from 1960 to 2023. While the negative slope suggests a potential decreasing trend in annual rainfall, the results are not statistically significant, and the observed variations are likely to be a result of natural short-term fluctuations rather than long-term climatic changes (Table 4.5).

Table 4.6: Keta Maximum Temp

Mann-Kendall Test	
Maximum Temperature (Keta)	
Alpha	0.05
MK-stat	1417
s.e.	172.6007
z-stat	8.203907
p-value	2.33E-16
Trend	Yes
Sen's Slope	
Alpha	0.05
Slope	0.049137
Lower	0.042573
Upper	0.056593

Source: Author's Field Work, 2024

The results of the Mann-Kendall test in Table 4.6 show that the Mann-Kendall statistic (MK-stat) is 1,417. This points to a strong upward trend in the maximum temperature data. The corresponding z-statistic is 8.20, which is significantly high, suggesting that the observed increase in temperature is not due to random fluctuations but rather a systematic trend. The p-value associated with this z-statistic is 2.33 x 10^{-16}, which is far smaller than the significance level (α = 0.05). This provides 10^{-16},overwhelming evidence to reject the null hypothesis of no trend, confirming the presence of a statistically significant increasing trend in maximum temperatures over the 63-year period. The standard error is 172.60 and given the magnitude of the MK-statistic and z-statistic, this confirms that the observed upward trend is highly significant and not a result of natural variability (Table 4.6).

Sen's slope was calculated as 0.049 mm/year, which indicates that the maximum temperature has been increasing by 0.049°C per year on average over the study period. The 95% confidence interval for the slope ranges from 0.042°C to 0.057°C per year, suggesting that the rate of increase is not only significant but also fairly precise within this range. The increasing trend in the maximum temperatures in Keta from 1960 to 2023 is robust, as demonstrated by the tight confidence interval (Table 4.6).

Table 4.7: Keta Minimum Temp

Mann-Kendall Test	
Minimum Temperature (Keta)	
Alpha	0.05
MK-stat	-307
s.e.	172.6007
z-stat	-1.77288
p-value	0.076249
Trend	No
Sen's Slope	
Alpha	0.05
Slope	-0.00809
Lower	-0.01751
Upper	0.00122

Source: Author's Field Work, 2024

The Mann-Kendall test results (Table 4.7) indicate that the Mann-Kendall statistic (MK-stat) is -307, which suggests a slight decreasing trend in minimum temperature over the study period. The z-statistic is -1.77, showing that while there is a downward trend, it is not strong enough to be statistically significant. The p-value associated with this z-statistic is 0.076, which is slightlygreater than the significance level (α = 0.05). As a result, we fail to reject the null hypothesis of no trend, indicating that there is no statistically significant trend in minimum temperatures for Keta over this period. The standard error (s.e.) is 172.60, which is comparable to that in the maximum temperature estimator, which in this case does not support any significant trend in the data (Table 4.7).

Sen’s slope estimation was performed to quantify the rate of change in minimum temperatures. The Sen's slope was calculated as -0.008°C per year, indicating a very slight decline in minimum temperatures over the study period. However, the 95% confidence interval for the slope ranges from -0.017°C to 0.001°C, which crosses zero, confirming that the observed change is not statistically significant (Table 4.7). It is to be noted that there is a small negative slope (indicating a slight decline in minimum temperatures). The absence of a significant trend in minimum temperatures contrasts with the significant rise observed in maximum temperatures, indicating that warming in the region may primarily affect daytime rather than nighttime temperatures (Table 4.7).

Table 4.8: Ada Rainfall

Mann-Kendall Test	
Rainfall (Ada)	
Alpha	0.05
MK-stat	-197
s.e.	172.6007
z-stat	-1.13557
p-value	0.256137
Sen's Slope	
Alpha	0.05
Slope	-1.80694
Lower	-4.83404
Upper	1.679487

Source: Author’s Field Work, 2024

The Mann-Kendall test results (Table 4.8) show that the Mann-Kendall statistic (MK-stat) is -197, indicating a slight decreasing trend in rainfall over the study period. The z-statistic is -1.14, which suggests a weak downward trend, but it is not statistically significant. The p-value for the test is 0.256, which is higher than the significance level (α = 0.05). Since the p-value exceeds the threshold, we fail to reject the null hypothesis of no trend. This indicates that there is no statistically significant trend in rainfall in Ada over this period. The standard error is 172.60, similar to other analyses, but in this case, it does not support the presence of a statistically meaningful trend.

The Sen's slope estimator was calculated to be -1.81 mm per year. This suggests a very small decrease in rainfall over the 61-year period. However, the 95% confidence interval for the slope ranges from -4.83 mm/year to 1.68 mm/year, meaning the confidence interval crosses zero. This further confirms the absence of a statistically significant trend in the data (Table 4.8).

Table 4.9: Ada Maximum Temp

Mann-Kendall Test	
Maximum Temperature (Ada)	
Alpha	0.05
MK-stat	282
s.e.	172.5978
z-stat	1.628062
p-value	0.103512
Trend	No
Sen's Slope	
Alpha	0.05
Slope	0.006401
Lower	-0.00146
Upper	0.013607

Source: Author’s Field Work, 2024

The results indicate that the Mann-Kendall statistic (MK-stat) is 282, suggesting a slight upward trend in maximum temperatures over time. However, the z-statistic of 1.63 implies that this trend is weak. The p-value for the test is 0.104, which is greater than the significance level of α = 0.05. Since the p-value exceeds the threshold, we fail to reject the null hypothesis of no trend. This means that there is no statistically significant trend in maximum temperature in Ada over the period (Table 4.8). The standard error of 172.60 provides a measure of the variability in the test results, but the relatively small z-statistic and non-significant p-value point to an absence of a clear temperature trend (Table 4.8) The Sen's slope estimate is 0.0064°C per year.

Table 4.10: Ada Minimum Temperature

Mann-Kendall Test	
Minimum Temperature (Ada)	
Alpha	0.05
MK-stat	1416
s.e.	172.6036
z-stat	8.197975
p-value	2.44E-16
Trend	Yes
Sen's Slope	
Alpha	0.05
Slope	0.028472
Lower	0.023865
Upper	0.033491

Source: Author’s Field Work, 2024

This small positive slope suggests a very slight increase in maximum temperatures annually. However, the 95% confidence interval for the slope ranges from -0.0014°C/year to 0.0136°C/year, meaning that the confidence interval includes zero. This reinforces the finding that the upward trend is not statistically significant. Although there is a small positive slope indicating a possible increase in maximum temperatures over time, the lack of statistical significance in both the Mann-Kendall and Sen’s slope analyses suggests that this trend is not strong enough to be conclusive (Table 4.8).

A Mann-Kendall statistic (MK-stat) of 1416, indicating a strong upward trend in minimum temperatures during the analysis period was calculated. The corresponding z-statistic of 8.20 is significantly higher than zero, further confirming the presence of an increasing trend.

The p-value for this test is 2.44×10^{-16}, which is far smaller than the significance level of $\alpha = 0.05$. With this extremely low p-value, we can reject the null hypothesis of no trend. Thus, there is strong evidence of a statistically significant upward trend in minimum temperatures in the Ada region over the study period. The standard error of 172.60 shows the variability around the trend, though the z-statistic and p-value clearly support a significant warming trend (Table 4.9).

The Sen's slope is calculated as 0.0285°C per year, which suggests that the minimum temperature in Ada has been increasing by approximately 0.028°C each year. The 95% confidence interval for the Sen's slope is between 0.0239°C/year and 0.0335°C/year, meaning that the increase in minimum temperature is statistically significant. Since the confidence interval does not include zero, it further reinforces the conclusion of a warming trend. Thus Ada has experienced a consistent and measurable increase in minimum temperatures, with an estimated rise of 0.028°C per year. (Table 4.10).

4.4.2 Mapped Climate conditions in the risk model

This rainfall map was generated using an interpolation method in ArcMap, utilizing Kriging, to estimate precipitation across the lower Volta delta area. The map visualizes spatial variability in rainfall distribution across the selected region, using different color gradients to represent rainfall intensity in millimetres (mm). This rainfall map provides a spatial representation of rainfall distribution, showing a clear west-to-east gradient with increasing rainfall toward the west of the volta delta. The western region of the area (Ada Foah, Sogakope) experiences the highest amount of rainfall, particularly the Ada Foah region, which lies within the blue to green delineation (800.7

mm to 809.0 mm).

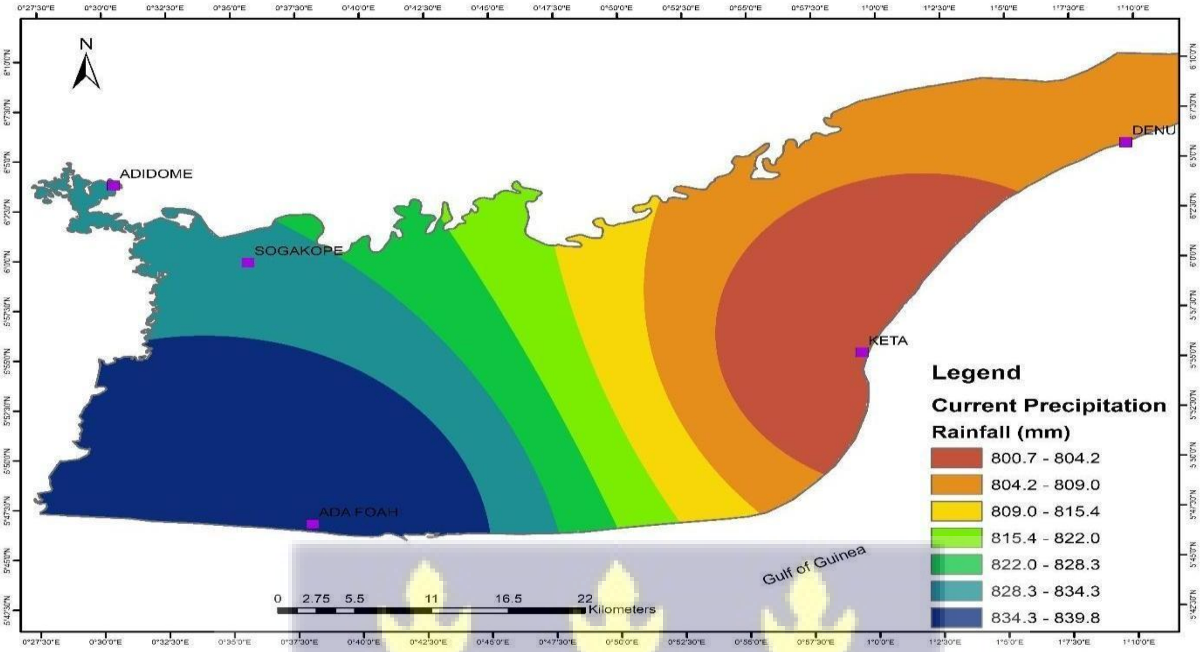


Figure 4.24: Rainfall in Volta basin delta Source: Author’s Field Work, 2024

In the central part of the study area (Keta) there is moderate rainfall, with values progressively decreasing toward the coast. The transition from yellow to orange indicates a steady decrease in rainfall amounts. The eastern edge of the region, near Denu, shows the lowest recorded rainfall, indicating a significant difference in precipitation compared to the western areas (Figure 4.22).

The minimum temperature map (Figure 4.25), generated using the kriging interpolation method in ArcMap, visualises the spatial distribution of minimum temperature values across the lower Volta delta area. The map shows a clear temperature gradient from east to west, with the coolest minimum temperatures along the eastern and coastal areas and progressively warmer minimum temperatures towards the west.

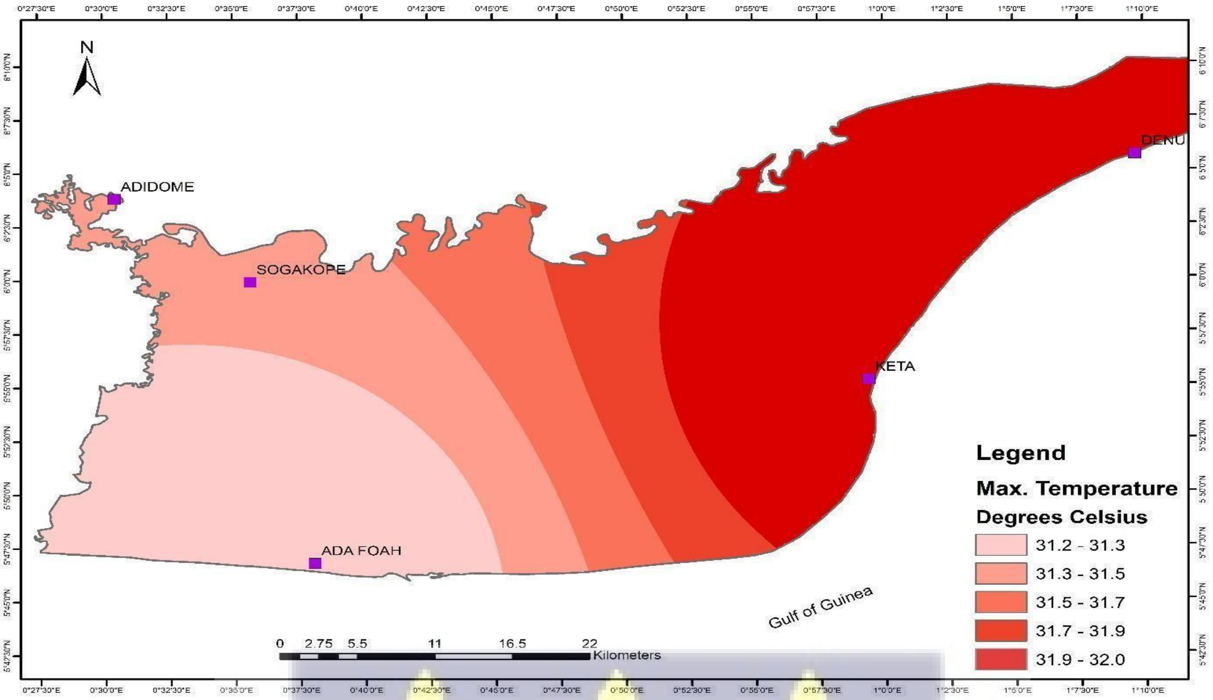


Figure 4.25: Minimum temperature in Volta basin delta Source: Author's Work, 2024

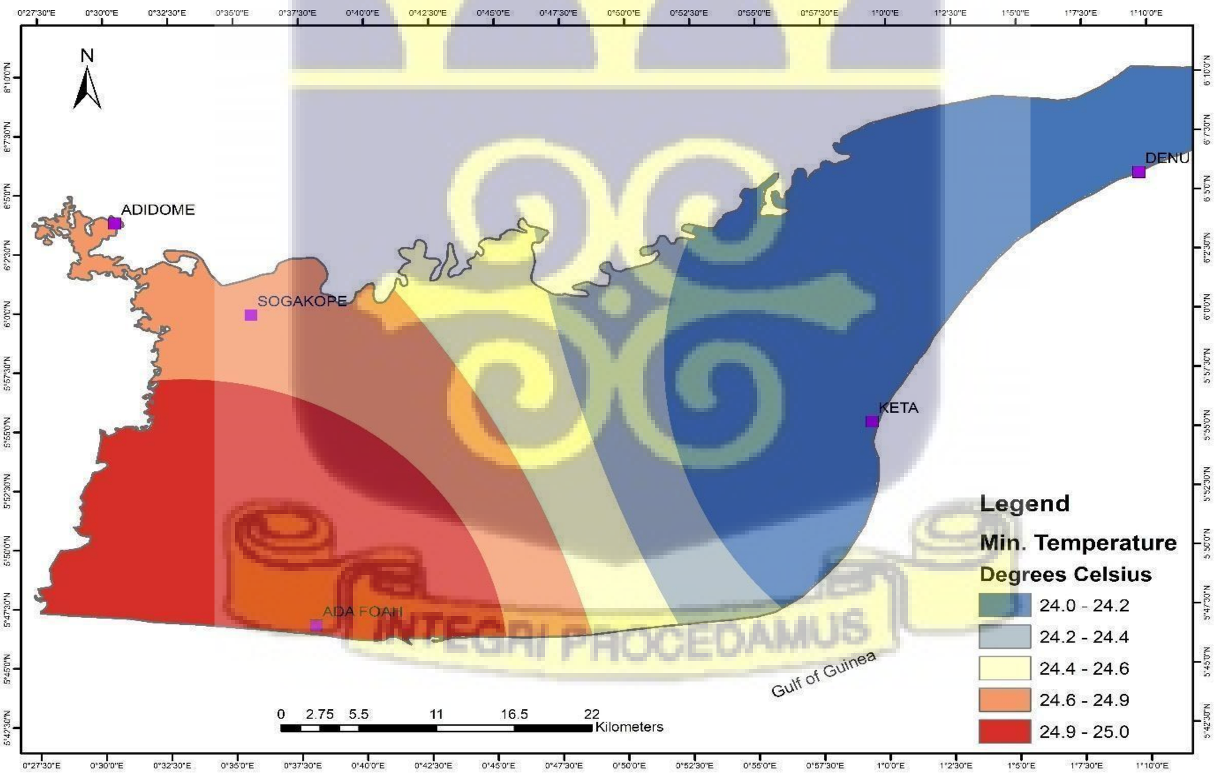


Figure 4.26: Maximum temperature in Volta basin delta Source: Author's Field Work, 2024

This maximum temperature (MaKeta) was also generated using the interpolation method in ArcMap. Ada Foah and Sogakope have slightly lower maximum temperatures compared to the eastern part of the lower Volta delta. The gradient shows increasing warmth inland and toward the east. The Keta and Denu areas experience the highest maximum temperatures of up to 32.0°C, as represented by the dark red colour (Figure 4.26).

The figure (4.25) presents four maps contributing to a flood risk assessment: land use/land cover (LULC), digital elevation model (DEM), slope, and river buffer zones. Each map provides crucial spatial information to understand flood vulnerability.

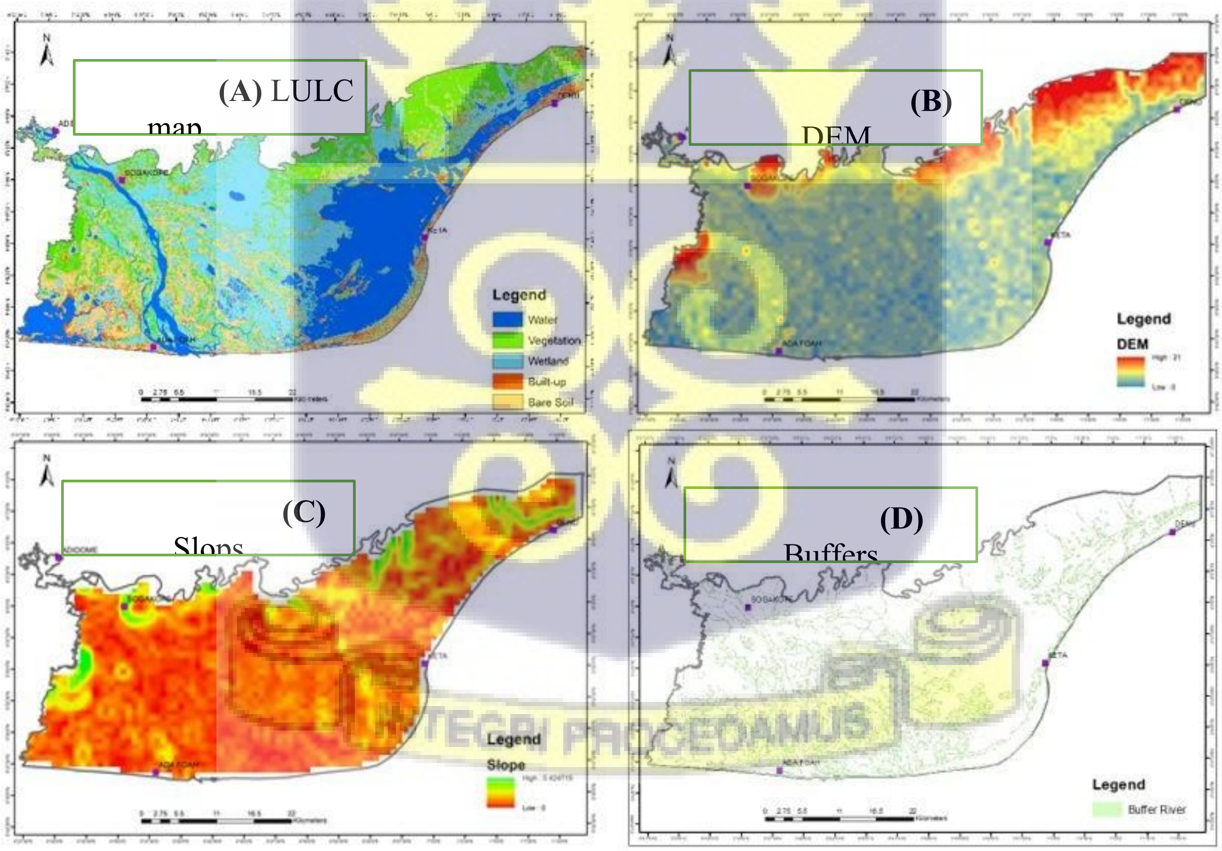


Figure 4.27: Land Cover and Land Use Map Source: Author’s Field Work, 2024

The **LULC map (A)** displays the spatial distribution of different land cover types. The map shows the areas covered by water bodies (rivers, lagoons, and the sea), vegetation (likely indicating areas with higher infiltration capacity and potential buffering against flooding), wetlands (also acting as natural buffers), built-up areas (identified as more vulnerable due to limited infiltration and increased surface runoff), and bare soil. The relative proportions of these land cover types across different regions are important indicators of flood susceptibility. Areas with a higher proportion of impervious surfaces (built-up areas) are likely to experience increased surface runoff and a higher risk of flooding compared to regions dominated by vegetation or wetlands.

