

UNIVERSITY OF GHANA

COLLEGE OF BASIC AND APPLIED SCIENCES

CENTRE FOR CLIMATE CHANGE AND SUSTAINABILITY STUDIES



**EXPLORING THE TRENDS AND IMPACTS OF CLIMATE CHANGE-INDUCED
COASTAL HAZARDS IN KETA, GHANA: EXISTING ADAPTATION STRATEGIES
AND POSSIBILITIES OF NATURE-BASED SOLUTIONS.**

BY

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**THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN
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MASTER OF PHILOSOPHY (MPHIL) IN CLIMATE CHANGE AND SUSTAINABLE
DEVELOPMENT DEGREE.**

JULY, 2021

DECLARATION

I, **Gontorwon Saye Lah**, hereby declare that this thesis is a result of my research and that all references have been duly acknowledged. Furthermore, I affirm that this work has neither been partially nor wholly submitted at any other institution for the award of any degree.



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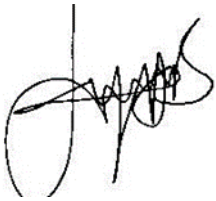
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CERTIFICATION

We hereby certify that this thesis was supervised following procedures laid down by the University of Ghana.



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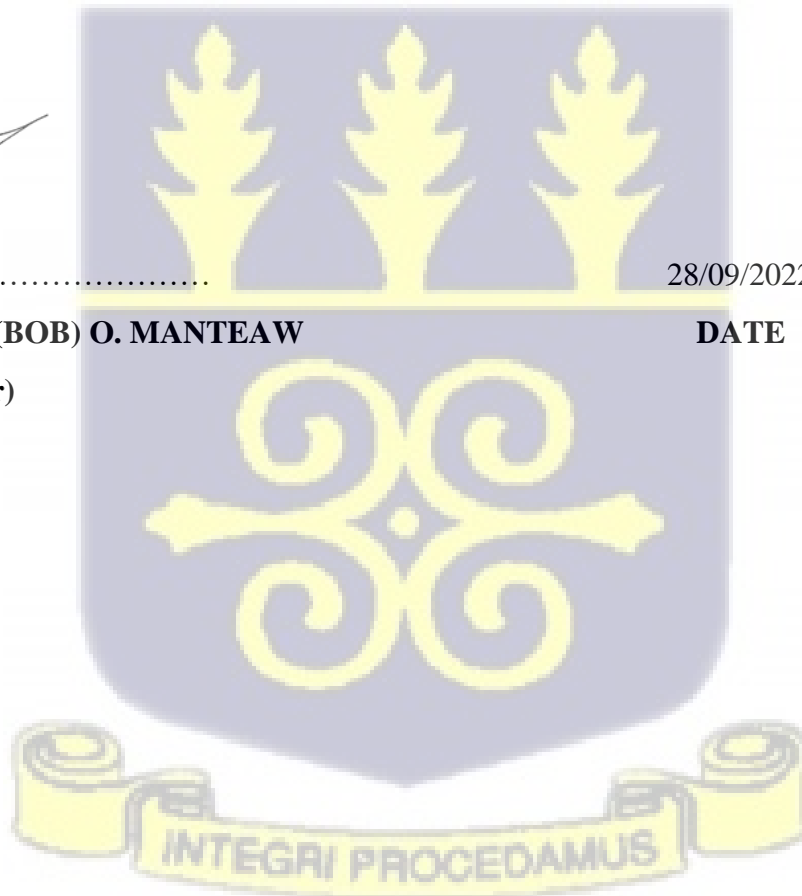


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ABSTRACT

The rise in climate change-induced hazards including floods, erosion, tidal waves, and storms across coastal socio-ecological zones in recent years poses significant threats to the achievement of sustainable development. The Keta Municipality in the Volta Region of Ghana is arguably one of the most vulnerable to a range of climate-induced coastal hazards. The main purpose of the study is to explore the trends and impacts of climate change-induced coastal hazards in Keta, Ghana, with existing adaptation strategies and possibilities of nature-based solutions. The study employed household questionnaire surveys (n=90), key institutional stakeholder surveys (n=18), and Landuse/Landcover Change (LULC) assessment of the years 2010 and 2020 for data collection and analysis. Results for the trends and impacts of climate change-induced hazards in the Keta township show that respondents reported (51%) for floods and (28%) for erosion as the most common climate change-induced coastal hazards. 18% of respondents identified high tide in certain parts of the township with fewer reports for stormwater (3%). The impacts of these hazards according to respondents over the years have included the displacement of households (57%) and destruction of properties (77%) in the township. The existing local-level adaptation and mitigation options for these hazards over the years have been; (i) the filling of compounds with sea sand to reduce floods and erosion impacts in Xekpa (26%), Tetekorpe (16%), Gobamodzi (21%), and Keta (21%) communities, (ii) the creation of holes in fence walls to reduce floods and tidal waves impacts by respondents in Xekpa (12%), Tetekorpe (10%), Gobamodzi (9%), Abutiakorpe (11%), Keta (21%), Vui (13%), and Dzelukorpe (20%), and (iii) the planting of trees to reduce erosion and other benefits in the township. Evidence of Nature-based solutions exists in the communities' approaches to managing climate change-induced hazards in the township. However, the majority of respondents preferred floodwater transfer (37%), planting trees and grass (52%), construction of wetlands (50%), and managing of ponds (53%) to reduce climate change-induced hazards

impacts in the township. Challenges to adopting nature-based solutions in the township included the cost of managing hazards (84%), availability of space for nature-based solutions (57%), availability of materials (66%), and severity of the climate-induced hazards (69%). Results from the landuse/landcover change assessment show that an increase in waterbody (0.4%), vegetation (1.4%), and farmlands (4%) occurred. Significant loss of settlements (5.5%) and bareland (3.3%) also occurred. This result has several implications on future climate-induced hazards impacts in the Keta township. Key institutional stakeholders' study reveals that the lack of expertise, inadequate finance, lack of engagement with the local community, and political influence were major hindrances to the design, implantation, and management of Nature-based solutions in the township. To ensure that the Keta township is adequately prepared to adapt to climate change-induced hazards, the following recommendations should be considered. There should be a holistic involvement of all institutional stakeholders and the local community members at every stage of adaptation and Nature-based solutions planning and implementation. Secondly, adaptation strategies to managing climate-induced hazards should consider the use of sustainable long-term solutions while incorporating traditional ecological knowledge of the use of the natural environment. Furthermore, there should be adequate provision of human and infrastructural resources and planning of budgetary to support the adoption of nature-based solutions in the Keta township. As climate change-induced coastal hazards pose possible future threats in Keta, there should be occasional monitoring of the trends and impacts of hazards within the township.

Keywords: Climate change, Adaptation, Nature-based solutions, Coastal, Hazards, Keta, Impacts

DEDICATION

This work is dedicated to ANNA LAH, for her strong desire and selflessness of character to make a difference for the sake of family.

Finally, to my only true friend, father figure, and best motivating cousin, SAYE LAH for your endless support, both financial and moral, to facilitate my personal growth and educational achievements. Your prayers, thoughtfulness, and spiritual backing have been instrumental in unlocking the doors of achievement and success. I remain forever grateful.



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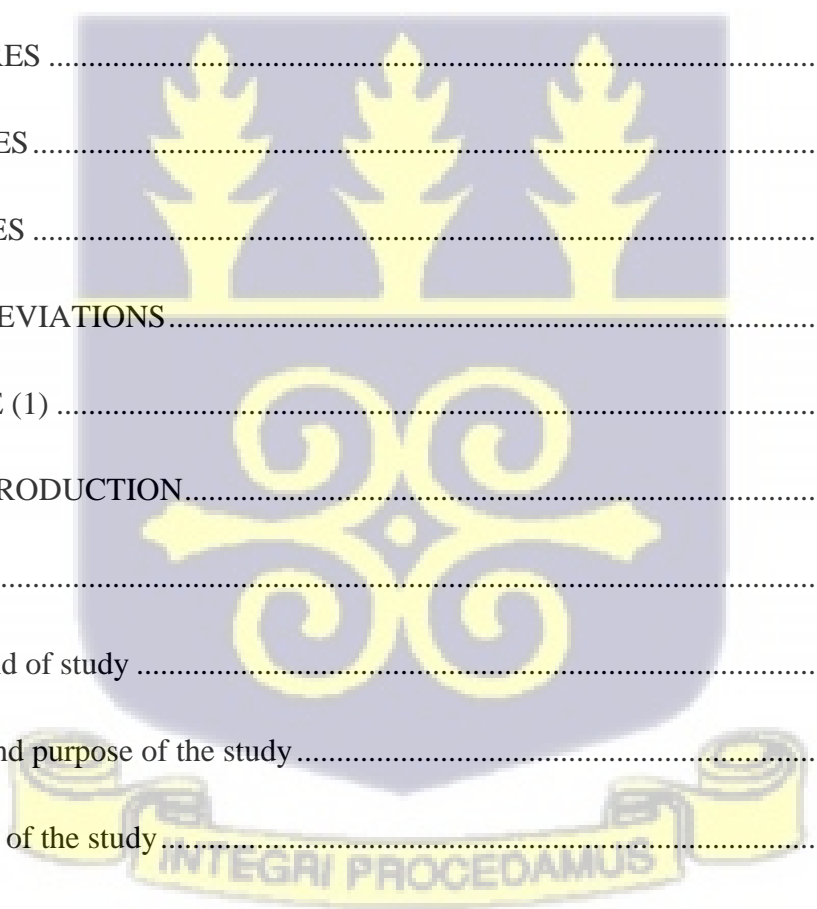
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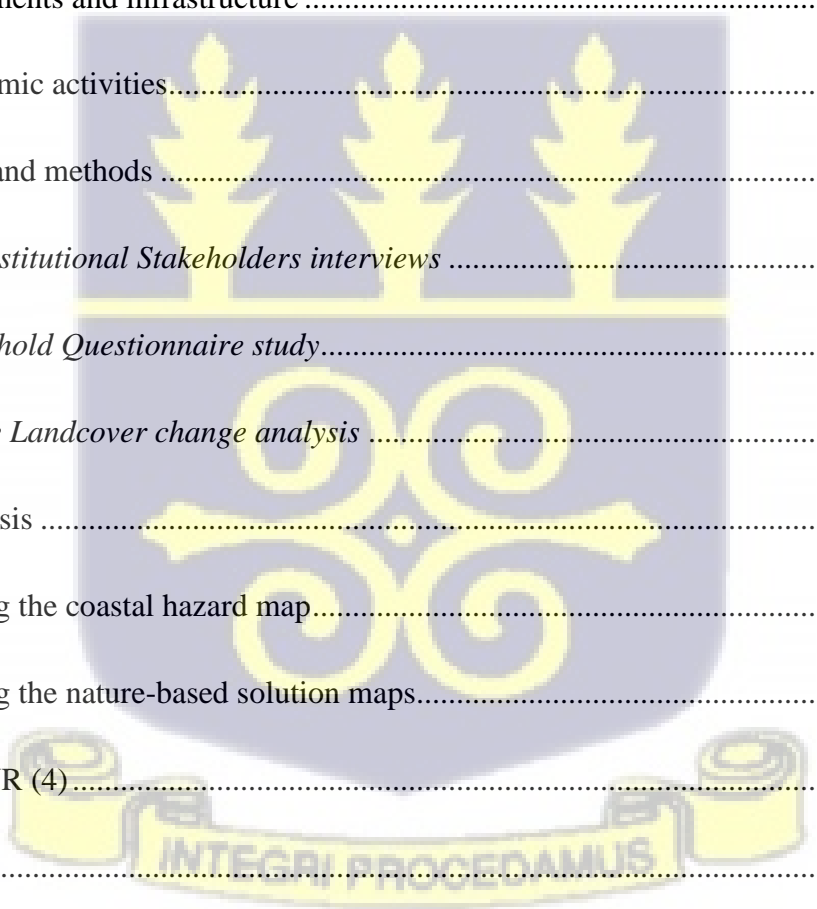
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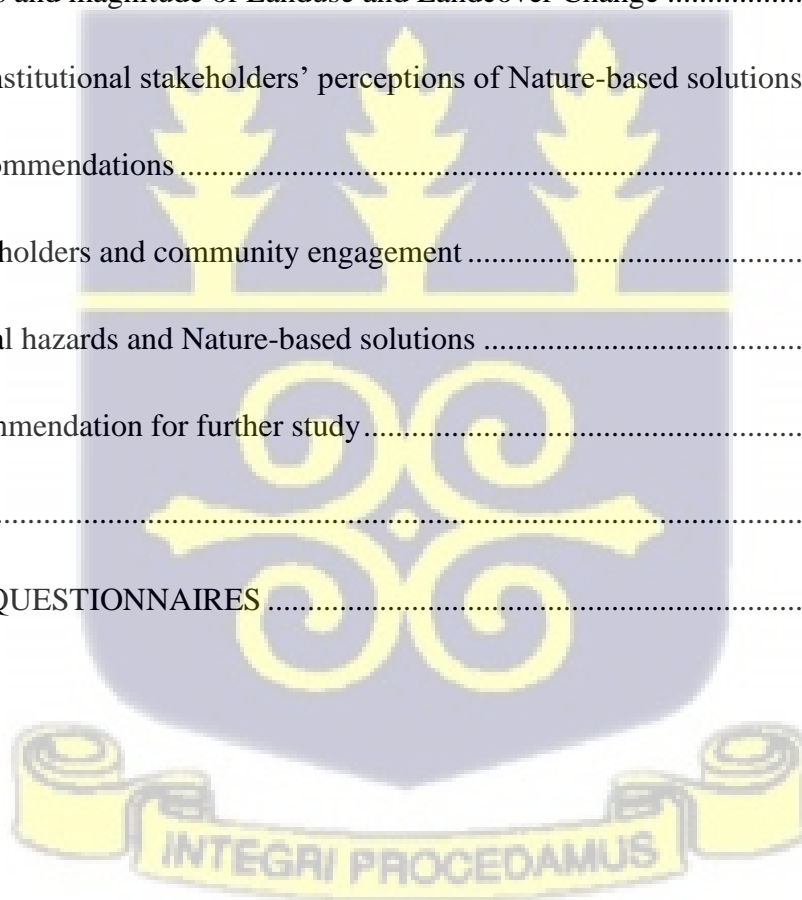


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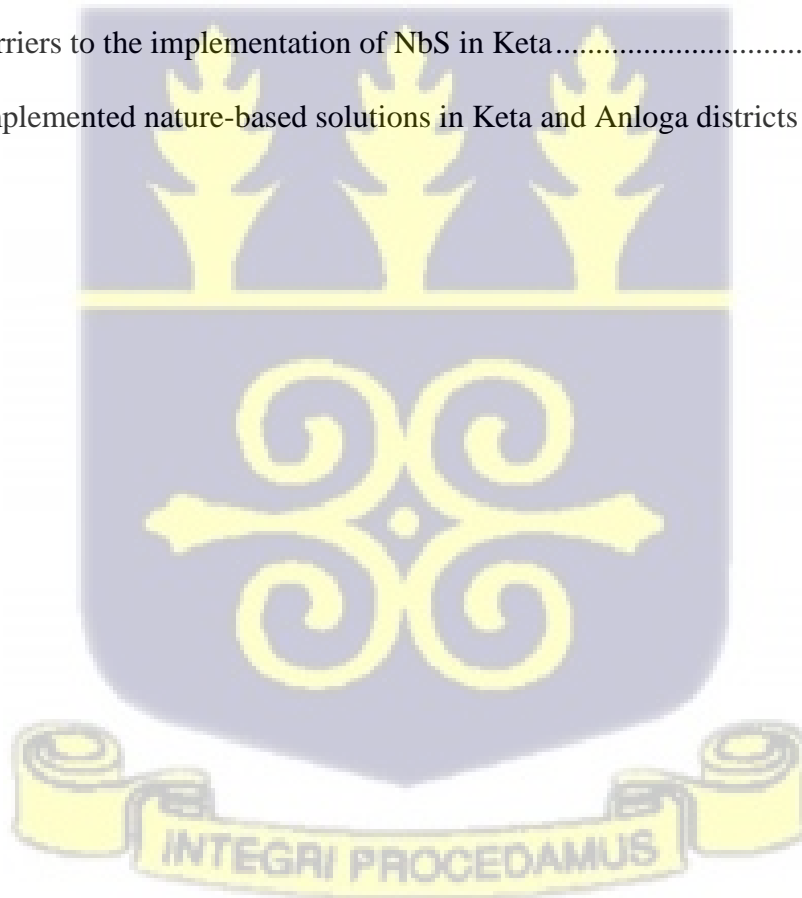
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LIST OF ABBREVIATIONS

IPCC	Inter-governmental Panel on Climate Change
CO ₂	Carbon Dioxide
IUCN	International Union for the Conservation of Nature
NbS	Nature-based Solution
EC	European Commission
UNDRR	United Nations Office for Disaster Risks Reduction
WACA	West Africa Coastal Areas
SDGs	Sustainable Development Goals
LULC	Landuse and Landcover Change
GIS	Geographic Information System
UNFCCC	United Nations Framework Convention on Climate Change
GHGs	Greenhouse Gases
C-GTOS	Coastal Global Terrestrial Observing System
MA	Millennium Assessment
UNEP	United Nations Environment Programme
NOAA	National Oceanic and Atmospheric Administration
LECZ	The Low Elevation Coastal Zone
RS	Remote sensing
CP	Coastal protection
CCA	Climate Change Adaptation
MoFA	Ministry of Food and Agriculture
GSS	Ghana Statistical Service
IPLCs	Indigenous peoples and local communities

CHAPTER ONE (1)

GENERAL INTRODUCTION

Introduction

According to substantial evidence, both natural and human-induced climate change currently presents a significant challenge to societal growth (IPCC, 2021). It has evolved into one of the most serious threats to the world's long-term viability. Climate patterns are shifting, and severe occurrences are having unprecedented consequences on social, environmental, and economic development, demanding immediate action and solutions. This chapter presents the introduction to the study which includes definitions and explanations of key terms in the study, the study's objectives, questions, justification and organization.

1.0 Background of study

Coastal habitats and ecosystems are among the most sensitive and dynamic locations on the globe (Mukhopadhyay et al., 2012). They accommodate more than half of the world's population (Woodroffe, 2003; Mukhopadhyay et al., 2012) and have contributed to significant human and biological habitats for millennia. Critical habitats such as wetlands, mangroves, coral reefs, dunes, and beaches constitute coastal ecosystems. The IPCC (2019) estimates that 680 million people live in low-lying coastal zones now, with that figure expected to rise to over one billion by 2050. More than 600 million people (about 10% of the global population) live in coastal areas with elevations of less than 10 meters above sea level (UN, 2017). Furthermore, almost 2.4 billion people (about 40% of the global population) live within 100 kilometers (60 miles) of the shore (UN, 2017). The survival of coastal dwellers according to the fifth World Ocean review (2017), depends largely on habitats such as dunes, coral reefs, and mangroves as they perform key protective functions of reducing coastal winds and sea swells, which regulates the oceans' physical forces. Many coastal

cities including the Ivory Coast, the Dutch city of Amsterdam, Lagos, or Durban in South Africa are protected by seaward dunes infrastructures. Other benefits of coastal areas include “regulating water exchange between land and sea, the chemical composition of sediments and water regulation, storage and recycling of nutrients and human wastes, maintenance of biological and genetic diversity, aquaculture, transportation and navigation, as well as recreation and tourism by providing an array of aesthetic, historical, cultural, and scientific information” (Mukhopadhyay et al., 2012). Tourism has become a part of the world’s fastest-growing industries as many coastal nations especially developing countries and most small island states derive a significant proportion of their Gross Domestic Production (GDP) from coastal and marine tourism (GRIDA, 2009). Coastal areas contribute 56 percent of West Africa’s GDP and house nearly a third of the population, according to the World Bank (2019). These advantages make living by the coast appealing. Apart from their diverse relevance, coastal and marine habitats are becoming increasingly vulnerable to numerous coastal hazards (e.g., sea-level rise, coastal floods, erosion, storm surges, tsunamis, and flooding (Kaiser, 2006)) as a result of either human-induced or natural phenomena such as climate change.

The increase in average global temperature has become unequivocal since the middle of the 18th century with most of the observed changes happening over the last three decades (IPCC, 2014). This change in Climate as a result of a long-term shift in the mean state of the climate or its variability has caused a rise in the earth’s average surface temperature (Gornitz, 2000), causing changes in many Earth systems. Significant warming has occurred in the atmosphere and the ocean which has resulted in the melting and reduction of the amount of snow and ice cap facilitating the increase in sea level because of high concentrations of atmospheric greenhouse gases (IPCC, 2013). According to the IPCC (2013) report, emissions from Carbon Dioxide (CO₂), Methane

(CH₄), and Nitrous Oxide (N₂O) largely generated by economic activities and population growth have increased and are now higher than ever. The concentrations of CO₂ alone have increased by 40% since the pre-industrial times, primarily from fossil fuel emissions and land-use changes (IPCC, 2013). The accelerated sea-level rise represents a significant coastal management challenge for many coastal nations, especially in developing nations and the Small Island States. A blend of socio-economic activities with complex ocean processes results in certain morphological changes and has influenced coastal environments considerably (Apeaning Addo K., 2011). Sea-level in addition to human interference on the coast have exacerbated the occurrence of coastal hazards such as erosion, floods, storm surges, and inundation of vulnerable areas. This has reduced many ecosystem benefits and livelihood support of most coastal dwellers.

The issues of flooding, high winds and tides, coastal erosion, storm surges, and coastal development along the coast are all factors that contribute to coastal vulnerability or risk (Thior et al., 2019). According to several studies (Alves et al., 2020; Aman et al., 2019; Thior et al., 2019; Angnuureng et al., 2020), coastal hazards experienced on the coast of West Africa are mostly a result of the complex and bare nature of its coast to the impacts of diverse waves energy from different directions. This has led to the degradation and inundation of many of its coastal cities due to the increase in sea level and high wave energy. There are several significant impacts such as threats to coastal ecosystems (i.e mangroves, coastal wetlands, salt marshes, and so on), and landwards migration of shorelines which results in the loss of life and properties, collapse of coastal businesses, and loss of revenue to the private, local and national governments (Apeaning Addo K., 2014). The social problems faced by coastal hazards have prompted states, academic research, and corporate entities to work together to prevent or reduce coastal vulnerabilities. Efforts to safeguard coastal regions have taken several forms across the world. Various

governments have implemented steps to mitigate coastal risks on a local level. Several projects involving coastal defense systems including groins, jetties, seawalls, and breakwaters (Angnuureng et al., 2013; Laibi et al., 2014) may be found on most of the West African coastlines. Despite these immediate hard engineering coastal protection interventions, the rate and magnitude of coastal hazards continue to affect coastal nations considerably due to the changing climatic variabilities. The benefits of these hard engineering solutions are limited and short-lived as they are found just within the sites where they are built. Their construction also poses a greater risk to the natural coastal ecosystem and adjoining coastal communities. This supports previous research that suggests grey infrastructure solutions may not be the best option since they would have negative consequences on nearby beaches (Alves et al., 2020), requiring the need for long-term solutions.

As the coastal population increases worldwide in this era of changing climate, a greater number of people and infrastructure are at risk from a range of potential climate-induced coastal hazards. A projected change in climate has identified the West African coastal zone to be at risk of being flooded by the year 2080 (Nicholls and Tol, 2006). A study conducted by Dasgupta et al. (2007) revealed that in many developing countries, hundreds of millions of people are likely to be displaced by sea-level rise within this century which will cause severe economic and ecological damage for many people, economies, and the environment. The capacity of people living on the coast to cope with the impacts of these hazards is often not sufficient which renders them vulnerable. It has therefore become necessary to explore long-term measures to protect the natural capital and value ecosystem services of the coast to achieve smooth progress towards fulfilling the sustainable development targets within the United Nations Agenda 2030. In the last decade, a variety of terms have emerged to identify different types of solutions which include “*Building with*

Nature”, “*Living Shorelines*”, “*Engineering with Nature*”, “*Ecological Engineering*”, “*Green Infrastructure*”, etc (Borsje et al., 2011; Bridges et al., 2015; Chapman and Underwood, 2011).

The International Union for the Conservation of Nature (IUCN) defined Nature-based Solutions (NbS) as “*actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*” (Cohen-Shacham et al., 2016). Nature-based solutions are considered to be appropriate adaptation options for coastal protection against wave intensity, coastal erosion, flooding, and stabilization of shorelines compared to the conventional concrete-based hard defense mechanisms. NbS indicators exist in several different forms, and they function on a variety of spatial and temporal dimensions. They have the potential to sustainably reduce or mitigate the consequences of coastal hazards while creating additional benefits for the environment and society (Davis et al., 2015). Although the concept of nature-based solutions is still in its developing stages, the interests in the practice are on the rise around the world. There is still a certain vagueness of the definition and scope of the term but it is founded in climate change mitigation and adaptation and best described as an umbrella concept for simultaneously tackling many policy goals at once. The concept of NbS was derived from the relationship between biodiversity and human well-being (Cohen-Shacham et al., 2019) and has existed within traditional knowledge (Berkes, 2012), for centuries. It was birthed towards the end of the 20th century by the World Bank and IUCN (2009) to emphasize the relevance of biodiversity conservation to the contribution of climate change mitigation and adaptation. The term was presented within the context of the Climate Change negotiations in Paris and promoted mainly by the IUCN as “ways to mitigate and adapt to climate change, secure water, food and energy supplies, reduce poverty, and drive economic growth” (IUCN, 2014). The concept of NbS focused specifically on

integrating policy influence with on-the-ground operations to execute NbS (IUCN, 2014). Eight principles were proposed to highlight the role of NbS to address global challenges by the IUCN as a core or foundation for NbS concept including other issues of economies of scale, harnessing both public and private finance, simplicity of communication, and comparability of solutions (van Ham, 2014). The body of the European Commission (EC) also in recent years adopted the concept of NbS in its Horizon 2020 research programme with the focus on urban development (EC, 2015). According to the commission, Nature-based solutions are “actions that are inspired by, supported by or copied from nature” (EC, 2015) or, “Solutions that aim to help societies address a variety of environmental, social and economic challenges in sustainable ways”.

There are key challenges in mainstreaming the concept into national policies and planning agendas (Frantzeskaki et al., 2019). The planning and implementation processes of NbS take into consideration important factors in addition to the existing local conditions of the intended area (Kabisch et al., 2017). A gap in knowledge and research (Wong et al., 2013; Davis et al., 2015) about the applicability, effectiveness and uncertainty specifically about the long-term performance of NbS continues to exist within various fields.