The **DEM (Digital Elevation Model) map (B)** illustrates the elevation variations across the study area. Lower elevations concentrated along coastal zones are visually apparent, while higher elevations are located inland. This elevation data is critical in identifying low-lying areas that are particularly vulnerable to flooding due to their proximity to water bodies and limited drainage capacity. High-elevation areas, on the other hand, are less prone to flooding because water is more likely to flow away from these regions. The DEM therefore provides crucial information for assessing the spatial distribution of flood risk based on elevation alone.

The **slope map** (**C**)depicts the gradient of the terrain, visualizing the steepness of slopes. Steeper slopes facilitate faster water runoff, making them less susceptible to flooding. Conversely, flat and gently sloping areas are more prone to water accumulation, increasing the likelihood of flooding. The slope map reveals the areas where water is likely to pond or accumulate during rainfall events. The prevalence of low-sloping areas in certain regions further increases flood susceptibility in those areas.

Finally, the **river buffer zones map (D)** illustrates zones established at varying distances from rivers to assess the proximity of flood-prone areas to water bodies. This map helps visualize regions particularly vulnerable to flooding due to their proximity to major rivers. Regions within these buffer zones, especially those characterized by flat terrain and low-lying land, face a higher risk of inundation due to the rivers' capacity to swell during intense rainfall events. The proximity of settlements and farmlands to these buffer zones is also an important factor in assessing flood risk. Flood risk mapping was conducted using key factors that influence the vulnerability of the study area to flooding. Among the primary datasets utilized were land use/land cover (LULC), a Digital Elevation Model (DEM), and slope, which was derived from the DEM. Each of these factors played a significant role in identifying potential flood-prone areas within the study region (Figure 4.27).

The LULC map (Figure x) highlights the spatial distribution of different land cover types, including water bodies, vegetation, wetlands, built-up areas, and bare soil. The LULC played a crucial role in flood risk, as impervious surfaces in built-up areas can lead to higher surface runoff, while wetlands and vegetated areas can act as natural buffers against flooding. In this analysis, the built-up areas, particularly near the coast, were identified as more vulnerable due to the limited infiltration capacity.

Also, the DEM map (Figure x) shows the elevation variations across the study area, with lower elevations concentrated along the coastal zones and higher elevations found inland. The elevation significantly influences water accumulation and drainage patterns. Low-lying areas were found to be at higher risk of flooding due to their proximity to water sources and poor natural drainage. High-elevation areas showed minimal flood risk as water is more likely to flow away from these regions.The slope map (Figure x) derived from the DEM depicts the gradient of the terrain. Steeper slopes are typically less prone to flooding due to faster water runoff, whereas flat and gently sloping areas were considered more susceptible to water accumulation. Most of the study area has relatively low slopes, especially along the coast, further increasing the likelihood of flood occurrences.

In this study, buffer zones were established at varying distances from the rivers to assess the proximity of flood-prone areas to these water bodies. The analysis revealed that regions within proximity to major rivers, especially where there is a combination of flat terrain and low- lying land, were highly vulnerable to flooding. Areas surrounding the Volta river and its tributaries in the study region demonstrated an elevated flood risk. This is due to the rivers' capacity to swell during periods of intense rainfall, affecting nearby settlements and farmlands.

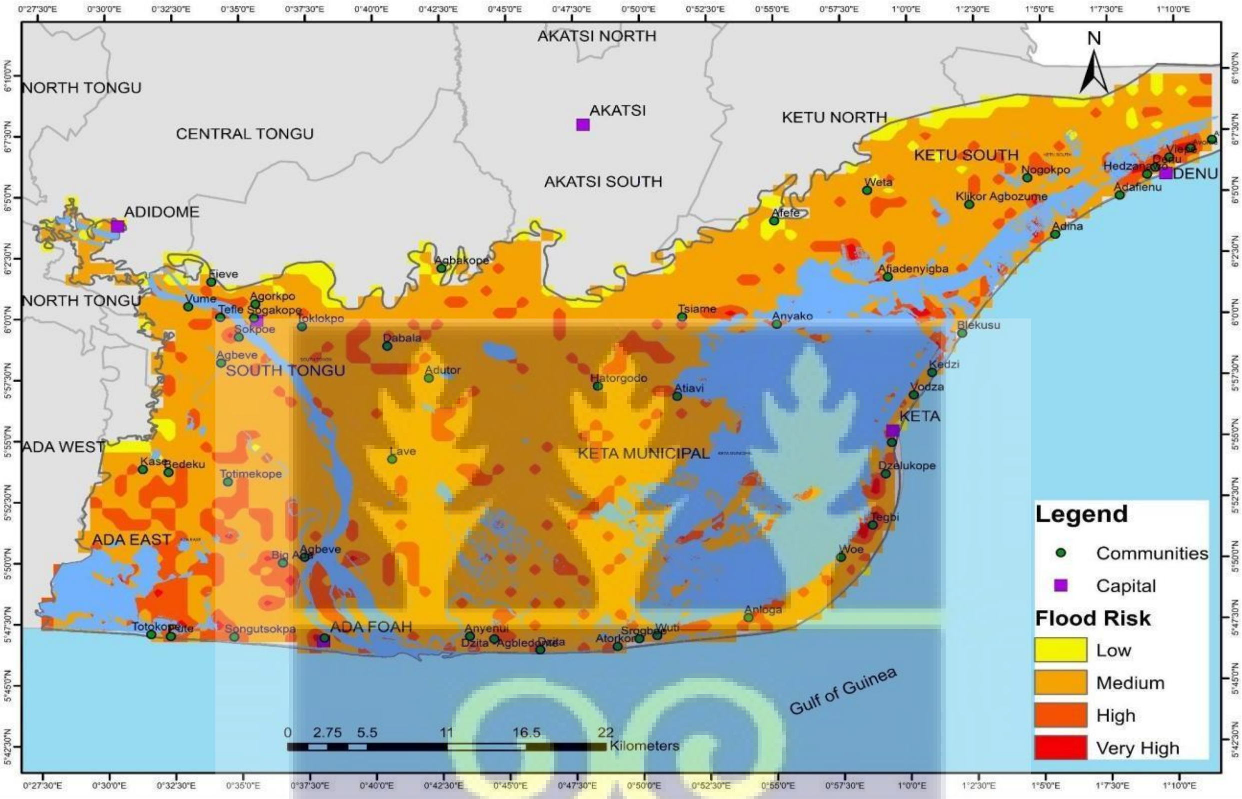


Figure 4.28: Flood Risk Zone Map Source: Author's Field Work, 2024

The flood risk map was created using a weighted overlay analysis in ArcGIS, with various factors contributing to flood susceptibility, including rainfall, slope, elevation (DEM), land use, river proximity and road proximity. The flood risk is categorised into four levels: low (yellow), medium (orange), high (darker orange), and very high (red), with the red areas representing regions susceptible to flooding. (Figure 4.28).

Very High Flood-Prone Areas (Red Zones): These areas are concentrated along the coast, especially near Keta Municipal and some parts of Ada Foah. Coastal zones are typically at lower elevations and in this area closer to rivers, estuaries, lagoons, and the sea. This increases the area's vulnerability to flooding due to heavy rainfall, storm surges, and/or sea-level rise. Communities in these regions, like Keta, Dzita, Woe, and parts of Ada Foah, are particularly at risk of frequent or severe flooding events (Figure 4.26).

High and Medium Flood-Prone Areas (Orange Zones): The high flood-prone areas (in dark orange) extend further inland from the coast and appear in regions like South Tongu and Ada West. In these high flood-prone areas, the risk is influenced mostly by a combination of low slope angles, nearness to rivers and large streams, and land use patterns. The medium-prone areas are more dispersed and occupy a larger portion of the map, covering almost the entire region, including Ketu South, Ketu North, and parts of South Tongu. The risk in these areas is influenced by a combination of lower slopes, proximity to river networks, land use patterns that affect drainage and water retention and possibly soil types that affect infiltration and retention rates (Figure 4.26).

Low Flood-Prone Areas (Yellow Zones): The yellow zones represent regions with the lowest flood susceptibility. These are generally located further inland, in areas like Akatsi South and Ketu South, which likely have higher elevations or more favourable slopes for water drainage.

Communities located in these areas include Afefe, Agbakope, Fieve, and Adidome. Areas with less proximity to rivers or flood-prone infrastructure (roads) also fall under this category. However, proper land use management and adherence to buffer zone policy are still challenges in these areas, and therefore, they owe their low risk to elevation, slope and proximity to water bodies . (Figure 4.26).

Box 4.3: Knowledge Flood Risks – Narrated by Resident in Fuveme (Madam Alice Atakpah)

The sea has taken all our lands from a distance, and every year there are floods. The floods occur during high tides in August. Many floods also happen during the rainy season, especially in June. Over the years, our properties have been destroyed, and we no longer do gardening, as all our lands are submerged. Fishing is no longer an adequate source of income, and the men are without reliable employment. The men's decision to stop fishing also impacts the quantity of fish that we, as women, take to market for sale. We have been going to other communities to buy fish at higher costs. Many of the youth have migrated out of the community, but some come home for funerals. Gradually, many of our children hardly come home, as all the land available for building is now in the sea or has become beaches and wetlands.

She pointed at the temporary structures serving as their residences, with no drains or other services in the settlement. The risks of floods are many, and we could not account for all of them. We are more concerned about the loss of livelihoods, the sources of income, and the property damage, but not the deaths, as we have always been careful since the floods have been perennial. Last year, she pointed from the far west towards the estuary and the east, indicating that the whole settlement was flooded. Many houses were heavily, severely, and unexpectedly flooded. Some farms planted with vegetables, pointing towards Nyanui, the next community, were also destroyed.

Source: Author's Work, 2024

> *"The relentless encroachment of the sea and the Volta River is forcing us out of our homes. Growing up, I remember having to walk a considerable distance to reach the sea, which was once a pristine beach with numerous sand dunes. Over time, however, the sea has gradually eroded the sand dunes, our communities, and everything in its path, leaving behind a trail*

> *of devastation. Today, our communities are plagued by frequent flooding from the Volta River, occurring every three months, and intermittent high tides that threaten our livelihoods and properties* **(Resident at Atiteti, 2023)."**

> *"We consider a hazard to pose as a threat or risk of causing disaster when our livelihoods, which is also our source of income, are being threatened".*

> *"Because our livelihoods depend on the coast, we do not see or assume living here to be a risk"* (The Assemblyman at Adafianu).

> *"The people consider living here as risky and that is what has informed the number and type of structures, they put up here. Before the sea defence wall, only a few people invested heavily in block housing structures because, at a point in time, they were afraid of losing their investment in the form of a major building to erosion or floods from the sea. The potential of losing everything was high" (The Unit Committee Member, Blekusu).*

> *"Yes, we know that living here, our lives are at risk, but we have no choice but to stay here because all our land has been eroded. We have no land again left to relocate to" (Resident, Fuveme).*

> *"Yes. We know that living here is risky. That is why we are crying for the sea defence project to be completed" (The Community Leader of Fuveme).*

> *"Because there is no more access road and clinic in the town, it becomes fatal when there is an emergency"."When there is an emergency here, because of the inaccessible nature of the place, the canoo owners charge exorbitant prices(Fuveme Resident)".*

4.5 Application of Principal Component Analysis for Flood Risk Assessment

This section presents the results of the Principal Component Analysis (PCA), including the number of factors selected and the total variance explained by these factors. PCA was used as the extraction method, with Varimax employed for rotation to enhance interpretability. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy yielded a value of 0.813, indicating that the sample size is suitable for PCA. Additionally, Bartlett's Test of Sphericity returned a significant value of 0.00, confirming that the correlation matrix is not an identity matrix and that the data are appropriate for PCA.

Table 4.9: Communalities Before and After Extraction

Variables	Initial	Extraction
Minimum Temperature	1.00	0.840
Maximum Temperature	1.00	0.781
Average Precipitation	1.00	0.622
Coastal Erosion	1.00	0.781
Population Density	1.00	0.801
Average Household Size	1.00	0.705
Female Population	1.00	0.846
Child Population	1.00	0.930
Socially Disadvantaged People	1.00	0.872
Rural Population	1.00	0.733
Poverty	1.00	0.631
Agricultural Dependency	1.00	0.607
Unemployment	1.00	0.616
Literacy Rate	1.00	0.859
Work participation Rate	1.00	0.964
Home Ownership	1.00	0.784
Healthcare centers	1.00	0.840
Educational Institutions	1.00	0.672
Road Density	1.00	0.676
Electricity	1.00	0.785
Safe Drinking Water	1.00	0.813

Source: Author’s Work, 2024

Table 4.9 provides the communalities, which represent the proportion of variance in each variable explained by the extracted factors. For example, over 84.0% of the variance in minimum temperature is explained, while 78.1% of the variance in maximum temperature is accounted for by the selected factors.

Table 4.9 shows the importance of each of the 21 principal components using the eigen values. The first four have Eigen values over 1.00 which explains over 80.515% of the total variability in the data. Hence, it would be concluded that a four-factor solution will be adequate in determining the vulnerability in Volta Basin.

Table 4.10: Total Variance Explained

Component	**Total**	**Initial Eigen Values**	
		% of Variance	Cumulative %
1	2.425	11.550	11.550
2	1.801	8.579	20.128
3	1.758	8.373	28.501
4	1.673	7.966	36.467
5	1.500	7.144	43.612
6	1.411	6.717	50.329
7	1.281	6.102	56.431
8	1.095	5.212	61.643
9	1.031	4.912	66.555
10	0.959	4.567	71.122
11	0.923	4.396	79.434
12	0.823	3.917	83.189
13	0.788	3.755	86.483
14	0.692	3.294	89.529
15	0.640	3.046	92.393
16	0.602	2.865	94.596
17	0.462	2.202	96.522
18	0.404	1.926	98.075
19	0.326	1.554	99.342
20	0.266	1.266	100.000
21	0.138	0.658	

Source: Author's Work, 2024

Table 4.10 provides the detailed results of the factor loadings for the 21 variables derived from the Varimax rotation. Based on the PCA results, vulnerability has been estimated for all communities in the Volta Basin (Table 4.10). In the vulnerability analysis, three components explained 75.37% of the total variance for exposure, while four components accounted for 81.3% of the total variance for sensitivity, and three components explained 78.26% of the variance for adaptive capacity. The first component captured the largest share of the variance in the data (Table 4.10).

For the first component in the vulnerability analysis, variables such as maximum and minimum temperatures, average precipitation, coastal erosion, agricultural dependency, literacy rate, and household assets exhibited significantly high positive loadings. In contrast, variables like landholding and home ownership displayed strong negative loadings. Loadings, which measure the correlations between variables and components, range from

−1 to +1 (Table 4.10).

The second component primarily reflected variations in variables such as flood frequency, average household size, and child population. The third component was associated with variables including female population, road density, and access to safe drinking water. Finally, the fourth component, mainly related to adaptive capacity, highlighted work participation rates and the availability of educational institutions (Table 4.10).

In terms of climate, flood and erosion hazards, the rotated component analysis indicates that the Lower Volta Basin faces significant climate-related hazards. Component 1 shows strong loadings for average precipitation (0.877), coastal erosion (0.809), and temperature extremes (minimum = 0.839; maximum = 0.761). These variables collectively point to an environment characterised by intense rainfall, rising temperatures, and shoreline instability, which increase flood and erosion risks. Districts scoring high on this component are therefore hazard hotspots, requiring targeted interventions such as improved drainage systems, coastal protection, and early warning systems.

Table 4.11: Rotated Component Matrix

Variables				
	1	2	3	4
Minimum Temperature	0.839	0.513		
Maximum Temperature	0.761	0.636		
Average Precipitation	0.877			
Coastal Erosion	0.809			
Population Density	0.757	0.791		
Average Household Size		0.802		
Female Population	0.769	0.914		
Child Population	0.616	0.792		
Socially Disadvantaged People	0.526	0.530		
Rural Population	0.479			
Poverty	0.730	0.712		
Agricultural Dependency	0.263			
Unemployment	0.152			
Literacy Rate	0.623			
Work participation Rate				0.812
Home Ownership	-0.735			
Healthcare centers	-0.619	-0.679		
Educational Institutions				0.703
Road Density			0.811	
Electricity	0.725	0.554	0.613	
Safe Drinking Water			0.797	

Source: Author's Work, 2024

In terms of exposure and vulnerability, Component 2 captures patterns of population exposure and socio-economic vulnerability, with high loadings for population density (0.791), female population (0.914), child population (0.792), and poverty (0.712). These findings suggest that densely populated areas with vulnerable groups (children and women) are concentrated in hazard-prone zones. The negative loading for healthcare centres (−0.679) further indicates limited access to essential services, compounding vulnerabilities. This combination of high exposure and limited adaptive capacity underscores the need for integrated risk reduction strategies, including social protection programmes and improved health infrastructure.

In terms of livelihood capacity and connectivity, Component 3 reflects livelihood capacity, dominated by work participation rate (0.812), while Component 4 represents connectivity, with strong loading for road density (0.811). Districts with low scores on these components are likely to have weaker economic resilience and limited access to evacuation routes or emergency services, increasing their vulnerability during hazard events.

Taken together, the Lower Volta Basin exhibits a triple challenge: high climate hazards, concentrated population exposure, and socio-economic fragility. Areas scoring high on hazard and exposure but low on livelihood and connectivity represent priority risk zones for floods and coastal erosion. These insights provide a robust basis for designing multi-dimensional adaptation strategies, combining structural measures (e.g., embankments, drainage) with social interventions (e.g., poverty alleviation, health services) and infrastructure improvements.

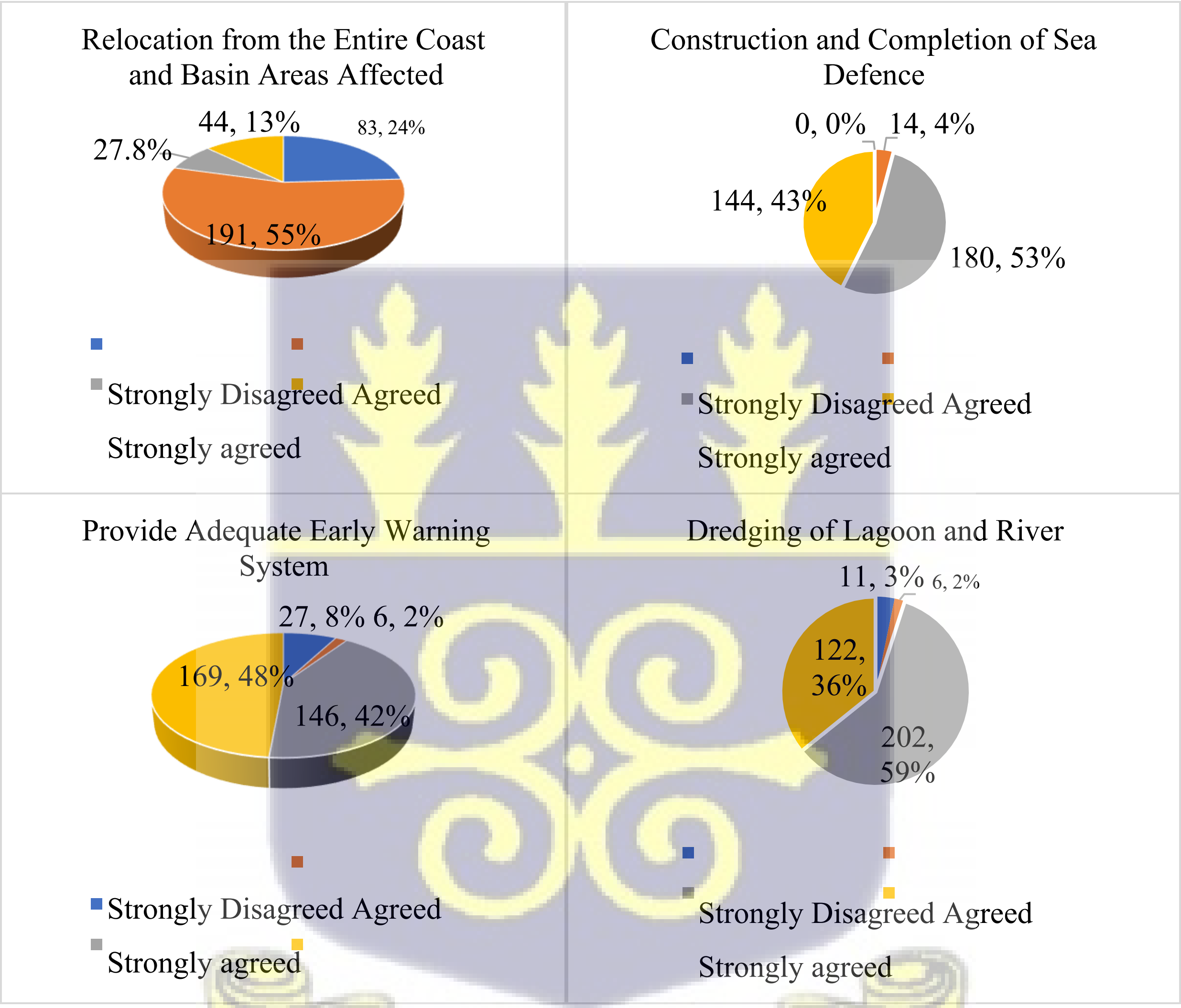
In the Table (4.11), Rotated Component Matrix showing variable loadings on four components. Component 1 represents climate and erosion hazards, Component 2 captures population exposure and social vulnerability, Component 3 reflects livelihood capacity, and Component 4 indicates connectivity. High positive loadings denote strong association with the component, while negative loadings indicate inverse relationships.

4.6 Risk Management and Reduction

4.6.1 Key Solutions by Respondents

The data offers a comprehensive view of community perspectives on key solutions to address erosion and flooding, providing valuable insights into the level of agreement or disagreement with different measures.

Construction and Completion of Sea Defence : Among the 338 respondents, a significant majority support the construction and completion of sea Defence s as a crucial measure to combat erosion and flooding. Specifically, 53.3% of respondents agreed, and 42.6% strongly agreed with this solution. Only a small number (4.1%) disagreed, and none strongly disagreed. This overwhelming support underscores the community's recognition of sea Defence s as essential for protecting coastal areas (Figure 30).



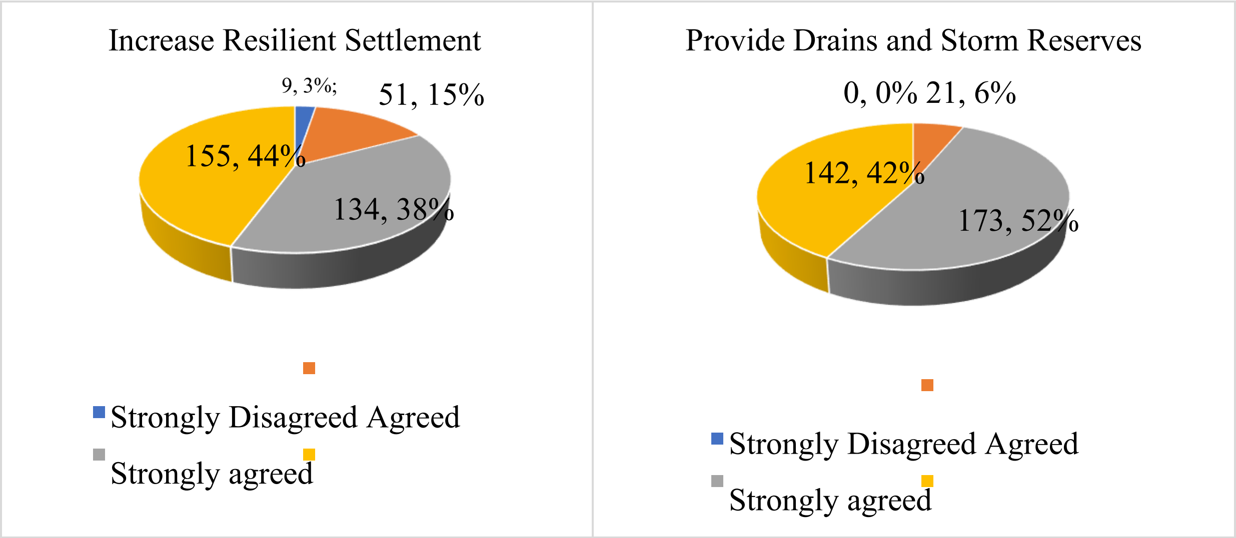


Figure 30: Key Flood Reduction and Management Solutions Source: Author’s Work

Dredging of Lagoon and River: The data shows strong backing for dredging activities to manage erosion and flooding. Out of 341 respondents, 59.2% agreed, and 35.8% strongly agreed with this measure. Only a minimal number of respondents (1.8%) disagreed, and 3.2% stronglydisagreed. This strong support suggests that the community views dredging as an effective strategy to address sedimentation and water flow management in lagoons and rivers.

Relocation from the Entire Coast and Basin Areas Affected: There is a high level of disagreement regarding the relocation of communities from affected coastal and basin areas. Out of 345 respondents, 55.4% disagreed, and 24.1% strongly disagreed with this solution. A smaller portion, 7.8%, agreed, and 12.7% strongly agreed. This significant opposition indicates a reluctance to relocate, likely due to strong ties to their homes and lands or perceived socioeconomic challenges associated with relocation (Figure 28)

Increase Resilient Settlements: There is substantial support for increasing resilient settlements as a strategy to manage erosion and flooding. Among 349 respondents, 38.4% agreed, and 44.4%

strongly agreed with this measure. Only a small fraction (14.6%) disagreed, and 2.6% strongly disagreed. This broad agreement highlights the community's recognition of the importance of building resilient infrastructure to withstand environmental challenges.

Provide Adequate Early Warning System: The data reflects strong community support for implementing adequate early warning systems. Out of 348 respondents, 42% agreed, and 48.6% strongly agreed with this measure. Only a small number (1.7%) disagreed, and 7.7% strongly disagreed. This consensus highlights the community's understanding of the critical role early warning systems play in mitigating the impact of natural disasters by providing timely information and enhancing preparedness (Figure 28).

Provide Drains and Storm Reserves: There is considerable agreement on the necessity of providing drains and storm reserves to manage flooding. Among 336 respondents, 51.5% agreed, and 42.3% strongly agreed with this measure. Only a small number (6.3%) disagreed, and none strongly disagreed. This overwhelming support indicates the community's acknowledgment of effective drainage systems as fundamental components of flood management strategies.

Community perspectives on addressing erosion and flooding show strong support for several key measures. A significant majority favour constructing and completing sea Defence s, viewing them as crucial for coastal protection. Dredging lagoons and rivers also receives considerable support, seen as an effective way to manage water flow and sedimentation. In contrast, there's significant opposition to relocating communities from affected areas, with a clear majority expressing strong disagreement, likely due to social and economic ties to their land.

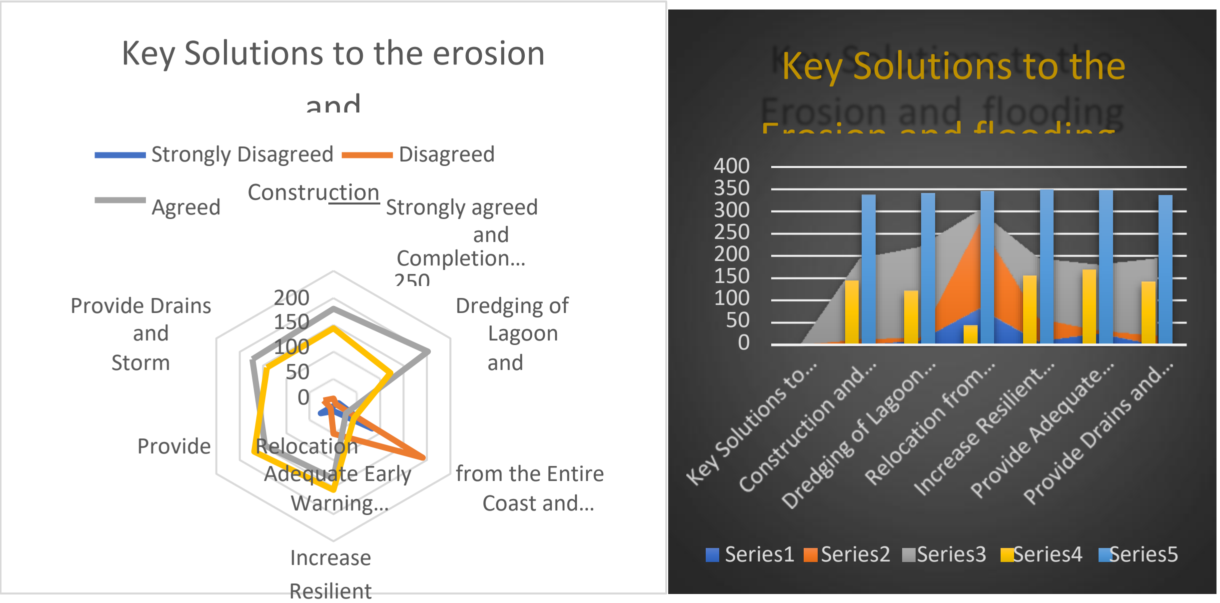


Figure 31: Further justification of the Areas of Concentration on Key Flood Solutions Source: Author’s Work, 2024

There's substantial agreement on increasing resilient settlements and implementing adequate early warning systems, highlighting the community's understanding of their importance in mitigating disaster impacts and improving preparedness. Finally, the community strongly supports providing drains and storm reserves as a fundamental aspect of flood management (Figure 31). Reduction and Management Measures as per DRR

Table 12: Planning (Preventive M/orsure)

Have there been any SDF and or structure plans to the knowledge		
Variables	Frequency of Respondents	Percentage
No	71	21
Not Aware	211	61
Yes	0	0
Indifferent	61	18
	343	100

Have there been any Local Plans for communities in the District		
Variables	Frequency of Respondents	
No	81	23
Not Aware	141	41
Yes	81	23
Indifferent	44	13
	347	
Are you aware of development and published of any building codes		
Variables	Frequency of Respondents	
No	55	16
Not Aware	116	33
Yes	51	15
Indifferent	123	36
	345	

Author's Work, 2024

The data (in Table 12) on respondents' awareness of Structure Development Framework (SDF) or structure plans reveals notable trends. Out of 343 participants, the majority, totaling 211 respondents (61.5%), indicated that they were not aware of any SDF or structure plans. A smaller group of 71 respondents (20.7%) clearly stated that there were no such plans to their knowledge. Interestingly, none of the respondents confirmed the existence of such plans, and 61 respondents (17.8%) expressed indifference towards the matter. This significant lack of awareness and the indifference shown by a notable portion of the respondents suggest a gap in communication and information dissemination regarding SDF or structure plans within the community (Table 12).

When examining the awareness of local plans for communities within the district, the data displays a more balanced distribution. Out of 347 respondents, 81 respondents (23.3%) were aware of the local plans, while an equal number of respondents (81, 23.3%) denied the existence of such plans. However, a larger segment, consisting of 141 respondents (40.6%), reported being unaware of these plans, indicating that there is still a substantial information gap. Additionally, 44 respondents (12.7%) expressed indifference. This mix of awareness levels suggests that while some efforts have been made to inform the public about local plans, there is still a considerable need for improved outreach and engagement to ensure broader awareness (Table 12).

In terms of awareness of building codes, the data indicates a significant portion of respondents are indifferent or uninformed. Out of 345 respondents, 123 (33.6%) were indifferent towards the development and publication of building codes. Another substantial portion, 116 respondents (33.6%), were not aware of such codes. The numbers of respondents who explicitly stated that there were no building codes and those who acknowledged their existence were relatively close, with 55 (15.9%) and 51 (14.8%) respondents, respectively. This distribution points to a critical need for enhancing awareness and education regarding building codes, which are vital for ensuring safe and compliant construction practices (Table 12).

Overall, the analysis of the respondents' awareness across these three areas, SDF and structure plans, local plans for communities, and building codes, highlights a prevalent lack of awareness and a notable level of indifference. To address these issues, authorities and stakeholders should focus on improving communication strategies and engaging with the community more effectively.

By ensuring that the public is well-informed and involved in planning and development processes, it will be possible to foster a more knowledgeable and participatory community.

Table 13: Mitigation Measures (Buffers, Sea and Defence)

Are there buffers to lagoon, river and sea		
Variables	Frequency of Respondents	
Not at all	125	36
Not Really Aware	41	12
Yes, aware.	181	52
Indifferent	1	0
	348	
To what extent these buffers have been enforced		
Variables	Frequency of Respondents	
Not Adequately,	132	53
Adequately	91	36
Indifferent	27	11
	250	
Have there been any sea defences?		
Variables	Frequency of Respondents	
No	55	16
Not Aware	13	4
Yes	182	53
Indifferent	91	27
	341	
To what extent have people developed river and lagoon defences?		
Variables	Frequency of Respondents	
Not Adequately,	217	63
Adequately	0	0
Indifferent	130	37
	347	

Author's Work, 2024

The data reveals varying levels of awareness and enforcement concerning environmental buffers and defences in the area.*Buffers to Lagoon, River, and Sea:* Out of 348 respondents, a significant majority, 181 individuals (52%), are aware of the existence of buffers to lagoons, rivers, and seas. However, 125 respondents (36%) reported the absence of such buffers. A smaller portion, 41 respondents (12%), were not aware of the buffers, and only 1 individual (less than 1%) expressed indifference. This suggests that while a majority acknowledge the existence of these buffers, a substantial minority either do not believe they exist or are unaware of them (Table 13).

Enforcement of Buffers: When it comes to the enforcement of these buffers, the responses indicate a lack of adequate implementation. Out of 250 respondents, 132 individuals (53%) believe that the enforcement has not been adequate. In contrast, 91 respondents (36.4%) feel that the buffers have been adequately enforced. Meanwhile, 27 respondents (10.8%) are indifferent to the issue. The data implies that more than half of the respondents perceive the enforcement measures as insufficient, indicating a need for stronger regulatory actions and implementation. (Table 13).

Sea Defence: Regarding sea Defence s, out of 341 respondents, 182 individuals (53.4%) acknowledged the existence of sea Defence s. However, 55 respondents (16.1%) indicated there are no sea Defence, while 91 respondents (26.7%) were indifferent. A small portion, 13 respondents (3.8%), were not aware of any sea Defence s. This shows a relatively high level of awareness and recognition of sea Defence s, although the significant indifference and the small percentage of unawareness suggest a mixed perception (Table 13).

Plate 4.7: Revetments in Keta and Groyne (Groins) at Blekusu

Plate 4.8: Un-engineered defences and erosions

Development of River and Lagoon Defences: The development of river and lagoon defences appears to be inadequate, based on the responses of 347 individuals. A large majority, 217 respondents (62.5%), believe that these defences have not been developed adequately. Interestingly, no respondents felt that the development has been adequate. Additionally, 130Respondents (37.5%) expressed indifference towards the development of these defences. This overwhelming perception of inadequacy underscores the urgent need for the improved and more extensive development of river and lagoon defences to protect against flooding and other environmental impacts (Table 13).

Maintenance of Sea Defences: When evaluating the maintenance of sea defences, the responses show a clear consensus on the inadequacy of current efforts. Out of 344 respondents, 195 (56.7%) believed that maintenance has not been adequate. Only 21 respondents (6.1%) felt that the maintenance had been adequately performed, while 128 respondents (37.2%) were indifferent. This indicates a significant concern regarding the upkeep of sea defences, which are critical for protecting coastal areas from erosion and flooding (Figure 4.31).The data provides insights into the community's awareness and perceptions regarding flood control measures, and environmental protection initiatives.

Table 14: Mitigation Measures (Reservoirs, Dredging, Maintenance of Infrastructure)

Have there been any dams or reservoirs to control flood plans		
Variables	Frequency of Respondents	
No	209	63
Not Aware	24	7
Yes	1	0
Indifferent	112	32
	346	
Has there been any dredging of the river plans		
Variables	Frequency of Respondents	
No	102	30

Not Aware	161	47
Yes	0	
Indifferent	77	23
	340	

Awareness and Implementation of Flood Control Measures: Regarding the implementation of dams or reservoirs for flood control, most respondents, totaling 209 out of 346 (60.4%), indicated that no such measures have been taken. Additionally, a significant portion, 112 respondents (32.4%), expressed indifference, and only 24 respondents (6.9%) were unaware of any plans. Notably, just one respondent confirmed the existence of such plans. This overwhelmingly negative perception underscores a substantial gap in the implementation or communication of flood control infrastructure (Table 14).

River Dredging Plans: When asked about river dredging plans, the responses show a similar trend. A large majority, 102 out of 340 respondents (30%), reported no dredging plans, while 161 respondents (47.4%) were unaware of any such plans. There was no indication from respondents confirming the existence of river dredging plans. Additionally, 77 respondents (22.6%) expressed indifference. This data indicates a general lack of awareness or action concerning river dredging, a crucial activity for maintaining water flow and reducing flood risk (Table 14).

Lagoon Dredging Plans: The awareness of lagoon dredging plans reveals a slightly different pattern. Out of 347 respondents, 121 (34.9%) indicated that no lagoon dredging plans exist, while 123 respondents (35.4%) were unaware of any such plans. Interestingly, 15 respondents (4.3%) confirmed the existence of lagoon dredging plans, suggesting that some efforts have been made in this area. However, a considerable number of respondents, 88 (25.4%), were indifferent. This mixed response highlights partial awareness and possible initial steps towards addressing lagoon dredging needs (Table 14).