Traditional knowledge has been passed down through the years, assisting indigenous peoples in the promotion of nature-based solutions with significant potential for adaptation methods at the local, national, and global levels. It has been maintained through oral history and practices, for years (Afsara et al., 2020). Indigenous peoples are in a unique position when it comes to catastrophe risk reduction, climate change mitigation, and adaptation. Indigenous traditional wisdom also promotes balance, respect, and harmony between humans and the environment, as well as climate change resistance. The traditional knowledge method strives to have a low environmental effect and support self-sustaining ecosystems and biodiversity (Hosen et al., 2020).

Most importantly, the IPCC acknowledged that indigenous people and local communities (IPLCs) may play a critical role in climate change mitigation. “Finally, the world’s best scientists understand what we have long known, that protecting our rights is a vital answer to the climate problem,” a coalition of indigenous peoples from 42 countries said in response (IPCC, 2019).

To explore the full benefits of the concept, an enabling environment between governance, relevant actors and institutions, and research academia need to be established in building the capacity for implementing, maintaining, and monitoring planned NbS. A global standard of the concept is required to establish that common language and understanding, engage relevant stakeholders, safeguard nature from overexploitation, increase its demand and supply of interventions and incentivize positive sustainable change. This is why the IUNC in pursuit of addressing the needs of mainstreaming NbS has developed the first-ever global standards for the design and verification of NbS (UNDRR, 2020) through the engagement with several relevant stakeholders from different countries, both within and outside the IUCN while building upon previous work of its definitions (Cohen-Shacham, 2016).

It is important to identify from the onset of this study that the term nature-based solutions can be classified into four different approaches as existing in whole or part (Pontee, 2016) of natural features that are designed to offer or improve coastal protection. A fully natural NbS involves the dependence or reliance on the protection provided entirely by the natural coastal habitat. The services and habitat are naturally occurring without any modification. A managed NbS consist of a partially modified coastal habitat designed to provide a specific coastal protection function. It involves an act of human intervention of design and management to either actualize its full benefit or ensure sustainable use. The hybrid concept of coastal NbS is described as a coastal habitat designed in combination with a ‘hard’ defense situated either in the landward direction (e.g. dykes)

or seaward direction (e.g. sills) of the natural habitat (Wheeler et al., 2008; Hardaway et al., 2009). The final approach involves the redesign of an existing hard engineering structure to make them more environmentally friendly. An example could be the provision of ecological niches in breakwaters and seawalls (Chapman and Underwood, 2011). All these approaches are characterized by the physical elements of the solutions being considered to give a clear understanding of what is being proposed to the different stakeholders (Pontee, 2016). Several countries have begun implementing NbS as part of wider coastal risk reduction strategies in dealing with sea-level rise and other coastal hazards which are impacting coastal habitats negatively.

1.1 Problem and purpose of the study

In the case of many coastal communities around the world, sea-level rise from climate change including other climate-induced coastal hazards (i.e flooding, erosion, storm surges, and tsunamis) have posed serious challenges to coastal nations and coastal zone management (Apeaning Addo, K., 2014). The increasing trend in the average global temperature is expected to progress over a long period (Nicholls et al., 2007) while exacerbating other coastal stressors resulting in threats to lives, properties, and ecosystems. About 70% of sandy beaches globally are experiencing acute erosion according to a study by Bird (1985). The occurrence of direct and indirect coastal erosion as a result of the impacts of high wave energy and inland flooding also affects lagoons and tidal basins considerably. Damages from storms and associated storm surges due to the interactions of winds wave energy, and rising water levels are amongst the most potent coastal hazards (Mukhopadhyay et al., 2012).

Ghana's 539-kilometer coastline has been characterized as a high-energy coast with three geomorphic zones: western, middle, and eastern coastlines (Ly, 1980; MESTI, 2012). According

to Armah and Amlalo (1998), Ghana's coastal zone is defined as a region below the 30m contour that covers 6.5 percent of the country's total land area of 238,535km². The coastal zone is home to more than a quarter of the country's population and accounts for up to 80% of yearly seafood output and consumption (Armah and Amlalo, 1998). A large number of industries, residential settlements, tourism and conservation sites, heritage, and historical monument can be found about 200m of the coastline (Jonah et al., 2016) with many of them consisting of built and densely populated settlements. Several of these communities are considered to be low-lying areas susceptible to a range of coastal hazards (i.e wave and tidal forces, coastal erosion, flooding, storm surges, etc) (Boateng, 2012; Appeaning Addo K., 2014; Jonah et al., 2016). As a mean to reduce coastal hazards within the most vulnerable coastal communities, the government have implemented several hard engineering sea defense projects (groynes, seawalls, and breakwaters) to protect critical coastal infrastructure, communities, and assets of national interest (Alves et al., 2020). Private property owners have also carried out small sea defense projects across many parts of the coastline to protect their investments (Jonah et al., 2015). The Keta Municipality which falls within the top 25 coastal erosion hotspots along the eastern coastline of Ghana is considered to be the worst affected area with an erosion rate of about 8 m/yr (Jonah et al., 2015). However, about 30% of its total land area of 1,086km² is interspersed with lagoons, creeks, and mangrove forests, offering great potential for tourism development, livelihood support and, biodiversity conservation. The Keta Lagoon Complex which happens to be the largest in Ghana is also a World-designated Ramsar site. However, the Keta municipal is vulnerable to a range of climate-induced hazards; flood, erosion, storm surges among others. The lowest point is about 1-3.5 meters below sea level along the coast of Vodza, Keta, and Kedzi townships (GSS, 2010). Parts of the town have experienced coastal erosion between the 1960s and 1980s (Keta Tourism, 2019). Persistent coastal

erosion estimated between 2 and 7 million cubic meters of sand per year according to Baird.com (n.d) has resulted in the loss of educational, residential, historical, social, and cultural edifices and the siltation of the lagoon basin. Communities around the Kata municipality have experienced severe coastal hazards; erosion, flooding, high wave energy, and inundation which have led to the loss of properties and decline in livelihoods activities of the residents (Baird, n.d). According to a WACA (2007) report, major challenges facing local coastal communities as a result of climate change and its impacts include the “reduction in land for agriculture (erosion and salinization), reduction of soil fertility, reduced yields, loss of coconut plantations, reduced fish catch (both lagoon and marine), coastal erosion and the perennial flooding of farms”. This prompted the intervention of the Keta Sea Defense Project (KSDP) which even though has reduced coastal erosion along the Keta and Kedzi stretch, has however led to an increase in coastal erosion in surrounding communities on the down-drift coast towards Ghana-Togo border by over 50% (WACA, 2007). This confirms the literature that shore-hardening techniques may not always be suitable for reducing coastal hazards (Angnuureng et al., 2013).

Studies conducted on coastal challenges in Ghana are mostly centered around identifying coastal hazards of affected communities or the entire portions of the coast; assessing coastal vulnerability to sea-level rise (Appeaning Addo, K., 2014), providing models for planning and managing coastal areas (Luna and Young, 2019); causes and existing management practices of coastal hazards; and the rate of shoreline change analysis of coastal communities along the coast of Ghana (Jonah et al., 2016). Most of these studies have only identified and recognized the need for long-term solutions to managing coastal hazards as compared to the existing infrastructures. Due to the scarcity of data and the volume of knowledge required (Ilieva and McPhearson, 2018; Jonah et al., 2016) to explore appropriate and long-term coastal management strategies and mainstream them

into national development policies and plans, this study will contribute to developing knowledge gaps and findings in the field.

This will be achieved through identifying existing adaptation strategies and possibilities for advancing knowledge, integration, and opportunities to fully realize the potential of nature-based solutions for protecting coastal communities and cities in Ghana. It is also relevant as it adds to the global and local database and literature on nature-based solutions to managing coastal challenges induced by climate and human interference of a country that is in the infancy of developing a shoreline management program. Results from this study will also inform and suggest how environmental planners and policymakers should explore the benefits of Nature-based Solutions to managing climate-induced coastal hazards.

1.2 Objectives of the study

The overall aim of the study is to explore the trends and impacts of climate change-induced coastal hazards in Keta, Ghana, with existing adaptation strategies and the possibilities of adopting nature-based solutions.

Specifically, the study aimed at pursuing the following objectives:

- 1) To assess the trends and impacts of climate change-induced hazards on households within coastal communities.
- 2) To identify and analyze the existing local-level adaptation and mitigation options for climate change-induced hazards and examine evidence of nature-based solutions therein.

- 3) To conduct spatio-temporal assessment of land use/landcover changes and options for adapting nature-based solutions for climate change-induced coastal hazards in the Keta Municipality.
- 4) To explore relevant institutional stakeholders' perception of nature-based solutions as instruments for reducing climate change-induced risks and vulnerabilities in Keta.

1.3 Research questions

The study sought to answer the following questions;

- 1) What are the trends and impacts of climate change-induced hazards on households within coastal the Keta township?
- 2) What are the existing local-level adaptation and mitigation options for climate change-induced hazards and what are the elements of nature-based solutions within these identified options?
- 3) What are the changes in land use and land cover in the Keta township due to the influence of climate-induced coastal hazards and what opportunities exist for integrating nature-based solutions as adaptation options?
- 4) What are the key institutional stakeholders' perceptions of nature-based solutions as instruments for reducing climate change-induced risks and vulnerabilities in Keta?

1.4 Justification of the study

Considering the overall goal of addressing global and local societal challenges, nature-based solution has the advantage of directly and indirectly contributing to Agenda 2030 Sustainable

Development targets and achieving the full benefits of the Sustainable Development Goals (SDGs) (SDGs, 2017; Faivre et al., 2017). Nature-based solutions can be specifically connected to food security, health and well-being, climate change, conservation and sustainable use of oceans, seas and marine resources, clean water and sanitation, sustainable cities and communities, and the protection, restoration, and promotion of sustainable use of terrestrial ecosystems (Lo, 2016; Dudley et al., 2017; Vasseur et al., 2017). Natural habitat offers solutions that support many other conservations, environmental, and development objectives when integrated with other conventional sectoral approaches (Holl, 2017). A key challenge of NbS is the ability to scale up and to connect and absorb small-scale interventions into broader and potentially impactful interventions (Cohen-Shacham et al., 2019). Without stronger policy coherence as proposed for NbS framework, this could not be possible. This study will contribute to the development of future research by building a robust evidence base for the contribution of NbS to addressing coastal challenges. Under Horizon 2020 (Raymond et al., 2017), NbS has been identified as a priority area for investment. This study will also contribute to providing evidence and knowledge for NbS development, implementation, and scaling up innovation (European Commission, 2018). Most times, the values of protection from coastal ecosystems, especially ecosystem services are often not accounted for nor internalized in decision-making which results in their permanent degradation for purposes of little value compared to the exploited ecosystem. Findings from the study can only inform policymakers, environmental managers, and academia about the existing adaptation strategies and possibilities for NbS to reduce climate-induced challenges on coastal ecosystem services but not necessarily place a value on the services. However, further ecosystem services valuation is recommended to enable policymakers to understand the full range of economic and environmental implications to inform public policy and investment alternatives. Finally, for data

to inform decision-making it needs to be accessible and timely while tools and processes are needed to interpret and translate the data into information such as hazard maps and ecosystem vulnerabilities. Observing the scarcity of data concerning the concept of NbS, this study will provide a foundation for obtaining primary data about the challenges and opportunities that exist in fully designing and implementing an NbS concept locally.

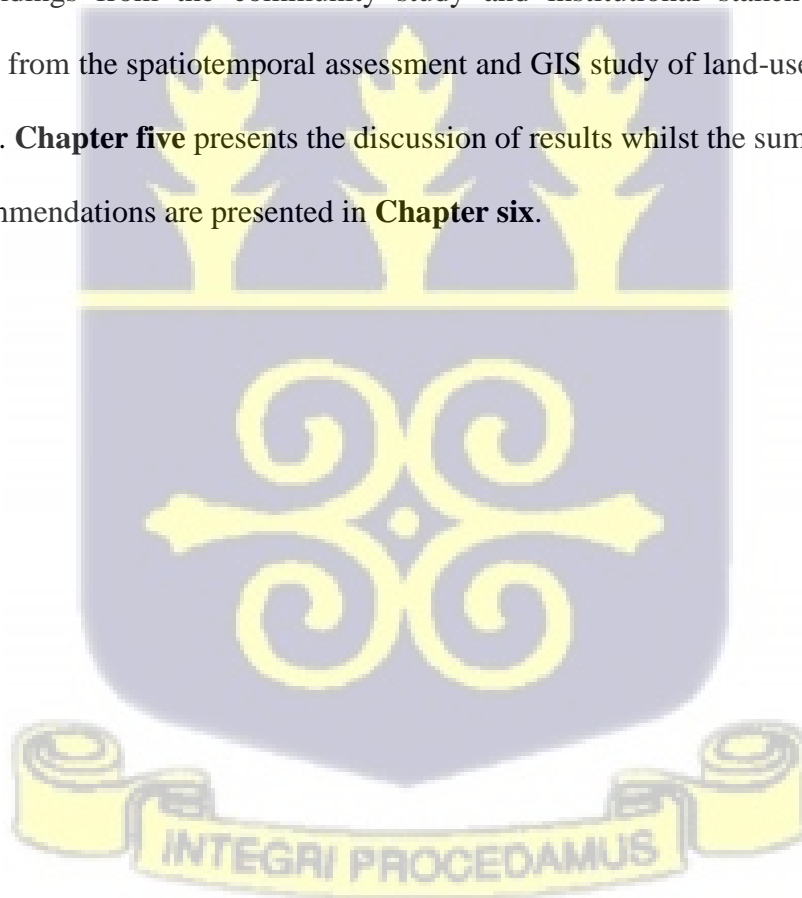
The methodology used for the study is the mixed-method design. This approach is necessary to enable the study to address a wide range of important factors that are key to the understanding of the study. The qualitative study will employ opened and closed-ended questions to obtain impartial data from relevant stakeholders through interviews of key informants, community leaders, professionals, and the local community. This will assess stakeholders' knowledge and understanding of the subject, first-hand experience and knowledge of the residents in the study area, and community practices of managing coastal hazards over the years. The qualitative result will provide adequate information to carry out the quantitative aspect of the study.

The quantitative portion of the study on the other hand will seek to conduct a spatio-temporal assessment of the study area. This will include a location analysis using geographic information system mapping to identify and map out climate-induced hazard-prone coastal communities. Hazard maps and nature-based solution maps will be designed from observations and data obtained from the community to gain a quantitative understanding of the spatiotemporal dynamics of Land Use Land Change (LULC) in the study area using the ground-truthing technique. The use of remote sensing technology will provide practical means for accurate and cost-effective multispectral and multi-temporal data collection of environmental changes at different spatiotemporal scales using satellite imagery coupled with geographic information system (GIS) and ground-truthing. This method is also important for identifying and mapping out the study phenomenon, interpretation

and understanding of change, targeting and detecting important patterns hidden in numerical data inputs, and providing visual answers to certain questions.

1.5 Organization of the study

This study is organized into six chapters. **Chapter one** consists of the research background, the problem of the study, the research objectives and questions, the purpose and significance of the study, and the organization of the study. **Chapter two** reviews relevant literature related to the study. **Chapter three** presents the methodology used for the study which includes the chosen population of the study, the sample size, the study area, and methods of data analysis. **Chapter four** present findings from the community study and institutional stakeholder's interviews including results from the spatiotemporal assessment and GIS study of land-use change activities of the study area. **Chapter five** presents the discussion of results whilst the summary, conclusion, and policy recommendations are presented in **Chapter six**.



CHAPTER TWO (2)

LITERATURE REVIEW

2.0 Introduction

This chapter presents the review of existing literature about the study highlighting the approaches and findings used by both international and local researchers, publications, and so on. The descriptive and analytical review methods are carried out in this chapter. It discusses an overview of the common tools, methodologies, and definitions used in selected materials that are relevant and applicable to this study. The arrangement of the reviews is in sections with the first section comprising of a general overview and definition of concepts and the impacts of climate change on coastal areas and communities, followed by sub-headings that discuss the composition, benefits, and vulnerability of coastal areas. Other relevant sections include coastal hazards, the spatiotemporal assessment of coastal hazards using the Land use/Landcover change analysis, management of coastal hazards with an introduction of nature-based approach to coastal management, and possibilities of the concept in different sectors and disciplines.

2.1 Climate change and coastal areas

2.1.1 Climate Change

The natural environment is constantly undergoing physical changes as a result of factors related to population growth, urbanization, natural resource exploitation, economic development, and natural forces. The impacts of climate change and variability in addition to anthropogenic factors are increasingly and rapidly changing the morphology of many earth systems including coastal environment (Beck, 2014). According to the 4th assessment Report of the Intergovernmental Panel on Climate Change (IPCC) published in 2007, a projected rise in the average global temperature of the Earth's atmosphere is likely to increase from 1.1° to 6.4° C by the end of this century,

relative to the baseline data of the periods 1980–1999. This increase is likely to have a positive or negative correlational change in precipitation patterns experienced differently depending on the location of any particular region of the world (Rodríguez Guerra et al., 2019). A changing climate is also expected to affect the composition and distribution of most ecosystems. The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as “a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods” (UNFCCC, 1992).

The basic science by the Inter-Governmental Panel on Climate Change (IPCC) underlying the concept of climate change has been that, as solar energy enters the earth’s atmosphere, it warms the planet’s surface. Some of the sun’s heat is reflected into the atmosphere and scattered. The earth’s atmosphere is often defined as the “gaseous envelope” surrounding the planet and consists of nitrogen (78%), oxygen (21%), and active greenhouse gases (GHGs). These GHGs include water vapor (H₂O), carbon dioxide (CO₂), methane (CH₄), nitrous oxide, ozone, and other trace gases (UNFCCC, 1992). They represent about 1% of the earth’s atmosphere and act as a “blanket” wrapped around the earth (UNFCCC, 1992). This “blanket” allows some of the heat from the sun to penetrate through and scatter in the atmosphere while trapping additional heat at a comfortable temperature that can sustain life on the planet. In the absence of a “blanket” to trap some of the heat, all heat would simply bounce back into the atmosphere and scatter resulting in the earth’s surface being too cold to support human life. However, if there is a high concentration of these GHGs in the atmosphere, then the blanket will become too “thick” and will trap even more heat, making the earth warmer. This phenomenon is called the “greenhouse” effect and can become

worse when more GHGs are released into the atmosphere. Several factors for the production and increase of these GHGs have been identified as driven mainly by anthropogenic activities.

Anthropogenic GHG emissions are a result of population increase, economic activity, lifestyle, energy use, land use patterns, technology, and climate policy (IPCC, 2014). The emissions of anthropogenic GHGs have been in motion since the pre-industrial era and have driven large increases in the atmosphere's concentrations. Between the period of 1750 and 2011, the total amount of anthropogenic CO₂ emissions into the atmosphere was 2040 ± 310 GtCO₂ (IPCC, 2014). It has been estimated according to the IPCC (2014) that about 40% of these emissions have remained in the atmosphere (880 ± 35 GtCO₂); while a significant amount has been removed from the atmosphere and stored in plants, soils, and the ocean. The ocean has remained the biggest absorber of about 30% of all emitted anthropogenic CO₂, resulting in ocean acidification (IPCC, 2014). Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010, with only about 1% stored in the atmosphere (IPCC, 2014). The impacts of a changing climate on the earth systems are devastating and significant.

Climate change has been observed and verified in the literature to have the most severe and extensive effects on natural systems (IPCC, 2014). Changes in precipitation, melting snow, and ice have been seen in many locations, producing changes in hydrological systems and impacting water resources in terms of quantity and quality (IPCC, 2014). In response to ongoing climate change, most terrestrial, freshwater, and marine species have modified their geographic ranges, seasonal activities, migratory patterns, abundances, and species interactions, posing grave threats and resulting in horrific losses (IPCC, 2014; Beck, 2014). Coastal exposure to erosion, inundation and extreme weather events affects hundreds of millions of vulnerable people, important

infrastructure, and tourism with significant losses to national economies and human suffering (Beck, 2014).

2.1.2 Coastal Areas

Coastal areas are regarded to be very dynamic in nature and home to an ever-increasing population all over the world (Mukhopadhyay et al., 2012; Appeaning Addo, K. 2014). The natural seashore is seen as a significant resource that supplies a wide range of products and services (Lindgren, 2011., Costanza et al., 1997; Beaumont et al., 2007). Coastal waters have strong primary and secondary production, and many fish and invertebrates, especially marine fish species, use them as breeding grounds and nurseries (Elliott and Dewailly, 1995; Beck et al., 2001; Able, 2005). Defining coastal areas has remained one of the early challenges for studies and protocols tasked to design the global coastal systems and factors driving what the term should entail (FAO, n.d). This task has neither been simple nor straightforward for the Coastal Global Terrestrial Observing System (C-GTOS) which has not considered a single definition but has instead reviewed several definitions and approaches adopted by potential users of the resource. The C-GTOS' review focused on categorizing users into three hierarchical levels: multilateral environmental agreements, international organizations, and the global/national assessment initiatives dealing with coastal issues. The definitional framework is centered around four discrete approaches varying in extent and characteristics. These definitions were categorized through descriptions of the coast from the perspective of management units, human use dynamics, area extent of the coastal zone, and ecosystem functionality.

Management units: According to the review, from the management units' approach and discussion, there were no common grounds on a clear and precise definition of coastal areas so long as the basic principles of integrated coastal management were valued and broadly agreed upon by the

various decision-makers. This approach has been widely embraced by a majority of national governments and international organizations.

Human use dynamics: The human use dynamics defined coastal areas from the “specific social use-value they provide and support such as recreational nature of the coast, zones with intense human population dynamics or intense urbanization, coastal agricultural areas, and coastal transportation nodes all comprising different dynamics to the task of defining coastal areas”.

Area extent of the coastal zone: This definition focuses on the distance between the beach and the coastal area, which is simply 100 kilometers. It is the most often used term for characterizing coastal areas based on geography.

Ecosystem functionality: The coastal zone may be most broadly viewed through linked system functions focused at the land-sea interface. Here, the coast is directly tied to scientists’ understanding of the value of coastal habitats. These areas of unique diversity and ecological value deserve more acute and direct attention.

Coastal areas and ecosystems have been described and defined differently by the following international organizations by either associating them with the ecosystem benefits or habitat types.

The Millennium Assessment (MA) reports on ecosystems and ecosystem services (MA, 2003) as one of the six reporting categories defined coastal areas as “the interface between ocean and land, extending seawards to about the middle of the continental shelf and inland to include all areas strongly influenced by the proximity to the ocean”. According to the report, using the boundary limits for mapping, the coast can be described as: “area between 50m below mean sea level and 50m above the high tide level or extending landward to a distance 100 km from shore. This includes coral reefs, intertidal zones, estuaries, coastal aquaculture, and seagrass communities”.

The Ramsar Convention on wetlands held in Ramsar, in 1971, defined and classified coastal areas based on the variety of coastal habitats. The classification system focused on wetland types and listed the following coastal wetlands: “permanent shallow marine waters; marine subtidal aquatic beds; coral reefs; rocky marine shores; sand, shingle or pebble shores; estuarine waters; intertidal mud, sand or salt flats; intertidal marshes; intertidal forested wetlands; coastal brackish/saline lagoons; coastal freshwater lagoons, and karst and other subterranean hydrological systems”. Wetlands were described under the original Convention as “areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres. They may incorporate adjacent riparian and coastal zones, islands or bodies of marine water deeper than six metres at low tide lying within the wetland”.

The United Nations Environment Programme UNEP (2004) believes that coastal ecosystems that are part of the Coastal and Marine Environment (CME) evaluation lack a precise description and geographical extent. Instead, a flexible methodology focused on current evaluation methodologies is recommended to decide the scope: the spatial structure of the assessment must be flexible and based on natural, political, and structural realities. Where possible, existing spatial and programmatic structures can be included. Coastal forests, estuaries and deltas, mangroves, coastal reefs, and seagrass beds are among the diverse ecosystems found in coastal waters.

The Coastal Ocean Observations Module of the Global Ocean Observing System (C-GOOS) developed for monitoring, assessing, and predicting the effects of natural variations and human activities on the marine environment and ecosystems of the coastal ocean UNESCO (2003c), described coastal areas as the “regional mosaics of habitats including intertidal habitats (mangroves, marshes, mudflats, rocky shores, sandy beaches), semi-enclosed bodies of water

(estuaries, sounds, bays, fjords, gulfs, seas), benthic habitats (coral reefs, seagrass beds, kelp forests, hard and soft bottoms), and the open waters of the coastal ocean to the seaward limits of the Exclusive Economic Zone (EEZ)”. According to Nicholls and Small (2002), this region is defined as the land edge within 100 kilometers of the coastline or even less than 100 meters beyond mean low tide, whichever occurs first.

The above concepts and frameworks on the notion of coastal areas by the different users are important to the study design because they provide a clear understanding of the study area and the current usage of the ecosystem services it provides. Previous definitions and concepts concerning coastal areas have focused more on the geography and management units (e.g. EEZ and various ICAM guidelines) (FAO, n.d). However, recent coastal management initiatives have had a greater focus on ecosystem functionality and also included interaction with human use dynamics.

2.1.3 Classification of Coastal features

Coastal ecosystems are probably one of the most dynamic habitats on the planet, as a result of terrestrial, marine, and atmospheric factors all interacting to produce them (Dethier and Harbor, 2011). According to Dethier and Harbor (2011), coastal categorization systems aid in understanding the relative contributions of the processes that form them, and classification-based mapping tools aid in visualizing how these processes differ in space and time. The categorization techniques used to describe coastal habitats are typically complicated due to their varied character (Dethier and Harbor, 2011).

In chapter one of the book published by Dethier and Harbor, (2011) on the classes of nearshore coasts, the global variation in types and classes of coastal environments were discussed in detail. They defined key variables that were important in distinguishing coastal environments and affecting marine organisms, humans, and their responses to climate change. The discussion was

restricted to benthic areas in the photic zone (including intertidal areas). According to the authors, the variables that defined coastal variations were the climate of the area, geomorphology, wave energy, substrate type, and in some cases, biota, such as reefs formed by corals. The identified classification systems were the means to conceptualize the important processes that affect coastal environments, whereas mapping systems served as the inventory to mappable features, from which dominant processes could be inferred. Issues of purpose, scale, and complexity of existing classification systems as well as how mapping systems differed from classifications were discussed. The focus of the entire discussion in the chapter was primarily on temperate coastal environments with some inferences to polar and tropical environs.