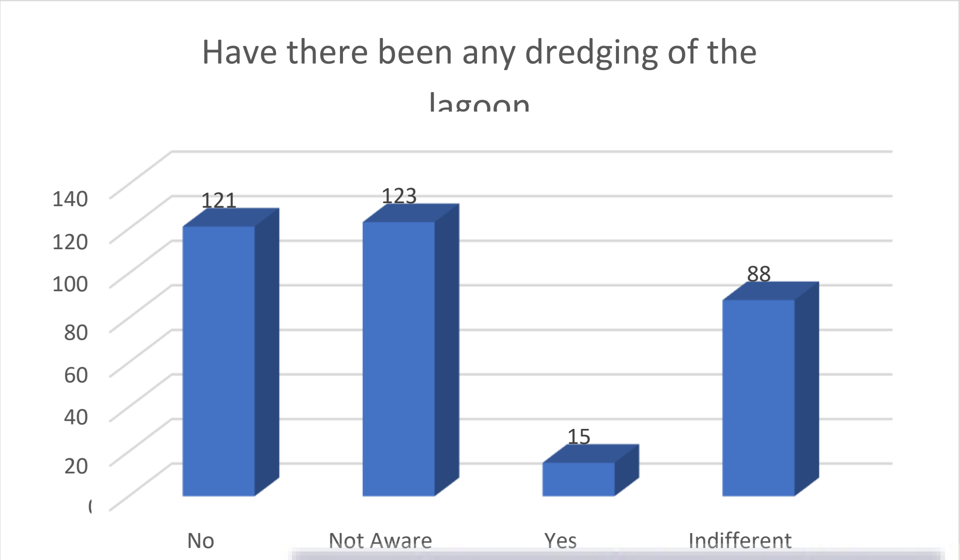


Figure 4.32: No Dredging in the Legoon

Considerable number in of 121 indicated that there have not been any dredging while about 123 people in the Figure 4.32, indicated that they were not aware of such exercise. There a lot of clear disagreement that the Lagoon has ever been dredged since the waters occupied those areas

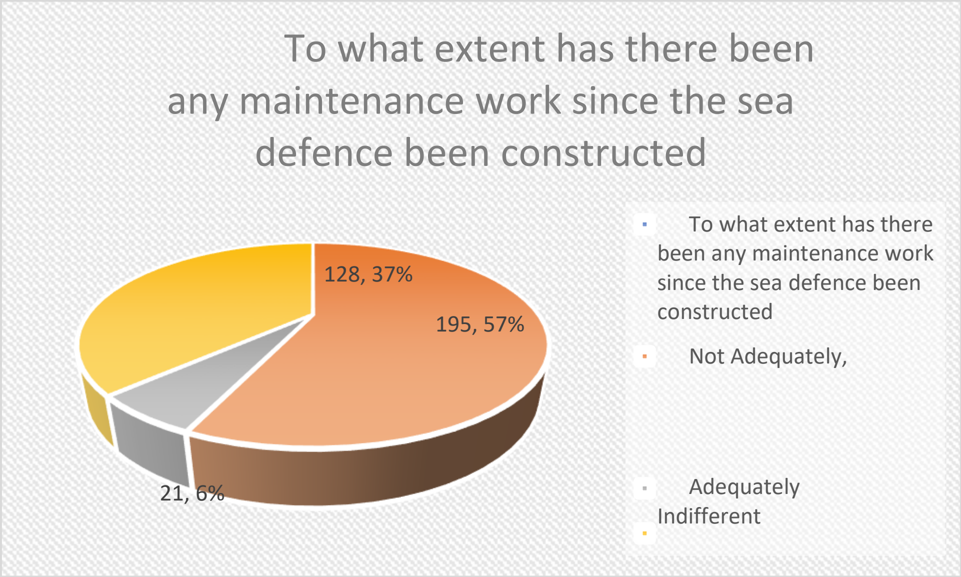


Figure 4.33 Maintenance Work on Defence Constructed

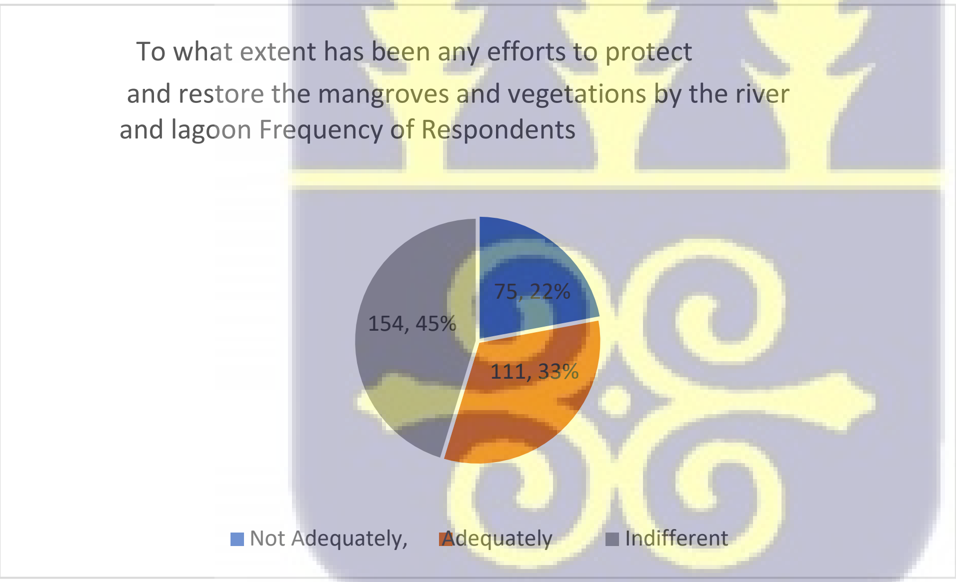


Figure 4.34: Effort to protect and restore the mangroves and vegetations

On issues of preparedness there were discussion and response on mangrove restoration, public education and issue of raising building foundation

Protection and Restoration of Mangroves and Vegetation: Regarding efforts to protect and restore mangroves and vegetation by the river and lagoon, the data reveals varied perceptions. Out of 340 respondents, 111 (32.6%) acknowledged that efforts have been adequate. However, a larger number, 154 respondents (45.3%), expressed indifference, and 75 respondents (22.1%) felt that the efforts have not been adequate. This indicates a mixed awareness and varying levels of satisfaction with the environmental conservation measures, suggesting a need for increased engagement and visible action in these areas (Figure 4.32).

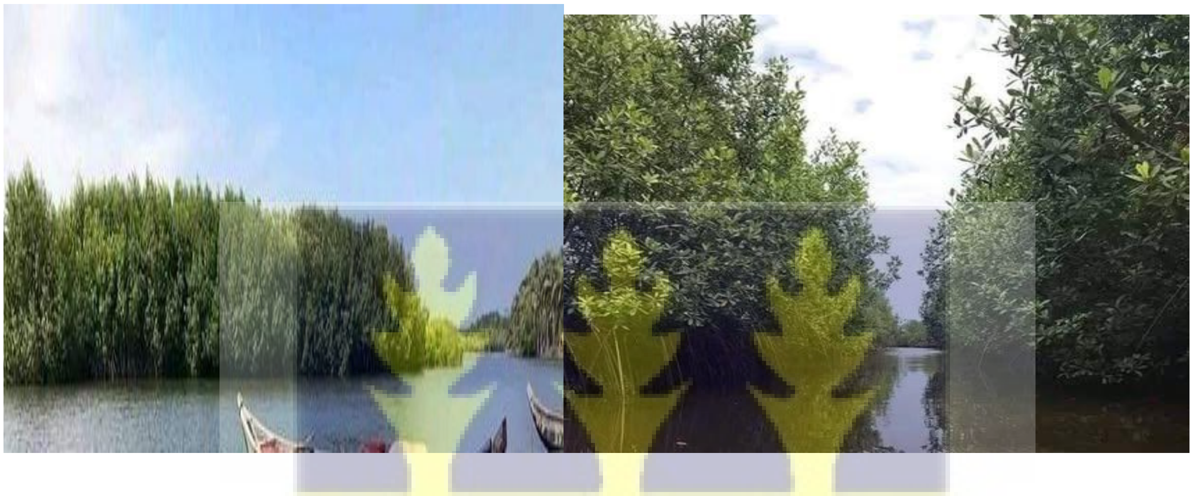


Plate 4.8: Existing Mangroves in Galow and Atiteti

Box 4.4: Timely Meeting Volunteers in Ada on Green Ghana Day

Prudential Life Insurance Ghana, the Strategic Youth Network for Development Ghana, and the Forestry Commission recently collaborated on a significant tree-planting initiative as part of Ghana's Green Ghana project. Last Friday, 2,000 mangrove seedlings were planted in Ada Foah Obane. This initiative aims to combat the decline of Ghana's mangrove forests, which are threatened by urbanisation, overexploitation, pollution, wildfires, and climate change and endanger the livelihoods of coastal communities such as Obane.

Adam Burge, Chief Financial Officer of Prudential Life Insurance Ghana, highlighted that this project aligns with the company's dedication to community well-being and environmental sustainability. By protecting these crucial wetlands, the initiative supports local fishing *communities, boosts the regional economy, and preserves the environment for both present and future generations. The Forestry Commission's expertise and active participation from the Obane community were pivotal to the project's success. The community have committed to nurturing the seedlings, showing their strong support for the initiative. Prudential is calling on other organisations to join these efforts to restore Ghana's wetlands and contribute to a more sustainable future.*

Table 15: Issues of preparedness (Building Foundation, Awareness and sensitisation)

To what extent have the communities been given enough education and sensitisation on climate change and floods		
Variables	Frequency	Percentage
Not Adequately,	125	36
Adequately	11	3
Indifferent	211	61
	347	
To what extent have education helped the communities to raise their buildings above flood levels		
Variables	Frequency of Respondents	
Not Adequately,	131	47
Adequately	52	19
Indifferent	98	35
	281	
Have there been adequate efforts by the communities to raise their building over the years above flood levels		
Variables	Frequency of Respondents	
No	121	35
Not Aware	123	35
Yes	15	4
Indifferent	88	25
	347	

Source, Author, 2024

The data offers a detailed view of community awareness, education, and efforts related to climate change, flood risks, and emergency preparedness.

Education and Sensitisation on Climate Change and Floods: The responses indicate a significant gap in education and sensitisation efforts. Out of 347 respondents, 125 (36%) feel that education on climate change and floods has not been adequate. Only a small fraction, 11 respondents (3.2%), believe that adequate education has been provided. A notable majority, 211 respondents (60.8%), expressed indifference. This suggests a substantial lack of effective communication andengagement efforts to educate the community on these critical issues, resulting in widespread indifference and insufficient knowledge.

Education on Raising Buildings Above Flood Levels: The data reflects similar concerns regarding education on constructing buildings above flood levels. Among 281 respondents, 131 (46.6%) stated that education on this matter has not been adequate, while 52 respondents (18.5%) indicated that it has been adequate. An additional 98 respondents (34.9%) showed indifference towards this issue. This distribution suggests that nearly half of the respondents feel unprepared or uninformed about measures to elevate their buildings above flood levels, highlighting the need for more comprehensive and accessible educational programs.

Efforts to Raise Buildings Above Flood Levels: When assessing whether communities have made adequate efforts to raise their buildings above flood levels over the years, the data shows a clear lack of action. Out of 347 respondents, 121 (34.9%) reported that no adequate efforts have been made, while 123 (35.4%) were not aware of any such efforts. Only 15 respondents (4.3%) confirmed that efforts have been made, with 88 respondents (25.4%) expressing indifference. This indicates a significant shortfall in proactive measures by the community to mitigate flood risks through building elevation, with a considerable number of respondents either unaware or indifferent to the issue.

Emergency Plans: The responses regarding the existence and adequacy of emergency plans reveal a concerning trend. Among 344 respondents, 98 (28.5%) stated that emergency plans have not been adequately implemented, while only 44 respondents (12.8%) believed that adequate plans are in place. A large majority, 202 respondents (58.7%), were indifferent. This suggests a critical need for better emergency preparedness and planning, as a significant portion of the community appears either uninformed or unconcerned about the measures in place to address emergencies.Table 16: Recovery (Training, Skills Building, Empowerment) (Response)

Table 16: Issues of preparedness (Building Foundation, Awareness and sensitisation)

To what extent have there been any emergency plans			
Variables	Frequency		
Not Adequately,	98	28	
Adequately	44	13	
Indifferent	202	59	
	344		
Have there been any training on community drills on flooding management			
Variables	Frequency		
No	121		
Not Aware	41		
Yes	88		
Indifferent	103		
	353		
To what extent have there been education on flood management			
Variables	Frequency		
Not Adequately,	98		
Adequately	58		
Indifferent	187		
	343		

Source: Author's Work, 2024

Data provides a comprehensive insight into community preparedness and education regarding flood management. Let's analyze the two aspects separately:

Training on Community Drills for Flood Management: Out of 353 respondents, the data indicates that a substantial portion of the community has not participated in training drills for flood management. Specifically, 121 respondents (34.3%) reported that no such training has been conducted. Additionally, 41 respondents (11.6%) were unaware of any training sessions. However, there is a significant number of respondents, 88 (24.9%), who confirmed that training drills have taken place. This data suggests that while there have been some efforts to conduct training, they have not been sufficiently widespread or communicated. A significant number of respondents, 103 individuals (29.2%), conveyed indifference regarding this issue, suggesting a possible deficiency in community engagement and the perceived significance of such training (Table 16).

Education on Flood Management: Regarding the extent of education on flood management, the responses reveal a mixed perception. Out of 343 respondents, a substantial number, 98 individuals (28.6%), indicated that education on flood management has not been adequate. In contrast, 58 respondents (16.9%) felt that the education provided was adequate. However, a significant majority, 187 respondents (54.5%), were indifferent to the level of education they had received on this topic. This high level of indifference points to a critical need for more engaging and effective educational programmes to raise awareness and preparedness within the community. (Table 16)

CHAPTER FIVE

DISCUSSION

5.0 Introduction

This chapter synthesis the findings of the study in accordance with literature and provide answers to the research questions. It focused on providing some understanding to the findings, including flood and sea level rise scenarios modelling as well as flood hazards, exposures and vulnerabilities in the selected areas. Furthermore, the chapter discusses the effectiveness of current flood risk governance and management, public awareness and participation in flood risk management. Also, institutional, policy, and social barriers to effective flood risk management formed part of the discussion and application of evidence-based flood resilience model options and practices for effective flood risk governance and management in the Lower Volta Basin.

5.1 General Background/Personal Information

In line with the philosophy of Ceswell (2013), the indicators of explaining the psychological processes of society included; education, gender, age and length of stay of respondents in their communities. Contrary to the GSS (2020) population and housing census report, where females are more than males, (51%), in this study, 66% of respondents who participated were males, ostensibly because of the cultural and social structure of the society in these areas. The age ranges of respondents reflected the global outlook of the Ghana's population where the youth constitutes the majority (48.8%). It was also important to establish that respondents with very good institutional and historic memory of situations in the Delta region were within the 46-60 bracket of the respondents and formed a significant 27.2%. Closely linked to the bracket with historic memory of the conditions was how long the respondents have lived in their communities. For any effective socio-economic, socio-cultural and socio-demographic interaction to take place (Comte, 1948), the length of stay in a community is essential. Instructively, 67% of the respondents in Keta and Ada have more than 10 years stay in the various communities and this makes it a significant period for such people to appreciate the extent of problems under observation.

5.2 Climate change and variabilities

According to Kossin et al, (2020), and Knutson et al, (2019), frequency and intensity of heavy rainfall have increased since the 1950s, and it is partly attributed to increases in emission of GHG as well as multi-model internal variability, as explained in the increases in temperature since the industrial revolution rising through the 20th century (IPCC, 2021). The findings of the study also observed increases in temperature trends and dovetails into the its relationship with certain rainfall occurrences. The IPCC affirms this standpoint and articulates that, increases in West African monsoon rainfall since the 1980s are partly due to the growing influence of GHGs and reductions in the cooling effect of human-caused aerosol emissions over Europe and North America (IPCC, 2021).

The rainfall trend as observed in this study, implies that, the consequences of heavy precipitation or rainfall and associated flooding events are projected to become more intense and frequent in the areas similar to the IPPC’s report (2021 and 2023) that, the intense and frequency flooding in the Pacific Islands and across many regions of North America and Europe will be experienced.

Understanding climatic variations is essential for effective climate change adaptation and disaster risk management in the Lower Volta Basin, including areas such as Ada and Keta. In Ada, the annual rainfall ranges from 359.2 mm to 1696.4 mm, with a coefficient of variation (CV) of 29.9% (Adu-Pra et al., 2017).

This indicates moderate variability in the rainfall patterns over the years. The linear trend analysis shows a weak negative slope of -3.03 mm per year, with an R^2 value of 0.0475. This suggests a slight decrease in rainfall over time, although the correlation is not strong enough to indicate a significant trend. Such a decrease could have implications for water resources and agriculture, potentially leading to drought conditions or reduced water availability (Appeaning Addo et al., 2018). Keta experiences a broader range of annual rainfall, from 220.9 mm to 1681.4 mm, with a higher CV of 36.7% (Ayamga, 2019).

This higher variability signifies more frequent and intense fluctuations in rainfall, which could result in both extreme droughts and severe flooding. Keta's linear trend also shows a weak negative slope of -2.6252 mm per year, with an even lower R^2 value of 0.0286, indicating an even less pronounced trend than Ada. The high variability in Keta's rainfall makes it more susceptible to unpredictable weather patterns, posing challenges for agricultural planning and water management (Tumawu et al., 2024).

Keta exhibits significantly higher variability in rainfall compared to Ada, which can lead to more frequent and intense flood and drought events. The weak rainfall trends in both areas indicate minimal changes over time, but Keta's higher variability poses greater risks and challenges for resource management. The maximum temperature in Ada ranges from 29.8°C to 32.2°C. The linear trend shows a weak positive increase of 0.0066°C per year, with an R^2 value of 0.0578, indicating a very slight warming trend with notable variability. This minor increase in maximum temperature might not have a significant immediate impact but could contribute to gradual changes in local climate conditions over the long term (EPA, 2020).

In Ada, the Mann-Kendall test for rainfall showed a slight decreasing trend (MK-stat = -197, z-statistic = -1.14, p-value = 0.256), which was not statistically significant. Sen's slope (-1.81 mm/year) also indicated a decrease, but the wide 95% confidence interval (-4.83 mm/year to 1.68 mm/year) encompassing zero confirmed the absence of a significant trend (Nyatuame et al., 2014). For Ada's maximum temperatures, the Mann-Kendall test results are reported (EPA, 2020; MESTI, 2021).

Keta exhibits maximum temperatures ranging from 30.1°C to 34.1°C. The linear trend reveals a strong positive increase of 0.0492°C per year, with a high R^2 value of 0.7973. This strong correlation indicates a significant warming trend, suggesting that maximum temperatures in Keta are rising rapidly. This could lead to increased heat stress for both humans and agriculture, affecting health outcomes and crop yields (IPCC, 2023). The strong warming trend in Keta points to the need for adaptive measures to mitigate the adverse effects of rising temperatures.

Keta shows a much stronger warming trend in maximum temperatures compared to Ada. The high R^2 value for Keta indicates a strong correlation and significant trend, whereas Ada's temperatures show greater variability with only a slight upward trend. This indicates that there must be tailored adaptation strategies to address the specific climatic challenges in each area (Mensah, 2020).

For minimum temperatures, Ada ranges from 24.0°C to 27.5°C. The linear trend shows a strong positive increase of 0.031°C per year, with an R^2 value of 0.6994, indicating a significant and steady warming trend. This upward trend in minimum temperatures could lead to warmer nights, which can impact human health, increase energy demands for cooling, and affect the natural environment, including local wildlife and vegetation (Mensah & Ahadzi, 2020).

Conversely, as in the case of Tamawu et al. (2024), the Mann-Kendall test for Keta's minimum temperatures indicated a slight decreasing trend (MK-stat = -307, z-statistic = -1.77, p-value = 0.076), but this trend was not statistically significant ($p > 0.05$), and the 95% confidence interval for Sen's slope (-0.017°C to 0.001°C) included zero (this range includes **zero**, meaning the true slope could be slightly negative, zero, or slightly positive). The decreasing nature of the temperature is also in contrast to the global temperature increase in a consistent manner since the Pre-Industrial Era (IPCC, 2023).

In summary, rainfall and temperature data for Ada and Keta reveal some differences in climatic patterns that have important implications for climate change adaptation and disaster risk management. Keta's higher variability in rainfall and stronger warming trend in maximum temperatures suggest that it faces greater climatic challenges compared to Ada. This variability can lead to more frequent and severe flooding, droughts, and heatwaves, all of which have serious repercussions for local communities, agriculture, and infrastructure adaptation.

Ada, while also experiencing some variability, shows less pronounced changes in both rainfall and temperature trends. The slight negative trend in rainfall and the moderate warming trend in both maximum and minimum temperatures indicate a more stable climatic pattern, though they are still susceptible to the impacts of climate change. The strong upward trend in minimum temperatures in Ada suggests a need for strategies to manage the impacts of warmer nights, such as improving building insulation and energy efficiency.

The spatial analysis, as consistent with Hossen et al. (2020), of rainfall and temperature in the

Lower Volta Delta, using kriging interpolation in ArcMap as done in the work of Hossen et al. (2019), reveals distinct patterns. The rainfall map displays a clear west-to-east gradient, with the western areas (Ada Foah, Sogakope) are experiencing significantly higher rainfall (800.7 mm to 809.0 mm) than the central (Keta) and eastern (Denu) regions.

This gradient suggests the influence of prevailing wind patterns and proximity to the coast, which likely contributes to reduced rainfall in the eastern areas. The transition from high rainfall in the west to moderate rainfall in the central region and low rainfall in the east highlights the spatial heterogeneity of precipitation within the delta. This spatial variation is crucial for understanding flood risk, as areas with higher rainfall are potentially more susceptible to flooding, especially when considering the impact of low-lying coastal areas and their limited infiltration capacity.