Wladimir Koppen recognized and established Earth's climate zones in the early 1900s as: tropical, desert, temperate, continental, polar, and highland. The surface temperature, amount of rainfall, and type of atmosphere are used to classify climate zones. Their impacts on weather patterns, latitude, elevation, and the existence of nearby mountains or large bodies of water help define climate zone.

The temperate zone refers to one of the earth's two middle latitude zones: The North Temperate Zone, which lies between the Arctic Circle and the Tropic of Cancer, and the South Temperate Zone, which lies between the Antarctic Circle and the Tropic of Capricorn. In summary, it is the field or zone between the Tropic of Cancer and the arctic circle, or between the Tropic of Capricorn and the Antarctic circle (Merriam-Webster.com). Four distinct seasons are typical in this area, with a wide range of temperature and precipitation. Except for Antarctica, every continent has at least a limited area of temperate soil. The continental United States, much of Canada and Europe, Central Asia, southern South America, and southern Australia are all in the temperate climate (Mentzer, 2021).

There is a greater variety in climates in the temperate zone, but many regions can be classified as either moist-continental or moist-subtropical. The moist-subtropical climates of the temperate zone are often located near large bodies of water or far away from large mountain ranges. The winters in this region are cool but relatively mild and summers are warm, wet, and stormy. The moist-continental climate zones on the other hand have cold, blustery winters with plenty of snow and strong wind. Summer here is cooler than in the subtropical zones (Mentzer, 2021).

The non-temperate zone begins at the equator and spreads about 25 degrees north and south of the imaginary axis. Rainfall in tropical areas averages 59 inches per year. Year-round, the temperature is typically above 64 degrees Fahrenheit. Rainfall is scarce in dry zones, and what does fall evaporates easily. These regions are located about 20-35 degrees north and south of the equator, further away from the equator. The polar zones, which are situated at high latitudes above 60-70 degrees north and south, are the coldest places on the planet (Mentzer, 2021).

The subsequent paragraphs will highlight and intend to understand how the selected variables by the authors determined the types of coastal variations and hence played an important role in the classification. According to Dethier and Harbor, (2011), there has been no classification system that existed globally in itself but a system that encompasses a broad geographic area must distinguish different climatic or biogeographic regions. Although the climate zone parameter is unlikely to have a direct impact on other physical parameters (such as coastal geomorphology), it does have a significant impact on the biota within the coastal class; therefore, any classification scheme with an ecological function and a large spatial scale must incorporate it. The most basic climate zone classifications are polar, temperate, and tropical, which are primarily determined by latitude. At the most general level, one classification links gross aspects of coastal topography to global plate tectonics (Inman and Nordstrom, 1971). They identified three general classes of coasts

based on the nature of plate boundaries: collision coasts, trailing edge coasts, and marginal sea coasts protected by island arcs. The classification scheme was especially useful in associating general terrains with regional morphologies. Some of the key attributes that define coastal landforms at a more detailed scale are coastal stability (is the feature erosional, accretional, or stable), coastal gradient (is the feature steep or very flat, creating a wide intertidal zone and a wide nearshore zone), and extent.

On a more localized level, coastal landforms are enormously influenced by a substrate. For example, steep shorelines are typically associated with hard substrate types and lower gradient shorelines with soft substrates. The substrate also affects coastal stability, with soft sediments more likely to be dynamic in contrast to stable bedrock shores. Coastal sediment supply also differentiates coastal classes; soft-sediment shorelines show a range of erosion and accretion landforms and linked sediment transport cells ('drift cells'). Rocky coastlines often show considerable fine-scale complexity in the irregularity or rugosity of rock surfaces; sedimentary rocks tend to be comparatively smooth, whereas igneous and metamorphic surfaces can be quite irregular.

Biotic communities in a coastal environment are very strongly influenced by the suite of climatic, geological, chemical, and hydrodynamic characters of an area. The biota is thus sometimes considered an output or endpoint that is determined by all the above-mentioned parameters.

2.1.4 Benefits of Coastal Areas

Coastal regions have become critical to economies all over the world besides their many uses and the energy that can be accessed from them (Kildow and McIlgorm, 2010; Visbeck et al., 2014). Due to coastal resources, almost a billion people live within 100 kilometers of the ocean (Kurt, Karaburun and Demirci, 2010). Aside from fishing, which is well-known for its economic

importance, there are various other businesses in coastal and marine areas that provide significant revenue. Controlling water flow between land and sea, regulating the chemical content of sediments and water, storing and recycling nutrients and human wastes, preserving biological and genetic diversity, providing space for agriculture, transportation and navigation, leisure and tourism, and a variety of other functions are all performed by coastal areas (Spalding et al., 2014). Coastal zones account for around 25% of global production and 13% of the world's urban centers (McGranahan et al., 2007). Coastal cities also account for two-fifths of cities with populations of one million to ten million people, and fourteen of the world's seventeen largest cities are located there (Angnuureng et al., 2013). Due to the abundance of rich resources, the coastal region is home to over half of the world's population (Woodroffe, 2002; Angnuureng et al., 2013), and this is expected to rise by around 32% by 2025 (Duedall and Maul, 2005).

2.1.4.1 Economic Value

Tourism is one of the world's fastest-growing industries, accounting for a considerable portion of many developed countries' GDPs. Coastal and marine tourism are important to small island states. For example, the industry employs a quarter of the Caribbean's workforce and accounts for a fifth of all jobs (GRID-Arendal, n.d.). The world's oceans also sustain a global shipping industry that has seen a remarkable expansion in recent years. By 2020, the pace of international commerce will have tripled from pre-1995 levels, with up to 90% of it traveling by water, according to the National Oceanic and Atmospheric Administration (NOAA) (McGinn, 1999). Sand, shale, coal, and mineral mining have been carried out in coastal seas and on continental shelves for decades. Offshore drilling presently supplies a significant amount of the world's oil and natural gas, and the offshore sector is likely to grow significantly in the foreseeable future (Stark and Chew, 2001).

While marine goods like fish, sand, and oil have long been valued, the oceans' crucial role in biological diversity and climate regulation has only recently been recognized. Ocean facilities are worth US\$23 trillion every year, according to a new estimate based on more than 100 studies done over the last two decades, only a bit less than the world's entire GNP (GRID-Arendal, n.d.). The climate is thought to supply two-thirds of all-natural resources in the form of oceans and seas (GESAMP, 2005).

2.1.4.2 Erosion Control

Coastal locations, with the appropriate landscaping technique and qualities, may assist mitigate the effects of wind, waves, and runoff, as well as safeguard property from storm and flooding-related damage. Plants are one of the most powerful natural barriers against the forces that erode and destabilize dunes, banks, and bluffs along the shore. Trees, shrubs, and smaller plants have root systems that physically anchor and bind soils, making them less vulnerable to wind and rain erosion. Furthermore, plants collect water directly from the ground, absorb water from their leaves, break the effect of raindrops or wave-splash, and physically slow the rate of water runoff, minimizing flows that can cause erosion. As a result, plants are a perfect solution to systemic erosion management when found in coastal areas.

2.1.4.3 Pollution control

Coastal landscapes help to keep the bay or harbor clean. Excess runoff can smother eelgrass beds and other habitats, as well as affect water quality when it is swept into coastal waterways. Nutrients from fertilizers, garbage, and septic tanks can lead to the growth of nuisance plants and algae, while bacteria from these two sources can lead to the removal of oyster beds and swimming places. Oils and greases washed off of roadways and driveways can damage water supplies. Plants on the

other hand act as a natural barrier, capturing and eliminating all of the poisons before they reach the coast (Commonwealth of Massachusetts, n.d.).

2.1.4.4 Habitat for species and beauty

Native trees, shrubs, groundcovers, and grasses that have sprung along the shore provide habitat, breeding grounds, and food for wildlife. These plants also provide beauty to coastal infrastructure, provide privacy screening, and safeguard the natural aesthetic of the seashore. On the other hand, extensive lawns lack visual appeal, erosion resilience (because of their shallow roots), and biodiversity benefits. Furthermore, lawn fertilizers and pesticides can impair water quality and constitute a risk to human health and animals (particularly in the levels necessary in sandy soils) (Commonwealth of Massachusetts, n.d.).

2.1.5 Vulnerability of coastal areas

Vulnerability is a concept that has recently gained prominence in climate change discourse. In basic terms, it can be characterized as a human being's or a community's proclivity to be negatively impacted by changes in living conditions caused by natural or human-induced processes. The coast is particularly fragile. As a result, assessing the degree of its risk is crucial because it affects the way decisions are taken on minimizing exposure to the consequences of coastal hazards. Several methodologies for evaluating the exposure of coastal areas to environmental hazards have been established. Most of these approaches understand the importance of including human factors, but only a handful have been effective in doing so (Cooper and McLaughlin, 1998).

Although there is no universally accepted definition of vulnerability (Cutter, 1996), and it is uncertain how it can be employed as a tool in environmental assessments (Gallopín, 2006; Füssel, 2007), it has now become an important aspect of studying the man-environment connection.

Indeed, several important evaluations have been produced in recent years (Adger, 2006; Eakin and Luers, 2006; Turner, 2010; Toro et al., 2012). The increase in risk studies might be due to the anticipation that the likelihood of being harmed will increase as a result of climatic changes caused by global warming (Heltberg et al., 2009). Bio-physical studies, political economics studies, and ecological resilience studies are all linked disciplines of research in vulnerability science (Eakin and Luers, 2006). Now that the notion of vulnerability has been established, it's time to talk about resilience and adaptability.

The word “resilience” was coined by ecologists to define a system’s ability to adjust to interruption and transition while maintaining the linkages that make it up (Holling, 1973). Holling’s notion of ecological resilience centers on the environment’s ability to rearrange itself to maintain its stability and productivity (Eakin and Luers, 2006).

Adaptive capacity has been interpreted in a variety of ways, but from the standpoint of vulnerability, it can be defined as the system’s ability to improve or at least sustain the quality of life of its human members in a given environment or set of environments (Gallopín et al., 1989).

Vulnerability manifests itself in three different ways. The three categories of vulnerability are vulnerability as a threat, vulnerability as a social reaction, and vulnerability of locations (Cutter, 1996). The amount, frequency, duration, and effect of biophysical processes are all susceptible as a result of risk exposure (Burton et al., 1993). Vulnerability as a social reaction measures how resilient society is in the face of threats such as storms, droughts, and diseases (Cutter et al., 2003; Dwyer et al., 2004).

Place attachment (Low and Altman, 1992), which defines the degree of danger preparedness, is a major determinant of social vulnerability, particularly in rural areas. It has recently been suggested

that social vulnerability has a clear temporal dimension (de Vries, 2011), meaning that a person's or a community's temporal condition has a major effect on their vulnerability to natural hazards. Place risk refers to a situation in which a group or person is exposed to natural disasters because he or she lives in a high-exposure environment and in a society that is unable to deal with the danger (Cutter, 1996).

2.2 Coastal hazards

Natural disasters have grown more prevalent in coastal areas. Unfortunately, coastal hazards are frequently underestimated before they cause major damage to coastal regions. As more people establish their assets and properties in coastal locations, the impacts of coastal hazard phenomenon grow. Natural disasters are events that have the potential to cause harm to humans (Mukhopadhyay et al., 2012). These processes might be triggered by hydrometeorological, geological, or even biological reasons. A hazard becomes a disaster only after it has caused harm to society (Mukhopadhyay et al., 2012). As a consequence, it appears that there is a cause-and-effect link between the two. It is impossible to tell whether a danger becomes a catastrophe, but it is obvious that the people's failure to react appropriately to the hazard causes the disaster (Mukhopadhyay et al., 2012). Erosion, hurricanes and related storm waves, tsunamis, and floods are examples of natural shore hazards, which can be referred to as coastal hazards (Kaiser, 2006). Furthermore, while the extent and rate of change are likely to differ over large spatial scales and are difficult to estimate locally, sea level rise has emerged as a significant type of coastal challenge (Cazenave and Llovel, 2010; Han et al., 2010).

Many simulations predict higher storm frequency or severity (Allison et al., 2009; Bender et al., 2010), but even if these characteristics remain constant, storm surge and wave effects are anticipated to intensify owing to rising baseline sea levels (Allison et al., 2009; Bender et al.,

2010). More severe coastal storm activity, as well as increased coastal erosion and flooding (Douglas et al., 2001), incremental inundation of low-lying areas, and in certain circumstances, groundwater salinization, would almost certainly result. Due to saltwater intrusion into coastal aquifers, this will disrupt the water supply for human consumption and agricultural uses. Low-lying coastal towns, coastal defense systems, and coastal infrastructures are the most fragile locations within coastal regions (Apeaning Addo, K. 2014). The Low Elevation Coastal Zone (LECZ), described by McGranahan et al. (2007) as coastal zones less than 10 meters above sea level, accounts for just 2% of global land area but 10% of the global population (McGranahan et al., 2007).

If no adaptation is made, 16–27 million people will be flooded every year by 2100, with annual damage costs varying between \$ 5 and \$ 9 billion, according to Hinkel et al. (2011). According to a report by Dasgupta et al. (2007), hundreds of millions of people in the developed world will be displaced by sea-level rise this century, with serious economic and ecological consequences for many. According to climate change estimates, the West African coastal region will be at risk of floods by 2080 (Nicholls and Tol, 2006).

Coastal erosion jeopardizes coastal investment, threatens ecosystems and resources, jeopardizes coastal inhabitants' livelihoods, has an impact on coastal ecology, and negative impact on the coastal climate. Approximately 38% of Africa's coastal biodiversity is considered highly endangered, and erosion rates in some areas of South Sahara Africa are estimated to be between 23 and 30 meters per year (Angnuureng and Addo, 2013). Owing to the risks of coastal flooding and rising sea levels, over a quarter of a million homes in Australia may be uninhabitable by the end of the century, and some cities have already started to demolish expensive homes constructed on fragile coastlines (Angnuureng and Addo, 2013).

2.2.1 Spatio-temporal assessment of coastal hazards

Space is referred to as spatial. The term temporal refers to the passing of time. When data is gathered in both space and time, the term spatiotemporal, or spatial-temporal, is used in data processing. Through visualizing how objects travel in space and time, spatial-temporal inference is used to solve multi-step problems. With the advent of efficient computational processors, spatio-temporal data processing has become an increasing field of study (OmniSci, n.d.). Biology, geography, meteorology, medicine, transportation, and forestry are all examples of applications for spatio-temporal data processing (OmniSci, n.d.).

According to studies, one of the most cost-effective methods of studying changes in coastal ecosystems is through global information system (GIS) analysis of aerial photography and satellite images (Al-Nasrawi et al., 2016; Akumu et al., 2010; Ozesmi et al., 2002; Cho et al., 2004). A study conducted by Ozesmi and Bauer (2002) provided an overview of the most appropriate satellite data and classification methods to use for studying wetlands. They also explored how aerial photos could provide complementary evidence, allowing them to conduct equivalent observations before the availability of satellite data, allowing them to investigate longer-term improvements in wetland morphology and shoreline locations.

Some studies have solely focused on satellite data, such as Cho et al. (2004) research in southeastern India, which successfully mapped wetland and shoreline changes on a large scale. The same methods have been used to monitor vegetation and shoreline changes in inland wetland conditions, such as Haack's (1996) analysis of the distribution and complex existence of small isolated wetlands in Kenya and Tanzania's plains and highlands, and Roshier and Rumbach's (2004) mapping of temporary wetlands in eastern Australia's Darling River basin.

Al-Nasrawi et al. (2017) used spatial technologies to determine the ecological and geomorphological (e.g., shoreline, land cover, and vegetation) changes in a deltaic system and its associated coastal wetland to assess potential options for conserving and managing the wetlands. The relevance of their work was to indicate how susceptible the estuary was to shoreline expansion or contraction, which caused changes in ecosystem accommodation space as a function of sediment transport and deposition from the catchment. Based on local literature, aerial photography, and satellite imagery, GIS imaging, tracking, and modeling were used to investigate the dynamics of landcover groups, shoreline migration, sedimentation patterns, and general deltaic progradation. Previous investigations of soil, sediment screening, particle size, X-ray diffraction (XRD), failure on ignition (LOI), and water quality analyses aided the GIS analysis.

A geographic information system (GIS) is a tool for recording, storing, viewing, interacting, converting, processing, and archiving georeferenced data, or data tied to particular positions on the Earth's surface. Geographic information systems supplement and, to some degree, replace maps, but they can still handle information in the form of satellite imagery of the Earth's atmosphere, as well as information from georeferenced surveys and administrative documents (Goodchild, 2004). Geographic information systems (GISs) had their roots in the mid-1960s. Following the example of Babbage and others, early computers were largely designed for numerical computation. Other applications, aided in part by the invention of sophisticated peripherals, such as pen plotters and map digitizers, began to emerge by 1965. Commercial GISs began to emerge in the 1980s, providing a vast variety of functions that were too complicated, repetitive, unreliable, or costly for humans to do by hand in different ways. Easy area and length measurements, data type transformations, and simple statistical analysis such as the estimation of measurands were among them (Goodchild, 2004). Commercial GISs began to emerge in the 1980s,

providing a vast variety of functions that were too complicated, repetitive, unreliable, or costly for humans to do by hand in different ways. Simple area and length measurements, data format transformations, simple statistical analyses such as the estimation of means and standard deviations, and a slew of more complicated and advanced approaches collectively known as spatial analysis were among them. In addition, GISs were granted advanced data display capabilities, such as routing and various modes of data visualization. A framework for precisely determining position on the Earth's surface is a necessary component of every GIS representation. Based on measurements from the Greenwich Meridian and the Equator, the Meridian Conference of 1884 defined latitude and longitude as the universal standard for georeferencing. Unfortunately, the Globe is not a spherical sphere, and it has been approximated by some mathematical functions over time and in various parts of the planet, each of which will result in significantly different latitude and longitude.

GIS has turned mapmaking from a costly and time-consuming procedure undertaken by a few highly qualified cartographers to a simple and inexpensive process open to anyone. Anyone with a computer, records, and basic software can create visually appealing maps. GIS displays are complex and immersive by nature. They can depict changes over time or enable users to zoom and pan to reveal new areas or more information. On a single screen, multiple displays can be produced at the same time. Tables and maps can be related in fascinating ways, and maps can be viewed alongside other modes of presentation, such as tables.

2.2.2 Land use/ Land cover change (LULC) dynamics

In natural ecosystems, human activities are one of the major driving factors in land use and land cover changes (LULC) (Tewabe and Fentahun, 2020). On a global and local scale, land-use changes affect the environment, exacerbate environmental disasters, and influences socio-

economic dynamics. As a result, determining land-use transition is critical when considering global patterns and their response to the catchment or basin's water flow, woodland, soil, rainfall, and runoff characteristics (Tewabe and Fentahun, 2020). Two distinct LULC terminologies are often used interchangeably. The biophysical characteristics of the earth's surface, such as the arrangement of plants, water, soil, and other physical attributes of the ground, are referred to as land cover. Though land use refers to how humans and their habitat have used land, it is generally focused on the practical role of land in economic activities (McConnell W.J, 2015; Arsanjani J.J, 2011). LULC changes have been attributed to major environmental changes including greenhouse gas emissions, global climate change, habitat loss, and soil resource degradation in previous research (Liping et al., 2018). The conversion of various land use forms is known as land use and land cover change (LULCC), and it is the product of dynamic relationships between humans and the natural world. LULCC is a major contributor to climate change, affecting ecological systems, biological cycles, and biodiversity (Liping et al., 2018). Natural and socio-economic factors, as well as human activity in time and space, influence land use and land cover change in a given region. Changes in land use and land cover (LULC) are primarily affected by population growth (Lambin et al., 2003), economic growth, and physical factors such as topography, slope condition, soil composition, and temperature (Setegn et al., 2009; Yalew et al., 2016). Where it comes to how people use the land, land-use reform is a historical phenomenon.

The abundance of numerous materials, such as trees, soil, and water are altered by LULC (Ahmad, 2014). Changes in land use have a significant impact on evapotranspiration, groundwater infiltration, and overland runoff. When it comes to global developments and their reactions to environmental and socio-economic drivers, land use and land cover change is a big concern (Akpoti et al., 2016; Bewket, 2002; Hurni et al., 2005). On a global and local scale, changes in

land use and land cover have negative impacts on climate trends, environmental disasters, and socio-economic dynamics (Chakilu and Moges, 2017; Hegazy and Kaloop, 2015; Sewnet, 2015).

Understanding and measuring LULC changes requires accurate and up-to-date land cover change data. Remote sensing (RS) and geographic information systems (GIS) are critical instruments for collecting reliable and timely land use and land cover spatial data, as well as assessing changes in a research area (Liping et al., 2018). At various scales, remote sensing is commonly used to track and control land use. Shift identification requires a versatile environment for capturing, saving, viewing, and reviewing digital data (Liping et al., 2018). Cellular and agent-based models, as well as hybrid models based on these two categories of models, are currently the most commonly used models of land use transition tracking and prediction (Sohl T.L et al., 2013; Myint S.W et al., 2006). The Markov chain and Cellular Automata (CA-Markov) model is a combination of the Cellular Automata and Markov models. It is one of several mixed models. This mixed model essentially incorporates the benefits of the Markov model's long-term projections with the ability of the Cellular Automata (CA) model to simulate spatial variation in a complex environment, and it can effectively simulate land cover change (He et al., 2014).

The Landsat image sensor is a unique sensor aboard the Landsat satellite platform that can capture multispectral imagery. Many bands of the electromagnetic spectrum are captured in Landsat multispectral images including visible, reflecting infrared, and thermal infrared radiation. Understanding the advantages and disadvantages of various types of sensor data is critical for selecting appropriate remotely sensed data for image classification (Gomez et al., 2016; Lu and Weng, 2007). The first step in a good classification is to choose appropriate sensor data (Ward et al., 2000). It necessitates taking into account considerations such as the user's needs, the size and characteristics of a research area, and the budget. It requires considering such factors as user's

need, the scale and characteristics of a study area, the availability of various image data and their characteristics, cost and time constraints, and the analyst's experience in using the selected image (Lu and Weng, 2007).

A study conducted by Tewabe and Fentahun (2020), to assess the trend of land use and land cover change in the Tana basin of Northwest Ethiopia employed remote sensing data with the help of GIS and ENVI software and investigated LULC changes in the study area. It was expected that findings from their study would contribute information for decision-makers, land managers, and planners for sustainable development and management of natural resources. Landsat satellite images of the basin were acquired for the years of 1986, 2002, and 2018. The study was interested in finding out the LULC change detection in these periods using Landsat images. For the remote sensing method, representative ground truth data was a prerequisite to associate the reflectance property to the object and the train classifiers and facilitate accurate automatic classification (Muzein, 2006). To investigate the trend changes in each land cover type, the entire image was classified by the supervised classification method using a maximum likelihood classifier (algorithm) environment. The study used Landsat images from the appropriate years for the study field, which were downloaded. For more use of the LULC classification, random control points, ENVI 5.3 and GIS 10.1 applications, and Google earth photos were collected. The authors concluded that, for the 32 years between 1984 and 2018, LULC shift identification in the basin showed that agricultural land and settlement areas had increased, while woodland, scrub, and pasture fields had decreased. The building of major lakes in the basin may have contributed to the comparable coverage of water bodies. The hydrology of the catchment may have been influenced by the shift in land usage and land cover.

2.2.3 Ground Truth Survey

The term “ground truth” is used in a variety of remote sensing techniques. It refers to data collected “on the ground” on the Earth’s surface about the characteristics of the Earth’s surface features (Deshmukh, 2017). Ground truth data supplement remote sensing data by assisting in the linkage of image data to ground reality (Deshmukh, 2017). It is worth noting that, even though the term “ground truth” includes the word “truth,” ground truth data may contain errors due to factors such as errors introduced during data collection, data processing, and deriving inferences from it. The method of gathering ground truth data entails gathering information about the study area from field surveys, analyzing aerial photographs or high spatial resolution data, and relying on personal experience (Deshmukh, 2017). Ground truthing is normally conducted on the field/site, with surface observations and measurements of different ground feature properties that are being analyzed on remote sensing images. When maps are created as a result of remote sensing data interpretation and analysis, it can aid in determining the accuracy of the maps produced by remote sensing data analysts or image analysis software (Deshmukh, 2017). This reduces the number of errors in the computer-assisted thematic data extraction procedures. Ground truthing is the procedure for gathering ground truth information. Field work, field survey, ground survey, surface data collection, and reference data collection are all terminology used by many researchers (Deshmukh, 2017).

2.3 Management of coastal hazards

Coastal protection (CP) generally refers to the protection of people, infrastructure, and other assets from the negative consequences resulting from flooding (high water levels and/or wave overtopping) and erosion (Möller, 2019). The Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCCAR5), as well as a follow-up report on the effects of a global temperature

increase of 1.5 degrees Celsius published in October 2018 (IPCC, 2018), outlined the immediate need to reduce potential coastal flood and deforestation danger due to expected improvements in external conditions. The acknowledgment that hard-engineered defenses might not be the most long-term CP approach has coincided with the recognition of increased flood and erosion risk due to shifting external conditions. Many people now advocate for “nature-based solutions” (also known as “living shorelines,” “soft infrastructure,” or other terms) to achieve CP (Möller, 2019). The retention and/or conservation of “soft” coastal landforms such as dunes and coastal wetlands, which serve as natural wave and tidal flow dissipaters, are often used in such approaches (Kabat et al., 2009; Narayan et al., 2017). Natural landforms, unlike hard-built systems, dynamically respond to external drivers (e.g., wave and/or tidal energy). However, seawalls and other shore-parallel barriers (such as revetments and bulkheads) are constructed to minimize coastal threats to facilities where natural beaches and dunes have been removed or severely limited, and where other risk-reduction solutions are limited by space or sediment. These hard walls are often designed to keep the shoreline in place by reducing wave strike, storm surge, and landward erosion. Although all shore-parallel systems capture wave energy, different structures are built for different coastal environments (N.A.P, 2018).