In contrast to the rainfall pattern, the temperature maps reveal a different spatial distribution. The minimum temperature map shows a gradient from cooler temperatures in the east and coastal areas to warmer temperatures in the west, while the maximum temperature map indicates higher temperatures in the east (Keta and Denu areas, up to 32.0°C) compared to the west (Ada Foah and Sogakope) (Appeaning-Addo et al, 2020). This east-west temperature gradient likely reflects the influence of distance from the coast and potentially other microclimatic factors, such as variations in elevation and land cover. This east-west gradient in maximum temperatures, combined with the west-east rainfall gradient, creates a complex spatial pattern of climate variability across the Lower Volta Delta. Understanding these spatial patterns is vital for implementing targeted flood risk management and climate change adaptation strategies within the region. The contrasting spatial distributions of rainfall and temperature also suggest different mechanisms influencing the regional climate and highlight the complexity of flood risk assessment in the Lower Volta Delta.

5.3 Flooding and Flood Projections

The study noted that the vast majority (98.8%, or 320 respondents) confirmed awareness of flood occurrence and experiencing floods, and for some people and location there were more severities and frequency. The occurrence of the flood has been confirmed so many literature and reports, including Appeaning-Addo (2020), Hossen et al (2020), Mattah (2022), Tumawu et al (2024). It is a phenomena has been linked directly to the global analysis and finding of severity and frequency of flood in coastal communities due to multiple factors (IPCC, 2022), Jonah et (2016).

In the Lower Volta Basin, studies have demonstrated that there are several sources and factors triggering the occurrence, including the climate change and rainfall intensity, sea level rise, sea erosion, underlying development impact such as the Akosombo Dam, Settlements development in the basin as well as the issue of cascading development impact and tidal strength from Western Coast including Accra (Codjo et al., 2020, Tumawu et al, 2024, Pabi et al, 2023; Jayson-Quashigah et al, 2013).

By the source and forms of flood that occur the respondents indicated various forms including flash floods, sea floods and the lagoon and this is asymmetrical to NASA (2021) flood classification model as river flood, coastal flood, storm surge, inland flooding and flash flood.

In the case of river-induced flooding, even though rainfall and its high intensity is the considered contributing factor in the Volta delta, it has been established that, it is not the regularity of the rainfall that causes the flooding, as consist with so many studies including even the IPCC (2022)' Assessment 6th Report Working Group III (i.e., *Impacts, Vulnerability and Adaptation*).

The findings indeed established that and were further supported by literature that a short period of rainfall with high intensity (torrential rainfall) has the propensity to cause flooding of severe proportion, and this is a dominant feature in the Keta and Ada municipal areas.

Additionally, the rivers also facilitate flooding relative to dam spillage (Akosombo and Kpone dams), which is described as ex-situ activities, rather than creating flooding in the areas. The dams recorded high-intensity rainfall (flash floods/waters) in the catchment areas in the northern part of Ghana, as well as in Burkina Faso, and released high volumes of water into the Akosombo and Kpone dams and required spillage of excess water in the dams to secure their structural integrity, findings consistent with Hossen et al. (2020) in their study that analyses three Delta flooding situations and also consistent with the work of Brempong et al. (2023). Eventually, the excess water from the dams fills up the river in these areas, causing flooding, and there is an immense penumbra of theory surrounding this observation.

Understanding and preparing for the future impacts of sea-level rise is critical for coastal communities worldwide. Two scenarios, SSP5-8.5 and SSP2-4.5, offer contrasting projections based on different greenhouse gas emissions pathways. This technical analysis delves into projected sea-level rise (SLR) under these scenarios, focusing on the years 2040, 2060, and 2100, while also examining the associated uncertainties and impacts.

2040 Projections:

In 2040, the SSP5-8.5 scenario projects that between 4.51% and 6.42% of the area will be below the lowest mean sea level (LMSL). In comparison, the SSP2-4.5 scenario estimates a slightly lower range, with 3.43% to 5.21% of the area below LMSL. This early projection highlights that even in the near term, different emissions pathways can influence flood risks. The maximum projection under SSP5-8.5 is about 1.2% higher than SSP2-4.5, suggesting that higher emissions can lead to increased coastal inundation even within the first few decades.

2060 Projections:

By 2060, the difference between the two scenarios becomes more pronounced. Under SSP5-8.5, the area below LMSL is projected to increase significantly, with estimates ranging from 12.8% to 18.99%. On the other hand, SSP2-4.5 projects a lower increase, with 6.11% to 15.67% of the area below LMSL. This stark difference indicates that more aggressive emissions in SSP5-8.5 lead to much higher flooding risks, nearly doubling the lower bound of SSP2-4.5's projections. This midterm analysis underscores the compounded effects of continued high emissions, resulting in greater coastal vulnerability.

2100 Projections:

By the year 2100, the projections diverge drastically. SSP5-8.5 estimates that between 25.43% and 39.31% of the area will be submerged below LMSL. In contrast, SSP2-4.5 projects a range of 18.52% to 26.32%. The gap between the two scenarios becomes significant, with the SSP5-8.5 scenario projecting a maximum area below sea level nearly 13% higher than SSP2-4.5. This substantial difference illustrates the long-term consequences of failing to control greenhouse gas emissions, with SSP5-8.5 indicating much more widespread coastal inundation and severe impacts on urban coastal centres and ecosystems.

2040 Uncertainty:

In 2040, SSP5-8.5 shows a difference of 1.91% between its minimum and maximum projections, while SSP2-4.5 has a slightly smaller range of 1.78%. Both scenarios exhibit a relatively small range of uncertainty, indicating more predictable sea-level rise in the short term. This means that early emissions pathways have a smaller effect, and short-term climate predictions are more accurate.

2060 Uncertainty:

By 2060, SSP2-4.5 displays a larger range of uncertainty (9.56%) compared to SSP5-8.5 (6.19%). This greater variability in outcomes under moderate emissions scenarios indicates that SSP2-4.5 may lead to a wider range of potential impacts. Nevertheless, the upper bound of SSP5-8.5 remains much higher, reflecting that high-emission pathways have more severe but predictable outcomes.

2100 Uncertainty:

In 2100, the uncertainty widens significantly for SSP5-8.5, with a difference of 13.88% between its minimum and maximum projections. SSP2-4.5, while showing a considerable range of 7.80%, remains more constrained and suggests a more predictable outcome. This increasing uncertainty in SSP5-8.5 highlights the greater unpredictability of high-emission pathways and emphasises the need for adaptable and flexible policies to address a wide range of flooding possibilities.

Severity of Impact:

The high-emission scenario, SSP5-8.5, consistently projects a larger area below sea level at each time interval. Up to 39.31% of the area could submerge by 2100, posing significant risks to urban coastal centres. These impacts are more severe in both mid-term and long-term projections, suggesting that continued high emissions will lead to substantial coastal flooding, loss of land, and displacement of populations.

On the other hand, the moderate-emission scenario, SSP2-4.5, shows significantly lower percentages of land below LMSL across all years. It suggests that mitigating emissions through international cooperation and policies can limit sea-level rise and its associated risks. However, even in this scenario, the impacts remain considerable, with up to 26.32% of the area potentially submerged by 2100, highlighting the importance of sustained mitigation efforts to reduce future flooding risks.

Rate of Increase Over Time:

The growth in the area below LMSL accelerates sharply between 2060 and 2100 under SSP5-8.5, with the gap widening dramatically as the scenario projects much larger impacts toward the end of the century. This speed-up suggests that high-emission pathways cause sea levels to rise at an exponential rate, which makes it harder and more expensive to adapt in the late 21st century.

In contrast, the rise in SSP2-4.5 is more gradual, with less acceleration between 2060 and 2100 compared to SSP5-8.5. This slower rate of sea-level rise in the moderate-emission scenario allows for more time to adapt and implement protective measures, providing a better opportunity for communities to prepare and reduce the long-term impacts of sea-level rise.

The comparison highlights the critical role that emissions play in shaping future sea-level rise scenarios. SSP5-8.5, representing a high-emission pathway, leads to significantly greater flooding risks compared to SSP2-4.5, a moderate-emission pathway. By 2100, the difference in area below

LMSL is stark, with up to 39.31% underwater in SSP5-8.5 versus 26.32% in SSP2-4.5. The data underscores the importance of immediate and aggressive mitigation efforts to control greenhouse gas emissions, thereby limiting future sea-level rise and its associated risks. Additionally, even under SSP2-4.5, moderate sea-level rise still presents considerable challenges, necessitating proactive adaptation strategies regardless of the emissions pathway. Lastly, both scenarios show increasing uncertainty over time, emphasising the need for flexible and adaptive policies to address a wide range of potential flood outcomes.

The high-emission scenario (SSP5-8.5) consistently projects far greater inundation, with considerably higher uncertainty in projections across all timeframes, highlighting the severe risks associated with unabated greenhouse gas emissions. The significant difference between minimum and maximum projections under SSP5-8.5 underscores the challenge of precisely predicting the future impacts of climate change and the necessity of flexible and adaptable flood management strategies. The substantial increase in projected inundation under SSP5-8.5, especially by 2100 (up to 39.31% of the area potentially submerged), highlights the urgent need for adaptation measures in coastal regions. The projection maps accompanying the SLR projections provide a crucial visual representation of the geographic areas most vulnerable to sea-level rise under each scenario and timeframe, facilitating informed decision-making for flood risk management and climate change adaptation. These visualisations clearly show the escalating risks associated with high greenhouse gas emissions.

5.4 Erosion and Shoreline Observation

The coast of the Lower Volta has been identified in the literature to be facing significant erosion, playing a substantial role in shoreline or sea erosion (Appeaning Addo et al., 2018; Boateng, 2017).

Shoreline images showed a complex pattern of shoreline change, highlighting both spatial and temporal variability (Mensah, 2020). Across the study area, shoreline changes were evident from 2016 to 2024, showing an overall landward retreat of the shoreline, (-3.07 m/yr) (Akyeampong, 2020).

However, it is essential to note that there is also a positive occurrence in the study areas experiencing shoreline progradation, highlighting inherent spatial heterogeneity, where erosion and accretion occur simultaneously (Jonah et al., 2016). The states of Ada and Keta presented a net erosion form the outcome of the study analysis, (-2.40 m/yr, and -2.24 m/yr), underscoring differences in sediment supply, coastal morphology (e.g., presence of cliffs, beaches, or estuaries), wave energy, and human activities in these areas (Kufogbe et al., 2019). Furthermore, the magnitude of erosion in other communities, such as Fuveme, varied and underscored the influence of local factors on erosion patterns (Amponsah et al., 2020). As noted by Mensah (2020), the nature of shoreline changes in terms of erosion is highly heterogeneous, with complexity differing degrees of erosion and even accretion.

5.4.1 Flood Risk Mapping and Analyses

The Volta River Delta in Ghana is a region highly susceptible to flooding due to its low-lying topography, proximity to water bodies, and human-induced changes in land use (Appeaning Addo et al., 2018; Boateng, 2017). This assessment utilizes four key spatial datasets: Land Use/Land Cover (LULC), Digital Elevation Model (DEM), slope, and river buffer zones. Each dataset provides critical insights into different aspects of flood risk and, when integrated, offers a comprehensive understanding for developing effective flood mitigation strategies.

The study presented the LULC as a diverse spatial distribution of land cover types, including water bodies, vegetation, wetlands, built-up areas, and bare soil (Mensah, 2020). Water bodies dominate the eastern part of the Basin, indicating the presence of a river system. Vegetation is patchily distributed, showing the influence of both natural and human factors. Wetlands, primarily along water margins, play a crucial role in flood mitigation by acting as natural buffers (Jonah et al., 2016). Built-up areas, especially in low-lying regions, are highly vulnerable due to their impervious surfaces which lead to increased runoff and reduced infiltration (Kufogbe et al., 2019). Bare soil areas are prone to erosion and contribute to higher surface runoff during heavy rainfall.

The proximity of settlements to these land cover types is essential in assessing human exposure to flood hazards. For instance, areas with high proportions of built-up land, such as Dzita, Woe, and Ada Foah, are highly vulnerable to flooding, categorized as Very High Flood-Prone Areas (Red Zones) (Akyeampong, 2020). In contrast, regions with more vegetation or wetlands are better protected against floods.

Analysis of the DEM provides a detailed elevation profile of the Volta River Delta. The analysis shows a relatively flat coastal plain with a gradual increase in elevation inland. Lower elevations along the coast are identified as highly susceptible to flooding, while higher elevations show minimal flood risk (Amponsah et al., 2020). Topographic gradients help identify areas where water is likely to accumulate during flooding events due to the flat terrain and limited drainage. Specific locations marked with monitoring points or settlements allow for a focused assessment of vulnerability relative to elevation data.

Integrating the DEM with rainfall and socio-economic data enhances the precision of flood risk assessments. Communities like Anyanui and Dzita, located in low-lying coastal areas, are particularly vulnerable due to their elevation, making them prone to frequent flooding (Boateng, 2017). In contrast, inland regions such as Afefe, Agbakope, Fieve, and Adidome, situated at higher elevations or with more flexible slopes for water drainage, are categorized as Low Flood-Prone Areas (Yellow Zones).

Slope analysis, depicting gradients from flat to steep, highlights the flood dynamics in the Volta River Delta. The predominantly flat coastal area and low slopes enhance flood risk, as water spreads more easily and drains slowly (Mensah, 2020). Steeper areas in the inland regions experience faster runoff, increasing the risk of flash flooding downstream. The location of settlements relative to these gradients is crucial for determining their vulnerability to different types of flood events, such as prolonged inundation versus flash flooding.

In terms of river buffer zone, it was found to have delineated areas at increased risk of flooding due to their proximity to the river. This spatial context is critical for assessing the vulnerabilities of settlements and infrastructure. Proximity to the river exacerbates flood risk, especially during periods of heavy rainfall or dam releases (Kufogbe et al., 2019). Land management decisions and integrated flood mitigation strategies must consider these buffer zones to effectively reduce flood impact.

Settlements located within these buffer zones, such as those in the South Tongu and Ada West districts, are identified as High and Medium Flood-Prone Areas (Orange Zones) (Akyeampong, 2020). These areas require specific attention for flood mitigation efforts, such as enhancing flood Defences and implementing early warning.

Following the analysis of the average annual trends in the Ada and Keta enclave between 1960 and 2023, variability and fluctuation showed a general trend suggesting a possible long-term decreasing trend in total annual rainfall (Kufogbe et al., 2019). Again, temperatures in Ada and Keta also showed consistent trends and fluctuations, and further showed gradual increases over time, peaking in 1973 at 31.8°C and the highest temperature recorded in 2022 at 32.0°C for Ada and in Keta, and maximum temperature which continued to rise with the highest value of 34.1°C in 2011 (Amponsah et al., 2020).

The scenarios for flood projection for the IPCC's timelines, 2040, 2060, and 2100, showed significant sea level rise and evidence of projected inundation from the scenarios, and erosion and shoreline changes across the entire area between 2016 and 2024 (-3.07 m/yr) revealing landward shoreline (Akyeampong, 2020). This has revealed the risk as demonstrated by respondents in terms of livelihoods, infrastructure, agriculture, and biodiversity, as affirmed in a study by Tumawu et al. (2024) and World Bank (2021).

Livelihoods (fishing, fish mongering, tourism services) are significantly impacted, as residents in Fuyeme echoed the sentiments and experiences of communities in the Delta Region, as noted by other studies (Appeaning Addo et al., 2018; Mensah, 2020). The challenge of fishing causing inadequate source of income, resulting in high unemployment and migration among the youth to other cities to seek alternative livelihood opportunities. Dwindling fishing activities also affect the selling and buying of fish at market centers, employing primarily women (Hossen et al., 2020).

Economically, the floods have halted trade activities and severely affected 15 individuals, as revealed by the study (World Bank, 2021). Infrastructure (education, health) has also been impacted, with many children hardly coming home, as all the land available for building is now in the sea or has become beaches and wetlands (Amponsah et al., 2020). School buildings have been submerged, and health facilities have been wiped out. Major disruptions have been in education, with 116 children severely affected across the region, indicating widespread school closures (Tumawu et al., 2024).

Agriculture (land use and land use changes) has also been impacted, as farming has been impeded in the red zone regions, and even gardening in Dzita and Ada Foah has become impossible as all lands are submerged (Appeaning Addo et al., 2018).

The rotated component analysis for the Lower Volta Basin strongly aligns with existing literature on climate hazards, exposure, and vulnerability. The first component, dominated by high loadings for precipitation, temperature extremes, and coastal erosion, reflects an environment increasingly characterised by intense rainfall, rising temperatures, and shoreline instability, which amplify flood and erosion risks, findings consistent with studies by Obuobie et al. (2025) and Appeaning-Addo et al. (2020) that document escalating extreme rainfall events and accelerated coastal retreat in the Volta estuary.

The second component, capturing population exposure and socio-economic vulnerability through variables such as population density, female and child population, and poverty, mirrors regional assessments by UNESCO (2025) and Limantol et al. (2022), which emphasise that densely populated, low-income communities with limited health infrastructure are disproportionately affected by climate-related hazards. Furthermore, components reflecting livelihood capacity and connectivity correspond with adaptation frameworks like the VFDM project, which advocate strengthening economic resilience and improving infrastructure access to reduce disaster risk. Taken together, these findings confirm that the Lower Volta Basin faces a triple challenge, high climate hazards, concentrated exposure, and socio-economic fragility, consistent with published evidence and adaptation strategies. This convergence underscores the urgency of multi-dimensional interventions that combine structural measures such as embankments and drainage systems with social programs targeting poverty alleviation, health services, and infrastructure improvements to build resilience against floods and coastal erosion.

5.5 Flood Risk Reduction

The five steps in disaster management, which are prevention, mitigation, preparedness, response, and recovery, are crucial in addressing the impacts of flooding in the Volta River Delta. The first step, prevention, involves engaging the people and putting in place policies and measures to prevent or minimize the occurrence of disasters.

According to the United Nations Office for Disaster Risk Reduction (UNDRR), prevention is a critical step in disaster management, and it requires a proactive approach to reducing the risks associated with disasters (UNDRR, 2015). In Ghana, the government has made efforts to engage the people through the development of policies such as the National Climate Change Policy (2013) and the Coastal Management Policy (2012) (IPCC, 2014).

However, the implementation of these policies has been a challenge, and there is a lack of integrated spatial planning for the whole basin (Burby, 2006). Although some of the District Assemblies have adopted and developed local plans, more needs to be done to ensure that these plans are effectively implemented and coordinated at the national level.

The various communities' perspective in addressing issues of flooding and erosion have been varied and clear explanations underpinning their perspective were revealing. As part of the management, the construction of the sea Defence (hard intervention) is critical. While the construction and completion of sea defence was a key solution communities indicated serves a good purpose, dredging of the lagoon and rivers, relocation, increase resilience, adequate early warning system made up the mechanism for addressing challenges.

The significance of providing sea defence in order to protect coastal areas was confirmed by 53.3% of the people, and 42.6% strongly believed that this solution is incontrovertible (Burby, 2006). This approach has been established in theory and practice and are found in several studies and reports to be useful (IPCC, 2014; UNDRR, 2015). Another potent approach in solving flooding and erosion challenges in the coastal areas such as Ada and east coast communities Fuyeme, Woe, Dzita, Anloga, Keta, Blekusu, Agavedzi, Adina is dredging of the lagoon and rivers (main and distributaries). Even though some studies presented as if dredging the river (Delta) would mean further increasing subsidence (coast height lowering to sea level) (Appeaning-Addo et al, 2020) , there is a strong backing for dredging activities as a means to manage erosion and flooding is impressive as a significant number, 59.2% agreed from the Keta and Ada areas. This strong support suggests that the community views dredging as an effective strategy to address sedimentation and water flow management in lagoons and rivers (Hossen et al., 2020).

In general terms practices such as growing of vegetation to store excess water, creating of terraces hill sides, construction of flood ways to direct water, establishment of levees, lakes, and construction of dams are among the methods employed for flood control. There were issues of early warning systems, which even though the District Assemblies seem to be doing mainly on response interventions during flooding, the community expressed that they were inadequate. Likewise education and awareness have also been inadequate.