Natural landforms may be able to survive climate-induced hazards as a result of the change, while constructed systems may not. Natural coastal defenses, on the other hand, need more space than designed defenses. Coastal inhabitants are often dependent on fixed structures (roads, homes, and industries) for a smaller “footprint,” which causes problems with the room needed for morphodynamical landform changes to rising sea levels and changing wave climates. The building of concrete dikes, seawalls, and embankments has arguably worsened the problem by creating a

false sense of protection and a consequent increase in population in flood-prone regions (Rumson et al., 2017).

Successful adaptation would rely on the need to enable and encourage natural environments to respond to a changing environment, while sustaining the ecosystem resources on which all life depends, according to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC, 2014). Ecosystem regeneration and effective natural resource management will also play an important role in improving people's capacity to avoid, deal with, and rebound from disasters. This is especially true for the most impoverished members of society, whose livelihoods are always reliant on natural resources.

Climate change adaptation (CCA) and disaster risk reduction (DRR) rely heavily on ecosystems and their resources. This is because healthy ecosystems can minimize people's and their properties' physical exposure to natural hazards by serving as defenses and/or defensive barriers, as well as reducing vulnerability by providing food, water, shelter, and other essential ecosystem services (UNU Press, 2013). Safe habitats, such as wetlands, parks, and coastal environments, including mangroves and dunes, for example, minimize exposure to hazards not only by protecting livelihoods but also by acting as physical barriers that mitigate the effect of hazards (IUCN, n.d). As a result, healthy ecosystems offer a variety of resources that help to control and mitigate the impacts of natural disasters. (SANBI and DEA, 2018).

Policymakers must ensure that coastal communities and their residents are resilient to climate change and less vulnerable to hazard risk. They must also acknowledge the importance of ecosystems in assisting cities and residents in preparing for, dealing with, and recovering from climate-related disasters. This necessitates a comprehensive knowledge of climate-related events and their consequences, as well as existing and potential human livelihood requirements and the

biophysical requirements of resilient habitats (Sauka, 2020). Systematic knowledge of climate change and the benefits given by ecosystems would ensure that African countries, in particular, will take advantage of the many climate adaptation opportunities created by ecosystems (Sauka, 2020).

Indigenous peoples and local communities help to mitigate climate change by preserving their forestlands, which operate as a carbon sink, absorbing and storing tons of carbon from the atmosphere each year (Afsara et al., 2020). According to research by Frechette et al (2018), indigenous peoples and local communities manage at least 17% of the total carbon stored in worldwide forest lands, or 293,061 million metric tons (Mt). Indigenous governance can also assist to conserve roughly one-fifth of the total carbon absorbed by tropical and subtropical forests (218 Gigatons) because they cover 40% of protected areas, according to the study. Indigenous peoples, in particular, manage a substantial portion of the world's most biodiverse regions, safeguard lands and oceans, and ensure that natural resources are used sustainably. They have deep economic, cultural, and spiritual ties to their natural surroundings. However, indigenous peoples' geographical areas and natural ecosystems are sensitive to the effects of climate change, rendering them vulnerable to natural disasters (Afsara et al., 2020). Indigenous peoples are also discriminated against and excluded from social, political, and economic power, limiting their ability to build capacity and resilience. Indigenous peoples have developed strategies based on their traditional knowledge to adapt to changing climate and environment. Indigenous groups in Africa's Sahel area, for example, use water gathering practices to adapt to climate change. This method is called 'zai pits' or 'tassa,' and it aids in the restoration of damaged drylands by using climate-smart agriculture (Afsara et al., 2020). Nature-based solutions' intersectional approach takes into account many forms of knowledge systems and worldviews anchored in traditional ecological or

indigenous knowledge (Afsara et al., 2020). Indigenous peoples' traditional wisdom is on the risk of extinction owing to a lack of acknowledgment. Enhancing efforts to close this gap and establishing tenured community land rights can help to restore and preserve natural ecosystems, boost food security, and reduce emissions. Recognizing indigenous peoples' contributions to climate change and conservation in appropriate sectoral, national, and global policies might help to resolve conflicts and improve ecological and socioeconomic resilience (UNEP, 2019).

As a result, safeguarding indigenous peoples' rights to maintain their lands, as well as building their capacities and making them financially self-sufficient, can help to develop and satisfy the requirements of nature-based solutions (Afsara et al., 2020).

2.4 Nature-based solutions

The International Union for Conservation of Nature (IUCN) and the European Commission (EC) have defined nature-based solutions (NbS) slightly differently, but share common ground by stressing that NbS are actions based in nature that should meet societal challenges (Hanson et al., 2020). The IUCN places high emphasis on protecting, sustainably managing, and restoring, natural and modified ecosystems (Cohen-Shacham et al., 2016), while the European Commission also includes solutions that are “inspired by nature” (EC, 2015). Both definitions relate to the idea that NbS can result in multiple benefits. Nature-based solutions are actions inspired by, supported by, or copied from nature (Cohen-Shacham et al., 2016; EC, 2015) that: deploy various natural features and processes in a resource-efficient and sustainable manner; are adapted to local systems into diverse spatial scales, redefining the role of nature in urban, rural, and natural environments; and face societal challenges leading to multiple benefits and supporting sustainable development and resilience.

The term NbS was first used in the early twenty-first century, and it was quickly adopted by some international organizations over the next few years. Early on, the emphasis was on ecosystem-based projects that aimed to save biodiversity and manage the environment (Eggermont et al., 2015). Economic and social aspects were gradually included, leading to further studies into ecosystem services. The role of nature in enhancing health and well-being while also fostering development and job creation was recognized by this integrated approach. NbS has been broadly adopted as a concept and moved ahead in the EU Research and Innovation Policy agenda since 2013, intending to encourage synergies between nature, culture, and the economy (Cohen-Shacham, 2019). In reality, NbS serves as an “umbrella” concept that builds on and endorses earlier concepts like ecological engineering and catchment systems engineering, green-blue infrastructure, natural infrastructure, ecosystem solution, ecosystem-based adaptation/mitigation, ecosystem services, renaturing, and natural resources (Somarakis et al., 2019). Nature is a source of motivation in NbS, providing long-term solutions for coping with the consequences of human activity while also maximizing natural resources (EC, 2015). The three major types of NbS are classified based on the degree of interference and the form of engineering: Design and maintenance of new habitats; NBS for preservation and multifunctionality of maintained ecosystems; and better utilization of protected/natural ecosystems (Somarakis et al., 2019).

Under certain socioeconomic and biophysical environments, ecosystem-based disaster risk management and climate adaptation are emerging as advanced, cost-effective, and effective solutions to coastal protection (Spalding et al., 2014). Coastal habitats are vital to the protection and maintenance of coastlines. By adding to the mechanisms that produce, trap, and disperse sediment around shorelines, coastal environments can dampen tides, attenuate water flow and floods, mitigate stormwater runoff, and build up coasts. Mangroves limit storm surge and flood

depth by dampening waves (World Bank, 2016). Waves can be attenuated and sediments can be stabilized by seagrasses (Koch et al., 2006). Waves are dampened by coral reefs, which often provide and trap sediment (Scyphers et al., 2011). Oyster reefs, in a similar way, can help to prevent shoreline erosion. Beaches, sandbanks, and dunes protect from storm surge and waves while being extremely diverse and nuanced (Hanley et al., 2014). Coastal species such as parrotfish also contribute to sediment production by secreting sand (Perry et al., 2015).

Evidence suggests that if natural coastal areas are preserved in their entirety, the number of residents, impoverished households, the aged, and the value of residential land that is most vulnerable to threats can be dramatically decreased (Schueler, 2017). Many livelihoods and sustenance practices depend on the resources offered by coastal ecosystems.

The above-mentioned types of NbS reflect the terms' open nature, which creates some challenges but also encourages broader adoption. The difficulty lies in describing "nature" and what constitutes "natural". Not all methods should be categorized as NbS since certain acts include various stages and forms of interventions. For example, according to Eggermont et al. (2015), if particular considerations such as biodiversity and ecology are neglected, the construction of vegetated roofs or walls to alleviate the urban heat island cannot be called an NbS. Furthermore, some natural processes, such as genetically engineered plants and biomimicry, are prohibited.

2.5 Challenges and opportunities of nature-based solution concepts

2.5.1 Opportunities of nature-based solution concept

Nature-based solutions have a multi-functional purpose that allows them to solve social, environmental, and economic aspects of global challenges (Somarakis et al., 2019). NbS has been described as vital for urban regeneration and improvement, coastal stability, multifunctional watershed management, and habitat conservation increasing the sustainability of matter and energy

usage, improving ecosystem insurance value, and increasing carbon sequestration (EC, 2015; Krauze and Wagner, 2019). The concept has been promoted by practitioners, especially the International Union for Nature Conservation (IUCN), and by policy (EC) as a way for the sustainable use of nature in solving societal challenges (Bulkeley et al., 2017). It has also been applied to challenges such as climate change mitigation, water management, land use, and urban development (Bulkeley et al., 2017; Eggermont et al., 2015). Furthermore, a bond has been identified between NbS and cultural heritage, which happens to be the fourth pillar of sustainable development¹ (Jurik et al., 2018). Cultural heritage, in combination with NbS, can help cities expand sustainably, increase competitiveness, and develop socially and environmentally transformative solutions. Working with nature to innovate and solve global issues has been translated into multiple priorities and incorporated in several reviews and action plans, one of which is the Horizon 2020 Expert Group on ‘Nature-Based Solutions and Re-naturing Cities’ final report. Sustainable urbanization, restoration of degraded habitat, adaptation and mitigation of climate change, and risk control and resilience are among the priorities of NbS, according to the European Commission’s report (EC, 2015). Likewise, a principal objective of NbS is to solve global issues directly related to the priorities for sustainable development. NbS contributes to numerous UN SDG, and not only to those relevant to biodiversity and habitats. Campaigns are using NbS with different SDGs all over Europe. Natural coastal conservation programs are linked to SDG 14 for the sustainable management of coasts and marine resources; vegetated roofs and pocket parks are linked to SDG 11 for sustainable cities and communities (Faivre et al., 2017).

Experts can then concentrate on how to incorporate NbS into applicable policies as a next step. Because of the multidimensionality and multifunctionality of NbS, which provides a wide range of benefits, it has a lot of potentials to resolve the following issues that most cities are dealing with

these days: sustainability, climate change adaptation, human health and welfare, social stability, and economic development. The development process would be inclusive in the sense that residents, corporations, non-governmental organizations, and the academic community will all be involved in the planning process. Many policy documents at the (local) municipal levels, such as those describing spatial growth, strategic development, environmental protection, noise levels, low carbon economy plans, and public transportation development, could be incorporated with NbS (Somarakis et al., 2019).

2.5.2 Challenges of Nature-based Solution concepts

The difficulty lies in describing “nature” and what constitutes “natural”. Aside from the definitional problem, NbS projects face a slew of other difficulties. Designing, implementing, and sustaining NbS, as well as quantifying (including economic valuation) the advantages and co-benefits of their ecosystem services, are not well understood (Somarakis et al., 2019). In various stages of NbS project growth, there is a lack of deep understanding among key actors, as well as a lack of skills and experience. Decision-makers and practitioners also lack the knowledge and skills needed to effectively overcome potential trade-offs and make the best use of available technological solutions (Somarakis et al., 2019). Furthermore, technically feasible solutions that can be used to solve a variety of problems are minimal, underdeveloped, and, in many cases, costly. The lack of ready-to-use technology, as well as ready-to-apply research findings and principles, makes NbS adoption much more difficult. There is also a scarcity of proof of NbS efficacy, as well as quantification of the environmental, economic, and social benefits. Inadequate, or in most cases absent, follow-up monitoring of implemented NbS obstructs the assessment of their efficacy, depriving decision-makers and practitioners of useful conclusions about cost-benefit analysis, efficiency, and long-term viability of NbS (Somarakis et al., 2019).

In the field of NbS, there is a growing movement toward technological innovation. Technical innovation can be found in all forms of NbS, but it is particularly prevalent in the design and management of new ecosystems. Smart engineering solutions, such as green roofs, urban forestry, vertical gardens, green barriers, and sustainable urban drainage systems, are among the most groundbreaking solutions in the urban context (SUDS) (Hoang L. and Fenner R.A. (2016). There are large-scale applications for the design and management of new habitats outside of metropolitan areas. Agroecosystems, protected areas or parks, green corridors, wetlands, river basins, and coastal zones are all receiving more attention. However, in the field of monitoring and quantifying the multi-scale NbS impacts, new technical, science, and innovation developments are also emerging. These developments are expected to open up a plethora of opportunities for evaluating NbS efficacy and expanding the expertise and evidence base.

The economic opportunities for implementing NbS are there for the taking, but conventional business models lack the system to allow the development of financial support for such schemes. Even though NbS is frequently more cost-effective than conventional grey infrastructure alternatives, the obstacles to their implementation are frequently more complex (Somarakis et al., 2019). These issues can be traced back to changes in management, a lack of knowledge, collaboration, and securing funding for NbS projects. Due to limited or restricted data, limited studies on quantified benefits, and a lack of organized information transfer many people fail to express the numerous benefits of NbS in financial terms. These variables will make it difficult to create a well-defined business case (Somarakis et al., 2019).

To be mainstreamed, NbS faces several challenges in its implementation, necessitating constructive and creative policy interventions. The majority of policies at all levels (local, regional, global, and international) were established without considering NbS as a viable alternative to grey

solutions or other similar methods (Somarakis et al., 2019). Current policies can make it difficult, if not impossible, to consider NbS projects. There is also a lack of understanding of how to mainstream and integrate NbS into urban policies, planning processes, and decision-making frameworks.

Certain types of NbS necessitate a large amount of land for implementation, which can be expensive and difficult for planners and local governments to consider, particularly in urban areas. This makes choosing NbS over conventional engineered approaches all the more unlikely, particularly if the broader environmental and social benefits aren't factored into decision-making (Davis et al., 2015).



CHAPTER THREE (3)

STUDY LOCATION, MATERIALS AND METHODS

3.0 Introduction

This chapter is divided into three main sections. The first section describes the physical and socio-economic background of the study area (Keta township) with detailed study area map. The second part of the chapter describes the study design, materials, and methods that have been employed in conducting the study. Subsections of the chapter will provide information about the research approach and sampling techniques used. The chapter will also describe the instruments of data collection, procedure, analysis, and limitations of data collection. The final section analyses the spatiotemporal assessment of land use change from field observation and survey of the study area. This will be aided by GIS data analysis for hazards and NbS mapping.

3.1 Study locations: physical setting

The coastal zone of Ghana accounts for about 7% of the country's land area (GSS, 2010). It is home to 25% of the population and 80% of the country's industrial establishments (Armah and Amlalo, 1998). The 539-kilometer-long coastline is divided into three zones: western, central, and eastern coasts (MESTI, 2012). The 149-kilometer eastern coast runs from Aflao (Togo Border) in the east to the Laloi Lagoon located west of Prampram.

The study area of this research is an important and historic coastal district along the South-Eastern coast of Ghana; the Keta Municipal district inhabits the coastal strands and mangrove swamps situated in the Volta region. It is one of the 25 administrative districts of the Volta Region with its capital as Keta. It was an important trading post between the 14th and late 20th century via a port and fort built by the Dutch in 1784 (WACA, 2007). Keta, Tegbi, Anloga, Anyanui, Anyako, and Shime are the six sub-districts that make up the Keta municipality. The municipality is located

between longitude 0.30E and 1.050E, and latitude 5.450N and 6.0050N (MoFA, 2019). It is about 160 kilometers east of Accra, off the Accra-Aflao high road, and east of the Volta estuary. The municipality is bordered on the north by Akatsi district, on the east by Ketu South district, on the west by South Tongu district, and the south by the Gulf of Guinea. **Figure 3.1** shows a map of the Keta Municipality where the study area, Keta township is highlighted on the eastern border.

3.1.1 Climate

The municipality is located within the dry equatorial climate with an annual average rainfall of less than 1,000mm (MoFA.gov.gh). The amount of rainfall reduces from the north towards the coast where about 800mm annual rainfall may be recorded. It is therefore one of the driest along the coast of Ghana. The major rainy season is experienced between March and July, while the minor begins in September and ends in November. Daily temperatures average about 30°C, coupled with high humidity, which promotes high evapotranspiration.

3.1.2 Vegetation and Drainage

Out of its total surface area of 1,086km², approximately 362km² (about 30%) is interspersed with lagoons, creeks, and mangrove forests, which offers a great potential for tourism development and biodiversity conservation. The largest of these is the Keta Lagoon, which stretches about 12km at its widest section and 32km² long. Hence, the remaining land area is only 72km, a situation that has created severe constraints on access to land for development within the district. According to the West African Coastal Areas (WACA) (2007), Keta is considered a low-lying coastal plain with the highest point of elevation only 53 meters above sea level around Abor in the north. The lowest point is about 1-3.5 meters below sea level along the coast of Vodza, Keta, and Kedzi townships. Parts of the municipal have experienced coastal erosion between the 1960s and 1980s (Ketatourism.com).

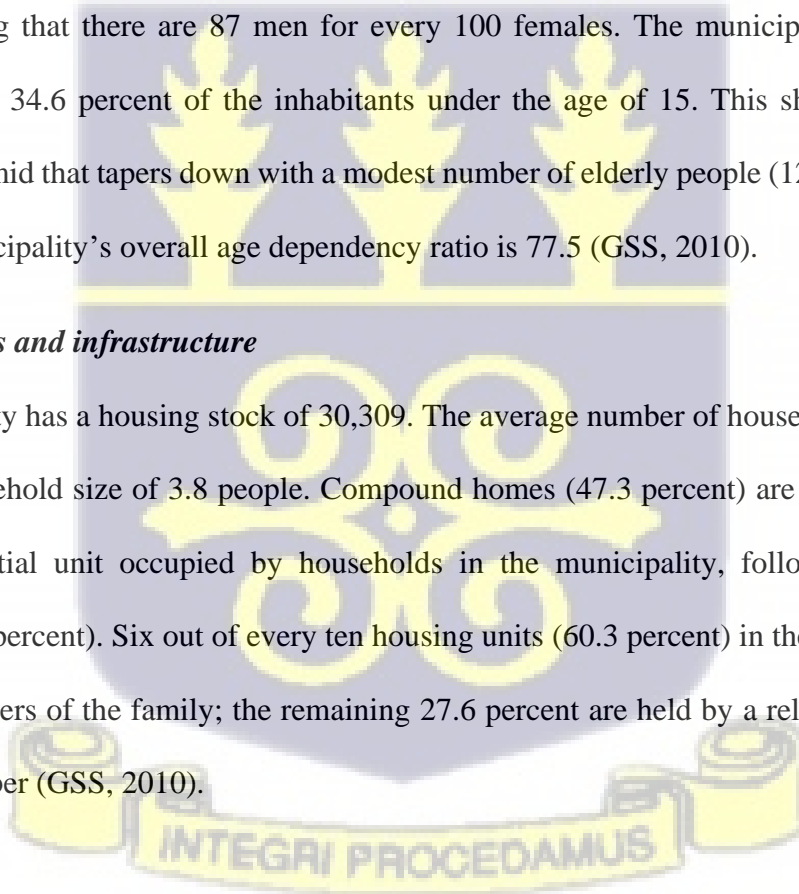
3.2 Socio-economic setting

3.2.1 Population

According to the Ghana Statistical Service (GSS) (2010) Population and Housing census, Keta is the sixty-third most populous settlement in Ghana with a total population of 147,168 natural persons (GSS, 2010). The figure represents seven percent (7.0%) of the region's total population. This number is made up of 68,556 males (46.4%) and 79,062 females (53.6%) (GSS, 2010). The Municipality is to a high extent an urbanized community of the Volta region, with more than half (53.3%) of the population living in urban areas which are significantly higher compared with the regional figure of 33.7 percent of the population living in urban areas. The Municipality's sex ratio is 86.7, implying that there are 87 men for every 100 females. The municipality has a young population, with 34.6 percent of the inhabitants under the age of 15. This shows a large base population pyramid that tapers down with a modest number of elderly people (12.1%) aged 60 and older. The Municipality's overall age dependency ratio is 77.5 (GSS, 2010).

3.2.2 Settlements and infrastructure

Keta Municipality has a housing stock of 30,309. The average number of households per house is 1.2, with a household size of 3.8 people. Compound homes (47.3 percent) are the most frequent form of residential unit occupied by households in the municipality, followed by detached dwellings (39.2 percent). Six out of every ten housing units (60.3 percent) in the Municipality are owned by members of the family; the remaining 27.6 percent are held by a relative who is not a household member (GSS, 2010).



3.2.3 Economic activities

According to the Ghana Statistical Service (2010) Population and Housing Census, approximately 64 percent (63.9 percent) of the population aged 15 and over is economically engaged, whereas 36.1 percent is not. 93.5 percent of the economically active population is employed, while 6.5 percent is jobless. Females (37.0 percent) are more likely than males to be economically inactive (35.0 percent). Students account for a substantial proportion of economically inactive individuals (45.4 percent), while 18.4 percent undertake home responsibilities and 8.2 percent are handicapped or too unwell to work. Approximately 34.8 percent of the working population is employed as skilled agricultural, forestry, and fisheries workers, 21.8 percent in service and sales, 25.4 percent in craft and associated trade, and 2.3 percent as managers.

The data reveals that 70.9 percent of those aged 15 and over are self-employed, 6.9 percent are contributing family workers, 3.4 percent are casual workers, and 0.5 percent are domestic staff (house helps). The Municipality's main employer is the private informal sector, which employs 91.1 percent of the population, followed by the public sector, which employs 5.6 percent.

The municipality is mainly an agricultural district, with a majority of the population engaged in crop farming, fishing, and other related trading activities. Agriculture households make for 34.4 percent of all households in the municipality. In rural areas, 43.2 percent of households are agricultural, whereas 27.0 percent of families in urban areas are agricultural. Crop farming is practiced by the majority of families in the municipality (67.7 percent). The most common livestock farming in the municipality is poultry (chicken).

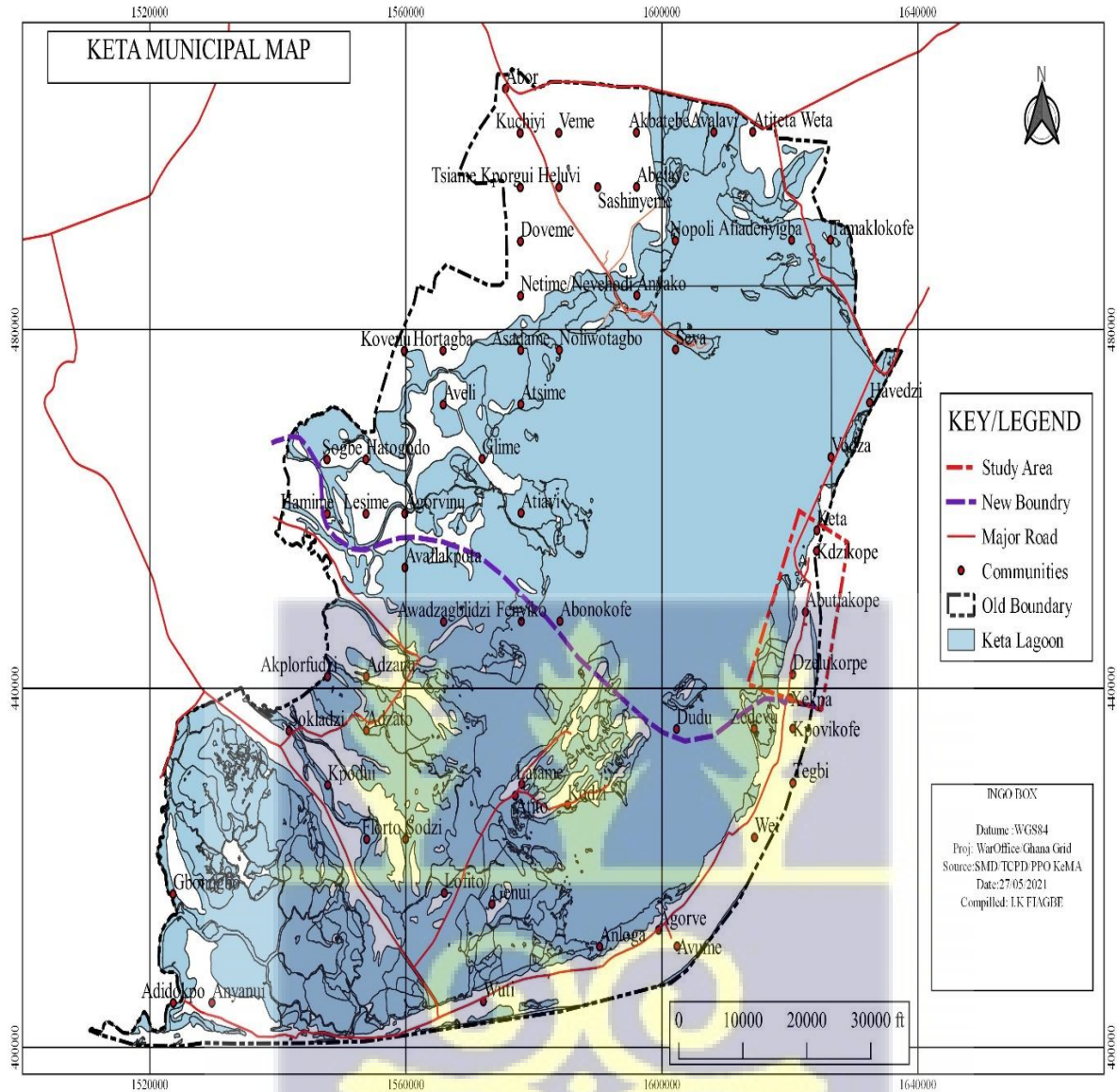


Figure 3. 1: Map of Keta Municipality showing the study area

Source: Keta Municipal Assembly Planning Office



3.3 Materials and methods

The study's methodological framework is divided into three sections; (i) key institutional stakeholders' interview, (ii) local community interview and (iii) land use land cover change analysis. Respondents' selection process targeted community households and key institutional stakeholders who are engaged in the development and ongoing management of the human and natural environment within the study area. The Keta township and Anloga District were selected for the key stakeholder's study while that of the community study focused on seven communities from the Keta township.

The selected study communities were Xekpa, Tetekorpe, Gobamodzi, Abutiakorpe, Keta, Vui, and Dzelukorpe. A total of 90 households were selected for the household study. Xekpa is a central community that shares boundaries with neither the Sea nor Lagoon. Three of the communities (Tetekorpe, Gobamodzi, and Abutiakorpe) share direct boundaries with the Sea. Two of the communities (Vui and Dzelukorpe) also share direct boundaries with the lagoon while the Keta community shares boundary with both the lagoon and the sea.