Theoretically, this current study seeking to 'assess' interventions in managing flood risk underscored the relevance of adopting the World Bank's flood risk management classification; hard engineering, soft engineering and non-structural strategies. Closely connected to these methods and classification, the 'Peacante' and 'MacKendell' and the broad methodical process of the United Nation Disaster Risk Reduction (UNDRR) or the step-by-step management procedures served the needed purpose relative to the study. It is evident that flood risk in the areas required efficient and effective management approaches that are comprehensive, systematic, participatory and community engagement-driven through planning, land-use planning, awareness creation of coastal concerns, research and data gathering.

5.6 Residents' Recommended Areas

The communities in Keta Lagoon Zone are advocating for relief services to alleviate their suffering from previous floods. Moreover, they emphasize the need to dredge the Keta Lagoon, which has never been dredged since its natural creation. The lagoon's silting has prevented seawater from staying in the lagoon, causing it to spill and inundate communities (Boafo, 2018).

Similarly, communities in Totope, Ada East, believe that dredging the lagoon and its connecting river would address their flood problems. This sentiment is echoed by residents across the stretch from Fuveme to Adafianu, who are counting on the government to complete the sea Defence project.

Dredging the Keta Lagoon is a viable solution, as it would improve water flow and reduce the risk of flooding. In fact, the government has planned to dredge the Keta Lagoon Complex to prevent annual floods and protect lives and properties in adjacent communities (Dredge Wire, August, 2021).

The Keta Sea Defence Project is another initiative aimed at controlling the release of periodic floodwaters from the area (Appeaning Addo and Oteng-Ababio, 2019). The project has constructed nine bird islands in the lagoon, which has helped to reduce erosion and flooding (Resident's Report, 2024). A flood risk assessment of Keta revealed that the area is highly vulnerable to flooding and erosion, which may be associated with sea level rise (Hossen et al, 2020). Therefore, it is essential to implement measures such as dredging, sea Defence , and early warning systems to mitigate the impacts of flooding. In addition to these measures, providing relief services to affected communities is crucial in alleviating their suffering. This can include providing food, shelter, and medical assistance to those affected by floods. In conclusion, the communities in Keta Lagoon Zone are advocating for a comprehensive approach to address flooding and erosion, including dredging, sea Defence , and relief services. The government and other stakeholders must work together to implement these measures and mitigate the impacts of flooding in the area.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATION

6.0 Introduction

This chapter provides general information on the entire study by way of a summary of the objectives of the study, methodology, findings and discussion components and draws the appropriate conclusions on the results. Additionally, the chapter makes some insightful recommendations targeted at researchers and duty bearers with the view to ensure practical actions are taken to address challenges identified and adopt the key findings to improve existing implementation efforts.

6.1 Summary of Major Findings

As part of the first objective examining how climate variability and long-term trends are reshaping hydro-climatic conditions in the Lower Volta River Basin and its deltaic coastline, the analysis of rainfall and temperature records (1960–2023) revealed strong seasonality coupled with notable interannual variability, a signature often associated with episodic flood-generating rainfall events.

Maximum temperatures display spatially differentiated trajectories: Ada shows a modest upward trend that explains a small share of variance, while Keta exhibits a much sharper warming signal since the 1980s with peaks reaching 34.0 °C in 2020. Minimum temperatures are less uniform: Ada trends upward, whereas Keta records a slight cooling with a pronounced dip between 1987 and 1990.

This heterogeneity underscores a core insight of the basin's climate reality: the drivers and manifestations of warming and rainfall variability are place-specific, implying that adaptation cannot be uniform across the coastal corridor. It must be tuned to local thermal regimes, rainfall timing and intensity, and the compound pathways by which extremes translate into inundation on low-lying terrain.

The second objective translated climatic and coastal drivers into spatially explicit flood scenarios. A GIS-based "bathtub" model using a 12 m DSM was applied under IPCC SSP2-4.5 and SSP5-8.5 across three horizons (2020–2040, 2040–2060, 2080–2100), producing inundation extents that differentiate between moderate and high-emissions futures. Under SSP5-8.5, the basin experiences substantially larger flood footprints and higher uncertainty, with the analysis projecting up to 39.31% of land area submerged by 2100, whereas SSP2-4.5 indicates up to 26.32% by century's end. Even the "moderate" pathway therefore demands robust adaptation given the persistence of greenhouse gas emissions and the compounding effect of intense rainfall on already saturated or tidally constrained coastal terrain. These scenario contrasts are not just percentages; they are planning signals that call for early, phased investments in protective measures and land-use controls.

This objective also confirmed the high frequency of flood occurrence among coastal communities: 98.8% of respondents recognized flooding as a recurrent hazard, with attribution pointing to torrential rainfall, dam spillage, and sea-level rise, the triad that, in different combinations, produces compound events. In the LVRB, compound flooding arises where river discharge peaks coincide with tide and surge anomalies, or where extreme precipitation overwhelms urban drainage and backwater effects restrict outflow into the sea or lagoon. By situating modelled inundation in this lived hazard context, the analysis strengthens confidence in the scenario suite and clarifies how risk communication should frame future flooding as a systemic rather than isolated threat.

Equally important, the shoreline and sea-level context of the LVRB suggests that slowly accumulating mean sea-level rise (SLR) interacts with short-lived storm anomalies and river discharge to magnify flood footprints. As coastal morphology evolves, through erosion of vulnerable reaches and accretion elsewhere, hydraulic connectivity changes, shifting flood pathways across salt-marshes, mangrove fringes, built-up settlements, and lagoon margins. In this light, climate variability is not merely a statistical property of time series; it is the process driver that, in concert with geomorphology and human land-use, determines where and when flood waters accumulate, stagnate, or recede. An increase erosion and lowering erosion has been found to be a major threat and expected increase flood via sea level risk.

The third objective integrated hazard surfaces with exposure and vulnerability indicators to generate a composite picture of risk. Using weighted overlay (AHP) in the GIS, to structure the relative contributions of rainfall, slope, elevation, land use, and proximity to rivers and roads, the mapping identified very high-risk polygons concentrated along the coastal fringe, especially Dzita, Woe, and Ada Foah, where low elevations, gentle slopes, and dense settlement overlap with degraded protective ecosystems. Inland areas generally show medium to high risk modulated by river corridors and slope gradients, while higher inland elevations correspond to lower risk classes. This spatial differentiation key, itc guides the siting of critical facilities, the prioritization of drainage upgrades, and the selection of nature-based buffers where they will deliver the greatest marginal protection.

The socio-economic lens clarifies what these polygons mean for livelihoods. Built-up areas with extensive impervious cover are highly vulnerable due to limited infiltration and rapid runoff accumulation. Flood impacts cascade through fishing, trade, schooling, health services, and crop farming, compounding short-term damages with longer-term socio-economic disruption. The quantified risk for Anloga District, GHS 3,089,493,185.14, renders these vulnerabilities legible to budgetary processes and underscores the costs of deferring adaptation. As a diagnostic, the third objective shows that risk is not evenly distributed; it is concentrated and layered, and therefore best managed through portfolios that mix drainage modernization, land-use controls, ecosystem restoration, and targeted social protection.

The fourth objective shifted from diagnosis to solution framing. Community preferences strongly favoured dredging lagoons and rivers, completing sea defences, and improving drainage systems, a profile of risk-reduction centered on hydraulic and structural measures. Support for early warning systems reflects awareness that timely information can save lives even when infrastructure is overwhelmed. However, significant resistance to relocation signals the political and cultural constraints that accompany managed retreat; without livelihood restoration, adequate housing alternatives, and genuine participation, relocation will struggle to gain social license. Just as crucial are the awareness and enforcement gaps: majorities reported limited knowledge of structural development plans and local building codes, while many perceive weak enforcement of river and lagoon defences and inadequate mangrove protection and restoration. Emergency planning shortfalls, few drills and limited community-level protocols, accentuate the reactive character of current practice.

These findings point to a pragmatic portfolio approach. Dredging can be part of sediment management when guided by ecological impact studies and sediment budgets to avoid adverse alongshore effects. Sea defences, where justified by cost–benefit and life-cycle maintenance plans, should be paired with nature-based solutions, mangrove rehabilitation, wetland conservation, dune stabilization, so that hard structures do not become single points of failure. Drainage modernization through retention and detention, blue, green corridors, and permeable surfaces can mitigate pluvial flooding in built-up areas. Community-centric EWS should be institutionalized with multi-channel alerts, local-language messaging, and routine drills that build preparedness habits. Land-use planning should embed coastal setbacks and no-build zones for very high-risk polygons, while fiscal and infrastructure incentives encourage development in lower-risk inland locations. Where exposure is acute and relocation unavoidable, design it as voluntary and incentive-based, with robust livelihood support and social protection to ensure acceptability. Finally, governance and finance matter: a basin-level coordination platform that harmonizes data, plans, and permits across agencies, and blended finance that links budgets to verified risk-reduction outcomes, can move the system from high awareness and low delivery to sustained implementation.

6.2 Conclusion

This study set out to interrogate the intertwined climatic, geomorphic, and socio-economic processes that shape flood risk in the Lower Volta River Basin and Delta system in Ghana, with particular attention to Ada East District, Anloga District, Keta Municipality, and Ketu South Municipality, and to the communities interfacing the Lower Volta River Basin, Keta Lagoon and the sea. Specifically, the study sought analyse climate change, flood risk and risk reduction measure, including first of assessing climate change, variability and extremes; secondly to assess flood occurrences and projections over time; thirdly assess the flood risks; finally to examine the flood risk reduction measures in the Basin.

The research responded to a persistent gap in the literature: the need for integrated assessments that move beyond describing flood hazards and biophysical exposures to consider, simultaneously and explicitly, the relationships among hazards, exposure, vulnerability, and risk-reduction measures in a coherent, decision-oriented framework.

The study combined long-term climate analysis, spatial inundation modelling, composite risk mapping, and community-level inquiry, the study offers a holistic account of how climate change, sea-level rise, coastal erosion, land-use change, and socio-economic conditions weave together to produce recurrent and compound flooding, and how policy and practice can be reframed to address risks that evolve over space and time.

The result is a decision-support product that feels both comprehensive and grounded in place, exactly what district planners need when hazard signals are shifting and resources are constrained. The picture that emerges is neither uniform nor simple: climatic trajectories differ across localities; flood hazard is amplified by coastal dynamics; and community preferences lean toward engineered fixes even where long-term resilience depends on ecosystems and governance. That overall narrative aligns with national and international assessments of Ghana's evolving climate risks and with the IPCC risk paradigm that defines risk as a function of hazard, exposure, and vulnerability (IPCC AR6; Ghana Climate Atlas).

Beginning with the climatic baseline, finding of strong seasonal rainfall and meaningful interannual variability is consistent with coastal Ghana's climatology, where dry-season warmth and the timing of the rains drive both hydrology and urban runoff. More striking is the divergence in local warming: Keta shows a clear upward trend in maximum temperature from the 1980s onwards (reaching 34.0 °C in 2020), while Ada warms modestly, and minimum temperatures split directionally, slight cooling in Keta and increases in Ada. That heterogeneity has two immediate implications. First, adaptation rules of thumb will underperform unless tuned to local thermal and seasonal signals, e.g., heat-health interventions and shading where Temperature maximum rises steeply, versus runoff controls timed to peak wet-season bursts. Second, this seasonal and thermal variability is a known precursor to compound stresses when warm episodes co-occur with pluvial events and elevated coastal water levels, a dynamic increasingly documented in coastal–estuarine systems worldwide and relevant to the Volta delta (coastal Ghana temperature variability; compound flood reviews).

The GIS "bathtub" inundation modelling under SSP2-4.5 and SSP5-8.5 provides a credible screening picture of end-century coastal exposure. The finding that SSP5-8.5 drives substantially greater extents and uncertainty, with land submerged up to 39.1% by 2100, is directionally consistent with IPCC AR6 projections (median global mean sea-level rise roughly 0.63–1.01 m by 2100 under SSP5-8.5 and 0.32–0.62 m under SSP2-4.5), which would be consequential for low-lying deltas even before accounting for local subsidence and vertical land motion (AR6 synthesis; NASA/NOAA projection tools). At the same time, the caution is well-placed: level-pool "bathtub" approaches can over- or under-predict inland extents because they ignore wave set-up, storm surge hydrodynamics, tide resonance, overtopping, drainage networks, and groundwater interactions. Recent commentary urges the scientific community to move toward physics-based

2-D/3-D hydrodynamics as computational feasibility improves, precisely to reduce the biases that can reach ±200% in flood area (AGU Earth's Future; Fathom/UC Irvine brief). For Keta specifically, analyses of extreme coastal water levels show flooding is often the compound result of tides, sea-level anomalies, waves, and atmospheric conditions, further reinforcing the recommendation to couple surge–wave–tide dynamics in future work.

The composite risk mapping that fuses an AHP-weighted overlay with PCA is a strong step toward operational risk stratification. By confirming very-high-risk polygons along the coastal fringe near Keta and Ada Foah, and medium–high risk along inland river corridors and slope transitions, the maps match a common pattern in multi-criteria flood studies: elevation, slope, land use, drainage/river proximity, and rainfall dominate susceptibility, while roads concentrate exposure (AHP reviews; geospatial AHP/WPM applications). The use of PCA to organize socioeconomic indicators mirrors best practice in social vulnerability analysis, where latent components, such as poverty, housing quality, service access, and social capital, explain differentiated outcomes and guide scenario-based risk reduction (PCA vulnerability frameworks). One of the most consequential findings is the positive role of wetlands: they store water, attenuate surge, trap sediment, and reduce downstream risk. Experimental and modelling work focused on Ghana's coast shows mangroves can substantially reduce erosion and wave energy, even under moderate sea-level rise, while Ghana's regulatory analyses note that weak enforcement and institutional fragmentation can inhibit wetland protection, diminishing their buffering value (Frontiers on mangrove NbS; Ghana coastal wetlands governance).

The shoreline analysis (2016–2024) captures the essential heterogeneity of the coastal cell: average net erosion of roughly −3.07 m/yr co-exists with local accretion of about +1.47 m/yr; erosion hot-spots include Fuveme (≈−4.56 m/yr), Ada (≈−2.40 m/yr), and Keta (≈−2.24 m/yr).

This pattern is consistent with longer-term studies of the Volta estuary and eastern Ghana coast, which attribute heightened erosion to sediment starvation after the Akosombo/Kpong dams and to alongshore feedbacks induced by selective sea-defence placement, protection in one reach, downdrift erosion in another (Volta estuary shoreline trends; World Bank case study). A recent national mapping shows roughly 20% of Ghana's 550 km coastline now armored with grey infrastructure (groynes, revetments, seawalls), underscoring the need to anticipate spillover effects and socio-economic trade-offs in project selection (coastal infrastructure mapping).

Community inquiry adds crucial texture: high hazard awareness sits alongside fragmented, reactive practice and a marked preference for dredging, sea defences, and drainage upgrades, while relocation remains unpopular and awareness of plans and codes is uneven. That profile mirrors broader Ghanaian coastal experience, where engineered solutions are favored and relocation is resisted due to livelihoods and cultural ties; yet, selective defences, absent sediment continuity, can intensify erosion down-drift and fuel inequality by privileging protected reaches and displacing vulnerable communities (political-ecology findings; national reportage on tidal wave impacts and displacement). This is precisely why the identification of wetlands as risk reduction assets matters: technically effective adaptation needs socio-institutional legitimacy, and nature-based measures, co-designed with communities, can offer protection without exacerbating alongshore harm, provided they are funded, maintained, and protected by enforceable rules (wetlands governance analyses).

The study recognizes that bathtub screening is efficient for scoping but not sufficient for risk decisions; that 12 m DSM limits micro-topographic realism; and that socioeconomic sampling can carry self-report bias. The literature directly supports to adopt 2-D/3-D hydrodynamic models that couple tides, waves, surge, and rainfall under AR6-consistent sea-level rise; move toward

LiDAR-grade elevation and building-level attributes (floor heights, construction materials); and introduce hydraulic connectivity and surface roughness rather than simple level pooling. Studies comparing enhanced versus simple bathtub methods confirm that adding slope/roughness/connectivity and favouring DSM/DTM appropriately can materially improve plausibility while necessary to build toward full hydrodynamics (AGU commentary; enhanced bathtub modelling).

Finally, the bridge from evidence to implementation runs through governance and finance. Here, Ghana has practical tools: district-level climate integration toolkits and the National Climate Change Adaptation Strategy (NCCAS) set out how Metropolitan, Municipal, and District Assemblies can mainstream climate risk into Medium-Term Development Plans (MTDPs), from prioritization and gender-responsive budgeting to monitoring and accountability. Embedding the hotspot actions, coastal hybrid defences with sediment management; wetland restoration and setbacks; drainage retrofits and code enforcement in MTDPs and sector plans turns maps into budgets and drills, with measurable resilience gains.

The study powerfully operationalizes the risk paradigm for a complex coastal delta, and its major findings interlock: place-specific climate signals demand tailored heat and runoff strategies; inundation screening justifies early adaptation while motivating hydrodynamic upgrades; composite risk mapping and PCA clarify where exposure, biophysical susceptibility, and low adaptive capacity overlap; shoreline evidence warns against single, hard-structure fixes that ignore sediment continuity; and community preferences must be met with credible, co-designed options, including wetlands and hybrid solutions. If the next phase couples physics-based flood modelling with improved elevation and asset data, protects and restores buffering ecosystems, and routes actions through district plans and enforceable codes, the evidence assembled can be translated into durable outcomes for Keta, Ada Foah, Anloga, and the wider delta

6.3 Recommendation

The projected rise in sea levels and the increasing frequency of flooding events pose severe and imminent risks to lives, property, ecosystems, and critical infrastructure in the Lower Volta Basin, whether from flash floods, lagoon overflow, or river inundation. These threats are compounded by high exposure and vulnerability among communities whose livelihoods and physical assets remain at stake. Addressing these challenges requires a multi-dimensional and coordinated approach involving research, planning, infrastructure development, community engagement, and policy action.

First, future studies should incorporate additional datasets such as bathymetry, sediment transport, and historical shoreline positions to improve understanding of the underlying drivers of spatially variable shoreline change. This research should be led by the Water Research Institute of the Council for Scientific and Industrial Research (CSIR-WRI) and academic institutions such as the University of Ghana, Kwame Nkrumah University of Science and Technology (KNUST), and the University of Cape Coast, supported by the Hydrological Services Department (HSD) for hydrological data. These studies will establish a scientific foundation for targeted interventions and predictive modelling.

Communities within the basin must remain vigilant and prepare for early responses to flood situations through robust early warning systems. The Ghana Meteorological Agency (GMeT) should strengthen its forecasting capabilities and ensure timely dissemination of alerts, while the National Disaster Management Organization (NADMO) and local assemblies should coordinate emergency drills and community-level preparedness programmes. Public education campaigns should complement these efforts by enhancing awareness and readiness.

Urban planning and flood management must be prioritised at both the national and local levels. The Land Use and Spatial Planning Authority (LUSPA), the Environmental Protection Agency (EPA), and the Ministry of Environment, Science, Technology and Innovation (MESTI) should integrate climate risk into planning frameworks, while the Physical Planning Department of the MMDAs enforces resilient layouts and building codes. Assemblies, chiefs, and opinion leaders must collaborate to ensure community-level compliance and ownership of these plans.

Sea defence construction and maintenance should be accelerated under the leadership of the Ministry of Works and Housing and the Ghana Coastal Development Authority (GCDA), with technical input from the Ghana Ports and Harbours Authority (GPHA). These structures are critical for protecting coastal communities from storm surges and erosion. Similarly, lagoon and river dredging programmes should be developed and implemented by the Hydrological Services Department and Water Resources Commission (WRC), ensuring transparency and community engagement throughout the process to maintain trust and accountability.

Improving drainage infrastructure requires substantial investment by the Department of Urban Roads and the Ministry of Roads and Highways, complemented by local assemblies maintaining smaller drains and enforcing building codes. Community awareness and preparedness must be enhanced through educational programmes, drills, and accessible information dissemination led by NADMO, MLGRD, and the Information Services Department. These initiatives will help bridge the gap between structural interventions and behavioural adaptation.

Mangrove protection and restoration should be spearheaded by the Forestry Commission and EPA, engaging local communities in conservation efforts to strengthen natural flood defences. Climate change considerations must be integrated into all flood risk management strategies, with MESTI and EPA mainstreaming projections and the National Development Planning Commission (NDPC) embedding adaptation into national development plans. This integration ensures that long-term planning accounts for evolving climate risks.

Strategic investment in policy and technology by the Ministry of Finance, NDPC, and development partners such as UNDP and the World Bank are essential to fund both structural and non-structural solutions. Relocation may be contentious due to socio-economic ties; however, the MLGRD, NADMO, and Social Welfare Departments should investigate inclusive, systematic approaches as needed, ensuring that affected communities are consulted and supported throughout the process. Assemblies must incorporate resilience-building measures into medium- and long-term plans, covering infrastructure, livelihoods, and ecosystem integrity.

Another strong recommendation emerging from the findings is the urgent need to establish and strengthen early warning systems, coordination mechanisms, public education, and emergency planning to reduce flood and erosion risks in the Lower Volta Basin. This requires a multi-institutional approach where the Ghana Meteorological Agency (GMeT) plays a central role in improving weather forecasting and issuing timely alerts for extreme rainfall and storm events. The National Disaster Management Organization (NADMO) should coordinate emergency preparedness activities, including community drills, evacuation planning, and response protocols, ensuring that vulnerable populations are adequately protected. At the local level, Metropolitan, Municipal, and District Assemblies (MMDAs) must work closely with NADMO to disseminate warnings, mobilise volunteers, and enforce emergency plans. The Information Services Department should lead public education campaigns to raise awareness about flood risks, building codes, and safety measures, while the Ministry of Local Government, Decentralisation, and Rural

Development (MLGRD) should ensure the integration of these strategies into local governance frameworks. Additionally, the Environmental Protection Agency (EPA) and Ministry of Environment, Science, Technology and Innovation (MESTI) should incorporate climate risk projections into planning and policy to support proactive adaptation. Together, these institutions must create a coordinated, transparent, and community-driven system that combines technology, education, and governance to minimise disaster impacts and build resilience in the basin.

Finally, longitudinal research should monitor the effectiveness of implemented projects, while future studies investigate the combined influence of sea-level rise, storm events, and human interventions on shoreline dynamics. These efforts will require collaboration among CSIR-WRI, universities, and regulatory agencies to ensure evidence-based decision-making and adaptive management.

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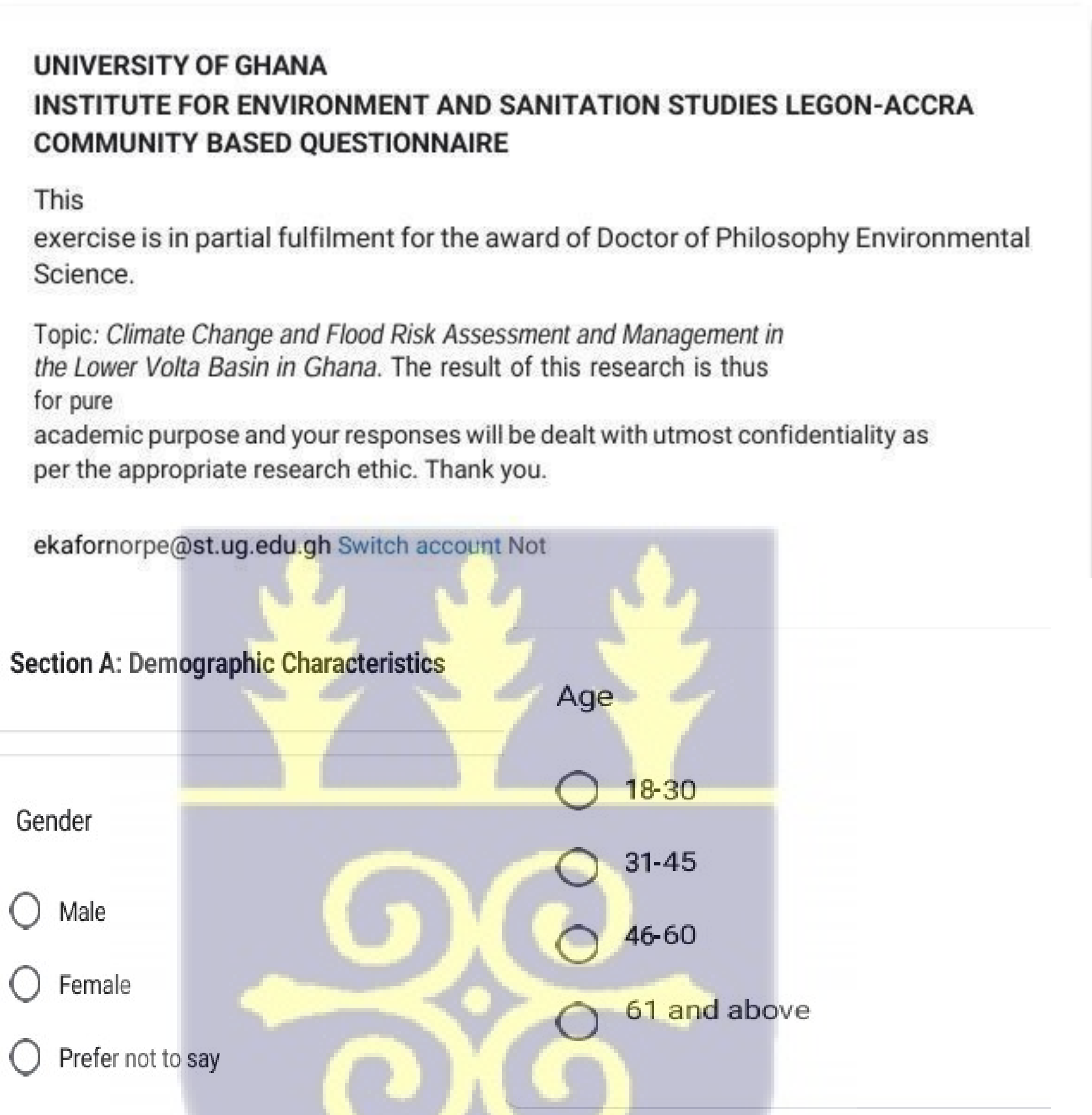
APPENDICES

APPENDIX 1: PHOTO GALLERY

APPENDIX 2: QUESTIONNAIRES



UNIVERSITY OF GHANA
INSTITUTE FOR ENVIRONMENT AND SANITATION STUDIES LEGON-ACCRA
COMMUNITY BASED QUESTIONNAIRE

This exercise is in partial fulfilment for the award of Doctor of Philosophy Environmental Science.

Topic: *Climate Change and Flood Risk Assessment and Management in the Lower Volta Basin in Ghana.* The result of this research is thus for pure academic purpose and your responses will be dealt with utmost confidentiality as per the appropriate research ethic. Thank you.

ekafornorpe@st.ug.edu.gh Switch account Not

Section A: Demographic Characteristics

Gender

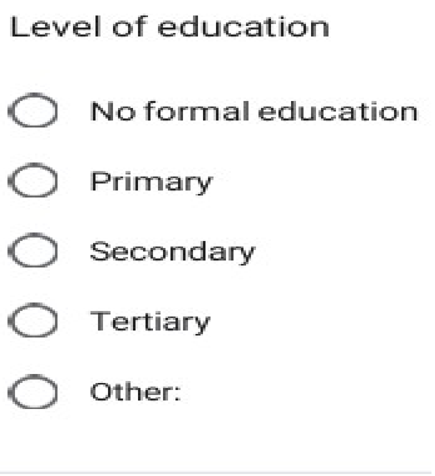
○ Male
○ Female
○ Prefer not to say

Age

○ 18-30
○ 31-45
○ 46-60
○ 61 and above

Occupation

○ Farmer
○ Fisherman
○ Trader
○ Formal/White Colour Employee
○ Student
○ Other:



Level of education

○ No formal education
○ Primary
○ Secondary
○ Tertiary
○ Other:

How long have you lived in your community?

○ Less than 1 year
○ 1-5 years
○ 6-10 years
○ More than 10 years

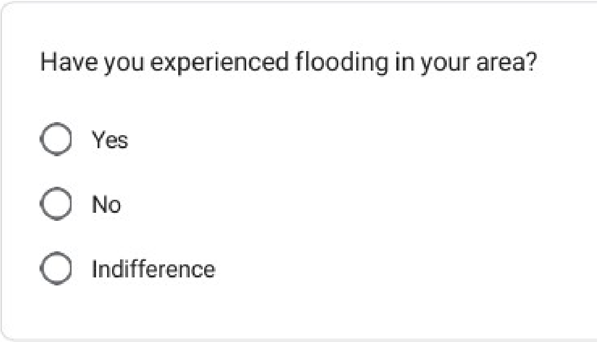
Age group of vulnerable members in the family (specific age and relation)

☐ Senior citizen
☐ Children
☐ Women
☐ Other members
☐ Other:

Section B: Awareness and Experience of Flooding Events and Characteristics of Flood

Are you aware of any flooding events in these areas?

○ Yes
○ No
○ Indifference

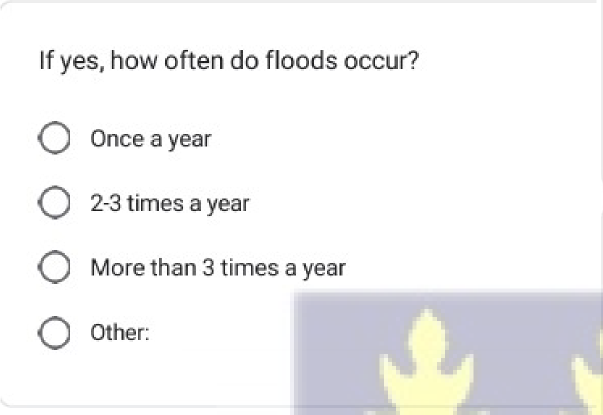


Have you experienced flooding in your area?

○ Yes

○ No

○ Indifference



If yes, how often do floods occur?

○ Once a year

○ 2-3 times a year

○ More than 3 times a year

○ Other:

When was the last time you experienced a flood in your area?

○ Less than 1 year ago

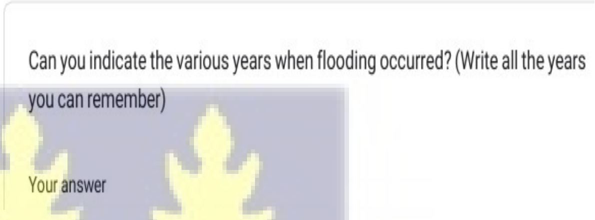
○ 1-2 years ago

○ 3-5 years ago

○ More than 5 years ago

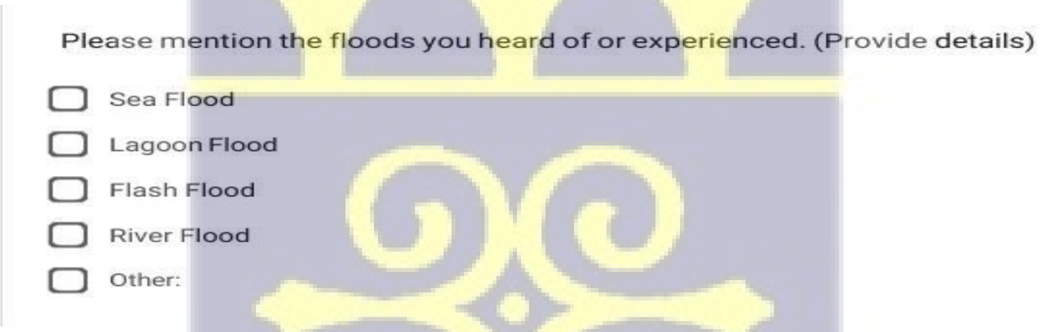
○ Never

○ Other:



Can you indicate the various years when flooding occurred? (Write all the years you can remember)

Your answer



Please mention the floods you heard of or experienced. (Provide details)

☐ Sea Flood

☐ Lagoon Flood

☐ Flash Flood

☐ River Flood

☐ Other:

What were the main causes of flooding in your area? (Select all that apply)

☐ Heavy rainfall

☐ Overflow of rivers

☐ Poor drainage systems

☐ Deforestation

☐ Other:

Did the floods affect you?

○ Yes

○ No

○ Indifference

How did the floods affect you? (Select all that apply)

☐ Loss of crops

☐ Damage to property

☐ Displacement from home

☐ Health issues

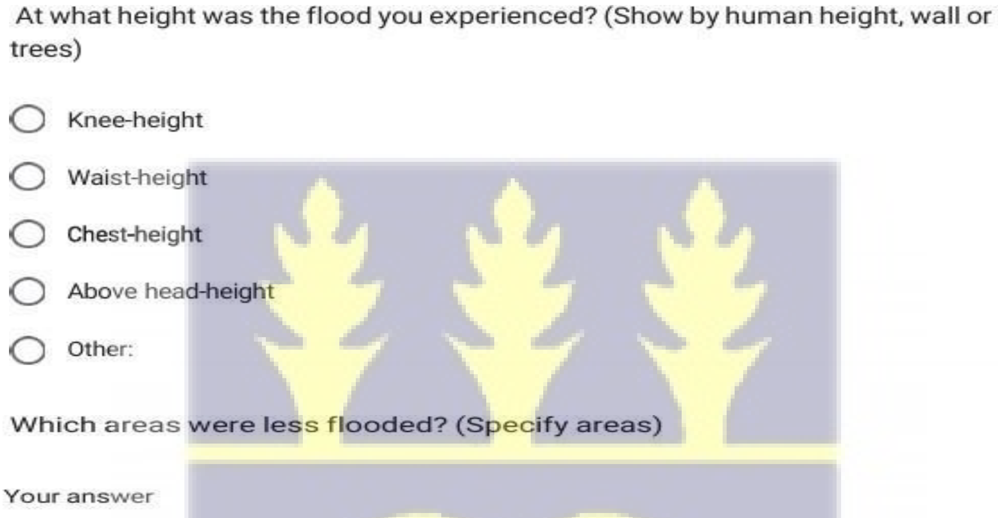
☐ Other:

Did the floods affect your livelihood?

○ Yes

○ No

○ Indifference



At what height was the flood you experienced? (Show by human height, wall or trees)

○ Knee-height

○ Waist-height

○ Chest-height

○ Above head-height

○ Other:

Which areas were less flooded? (Specify areas)

Your answer

Were there any properties destroyed? (Select all that apply)

☐ Houses
☐ Schools
☐ Churches
☐ Markets
☐ Roads
☐ Other:

Were any farms, streams, lagoon or drinking water sources destroyed?

○ Yes
○ No
○ Indifference

If yes, please specify

Your answer

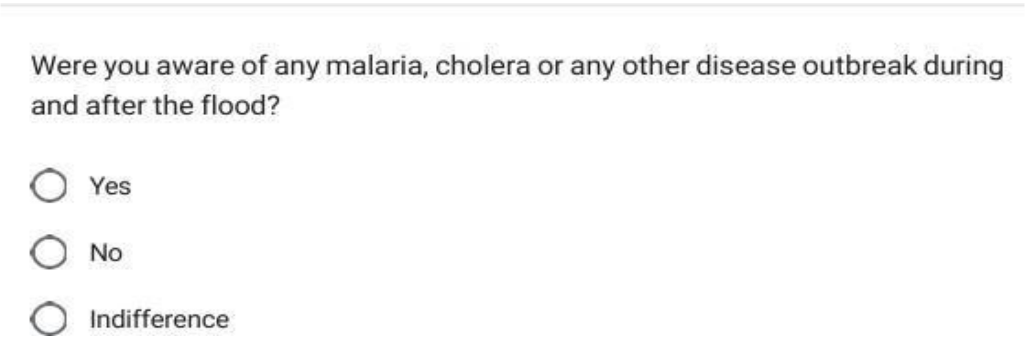
Which areas were more flooded? (Specify areas)

Your answer

Section C: Specific Questions on Damage and Effects

What were the effects of the flood on the community? (Select all that apply)

☐ Displacement of residents
☐ Loss of lives
☐ Economic losses
☐ Health issues (waterborne diseases, injuries)
☐ Disruption of education
☐ Food and water shortages
☐ Sea defense structures
☐ Other:



Were you aware of any malaria, cholera or any other disease outbreak during and after the flood?

○ Yes

○ No

○ Indifference

Were people still going to sea when the flood occurred?

○ Yes

○ No

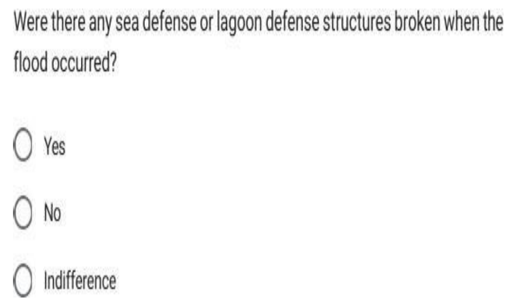
○ Indifference

Were shops and markets closed down due to the flood?

○ Yes

○ No

○ Indifference

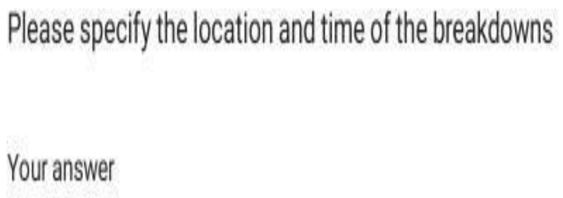


Were there any sea defense or lagoon defense structures broken when the flood occurred?

○ Yes

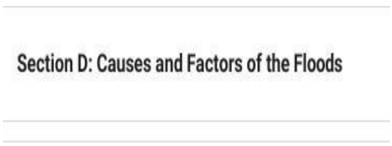
○ No

○ Indifference



Please specify the location and time of the breakdowns

Your answer



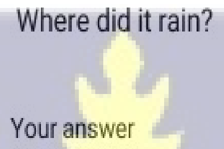
Section D: Causes and Factors of the Floods

Was there rain before the flood?

○ Yes

○ No

○ Indifference



Where did it rain?

Your answer

Was there any flood from the sea spill off?

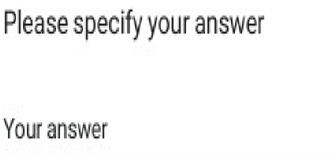
○ Yes

○ No

○ Indifference

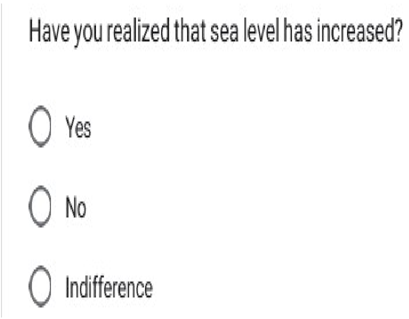
Where exactly did the sea spill off onto the land?

Your answer



Please specify your answer

Your answer

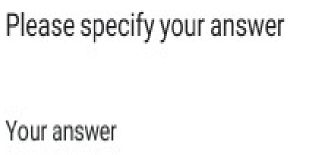


Have you realized that sea level has increased?

○ Yes

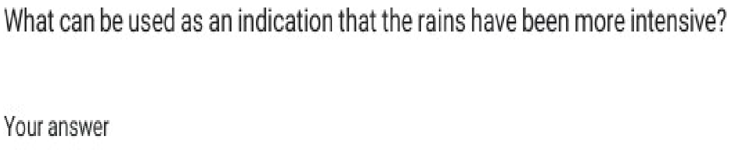
○ No

○ Indifference



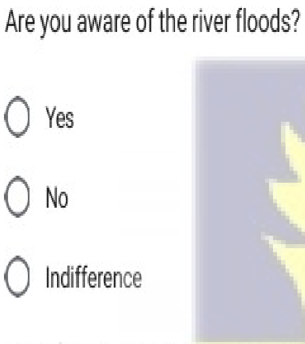
Please specify your answer

Your answer



What can be used as an indication that the rains have been more intensive?

Your answer



Are you aware of the river floods?

○ Yes

○ No

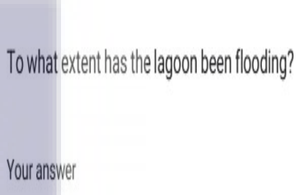
○ Indifference

Are you aware of the last Akosombo Dam spillag

○ Yes

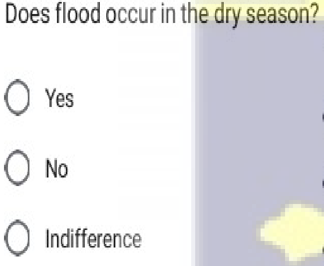
○ No

○ Indifference



To what extent has the lagoon been flooding?