A series of key informant interviews, questionnaire surveys, and group discussions were conducted for two sets of respondents (at the local community level and the institutional management level) to canvass opinions regarding issues of climate change and management of its impacts, land use land cover change activities, and the concept of nature-based solutions to reducing coastal hazards and coastal community vulnerabilities. The time allocation for each interview and group discussion lasted between 15 minutes to one hour. Data were collected between January and June 2021.

3.3.1 Key Institutional Stakeholders interviews

Based on a reconnaissance study, observations, and interactions, key institutional stakeholders' perceptions were assessed of the Keta Lagoon Complex as a Nature-based solution for reducing

climate change-induced risks and vulnerabilities. A total of 18 key institutional stakeholder groups were chosen for the study (**Table 3.1**). The institutional stakeholders' interview guide was structured into three themes: Benefits of the Keta lagoon complex, climate-induced coastal hazards in the study area, and nature-based solutions. The interviews were also structured into nine sections and divided into three parts.

The study was based on preliminary results from 53 semi-structured face-to-face interview questions administered between February 10th and 15th, 2021. A total of 21 questions were administered to the Anloga and Keta district administration, while 16 interview questions were administered to local institutions of schools, hospitals, the hospitality industry, and NGOs. Out of the 18 institutional interviews conducted, 4 were focus group discussions whereas 14 were one-on-one interviews. The time allocation for the one-on-one interviews was 15-30 minutes while that for the focus groups lasted between 45 minutes to one hour.

Table 3. 1:Demographic characteristics of key institutional stakeholders

Stakeholder category	Communities / institutions	Participants / Positions	No. of interviewees	Stakeholders' roles in NbS design and implementation
Anloga and Keta local administrations.	1. Anloga District Coordinating Office	District Director	1	1. Work with other stakeholders in the design of NbS project 2. Manage the human-environment communication of NbS project 3. Provide information for suitable areas for projects and advocate. 4. Enforcement of the law, public education. 5. Nursery, provision, and planting of tree seedlings 6. Create awareness through health advocacy on NbS.
	2. Anloga District Social Welfare Office	Social Welfare Office	1	
	3. Anloga District Planning Office	District Planning Officer	1	
	4. Anloga D.C.E Office	District Chief Executive	1	
	5. Anloga Forestry Commission.	Forestry commission head.	1	

	6. Keta Municipal NHIS office 7. Keta Municipal Finance department 8. Keta Municipal NADMO office 9. Keta Municipal Social Welfare Office 10. Keta Municipal Planning office 11. Woe chiefs' Palace 12. Anloga District Statistician	NHIS officers Municipal Finance Director Municipal NADMO officers. Municipal Social Welfare Officer. Municipal Planning officer Chief District Statistician	3 1 4 1 1 1 1	7. Advocate, seek and facilitate funding for NbS projects 8. Coordinate disaster risk reduction. 9. Sensitization of the public and local community, education and awareness 10. Design budget for funding, provide materials. 11. Advocacy, distribution, and planting of trees. 12. Contribute to data collection and communication
Local authorities schools and hospitals	13. Keta Municipal hospital 14. Ghana Education Service 15. Keta Senior High School 16. Tegbi Health Center	Municipal hospital Superintendent Education Service Director Teachers Hospital staff	1 1 3 3	13. Enforcement of bylaws, education, and volunteering 14. Plant trees, engage in the research as education director 15. Explore education and create the awareness. 16. Serve as an advocate and take part in NbS planning.
Local authorities hospitality and NGO	17. Fort Prinzenstein 18. Keta, Butterfly Ghana Foundation NGO	Fort Prinzenstein manager NGO Manager	1 1	17. Sensitization of the public, education and awareness 18. Educate people about the role and benefits of the environment. Create awareness of NbS and particularly tree planting

Source: Fieldwork, January-May, 2021

3.3.2 Household Questionnaire study

The study employed a semi-structured questionnaire to interview ninety (90) households within the Keta township. The interviews were undertaken in seven segmented sub-communities namely

Xekpa, Tetekorpe, Gobamodzi, Abutiakorpe, Keta, Vui, and Dzelukorpe. The questionnaire sought for information on the impacts of climate change-induced hazards on households' livelihoods activities within coastal communities; and, existing local-level adaptation and mitigation options for climate change-induced hazards. Household questionnaires either require the respondents to self-fill answers or to choose between alternative answers (Likert structure). Data collection was carried out in communities within the Keta municipality. Using both random and purposive sampling techniques, approximately 10-20 households were randomly selected from each community in the Keta township.

To enable the comparison of views between different stakeholder groups, open-ended questions were administered to respondents individually and face-to-face. While eliciting a respondent's perception on a topic, clarifying and reflecting questions were asked to validate the interpretation and improve the interviewer's understanding. Additional topics introduced by the respondents were included in the analysis.

3.3.3 Land use Landcover change analysis

An accurate and up-to-date land cover change information was necessary to understand and assess land use land cover (LULC) changes in the study location. Remote sensing technologies were used to effectively record land cover situations and provide an excellent source of data, from which updated LULC information and changes can be extracted, analyzed, and simulated efficiently. The key components involved in land use land cover shift identification for this study are satellite image acquisition, ancillary data acquisition, preprocessing, image analysis, ground-truthing, and accuracy assessment. Landsat images with spatial resolutions of 30 meters were obtained for the study area for the years 2010 and 2020. For the year 2010, Landsat 7 imagery was used, and the dated imagery was obtained on the 8th of February 2010, which was corrected for scanline error.

For the year 2020, 27th January 2020 was the date of imagery used. All image acquisition and processing were carried out on the Google Earth Engine platform after which map composition was done in ArcGIS Pro. Google earth engine is an online platform that hosts lots of satellite images such as Landsat collection, Sentinel 1, Sentinel 2, MODIS, and other geospatial datasets at a planetary-scale and makes it available for scientists, researchers, and developers to detect changes, map trends, and quantify differences on the Earth's surface.

A shapefile of the study area was imported into the Google earth engine platform to clip out the specific study area from the Landsat image collections according to the respective years of interest. Going through the series of stacked images for each of the years, cloud-free images were obtained and used for the analysis.

Training samples were picked for each class within the study area. The training samples were then partitioned into 70% and 30% to serve as training and validation sets respectively. In other words, 70% of the training samples for each year were used to classify the satellite images and 30% of the same training sample also known as validation set was used to check the accuracy of the classified images. This was done to ensure that areas on the classified images were captured as the actual land cover type on the Landsat images. The type of supervised classification method used was the Random Forest classifier which consists of a combination of tree classifiers where each classifier is generated using a random vector sampled independently from the input vector, and each tree casts a unit vote for the most popular class to classify an input vector (Breiman 1999). Accuracy levels were derived after which classified images were imported into ArcGIS Pro for the creation of maps.

3.4 Data analysis

In analyzing the data from the field interviews and GIS data collected, the Statistical Package for Social Sciences (SPSS), Microsoft Word, Microsoft Excel software, and ArcMap were used. Excel was used to present the raw data into meaningful numerical information while the ArcMap was used to visualize the field data of households' interviews, land use areas, natural vegetation, and hazards prone areas.

3.5 Developing the coastal hazard map

In developing the coastal hazard map, an existing and up-to-date map of the study area was obtained. A hazard map highlights areas affected by or vulnerable to a particular hazard (oas.org, n.d.). When an area is exposed to more than one hazard, a multiple hazard map (MHM) is used to analyze all of them for vulnerability and risk. Maps can simply be defined as flat geographic portrayals of information through the use of symbols (oas.org, n.d.). A good introduction to the types and content of maps, data overlays and extractions, and land use and land cover mapping was obtained from the coastal mapping handbook (Ellis, 1978). The main purpose of MHM is to gather together in one map the different hazard-related information for a study area to convey a composite picture of the natural hazards of varying magnitude, frequency, and area of effect. An MHM may also be referred to as a “composite,” “synthesized,” and “overlay” hazard map. One area may suffer the presence of several natural hazards (oas.org, n.d.). The MHM is an excellent tool to create awareness of communicating and mitigating multiple hazards. It becomes a comprehensive analytical tool for assessing vulnerability and risk, especially when combined with the mapping of critical facilities. It also provides a more equitable basis for allocating disaster planning funds; stimulates the use of more efficient, integrated emergency preparedness response and recovery procedures; and promotes the creation of cooperative agreements to involve all

relevant agencies and interested groups (oas.org, n.d.). Studies by Kockelman and Brabb (1979) on the use of earth-science information by city, county, and regional planners and decision-makers in the San Francisco Bay region of the United States showed that the most effective use of hazard information is achieved when maps depict the likelihood of occurrence, location, and severity. The climate-induced hazards selected for this study were floods, erosion, high tide, and stormwater. A base map and scale appropriate to the study area upon which to place the listed hazards was obtained. The initial map may also serve as an index to more detailed hazard maps. The hazard map provided three elements; location, the types of hazards, and the severity of information of the identified hazards. Appropriate hazard information was obtained from various sources identified in books, detailed surveys, and photographs. Symbols were used to represent realities on the ground. Appropriate symbols were selected to convey a sense of the hazard. Locations were shown through the use of basic geometric symbols; a point, a line, or an area. The severity of hazards was shown as points, although lines are more often used. Areas were presented as shaded, pattern, or coloured.

3.7 Developing the nature-based solution maps

A recent review by the Sustainable Development Solution Network (SDSN) shows that national climate strategies do not integrate maps even though they are necessary to promote nature-based solutions. For this study, the nature-based solution map has the following key attributes: name of community and project, type of multi-hazards, a short description of the hazard, hazard category (s), and type of disaster risk reduction or nature-based solutions. The outcome or design of the nature-based solution map depends on the design of the hazard map of the entire study area. Communities found to be impacted by one or more hazards on the hazard map have an appropriate

NbS as a disaster risk reduction or mitigation option. The two maps are designed in a manner that enables an overlay of the two maps at any particular point in time. The NbS map contains natural disaster risk reduction solutions such as tree planting, planting grass for green space, citing of ponds, planting of mangroves, and so on.



CHAPTER FOUR (4)

RESULTS

4.0 Introduction

The purpose of this chapter is to examine and present the findings from all interviews and surveys conducted in seven communities within the Keta township. The results are presented and data analyzed under the study's objectives. The chapter is divided into two parts. The first part discusses the types and impacts of climate-induced hazards on households, and local level adaptation in the study communities. The second part of this chapter presents spatiotemporal and GIS assessments of land use land cover change in the study communities. The first part of chapter four presents a description of the general household and community demography, the types and impacts of climate-induced hazards on coastal households and communities, the types of local-level adaptation, and mitigation options used by households to minimize their vulnerability with evidence of NbS therein.

The second part of chapter four presents the findings from land use landcover change assessment and GIS study of the seven communities. It is divided into the discussion of the types of nature-based solution options for reducing coastal hazards, perceived values of the Keta lagoon as a nature base solution, and an assessment of climate-induced hazard situations in the study communities. The chapter also presents results on the design of nature-based solution maps based on the types of coastal hazards identified in the study communities.

4.1 Social survey

This section examines the findings from various interviews undertaken for the household's study. The first part looks at the results from the household questionnaire survey which focused on interviewees' perceptions of the most common climate induced coastal hazards and the extent of

climate-induced hazards and overall impacts in the Keta township. The second section assesses the type of local-level adaptation measures used by households, whereas the final section elaborates on the views and knowledge of households and institutional stakeholders on the use and reliance of nature-based solutions for adapting to the hazards induced by climate change.



Plate 4. 1: Selected study communities and locations within the Keta township

Source: Fieldwork, January-May, 2021



4.1.1 Socio-demographic characteristics of households

4.1.1.1 Respondents' Gender

The majority of respondents (54%) were females. The remaining (46%) were males

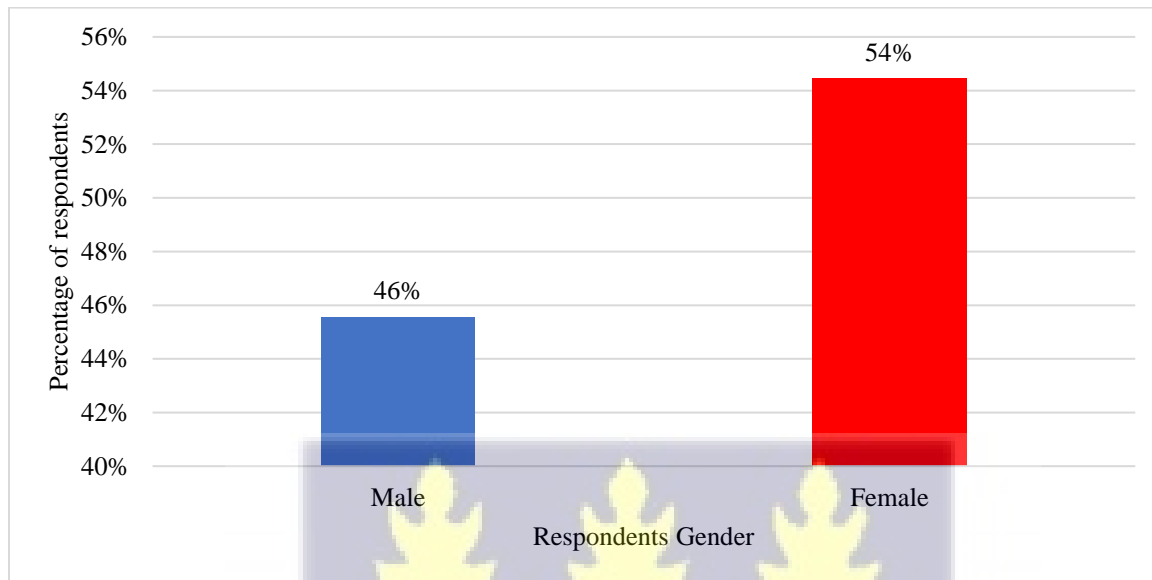


Figure 4. 1: Households' gender

Source: Fieldwork, January-May, 2021

4.1.1.2 Respondents Occupation

In terms of the occupational status of respondents, the study revealed that fishing and its related activities are the most dominant economic activity of the study district. This group of respondent accounts for 40% of the entire study population. Trading ranks next for the most dominant economic activities representing 19% of all activities undertaken by people in the community. Other equally important occupations of the respondents include crop farming (13%), artisans (7%), and others (2%). Respondents who are in the formal sector constitute (9%) of the study population. The number of unemployed and retired respondents who took part in the study account for 10% of the study (Figure 4.2).

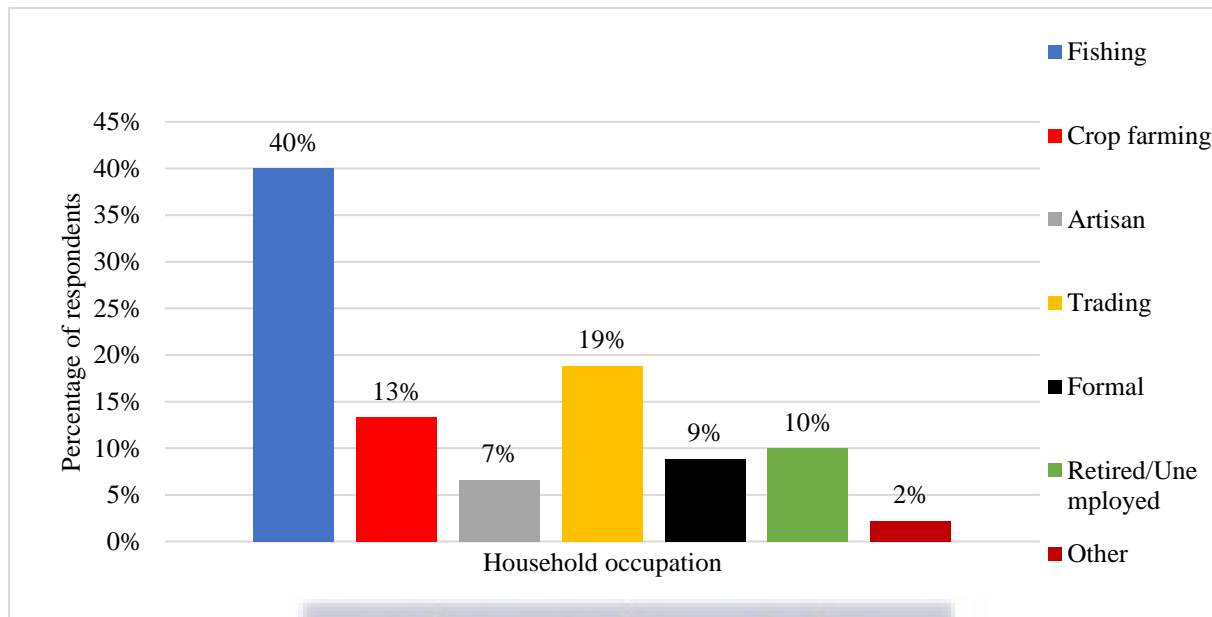


Figure 4. 2: Study households' occupation

Source: Fieldwork, January-May, 2021

4.1.1.3 Respondents Age distribution

In terms of age distribution, the study respondents fell within all age groups of the study which represents ages 21-80 years. An assessment of the age distribution of the respondents from the study shows that the majority (47%) belonged to the 41-50 age group. This was followed closely by 31-40 age groups (37%). The average age distribution of the study participant was 15. The age groups 21-30 and 71-80 formed the minority of the respondents interviewed. This represents a total of 3% of the entire study population (**Figure 4.3**).

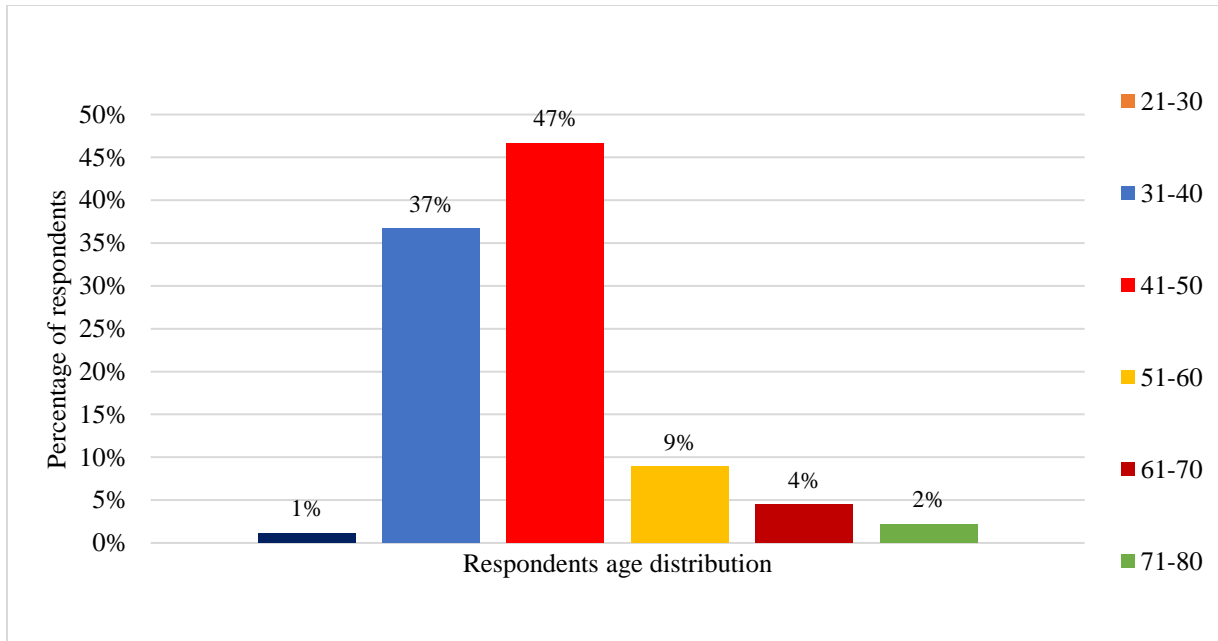


Figure 4. 3: Households' age distribution

Source: Fieldwork, January-May, 2021

4.1.1.4 Respondents duration of stay in the township

An assessment of how long each respondent of the study has stayed in the district revealed that the majority of respondents 62 (68%) have lived in the districts for more than seven years. This is followed closely by 23 (26%) who have stayed in the district for about 4-6 years. Only 5(6%) of the entire study participants have stayed in the district for less than 4 years (**Figure 4.4**).



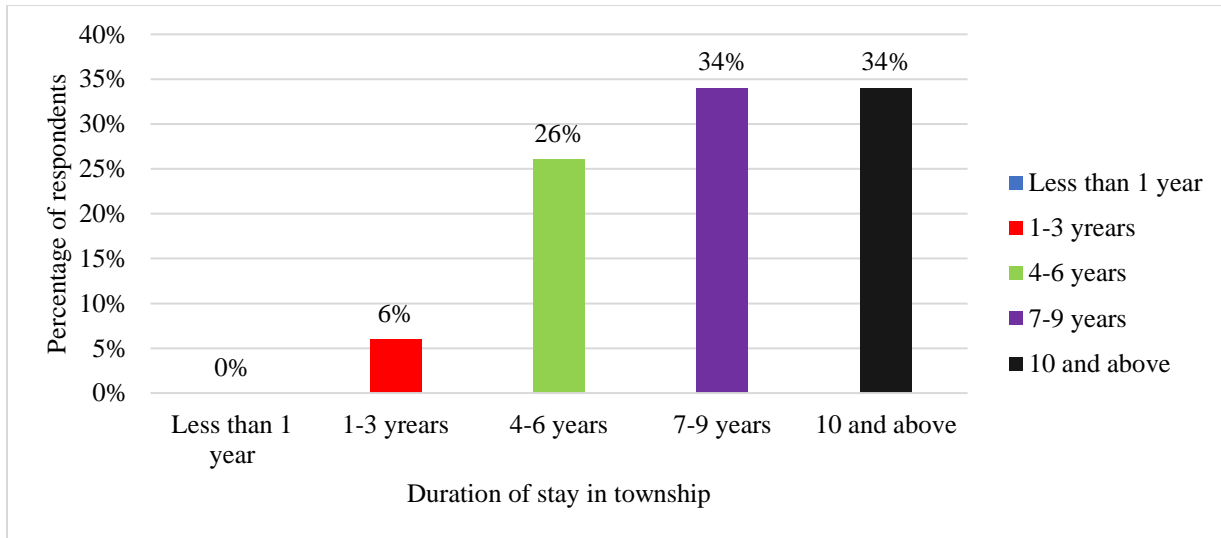


Figure 4. 4: Household’s duration of stay in the Keta township

Source: Fieldwork, January-May, 2021

4.1.1.5 Households residential status

In terms of the residential status of study participants, over half of the respondents (56%) lived in family homes whereas the remaining participants, 44% owned their own homes or lived in inherited properties from family members. There were no respondents who lived in a rented apartment for the study (**Figure 4.5**).

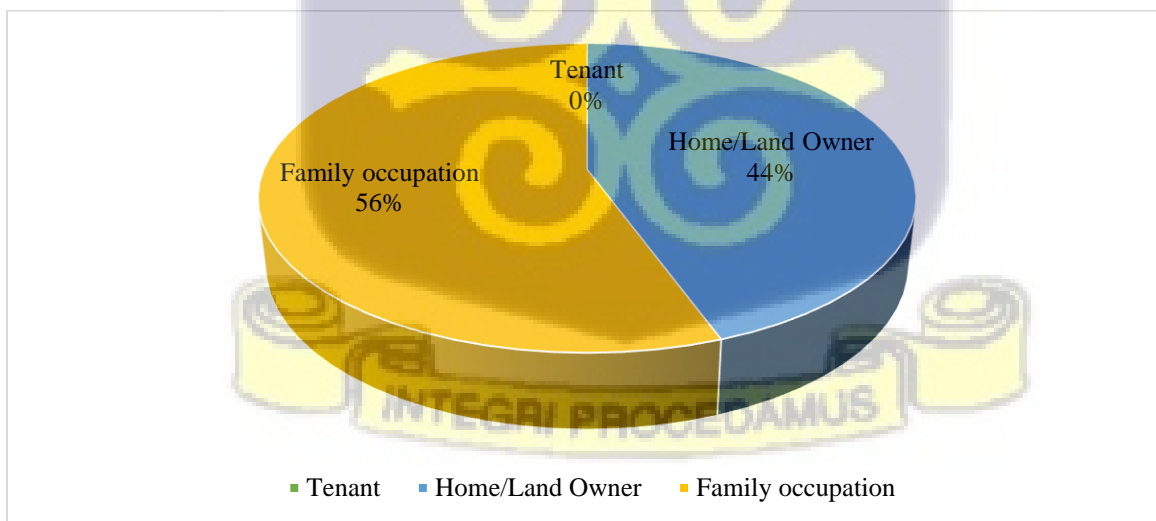


Figure 4. 5: Household residential status

Source: Fieldwork, January-May, 2021

4.2 Trends and impacts of climate change-induced hazards on households

4.2.1 Most common climate-induced coastal hazards

In this study, households from each of the study communities in the Keta township were asked to identify the most common climate-induced hazard they are exposed to and their frequency of occurrence (**Table 4.1**).

Table 4. 1: Most common hazards in Keta

Community	Climate-induced hazard							
	Flood		Erosion		High tide		Stormwater	
	N	%	N	%	N	%	N	%
Xekpa	7	15	3	12	0	0	0	0
Tetekorpe	6	13	0	0	4	25	0	0
Gobamodzi	3	7	4	16	2	13	1	33
Abutiakorpe	1	2	2	8	7	44	0	0
Keta	11	24	7	28	2	13	0	0
Vui	8	17	4	16	0	0	1	33
Dzelukorpe	10	22	5	20	1	6	1	33
Total	46	100	25	100	16	100	3	100

N: Number of respondents %: Percentage of respondents

Source: Fieldwork, January-May, 2021

Overall, flooding is the most common climate-induced hazard according to households interviewed (51%). The second most common hazard is erosion (28%), followed by high tides (18%), and lastly stormwater (3%).

In the case of flooding, the respondents from Keta (24%), Xekpa (15%), Tetekorpe, and Vui (17%) respectively, flooding is the most common hazard in their communities. Respondents from Dzelukorpe (22%) also identified flooding as a common hazard in their community. The occurrence of floods was mostly a result of heavy rains during the rainy seasons and the overflow of the Keta lagoon due to spillage of the Akosombo dam.

The next hazard identified in the district as most common is erosion. Respondents from Gobamodzi (16%) identified erosion as the most common hazard in their community. Flood was ranked next as a common hazard by (7%) of the study participants from Gobamodzi. Other communities where erosion is identified as a common hazard are Keta (28%), Vui (16%), and Dzelukorpe (20%).

Respondents from Abutiakorpe (44%) recognized high tides as the most common climate-induced hazard in their community. Almost half of the respondents from Tetekorpe (25%) also identified high tides as a common hazard in the community.

The occurrence of stormwater in the Keta district was less significant. According to the majority of the respondents (33%) from all the study communities, stormwater was not as common as other hazards in the district. **Figure 4.6** provides a graphical representation of the responses from the study communities.

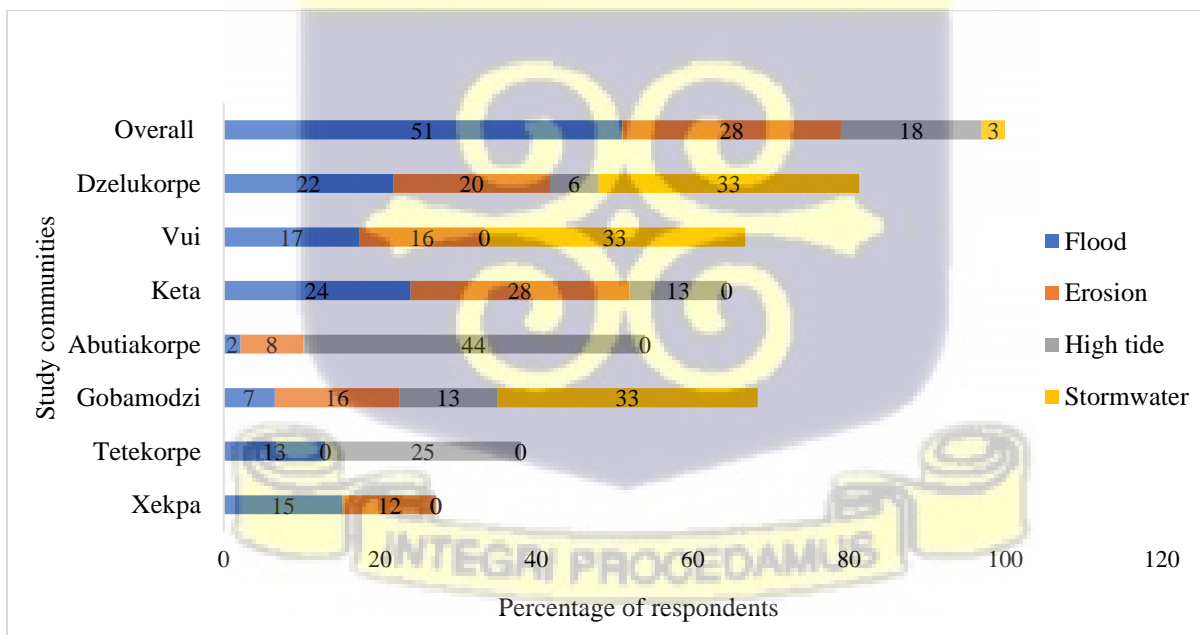


Figure 4. 6: Most common hazards in Keta

Source: Fieldwork, January-May, 2021

A chi-square test was performed to establish if differences between data were due to changes or a relationship between the variables. **Table 4.2** shows the p-values calculated for the four likely climate-induced coastal hazards in the Keta district.

Table 4. 2: Chi-square values table for most common climate-induced coastal hazards

Types of Hazards	P. Vales	Likelihood ratio p-value (LRPV)
Flood	0.227	0.853
Erosion	0.243	0.750
High tide	0.260	0.597
Stormwater	0.321	0.144

Source: Fieldwork, January-May, 2021

Results show p-values >0.05 for all hazards in the township. However, the likelihood ratio shows that flood (0.853) is more likely to occur in the district, followed closely by erosion (0.750) and subsequently by high tides (0.597). Stormwater is less likely with an LRPV of (0.144)

4.2.2 Extent of climate-induced coastal hazards in Keta township

In addition to identifying the most common hazards in the study communities, the study asked respondents to describe the extent of these hazards over the past five years of their stay in the communities. Respondents provided their views on whether the assessed hazards had increased, decreased, unchanged or they are unsure.

Flooding: In the case of flood extent in the Keta township, 15% of respondents from Xekpa believe it has remained unchanged. Respondents from Tetekorpe (17%) described the extent of flood in the community as unchanged over the past five years. 15% of the respondents from Gobamodzi believe the extent of flood has decreased. According to respondents from Abutiakorpe, 12% believe floods have remained unchanged. In the Keta community, 20% of the respondents believe the extent of floods has remained unchanged. Results from the two lagoon communities of the study revealed that over half of the respondents from Vui (33%) confirmed the extent of floods

has increased over the past five years while flooding has also increased according to 38% of respondents from Dzelukorpe (**Figure 4.7**).

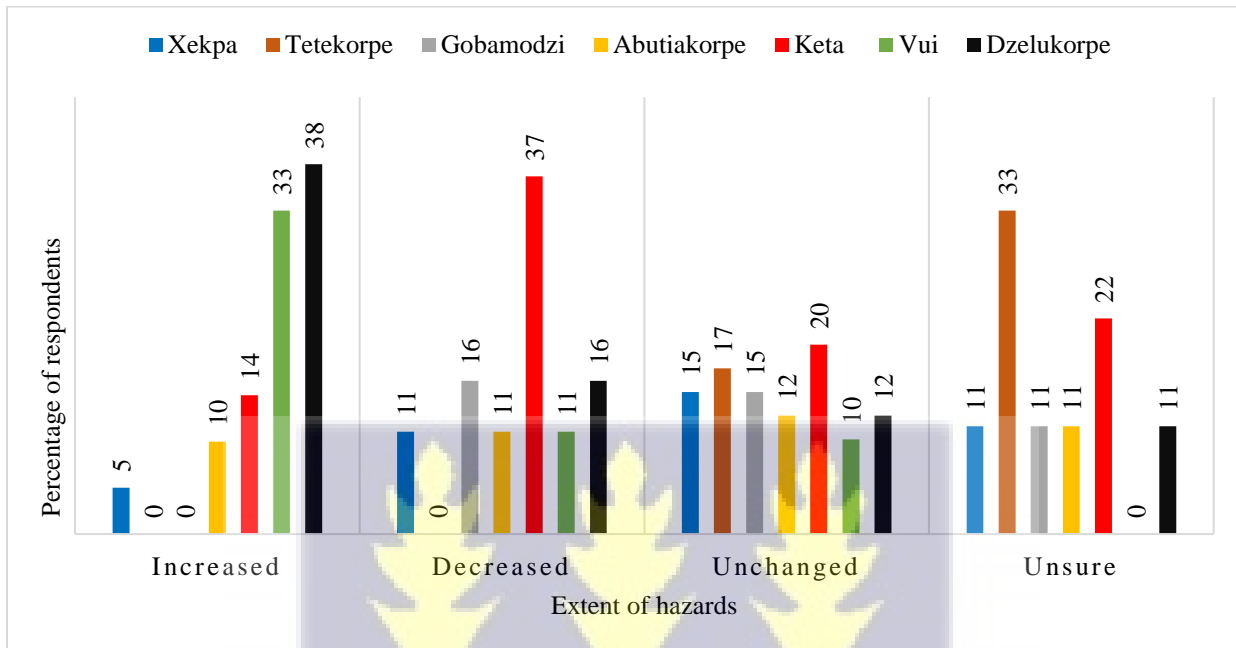


Figure 4. 7: Extent of floods in Keta township

Source: Fieldwork, January-May, 2021

Erosion: In the case of erosion for the township, 31% of the respondents from Xekpa believed erosion has increased in frequency of occurrence within the past five years. Respondents from Tetekorpe (25%) also described the extent of erosion in the community as increased. 15% of the respondents from Gobamodzi believe the extent of erosion has remained unchanged. Respondents from Abutiakorpe (31%) believe the extent of erosion has increased over the past five years. 23% of the respondents from Keta believe the extent of erosion has remained unchanged. 16% of respondents from Vui also reported erosion has remained unchanged while a majority (26%) from Dzelukorpe also believes erosion has remained unchanged over the period (**Figure 4.8**).

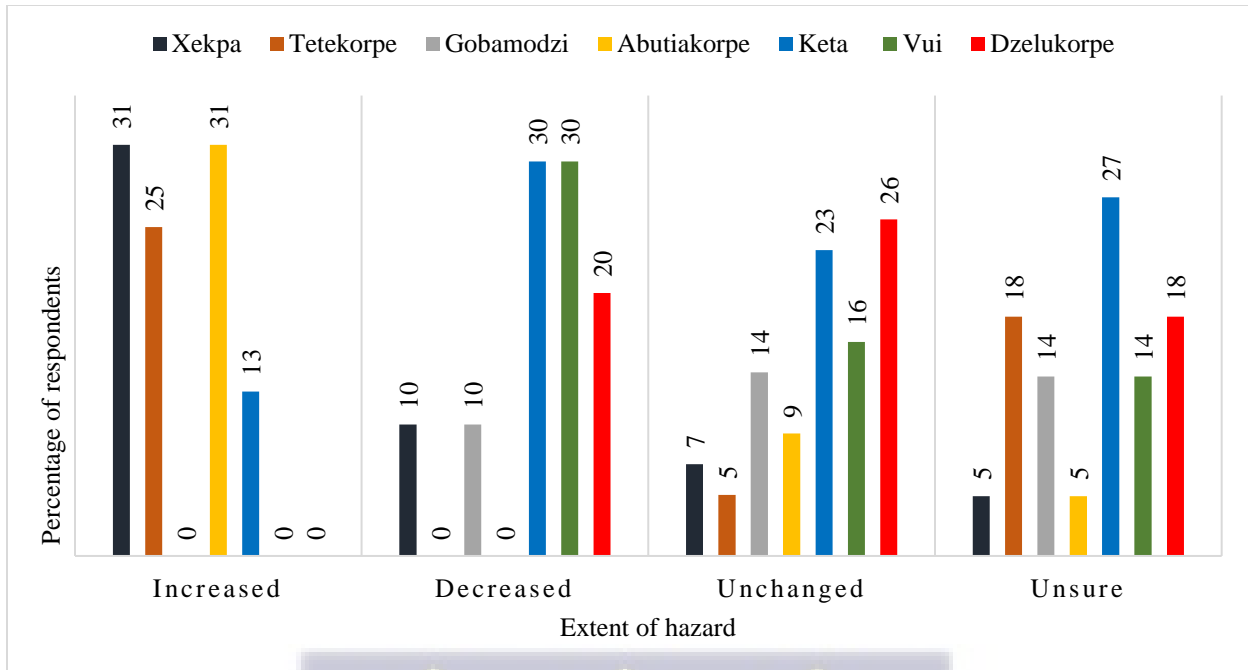


Figure 4. 8:Extent of erosion in Keta township

Source: Fieldwork, January-May, 2021

High tides: In the case of high tides extent in the Keta township, the majority of the respondents (41%) from Xekpa were not sure of the extent of high tides because these hazards were not identified within their community. 12% of the respondents from Tetekorpe said high tides have decreased over the past five years. Respondents from Gobamodzi (16%) identified high tide as having decreased. The extent of high tides has also decreased according to 12% of the respondents from Abutiakorpe. 27% of respondents from Keta said hightide had decreased. 12% of respondents from Vui confirmed the extent of hightide has decreased over the past five years while for Dzelukorpe, (20%) of the respondents believe the extent high tides have also decreased (**Figure 4.9**).

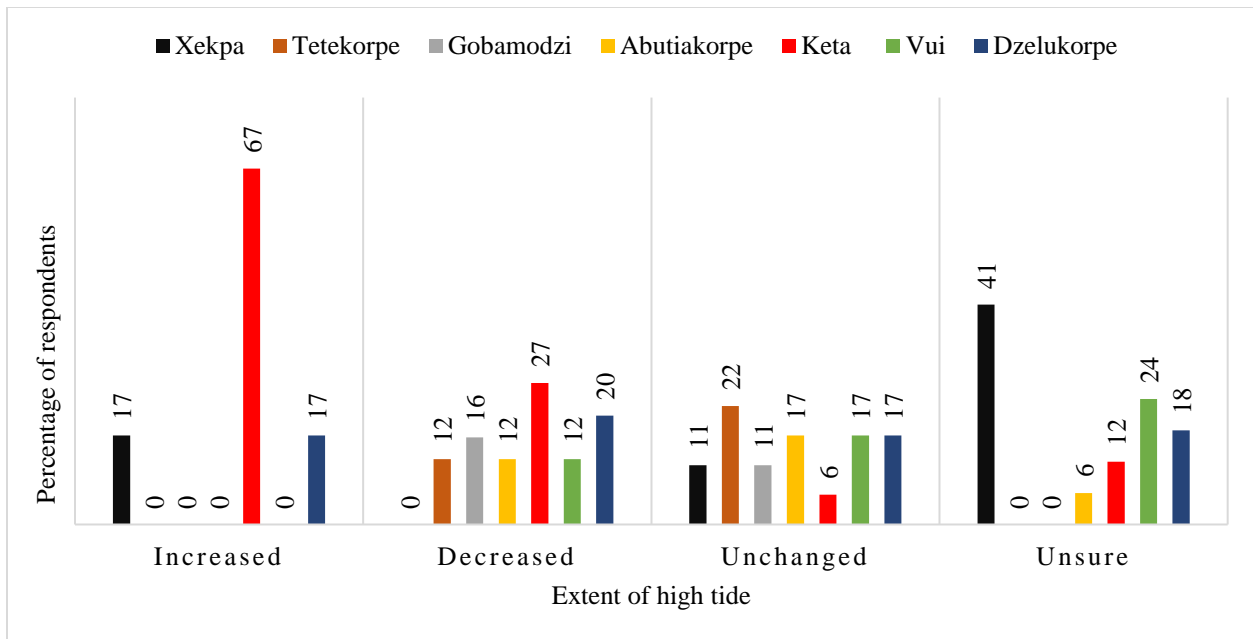


Figure 4. 9: Extent of high tides in Keta township

Source: Fieldwork, January-May, 2021

Stormwater: The majority of respondents from Xekpa (41%) were not certain about the extent of high tides in the Keta township over the past five years. A large number of the respondents from Tetekorpe (20%) were not certain of the extent of stormwater as only a few of the respondents said the hazard has remained unchanged over the period. The extent of stormwater in Gobamodzi has remained unchanged over the period according to (18%) of the respondents from the community although almost half of the respondents (10%) were not sure of its extent. Respondents (13%) from Abutiakorpe are also not certain of the extent of stormwater. In the case of the above-mentioned communities, 28% of respondents from Keta were also not certain of the extent of stormwater in their community. 33% of the respondents from Vui confirm stormwater has decreased over the same period while in Dzelukorpe stormwater has also decreased in the community as supposed by 43% of the respondents (**Figure 4.10**).

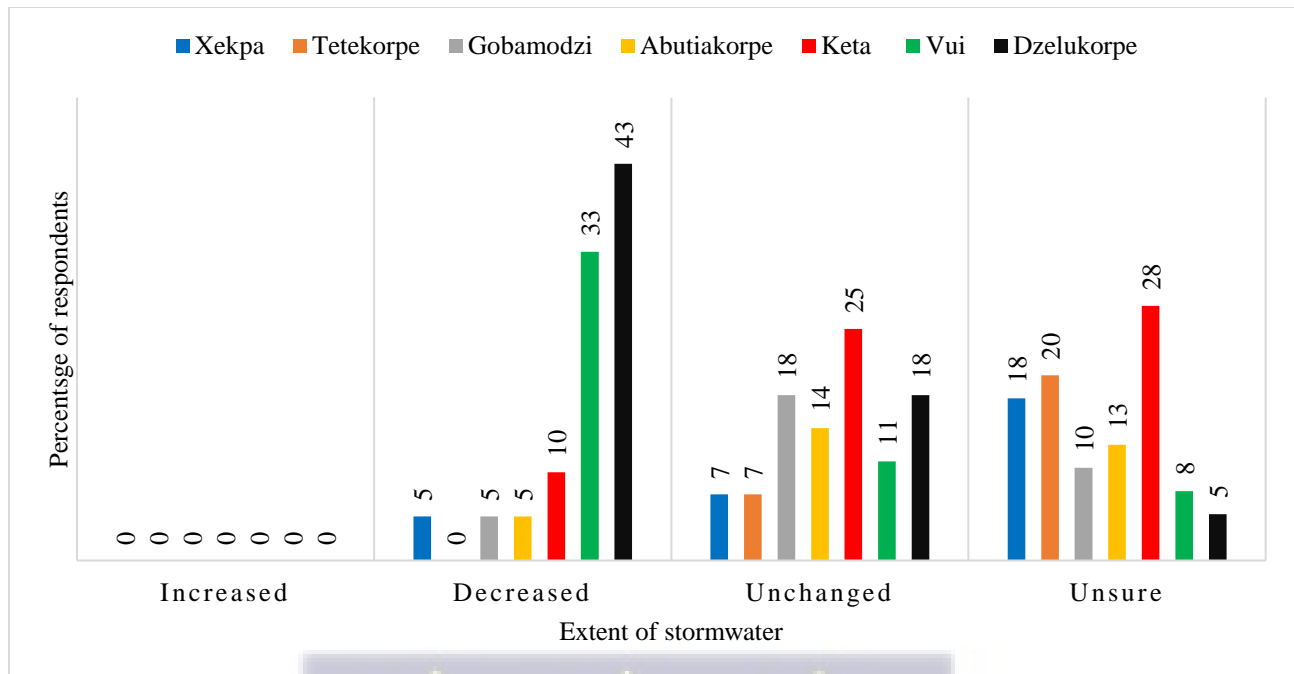


Figure 4. 10: Extent of stormwater in Keta township

Source: Fieldwork, January-May, 2021

The study examined the probability values of the extent of climate-induced hazards in the study district over the past five years. Table 4.3 shows the p-values for the results.

Table 4. 3:Probability values table for the extent of climate-induced coastal hazards in Keta

Extent of hazards over 5yrs	P.Values	Likelihood ratio p-value (LRPV)
Increased	0.261	0.212
Decreased	0.213	0.270
Unchanged	0.213	0.270
Unsure	0.238	0.216

Source: Fieldwork, January-May, 2021

Results show that the p-values for the extent of climate-induced coastal hazards of the Keta district are >0.05 (**Table 4.3**). This indicates that the extent of hazards in the district had likely decreased or remained unchanged with a likelihood ratio of (0.270)

4.2.3 Impacts of climate-induced hazards on households and properties

This section presents the impact of climate-induced coastal hazards within the seven selected study communities of the Keta township. This part of the study sought to identify the number of

households that have relocated or became homeless as a result of flood, erosion, high tides, or stormwater occurrence within their communities. The two impacts areas assessed were the displacement of households (**Table 4.4**) and the destruction of properties (**Table 4.5**).

From the results, displacement by climate-induced hazards was reported by all households across the study communities. The majority of the reports were from Dzelukorpe (25%), followed by Keta (21%), Vui (18%), and Tetekorpe (18%) for flood-driven displacement in the township. Xekpa households reported the least (3%) as far as displacement is concerned. Flooding was reported by the majority of interviewees (38%) as the climate-induced hazard most responsible for displacing households in the Keta township. High tide was reported as the second hazard causing displacement in the study area (30%). Erosion (18%) and stormwater (14%) were reported as the third and fourth hazards, respectively responsible for displacement in the study area.

At the community level, Dzelukorpe households experience flood-driven displacement (25%) than any of the studied communities. Keta (21%), Vui (18%), and Tetekorpe (18%) households are also severely impacted by flood-driven displacement. Erosion-driven displacement is reported more by the households in Keta (31%), followed by residents in Dzelukorpe (19%).

Table 4. 4: Does climate-induced hazards result in the displacement of households in Keta township?

Community	Climate-induced hazards							
	Flood		Erosion		High tide		stormwater	
	N	%	N	%	N	%	N	%
Xekpa	1	3	0	0	2	7	0	0
Tetekorpe	6	18	2	13	5	19	1	8
Gobamodzi	3	9	2	13	4	15	1	8
Abutiakorpe	2	6	2	13	5	19	1	8
Keta	7	21	5	31	7	26	4	31
Vui	6	18	2	13	2	7	3	23
Dzelukorpe	9	25	3	19	2	7	3	23
Total	34	100	16	100	27	100	13	100

Source: Fieldwork, January-May, 2021 N: Number of respondents %: Percentage of respondents

From the results, the destruction of properties by climate-induced hazards was reported by almost all households across the study communities. The majority of the reports were from Dzelukorpe (30%), followed by Keta (20%), Vui (23%), and Tetekorpe (18%) for flood-driven destruction of properties in the township. Xekpa households reported no data as far as the destruction of properties is concerned. High tide-related disasters were reported by the majority of interviewees (46%) as the climate-induced hazard most responsible for destroying households' properties in the Keta township. Flood was reported as the second hazard destroying properties in the study area (44%). Erosion (32%) and stormwater (20%) were reported as the third and fourth hazards, respectively responsible for destroying properties in the study area.

At the community level, Dzelukorpe households experience flood-driven destruction of properties (30%) than any of the studied communities. Keta (20%), Vui (23%), and Tetekorpe (18%) households are also severely impacted by flood-driven disasters. Erosion-driven destruction of properties is reported more by the households in Keta (31%), followed by residents in Dzelukorpe (21%). Communities like Keta (32%) and Dzelukorpe (39%) also experienced major high tide and stormwater-driven disasters for the destruction of properties in the studied area.

Table 4. 5: Does climate-induced hazards result in destruction of properties in Keta township?

Community	Climate-induced hazards							
	Flood		Erosion		High tide		stormwater	
	N	%	N	%	N	%	N	%
Xekpa	0	0	2	7	3	7	1	6
Tetekorpe	7	18	2	7	5	12	0	0
Gobamodzi	3	8	1	3	5	12	0	0
Abutiakorpe	1	3	4	14	7	17	0	0
Keta	8	20	9	31	13	32	5	28
Vui	9	23	5	17	3	7	5	28
Dzelukorpe	12	30	6	21	5	12	7	39
Total	40	100	29	100	41	100	18	100

Source: Fieldwork, January-May, 2021 N: Number of respondents %: Percentage of respondents

Table 4. 6:Probability values of climate-induced coastal hazards displacement of households

Displaced households	P.Values	Likelihood ratio p-value (LRPV)
Yes	0.186	0.112
No	0.485	0.264
Unsure	0.512	0.276

Source: Fieldwork, January-May, 2021

Table 4. 7:Probability values of climate-induced coastal hazards destruction of properties

Destroyed properties	P.Values	Likelihood ratio p-value (LRPV)
Yes	0.243	0.750
No	0.227	0.853

Source: Fieldwork, January-May, 2021

4.2.4 Impacts of flood and erosion on households and communities

This part of the study sought to identify the number of households that have been impacted by flood and erosion-driven climate-induced hazards in the Keta township. Six impacts of the hazards were assessed in the communities; these include the impacts of floods (**Figure 4.11**) through the destruction of farmlands, displacement of residents, and cause of death. The impacts of erosion (**Figure 4.12**) assessed were the destruction of buildings, roads, and the reduction of soil quality.

4.2.4.1 Floods-driven climate-induced impacts on households and community

From the results, flood-driven climate-induced impacts were reported by almost all households across the study communities. The majority of the reports were from Keta (35%), followed by Dzelukorpe (17%), Vui (13%), and Tetekorpe (17%) for flood-driven causes of death in the township. Xekpa households reported no data as far as cause of death is concerned. The second impact of flood-driven hazard was reported by the majority of interviewees in Xekpa (11%), Tetekorpe (16%), Keta (20%), Vui (18%), and Dzelukorpe (21%) as the climate-induced hazard most responsible for destroying farmlands in the Keta township.

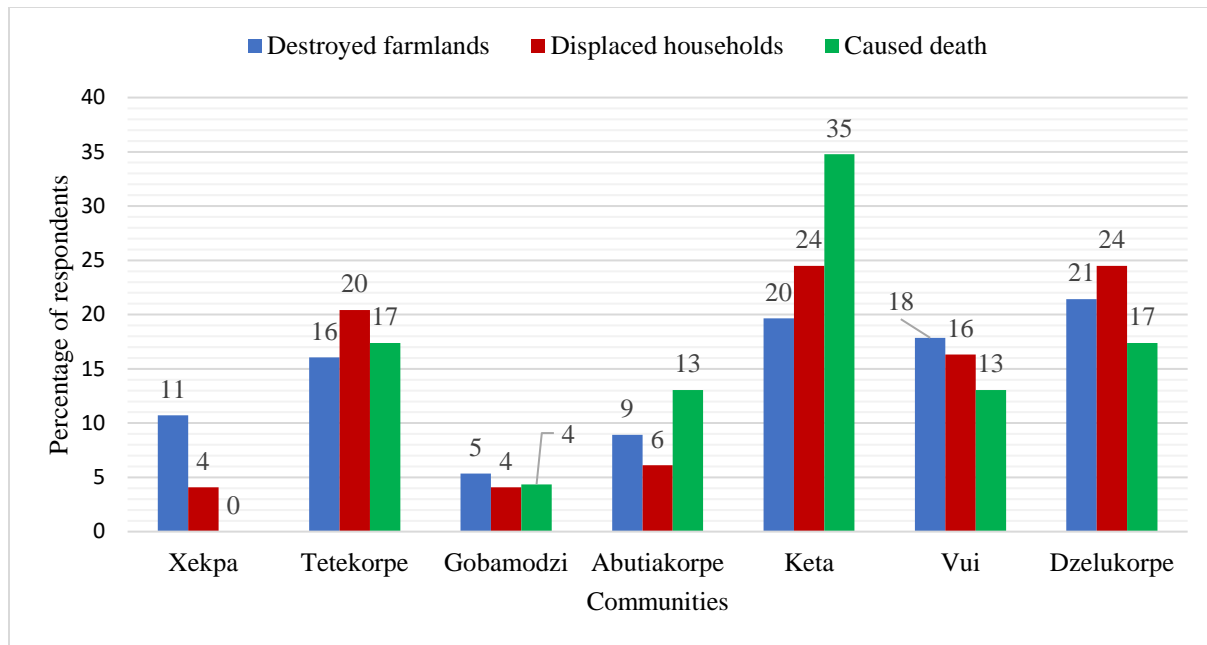


Figure 4. 11:Flood-driven impacts in the study area

Source: Fieldwork, January-May, 2021

Table 4. 8:Probability values for the impacts of floods in the Keta district

Flood impacts	P.Values	Likelihood ratio p-value (LRPV)
Yes	0.200	0.814
No	0.559	0.726

Source: Fieldwork, January-May, 2021

Results from **Table 4.8** show that the p-values for the impacts of floods in the Keta district is >0.05 . Floods impacts were more likely to occur with a likelihood ratio of (0.814).