Your answer

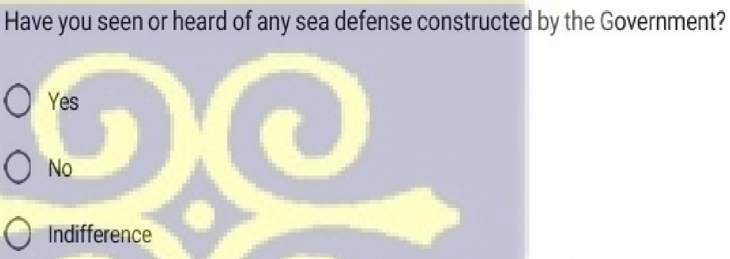


Does flood occur in the dry season?

○ Yes

○ No

○ Indifference

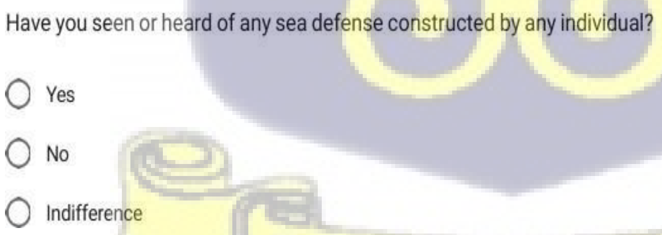


Have you seen or heard of any sea defense constructed by the Government?

○ Yes

○ No

○ Indifference

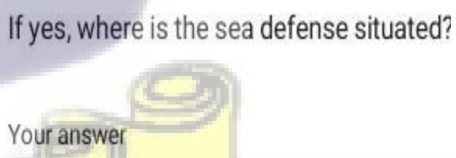


Have you seen or heard of any sea defense constructed by any individual?

○ Yes

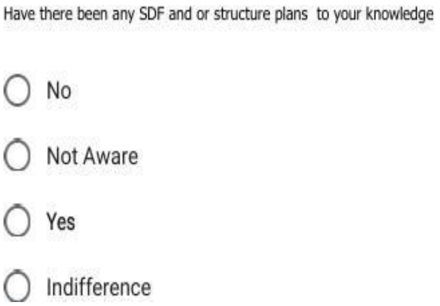
○ No

○ Indifference



If yes, where is the sea defense situated?

Your answer



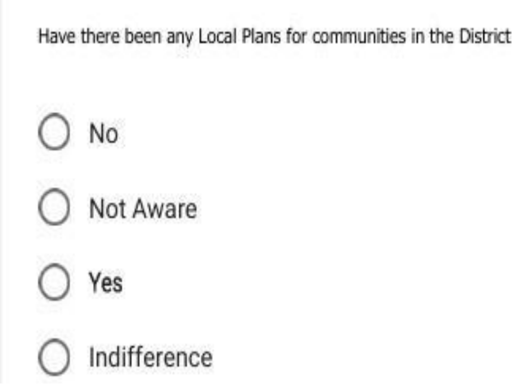
Have there been any SDF and or structure plans to your knowledge

○ No

○ Not Aware

○ Yes

○ Indifference



Have there been any Local Plans for communities in the District

○ No

○ Not Aware

○ Yes

○ Indifference

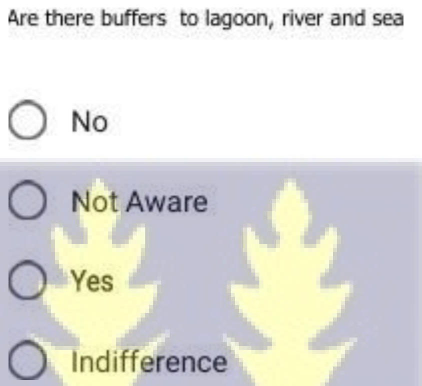
Are you aware of development and published of any building codes

○ No

○ Not Aware

○ Yes

○ Indifference



Are there buffers to lagoon, river and sea

○ No

○ Not Aware

○ Yes

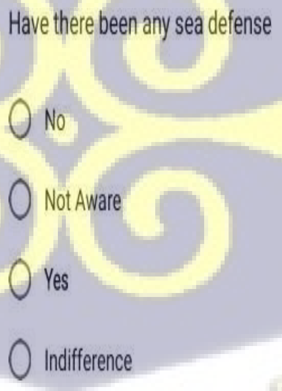
○ Indifference

To what extent these buffers have been enforced

○ Adequately

○ No Adequately

○ Indifference



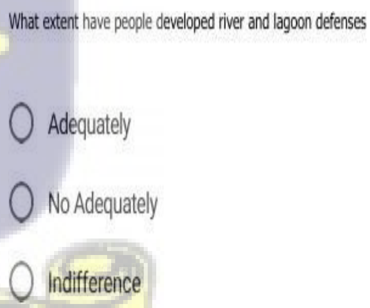
Have there been any sea defense

○ No

○ Not Aware

○ Yes

○ Indifference

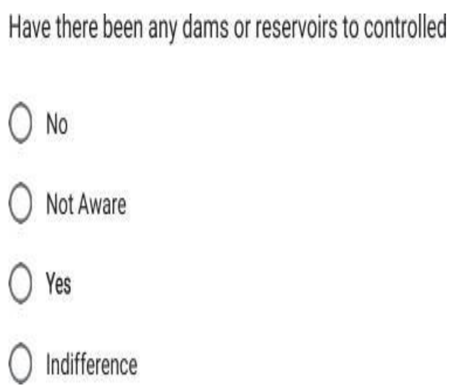


What extent have people developed river and lagoon defenses

○ Adequately

○ No Adequately

○ Indifference



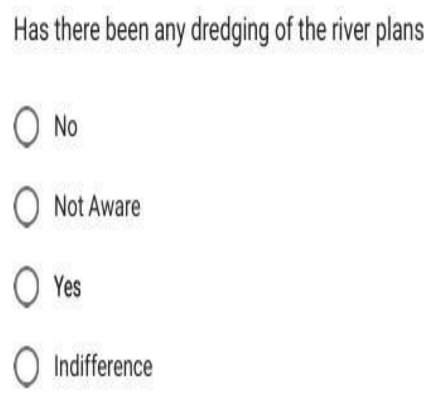
Have there been any dams or reservoirs to controlled

○ No

○ Not Aware

○ Yes

○ Indifference



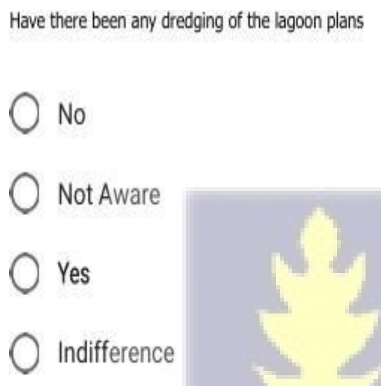
Has there been any dredging of the river plans

○ No

○ Not Aware

○ Yes

○ Indifference



Have there been any dredging of the lagoon plans

○ No

○ Not Aware

○ Yes

○ Indifference

To what extent has there been any maintenance work since the sea defense been constructed

○ Adequately

○ No Adequately

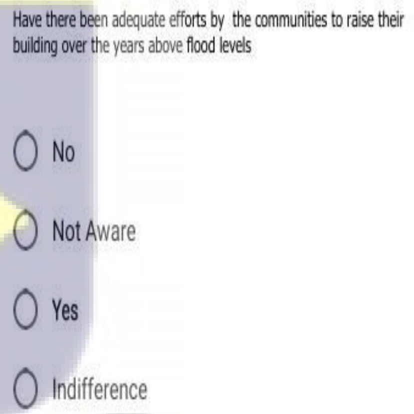
○ Indifference

What extent have the communities been given enough education and sensitisations on climate change and floods

○ Adequately

○ No Adequately

○ Indifference



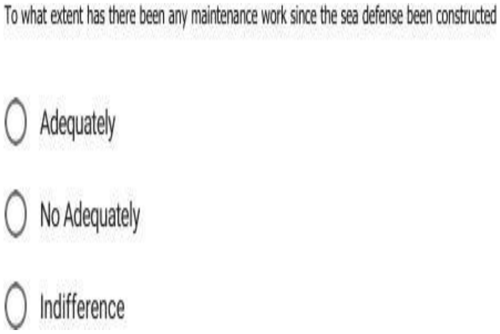
Have there been adequate efforts by the communities to raise their building over the years above flood levels

○ No

○ Not Aware

○ Yes

○ Indifference



To what extent has there been any maintenance work since the sea defense been constructed

○ Adequately

○ No Adequately

○ Indifference

Have there been adequate efforts by the communities to raise their building over the years above flood levels

○ No

○ Not Aware

○ Yes

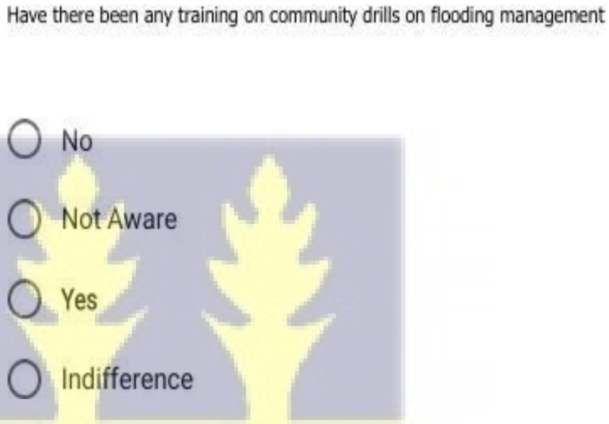
○ Indifference

To what extent have there been any emergency plans

○ Adequately

○ No Adequately

○ Indifference



Have there been any training on community drills on flooding management

○ No

○ Not Aware

○ Yes

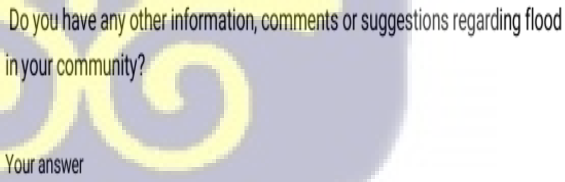
○ Indifference

To what extent have there been education on flood management

○ Adequately

○ No Adequately

○ Indifference



Do you have any other information, comments or suggestions regarding flood in your community?

Your answer

APPENDIX 3: CLIMATE DATA

Ada	Year Total	Mx Temp	Mn Temp	Mx average	Average	CV	anomaly	
1960	979.3	29.8	24.4	31.2	25.1	9.7	139.4	839.9016
1961	1044.2	30.3	24.4	31.2	25.1		204.3	839.9016
1962	1491.4	31.6	24.2	31.2	25.1		651.5	839.9016
1963	992.9	31.2	24.9	31.2	25.1		153	839.9016
1964	597.9	31.3	24.1	31.2	25.1		-242	839.9016
1965	838.1	31.5	24.4	31.2	25.1		-1.8	839.9016
1966	819.0	31.7	24.7	31.2	25.1		-20.9	839.9016
1967	1057.5	31.1	24.1	31.2	25.1		217.6	839.9016
1968	1696.4	31.3	24.8	31.2	25.1		856.5	839.9016
1969	619.9	31.3	25.1	31.2	25.1		-220	839.9016
1970	965.2	31.6	24.6	31.2	25.1		125.3	839.9016
1971	887.2	31.3	24.4	31.2	25.1		47.3	839.9016
1972	877.8	31.4	24.3	31.2	25.1		37.9	839.9016
1973	1118.2	31.8	25.0	31.2	25.1		278.3	839.9016
1974	1330.4	31.2	24.4	31.2	25.1		490.5	839.9016
1975	947.1	30.4	24.0	31.2	25.1		107.2	839.9016
1976	534.7	30.1	24.0	31.2	25.1		-305.2	839.9016
1977	373.1	30.5	24.7	31.2	25.1		-466.8	839.9016
1978	601.7	30.5	24.7	31.2	25.1		-238.2	839.9016
1979	574.4	31.1	25.1	31.2	25.1		-265.5	839.9016
1980	673.1	30.8	25.0	31.2	25.1		-166.8	839.9016
1981	899.4	30.9	25.0	31.2	25.1		59.5	839.9016
1982	1247.5	30.6	24.5	31.2	25.1		407.6	839.9016
1983	539.7	30.7	24.8	31.2	25.1		-300.2	839.9016
1984	726.9	31.0	24.8	31.2	25.1		-113	839.9016
1985	665.6	30.5	24.7	31.2	25.1		-174.3	839.9016
1986	495.8	30.3	24.6	31.2	25.1		-344.1	839.9016
1987	931.0	31.2	25.3	31.2	25.1		91.1	839.9016
1988	798.3	30.9	24.6	31.2	25.1		-41.6	839.9016
1989	949.9	30.7	24.7	31.2	25.1		110	839.9016
1990	655.9	30.7	25.1	31.2	25.1		-184	839.9016
1991	1298.1	31.1	25.1	31.2	25.1		458.2	839.9016
1992	359.2	31.7	24.9	31.2	25.1		-480.7	839.9016
1993	759.3	31.7	24.9	31.2	25.1		-80.6	839.9016
1994	701.2	31.6	24.9	31.2	25.1		-138.7	839.9016
1995	859.2	31.8	25.1	31.2	25.1		19.3	839.9016

1996	1191.2	31.6	25.1	31.2	25.1	351.3	839.9016
1997	1191.2	31.5	24.5	31.2	25.1	351.3	839.9016
1998	484.4	32.2	25.1	31.2	25.1	-355.5	839.9016
1999	716.0	31.7	25.0	31.2	25.1	-123.9	839.9016
2000	394.3	31.8	25.2	31.2	25.1	-445.6	839.9016
2001	779.2	31.8	25.4	31.2	25.1	-60.7	839.9016
2002	842.6	31.8	25.1	31.2	25.1	2.7	839.9016
2003	1061.9	31.8	25.5	31.2	25.1	222	839.9016
2004	698.4	31.8	25.3	31.2	25.1	-141.5	839.9016
2005	790.8	31.9	25.3	31.2	25.1	-49.1	839.9016
2006	746.0	31.9	25.6	31.2	25.1	-93.9	839.9016
2007	897.1	31.5	25.2	31.2	25.1	57.2	839.9016
2008	767.3	31.5	25.2	31.2	25.1	-72.6	839.9016
2009	1070.0	30.9	25.4	31.2	25.1	230.1	839.9016
2010	957.4	31.4	26.1	31.2	25.1	117.5	839.9016
2011	893.5	30.8	25.5	31.2	25.1	53.6	839.9016
2012	669.7	30.7	25.5	31.2	25.1	-170.2	839.9016
2013	636.0	30.7	25.6	31.2	25.1	-203.9	839.9016
2014	830.3	31.1	25.5	31.2	25.1	-9.6	839.9016
2015	852.5	30.9	25.3	31.2	25.1	12.6	839.9016
2016	864.8	31.3	25.8	31.2	25.1	24.9	839.9016
2017	798.2	31.0	26.2	31.2	25.1	-41.7	839.9016
2018	672.8	31.0	26.3	31.2	25.1	-167.1	839.9016
2019	738.6	31.2	26.2	31.2	25.1	-101.3	839.9016
2020	831.1	31.4	26.2	31.2	25.1	-8.8	839.9016
2021	749.6	32.0	27.5	31.2	25.1	-90.3	839.9016
2022	872.4	31.1	26.6	31.2	25.1	32.5	839.9016
2023	849.9	31.3	26.9	31.2	25.1	10	839.9016
Overall	839.9016	31.2	25.1				
30 years	811.8	31.4	25.6				
last decade	790.6	31.2	26.2				

Keta	Year Total		Mx Temp	Mn Temp		
	1960	1079.1	31.3	23.9	32.1	24.0
	1961	1072.2	30.8	24.1	32.1	24.0
	1962	1386.9	30.8	24.2	32.1	24.0

1963	1143.5	31.6	24.6	32.1	24.0
1964	528.1	31.3	24.4	32.1	24.0
1965	765.5	30.2	23.7	32.1	24.0
1966	725.0	31.5	24.3	32.1	24.0
1967	913.9	30.4	23.8	32.1	24.0
1968	1681.4	30.8	23.9	32.1	24.0
1969	714.1	31.3	24.5	32.1	24.0
1970	588.6	31.3	25.3	32.1	24.0
1971	599.3	31.6	24.5	32.1	24.0
1972	469.5	31.5	25.2	32.1	24.0
1973	788.5	31.5	24.4	32.1	24.0
1974	1127.3	30.5	24.5	32.1	24.0
1975	809.9	30.6	24.3	32.1	24.0
1976	750.3	30.1	24.0	32.1	24.0
1977	439.4	31.1	24.6	32.1	24.0
1978	620.0	31.1	24.5	32.1	24.0
1979	804.6	31.2	24.8	32.1	24.0
1980	748.9	31.1	25.1	32.1	24.0
1981	618.2	31.5	25.3	32.1	24.0
1982	1191.8	31.1	24.9	32.1	24.0
1983	220.9	31.4	25.1	32.1	24.0
1984	483.7	31.9	24.8	32.1	24.0
1985	547.6	31.9	24.5	32.1	24.0
1986	314.8	32.5	24.0	32.1	24.0
1987	677.7	32.2	21.3	32.1	24.0
1988	968.4	31.8	20.9	32.1	24.0
1989	879.4	31.6	21.3	32.1	24.0
1990	770.4	31.6	22.2	32.1	24.0
1991	1404.3	31.2	23.1	32.1	24.0
1992	385.0	31.6	23.9	32.1	24.0
1993	841.0	32.0	24.4	32.1	24.0
1994	658.2	32.2	24.6	32.1	24.0
1995	922.5	32.5	24.6	32.1	24.0
1996	1280.2	32.7	23.3	32.1	24.0
1997	1327.8	33.1	23.7	32.1	24.0
1998	1357.1	33.2	24.0	32.1	24.0
1999	950.9	32.7	23.3	32.1	24.0
2000	868.9	32.5	23.2	32.1	24.0
2001	726.3	32.7	23.0	32.1	24.0
2002	712.3	32.7	23.3	32.1	24.0

2003	959.4	32.6	23.3	32.1	24.0
2004	839.6	32.4	23.1	32.1	24.0
2005	236.0	32.8	23.6	32.1	24.0
2006	787.6	33.2	24.0	32.1	24.0
2007	539.1	33.1	24.1	32.1	24.0
2008	1170.4	32.8	23.9	32.1	24.0
2009	609.7	33.1	23.8	32.1	24.0
2010	863.4	32.5	23.2	32.1	24.0
2011	461.4	34.1	23.0	32.1	24.0
2012	784.0	33.0	23.6	32.1	24.0
2013	924.4	33.2	24.2	32.1	24.0
2014	436.6	33.4	23.8	32.1	24.0
2015	593.1	33.6	24.4	32.1	24.0
2016	412.9	33.3	23.8	32.1	24.0
2017	786.3	33.7	24.1	32.1	24.0
2018	546.7	33.5	24.4	32.1	24.0
2019	638.5	33.4	24.3	32.1	24.0
2020	863.2	34.0	25.0	32.1	24.0
2021	721.6	33.5	24.7	32.1	24.0
2022	612.3	33.3	24.2	32.1	24.0
2023	857.9	32.8	23.4	32.1	24.0
Overall	800.7	32.1	24.0		
30 years	807.4	33.0	23.8		
last decade	672.1	33.4	24.2		

APPENDIX 4: ETHICAL CLEARANCE

UNIVERSITY OF GHANA
ETHICS COMMITTEE FOR BASIC AND APPLIED SCIENCES (ECBAS)
P. O. Box LG 1195, Legon, Accra, Ghana

Ref. No: ECBAS 101/23-24

29th November, 2024

Mr. Eric Kofi Afornorpe
Institute for Environment and Sanitation Studies
University of Ghana
Legon, Accra

Dear Mr. Afornorpe,

ECBAS 101/23-24: ASSESSING CLIMATE CHANGE AND FLOOD RISK MANAGEMENT IN THE LOWER VOLTA BASIN

This is to inform you that the above referenced study has been presented to the Ethics Committee for Basic and Applied Sciences for a full board review and the following actions taken subject to the conditions and explanation provided below:

Expiry Date:	17/08/2025
On Agenda for:	Initial Submission
Date of Submission:	18/06/2024
ECBAS Action:	Approved
Reporting:	Annually

Please accept my congratulations.

Yours sincerely,

Professor Dorcas Osei-Safo
ECBAS Chairperson