4.2.4.2 Erosion-driven climate-induced impacts on households and community

From the results, erosion-driven impacts were reported by almost all households across the study communities. The majority of the reports were from Keta (32%), followed by Abutiakorpe (17%), Dzelukorpe (12%), and Tetekorpe (17%) for erosion-driven destruction of buildings in the township. Xekpa households reported the least (2%) as far as the destruction of buildings is concerned. Reduction in soil quality in the township is also a significant erosion-driven hazard reported by the majority of interviewees in Xekpa (11%), Abutiakorpe (13%), Keta (24%), Vui

(20%), and Dzelukorpe (25%) as the climate-induced hazard most responsible for destroying farmlands in the Keta township. Roads were also significantly impacted as reported by respondents in Keta (24%), Dzelukorpe (19%), and Vui (17%).

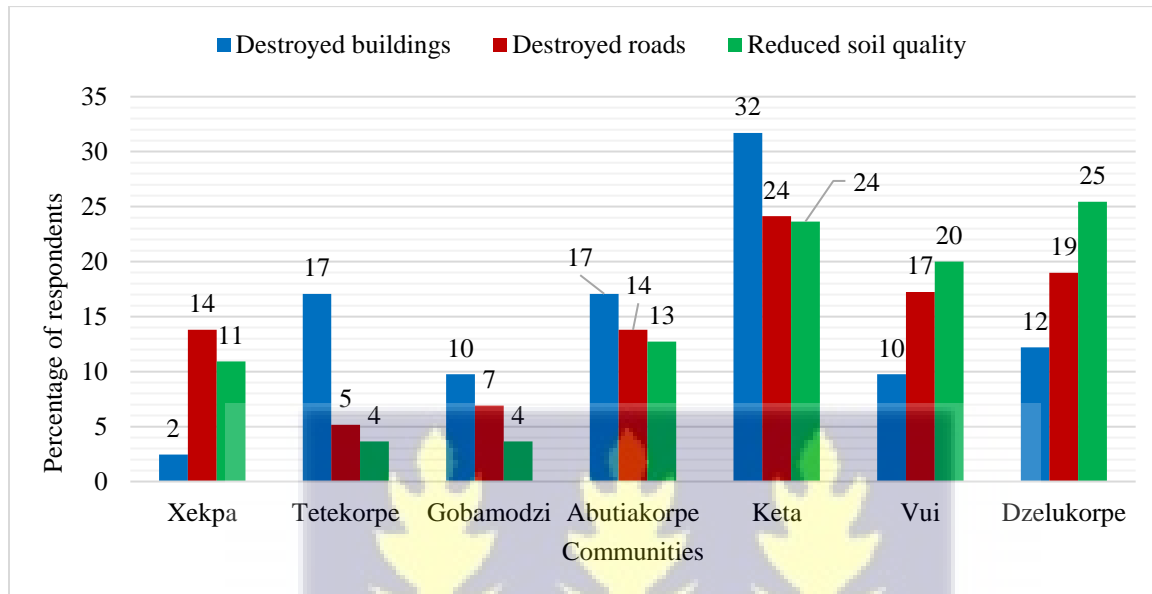


Figure 4. 12: Erosion-driven impacts in the study area

Source: Fieldwork, January-May, 2021

Table 4. 9: Probability values for the impacts of erosion in the Keta district

Erosion impacts	P.Values	Likelihood ratio P-value (LRPV)
Yes	0.420	0.926
No	0.678	0.802

Source: Fieldwork, January-May, 2021

Results from **Table 4.9** show that the p-values for the impacts of erosion in the Keta district are >0.05 . Thus, erosion impacts were more likely to occur within the district with a likelihood ratio of (0.926).

4.2.5 Impacts of high tide on households and communities.

Respondents from the study communities were asked to describe some major impacts of high tides in their communities and the district in general. Over the last decade, Kporkporbor, Fuveme, Dzita, Gavedzi, and Xorvi have been among the communities most endangered by rising tidal

waves that have destroyed physical infrastructure (Boateng, 2009). Many past events of high tides were narrated by the study respondents. These impacts of high tide affected the study communities in varied ways. Respondents from the lagoon communities benefited mostly from the rising tides.

“In the past, the frequent experience of high tides destroyed many properties and caused people to move away from the sea especially residents of the Keta community. However, when the tides were high, communities around the lagoon benefited most because excess water from the sea was channeled into the lagoon which improved the fish stock and other aquatic life which the community benefited from. Things have changed over the past years where excess water from the sea was channeled into the lagoon for these things to be realized” (Respondent of Xekpa).

According to another respondent from the Tetekorpe community, the Keta township experienced severe waves and tides in the past. *“Any time we experienced high tides in the past, the excess seawater would flood our homes and even come unto the roads and remain there for many days. Many public and private properties were abandoned in the process as many of the residents here moved far away from the sea. That structure you see there was a public toilet that has been destroyed by high tides and abandoned by the residence. There are many other residential properties along this community which people do not stay in anymore. (A fisherman from Tetekorpe).*

Plate 4.2 is an abandoned public structure in the Tetekorpe community. According to respondents in the community, the structure was the only public lavatory that served many of the residents. Due to the impacts of frequent high tides in the community in the past, the structure was abandoned.

Plate 4.3 is also a damaged structure in the Keta community situated very close to the sea. As a result of frequent high tide and erosion in the past, the structure was affected.



Plate 4. 2:An abandoned public structure in Tetekorpe
Source: Fieldwork, January-May, 2021



Plate 4. 3:A damaged structure in Keta
Source: Fieldwork, January-May, 2021

4.2.6 Climate change-induced hazards influence on biodiversity

The study assessed the impact of climate-induced coastal hazards on biodiversity in the Keta township. Respondents of the study were asked to describe any changes they have observed in plants and animal species in their communities. The changes in the timing of plants and animal species were also investigated. The study also assessed how these observed changes have impacted the lives of the study respondents.

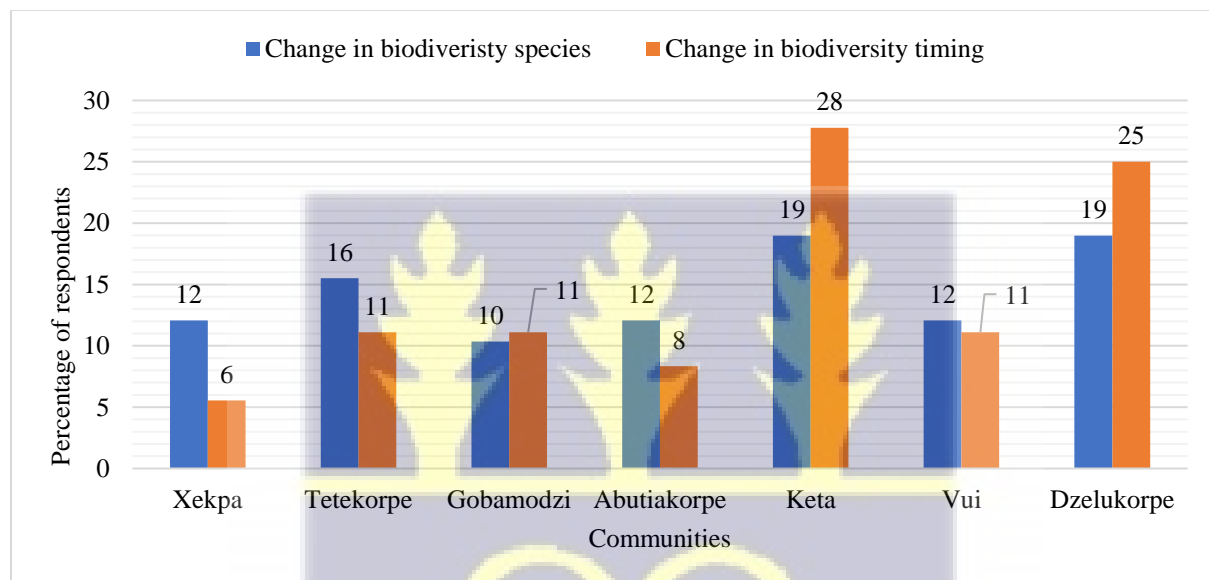


Figure 4. 13: Climate-induced hazard influenced on biodiversity

Source: Fieldwork, January-May, 2021

Results show that (Figure 4.13), 12% of the respondents from Xekpa have noticed changes in the existence of plants and animals while 6% have also observed changes in the timing of certain crops and animal species. According to one of the respondents, the pawpaw fruit is not easily available because the plants were not easily cultivated in their community. In addition, there has also been a reduction in the amount and types of fish caught from the lagoon and sea over the period especially during most times of the year. Most of the respondents from Tetekorpe (16%) have also observed changes in the existence of certain plants and animal species in their community over the

years. 11% of the respondents have observed changes in the timing of crops and animal species. However, more than half of the respondents did not notice any changes in the timing of plants and animal species. Respondents from Gobamodzi (10%) have observed changes in the existence of plants and animal species while (11%) have also observed changes in the timing of certain crops and animal species. In the Abutiakorpe community, 12% of the respondents have noticed changes in the existence of certain plants and animal species while 8% have also observed changes in the timing of certain crops and animal species. A significant number of respondents, 19% and 28% from Keta have observed changes in the existence of certain plants and animal species, and their timing respectively in the community over the period. About 12% and 11% of respondents have observed changes in the existence of certain plants and animal species, and their timing in the Vui community over the years. In addition, over half of the study respondents from Dzelukorpe, 19% and 25% have observed changes in the existence of certain plants and animal species, and the timing respectively over the years.

Results show that (Table 4.10), the p-values for the changes in plants or animals' species existence in Keta are > 0.05 . The likelihood ratio for the certainty in changes of biodiversity in Keta is (0.464) Yes, (0.236) No, and (0.597) Unsure.

Table 4. 10:P-Values of changes in plants or animals' species existence in Keta

Changes in plant and animal species	P.Values	Likelihood ratio p-value (LRPV)
Yes	0.279	0.464
No	0.301	0.236
Unsure	0.260	0.597

Source: Fieldwork, January-May, 2021

Results show that the p-values for the changes in the timing of crops or animals' species existence in Keta are >0.05 (Table 4.11). The likelihood ratio for the certainty in changes of biodiversity timing in Keta is (0.659) Yes, (0.464) No, and (0.597) Unsure.

Table 4. 11:P-Values of changes in the timing of crops or animals' species in Keta

Changes in timing of crop or animal species	P.Values	Likelihood ratio p-value (LRPV)
Yes	0.260	0.659
No	0.279	0.464
Unsure	0.260	0.597

Source: Fieldwork, January-May, 2021

4.3 Existing local-level adaptation and mitigation options and evidence of nature-based solution therein.

In light of the frequency and extent of climate-induced coastal hazards identified in the study communities and their impacts on biodiversity, the study assessed the types of local level adaptation used by respondents over the years to reduce their vulnerability. Respondents were first and foremost asked to identify adaptation measures implemented by their local assembly to reduce the impacts of flood, erosion, high tide, and stormwater in their communities. A reconnaissance study of key institutional stakeholders in the Keta township and Anloga district showed that several factors were hindering the implementation of certain projects in the district and township.

The respondents were also asked about specific adaptation methods they would prefer most from a list of adaptations to reduce the impacts of floods, erosion, high tide, and stormwater in their communities. In the process of discussion, participants were allowed to propose adaptation measures they would prefer most apart from the various options proposed by the study for each hazard.

4.3.1. Existing local adaptation measures

According to results from households' survey and observations (**Figure 4.14**), the filling of compound with sea sand is reported to be the most common adaptation measure used by locals over the years to reduce their vulnerability to flooding in Xekpa (26%), Tetekorpe (16%), Gobamodzi (21%), and Keta (21%) and other related problems in the district. According to the

majority of respondents, this measure is also effective in reducing rainwater runoff and erosion. It absorbs large amount of water and allows it to drain into the soil easily. The filling of compound with sea sand is applied in almost every home of the study communities.



Plate 4. 4: Filling of the compound with sea sand

Source: Fieldwork, January- May 2021.

Another common adaptation measure that has existed and adopted by most of the respondents in addressing the issue of flood-related disasters within their communities is the creation of holes in their fences (**Plate 4.5**) (**Figure 4.14**). This was reported by respondents in Xekpa (12%), Tetekorpe (10%), Gobamodzi (9%), Abutiakorpe (11%), Keta (21%), Vui (13%), and Dzelukorpe (20%) to let out excess water from floods, high tides, and heavy rains.





Plate 4. 5: Local Adaptation method to reduce flood impacts in Vui

Source: Fieldwork, January- May, 2021.

Evidence from community observation shows that some of these households are no longer using this method and have begun sealing these holes. The issue of high tides in the township especially in communities that shared direct boundaries with the sea has been addressed using two common methods over the years; moving away from the affected community during high tides and the use of inexpensive and non-permanent materials during construction. **Plate 4.6** contains two images, a part of the Gobamodzi community comprising of a cluster of over ten family residents. Image one is an outer view of the homes' fence while image two is an inner view of one of such properties.



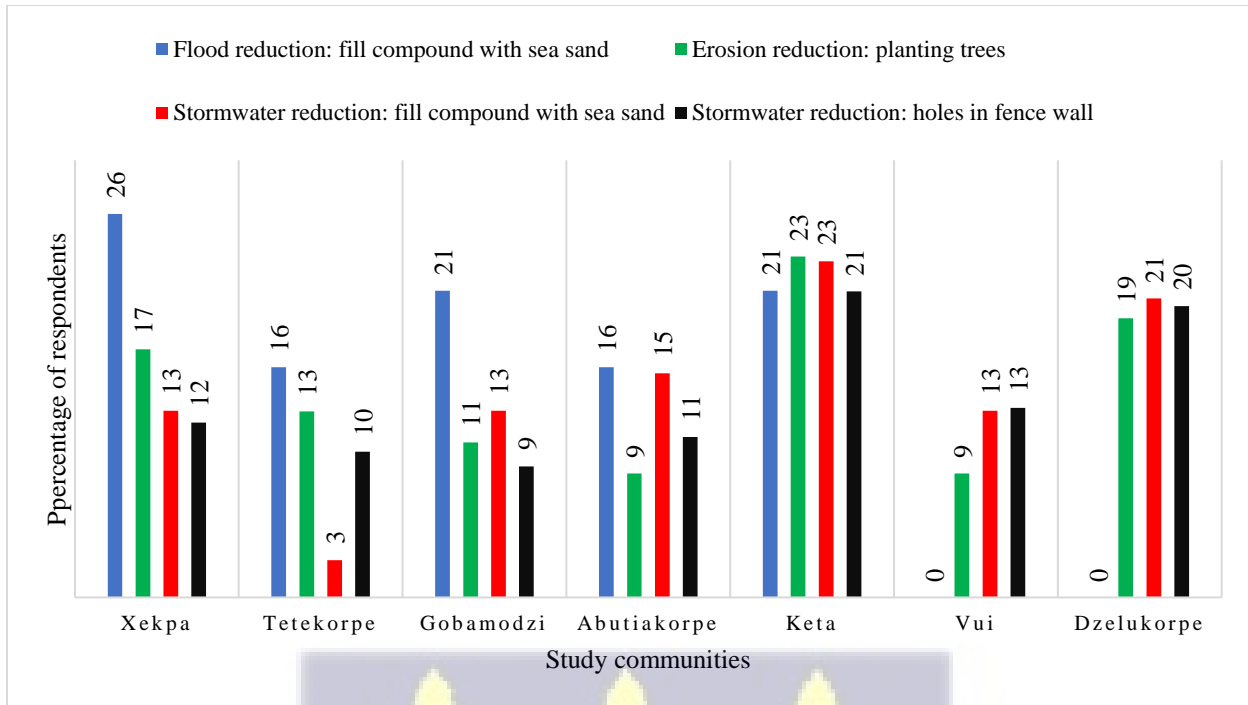


Figure 4. 14: Existing local adaptation methods in Keta township

Source: Fieldwork, January- May, 2021.





Source: Fieldwork, January- May, 2021.

Plate 4. 6: Adaptation to reduce high tide impact in Gobamodzi

4.3.2 Preferred Adaptation measures in Keta township

For the study, floodwater transfer, floodproofing of buildings, and floodwater storage were the options provided for the respondents to choose. Dredging of the lagoon and filling of compounds with sea sand were other adaptation methods proposed by the participants. From the results the majority of the reports preferred floodwater transfer (37%), followed by floodproofing of buildings (26%), filling of compound with sea sand (21%), and floodwater storage (7%) to reduce flood-driven hazards in the Keta township.

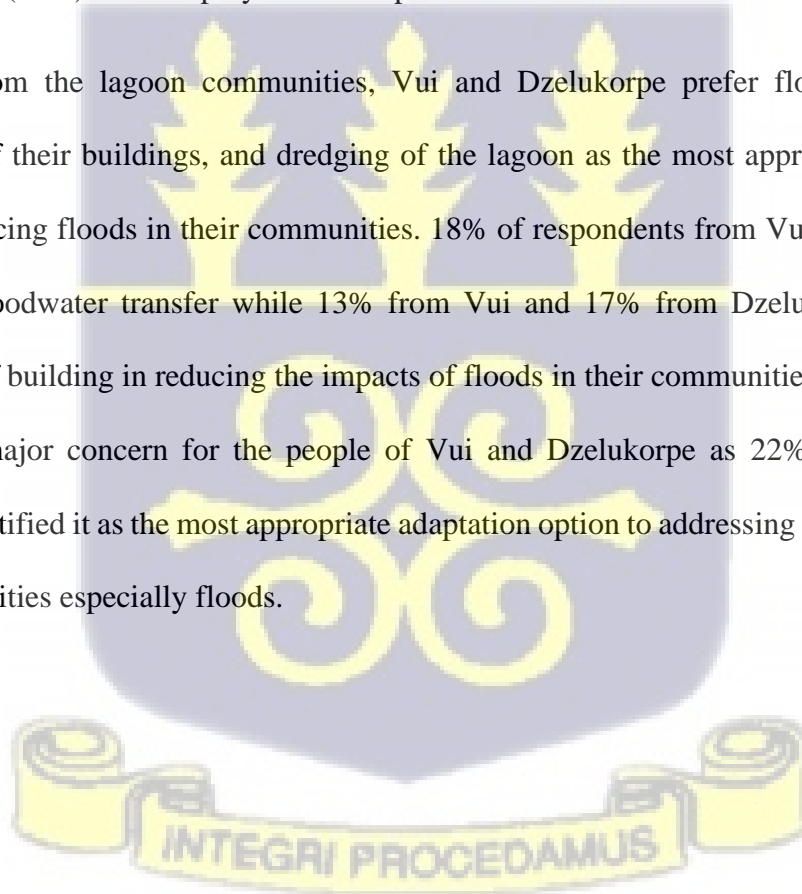
4.3.2.1 Preferred adaptations to reduce flood impacts

Results show that (Figure 4.15), respondents from Xekpa, 6% and 13% preferred floodwater transfer and floodproofing of buildings respectively for reducing the impact of flooding in their community. 26% of the respondents proposed the filling of their compound with sea sand as an

adaptation measure to reduce the impact of flooding. This has been a common adaptation method used over the years to address several challenges in their homes and communities.

According to the participants from Gobamodzi (15), Abutiakorpe (15%), and Keta (27%), floodwater transfer is the most preferred and convenient adaptation method to reduce flooding in their communities. Aside from Abutiakorpe and Gobamodzi, respondents of Tetekorpe (17%), and Keta (35%) also prefer floodproofing of building as an adaptation to flooding in their communities. Almost all the communities in the study rely on filling their compounds with beach sand to reduce flooding impacts. About 16% of the respondents from Tetekorpe, Gobamodzi (21%), Abutiakorpe (16%), and Keta (21%) have employed this adaptation method on their facilities.

Respondents from the lagoon communities, Vui and Dzelukorpe prefer floodwater transfer, floodproofing of their buildings, and dredging of the lagoon as the most appropriate adaptation options for reducing floods in their communities. 18% of respondents from Vui, and Dzelukorpe (15%) prefer floodwater transfer while 13% from Vui and 17% from Dzelukorpe also prefer floodproofing of building in reducing the impacts of floods in their communities. Dredging of the lagoon was a major concern for the people of Vui and Dzelukorpe as 22% and 56% of the participants identified it as the most appropriate adaptation option to addressing several challenges in their communities especially floods.



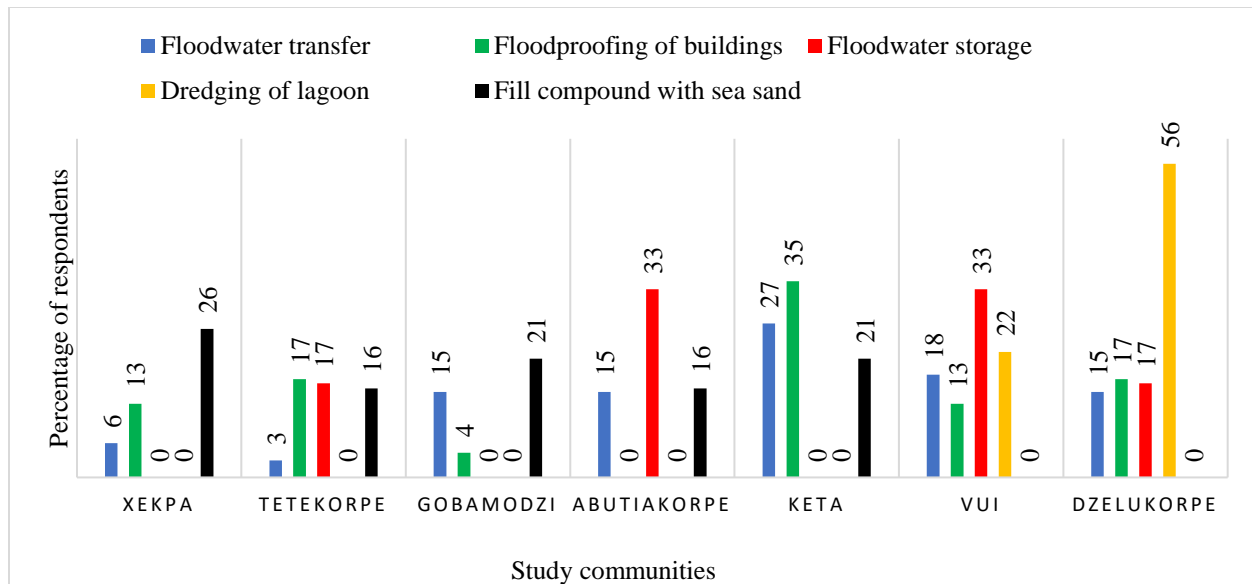


Figure 4. 15:Preferred adaptation methods for reducing flood impacts

Source: Fieldwork, January- May, 2021.

Results show that the p-values for preferred adaptation methods for flood reduction in the Keta district are >0.05 (Table 4.12). Thus, the likelihood ratio for the choice of floodwater transfer is (0.659), floodproofing of buildings (0.597), and dredging of the lagoon (0.516). Filling of the compound with sea sand was preferred at a p-value of 0.396.

Table 4. 12: P-values for preferred adaptation method of flood reduction in Keta

Preferred flood adaptation	P.Values	Likelihood ratio p-values (LRPV)
Floodwater transfer	0.260	0.659
Floodproofing of buildings	0.260	0.597
Floodwater storage	0.301	0.236
Dredging of lagoon	0.301	0.516
Fill compound with sand	0.279	0.396

Source: Fieldwork, January-May, 2021

4.3.2.2 Preferred adaptations to reduce erosion impacts

In addition, respondents of the study were assessed on specific adaptation methods they would prefer to reduce the occurrence of erosion in their communities (Figure 4.16). For the study, planting trees, planting mangroves, and planting grass were the options provided for the respondents to choose. Filling of the compounds with sea sand was another adaptation method

proposed by the respondents. From the results the majority of the reports preferred planting of trees (52%), followed by planting mangroves (24%), filling of compound with sea sand (22%), and planting grass (12%) to reduce erosion-driven hazards in the Keta township.

For erosion reduction, results show that 17% of the participants from Xekpa, 13% from Tetekorpe, 11% from Gobamodzi, 9% from Abutiakorpe, 23% from Keta, 9% from Vui, and 19% from Dzelukorpe have planted trees in their compounds and prefer this adaptation to reduce erosion, provision of food, shade, and so on. Participants from Gobamodzi (9%), Abutiakorpe (18%), Keta (23%), Vui (32%), and Dzelukorpe (18%) communities suggest the planting of mangroves along the coast, in and around the lagoon to reduce erosion.

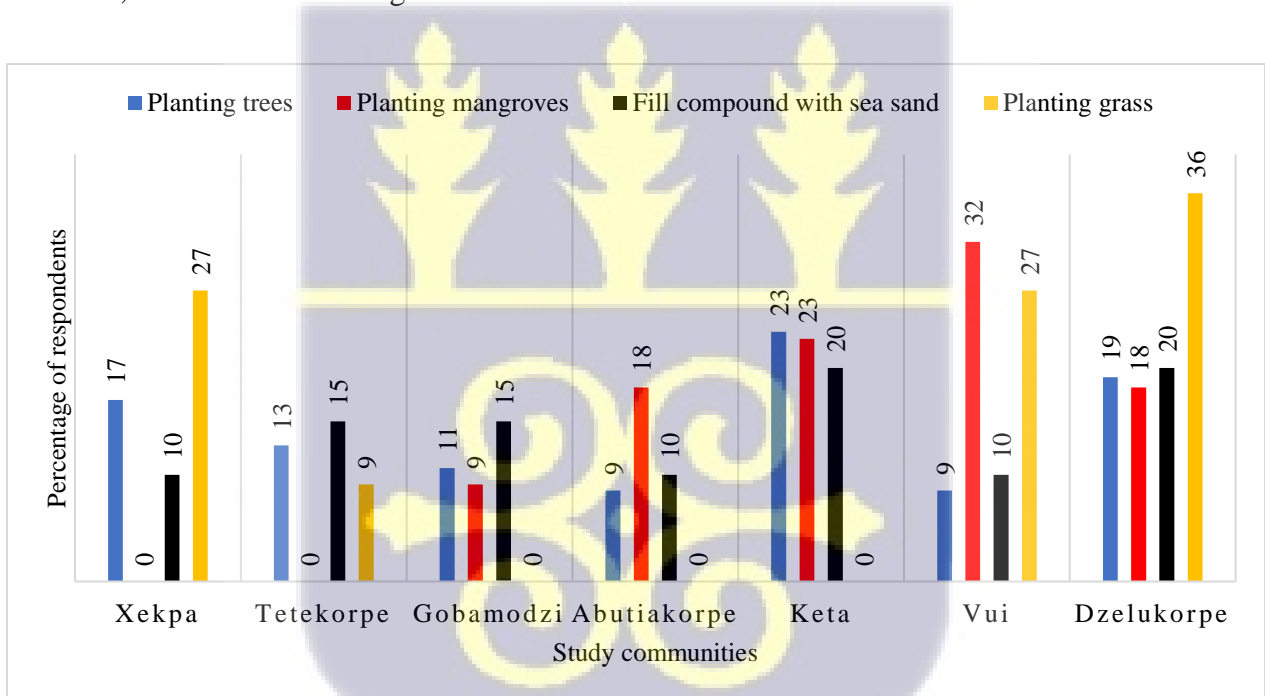


Figure 4. 16: Preferred adaptation methods for reducing erosion impacts

Source: Fieldwork, January-May, 2021



Plate 4. 7: Local Adaptation method for erosion reduction

Source: Fieldwork, January- May, 2021.

Results show that the p-values for preferred adaptation methods for erosion reduction in the Keta district are >0.05 (Table 4.13). Thus, the likelihood ratio for the planting of trees and mangroves in the district is (0.597). Planting of grass has a likelihood ratio of (0.453). Drainage construction and building seawall are less likely for the district.

Table 4. 13: P-values for preferred adaptation method of flood reduction in Keta

Preferred erosion adaptation	P.Values	Likelihood ratio p-value (LRPV)
Planting of trees	0.260	0.597
Planting of mangroves	0.260	0.597
Drainage construction	0.321	0.212
Planting of grass	0.321	0.453
Building seawall	0.321	0.144

Source: Fieldwork, January-May, 2021

4.3.2.3 Preferred adaptation to reduce high tides impacts

For the study, the raising of building level, building small dikes, and construction of floodgate were the measures provided to reduce high tide impacts. From the results, the majority of the reports from the township preferred small dikes (42%), followed by construction of floodgates (30%), and lastly raising of housing level (28%) to reduce hightide-driven hazards in the Keta township (**Figure 4.17**). Very little to nothing has been done on the part of most households concerning adaptation to the impact of high tides. Several reasons were attributed to the lack of local-level adaptation to high tides.

At the community level, a few of the respondents from Xekpa suggest the raising of housing level (8%), building small dikes (8%), and construction of flood gates 19% respectively to reduce high tide impacts in their communities and township.

The following respondents from Tetekorpe (13%), Gobamodzi (16%), and Abutiakorpe (16%) preferred the construction of small dikes to reduce the impacts of high tides. The raising of building level was not preferred much within the two communities because of the cost of adaptation involved. The existing adaptation option for high tide in these communities was to move inland during high tides. Many of them also used non-permanent structures in constructing their buildings. Similar activities were also done in Keta to reduce their vulnerability to high tides.

Most of the study respondents from the lagoon communities, Vui and Dzelukorpe also preferred the construction of small dikes and the siting of flood gates to direct excess water from high tides into the lagoon. 16% and 15% of the respondents from Vui prefer building small dikes and floodgates while 16% and 22% of the respondents from Dzelukorpe also prefer small dikes and floodgates respectively.

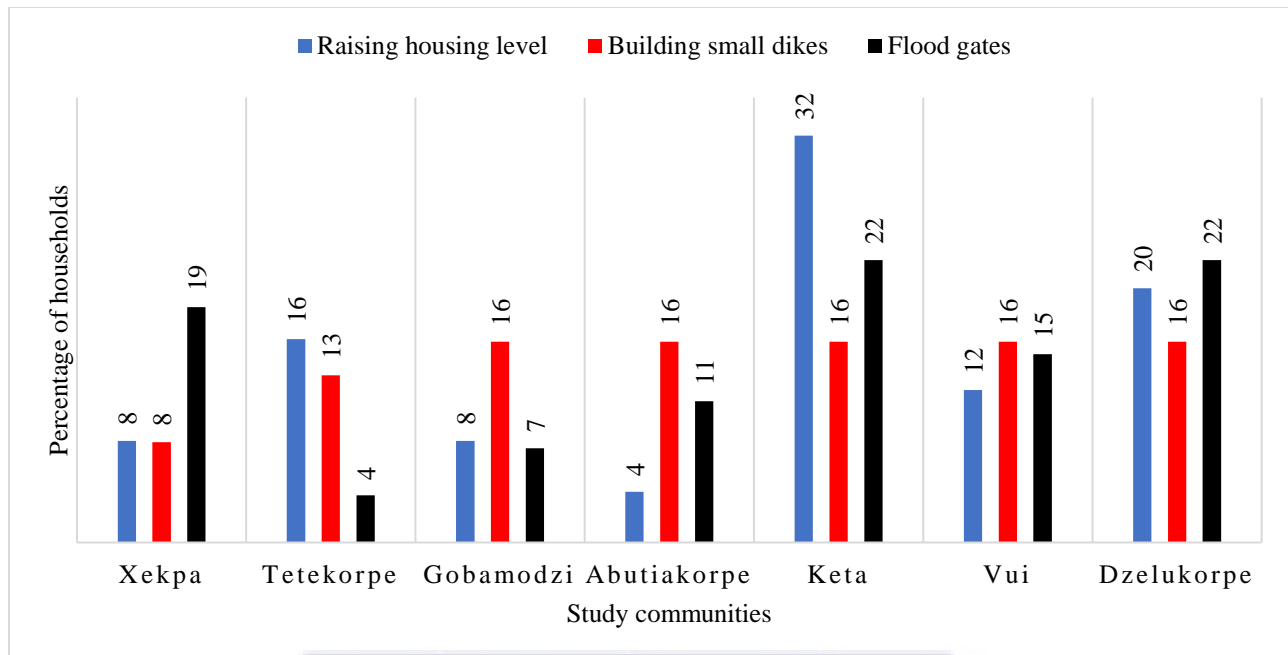


Figure 4. 17: Preferred adaptation methods for reducing high tide impacts

Source: Fieldwork, January-May, 2021

4.3.2.4 Preferred adaptation to reduce stormwater impacts

For this study, respondents were provided with the options of reducing paved areas, constructing bigger drains, and stormwater storage facilities for reducing stormwater impacts in the Keta township (**Figure 4.18**). The filling of compound with sea sand and dredging of the lagoon were proposed by respondents. From the results, the majority of the reports proposed filling their compound with sea sand (43%), reducing paved areas was preferred by (34%) of respondents followed by construction of bigger drains (13%) to reduce stormwater-driven hazards in the Keta township.

At the community level, 13% of the respondents from Xakpa have filled their compounds with sea sand to reduce stormwater impact while 13% prefer the reduction of paved areas to reduce stormwater. 8% of the participants suggested the construction of bigger drains in the community.

The limited support for the construction of bigger drains in Xekpa is a result of the issue of land scarcity and ownership for development.

Participants from the coastward communities, 23% from Tetekorfe, 13% from Gobamodzi, and 10% from Abutiakorpe prefer the idea of reducing paved surfaces to prevent the impacts from stormwater. A total of 3%, 13%, and 15% of the participants from these communities respectively have filled their compounds with sea sand.

A significant number of the participants (23%) from the Keta community have also engaged in similar activities of filling their yard with sea sand. 23% of these respondents also support the activity of reducing paved surfaces in the Keta township. The community has fewer existing drainage systems than the rest of the communities in the district. However, 33% of the participants think the construction of bigger drains will reduce the impact of stormwater in the district.

Finally, a significant number of the participants from Vui (13%) and Dzelukorpe (21%) respectively have filled their compounds with sea sand. Community observation also revealed that most of the wetlands were filled with sea sand when developing the lands for housing and other purposes. Over 80% of the respondents from the two communities think dredging of the lagoon will also address the issue of stormwater.



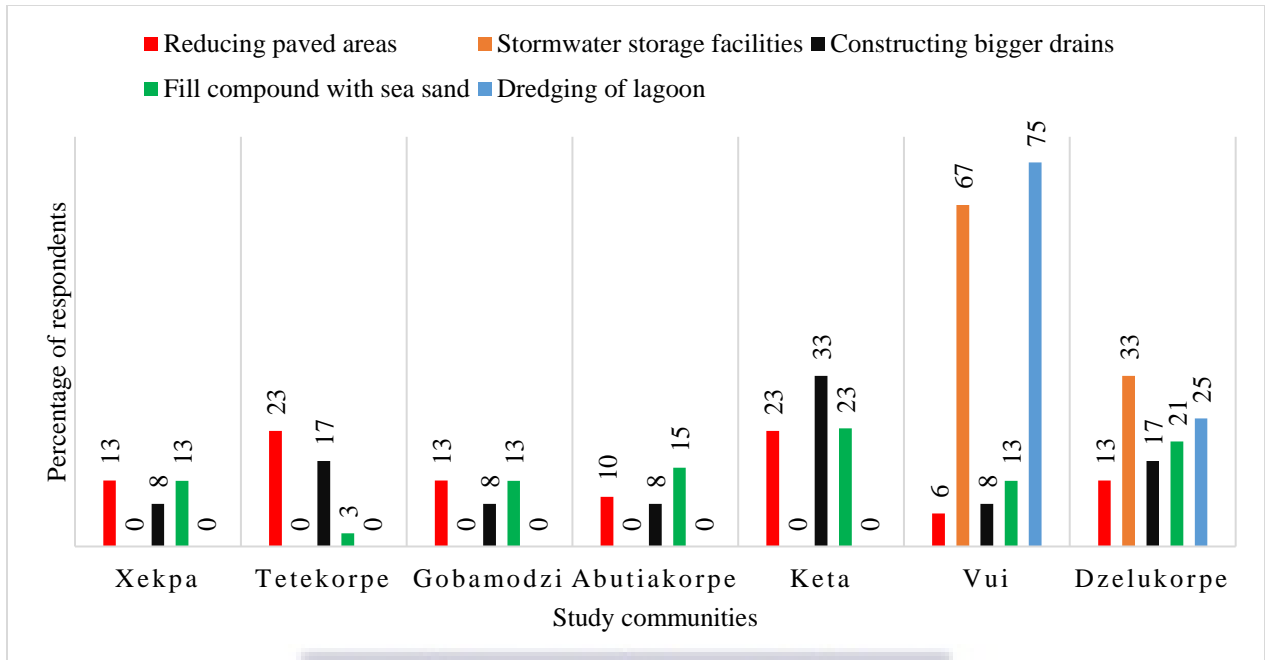


Figure 4. 18: Preferred adaptation methods for reducing stormwater impacts

Source: Fieldwork, January-May, 2021

4.3.3 Key considerations when choosing adaptation measure

The study sought to understand how cost, availability of space, availability of material, and severity of the coastal hazards affected respondents' choice of adaptation.

Respondents were asked to rank the factors in order of importance. The issue of cost was a major concern for almost all the households (84%). 69 percent of the study respondents also said the severity of the hazards influences their choice of adaptation. The availability of materials and space were major concerns for 66% and 57% of the study respondents respectively (**Figure 4.19**).



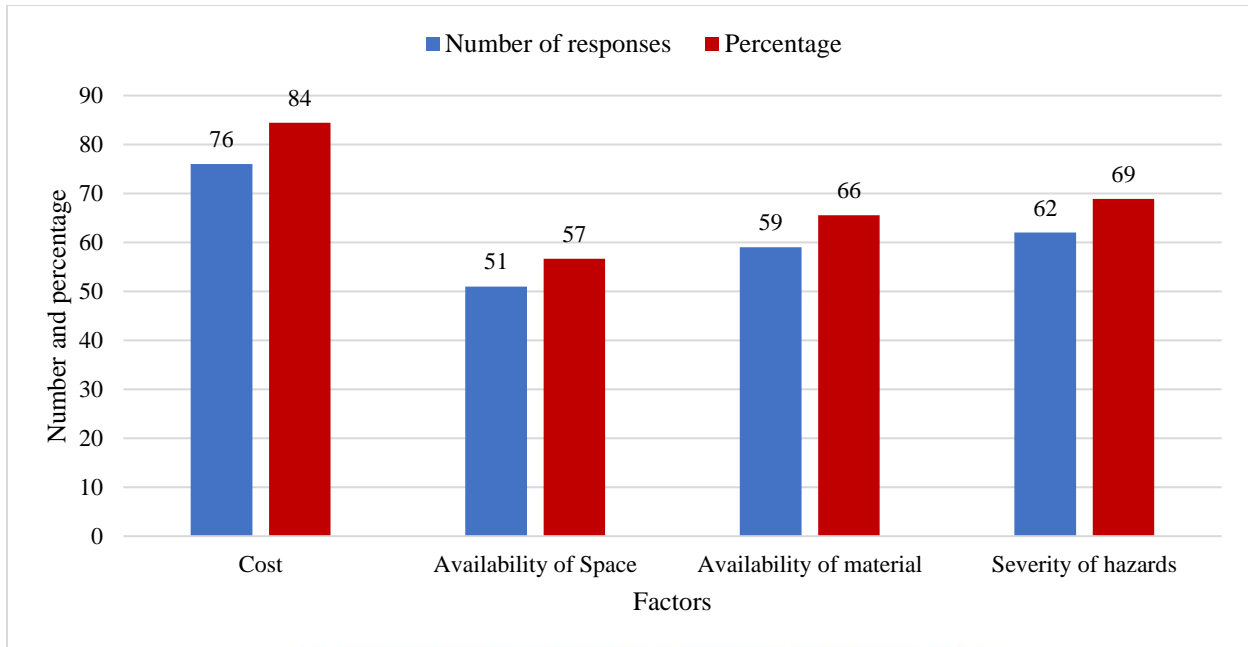


Figure 4. 19: Factors affecting choice of adaptation in Keta township

Source: Fieldwork, January-May, 2021

4.4 Extent and Degree of Households reliance on Nature-based Solutions and existing Adaptation Strategies.

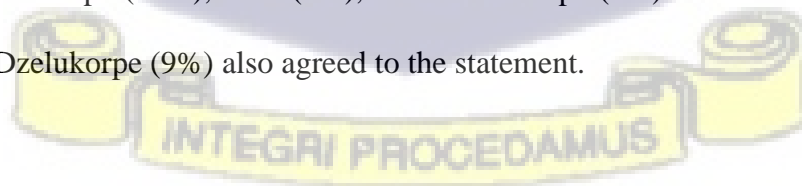
The second part of chapter four presents the result on households’ perceptions of nature-based solutions. It is structured into the following; forms of nature-based solutions to reducing climate change-induced coastal hazards in the Keta township, ecosystem services provided by the Keta lagoon, household’s level of participation in managing hazards in their communities, assessment of households’ level of participation in the designing, planning, and implementation of Nbs to reduce coastal hazards, identification of natural solutions that best qualifies as reduction mechanisms for coastal hazards, co-benefits of investing in nature-based solutions and motivation for stakeholders involvement in nature-based solutions.

The study assessed the perceptions of households on the concept of nature-based solutions for reducing the impacts of climate-induced coastal hazards. Respondents were asked to identify the benefits they enjoyed from the Keta lagoon complex as a nature-based solution. The respondents also identified natural solutions they believe best qualified as hazards reduction mechanisms for flood, erosion, high tides, and stormwater.

4.4.1 Perceived values of the Keta lagoon as a nature-based solution

The study further questioned respondents about the benefits they derived from the Keta lagoon and whether they considered the Keta lagoon resource as the most important source of NbS. A large number of the study respondents confirmed seven ecosystem services provided by the keta lagoon complex. According to the study respondents, the lagoon provides them with protein, water for construction, leisure, protection from floods, improving air quality, cooling of the communities, and water quality regulation.

To assess the level of importance of the Keta lagoon to the communities, the study examined how strongly households agreed with the statement that the Keta lagoon is the most important nature-based solution in the district. Results show that 53% of the respondents agreed while 47% strongly agreed with the statement of the Keta lagoon being the most important nature-based solution (**Figure 4.20**). At the community level, respondents reported strongly accepting the Keta lagoon as an NbS in Dzelukorpe (10%), Keta (8%), and Abutiakorpe (8%). Households in Keta (14%), Vui (10%), and Dzelukorpe (9%) also agreed to the statement.



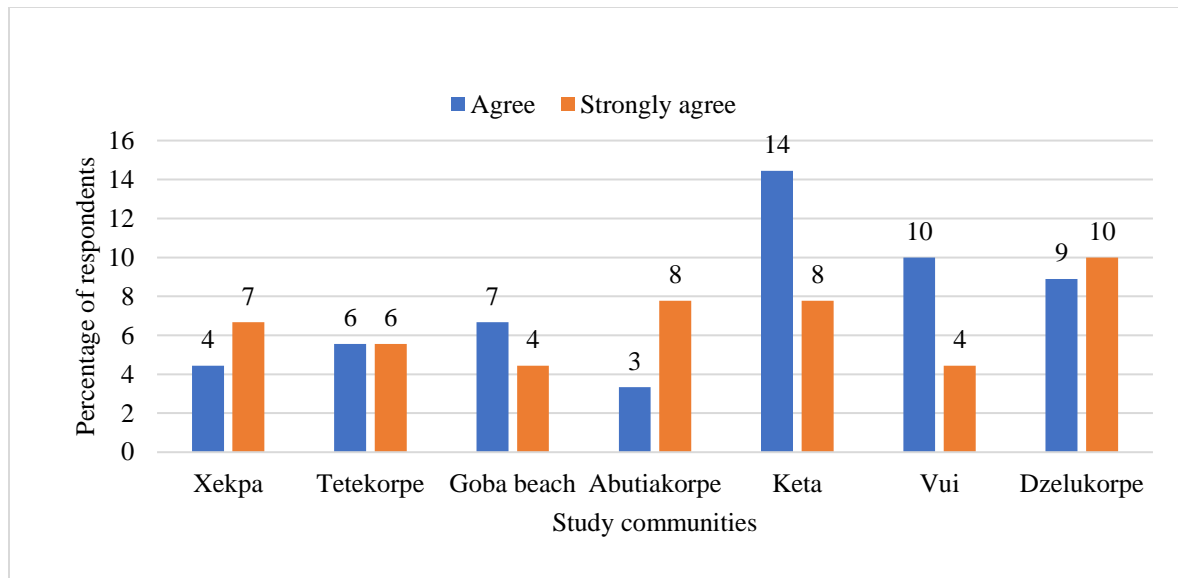


Figure 4. 20:Importance of the Keta Lagoon in the township.

Source: Fieldwork, January-May, 2021

4.4.2 Nature-based solution options for reducing climate change-induced hazards impact

Seven measures that best qualify as hazard reduction mechanisms for the communities were examined. To ensure easier identification of these measures to each study respondent, the natural solutions were presented in printed images. The planting of trees and grass in place of pavement, forest restoration, construction of wetlands, managing ponds and lagoons, planting of reefs, and the use of mangroves were assessed.

4.4.2.1 Nature-based solutions to reduce flood impacts

Results from the study show that overall, respondents in the township reported construction of wetland (60%) as a nature-based solution to reduce floods impacts in the township. Planting of mangroves was reported by 28% of the respondents to reduce flood impacts **Figure 4.21.**

At the community level, the construction of wetlands was reported most by respondents in Keta (13%), Dzelukorpe (10%), Vui (9%), and Abutiakorpe (6%).

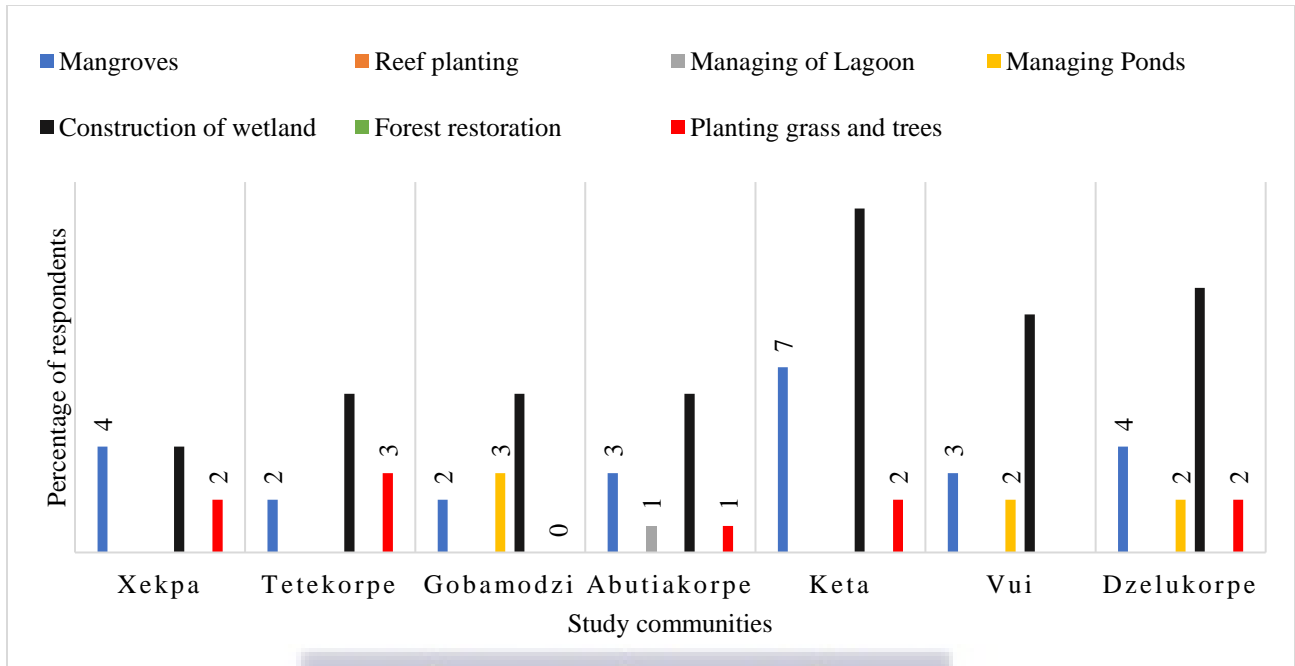


Figure 4. 21: Nature-based solutions for reducing flood impacts in the township.

Source: Fieldwork, January-May, 2021

4.4.2.2 Nature-based solutions to reduce erosion impacts

Results from the study show that overall, the majority of respondents in the township reported the planting of trees and grass (69%) as a form of nature-based solution to reduce erosion impacts in the township. Planting of mangroves was reported by 33% of the respondents to reduce erosion impact **Figure 4.22**.

At the community level, the majority of respondents from Keta (13%), Dzelukorpe (12%), Gobamodzi (9%), and Xekpa (8%) reported the planting of trees and plants to reduce erosion in the Keta township.

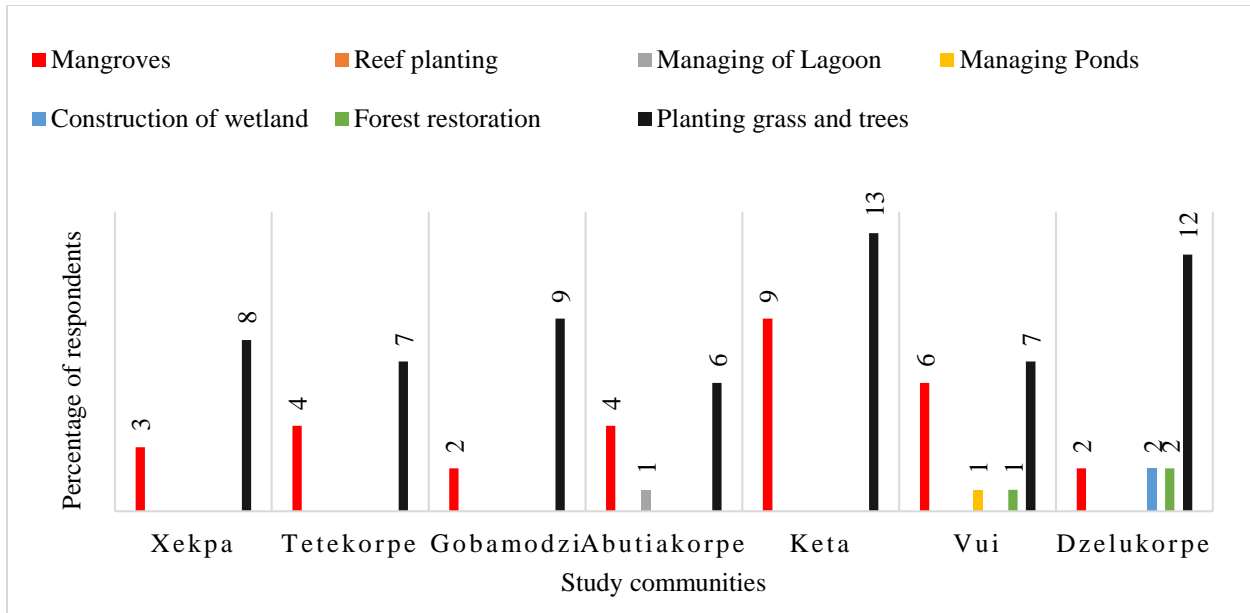


Figure 4. 22: Nature-based solutions for reducing erosion impacts in the township.

Source: Fieldwork, January-May, 2021

4.4.2.3 Nature-based solutions to reduce hightide impacts

Results from the study show that overall, the majority of respondents in the township reported the construction of wetlands (50%) as a nature-based solution to reduce hightide impacts in the township. Planting of mangroves was reported by 42% of the respondents to reduce hightide impact **Figure 4.23**.

At the community level, the majority of respondents from Keta and Dzelukorpe (11%) respectively, Vui (8%), and Tetekorpe (6%) reported the construction of wetlands as nature-based solution to reduce high tides in their communities. The planting of mangroves was also reported by Xekpa (8%), Keta (7%), and Tetekorpe (6%) to reduce high tide.

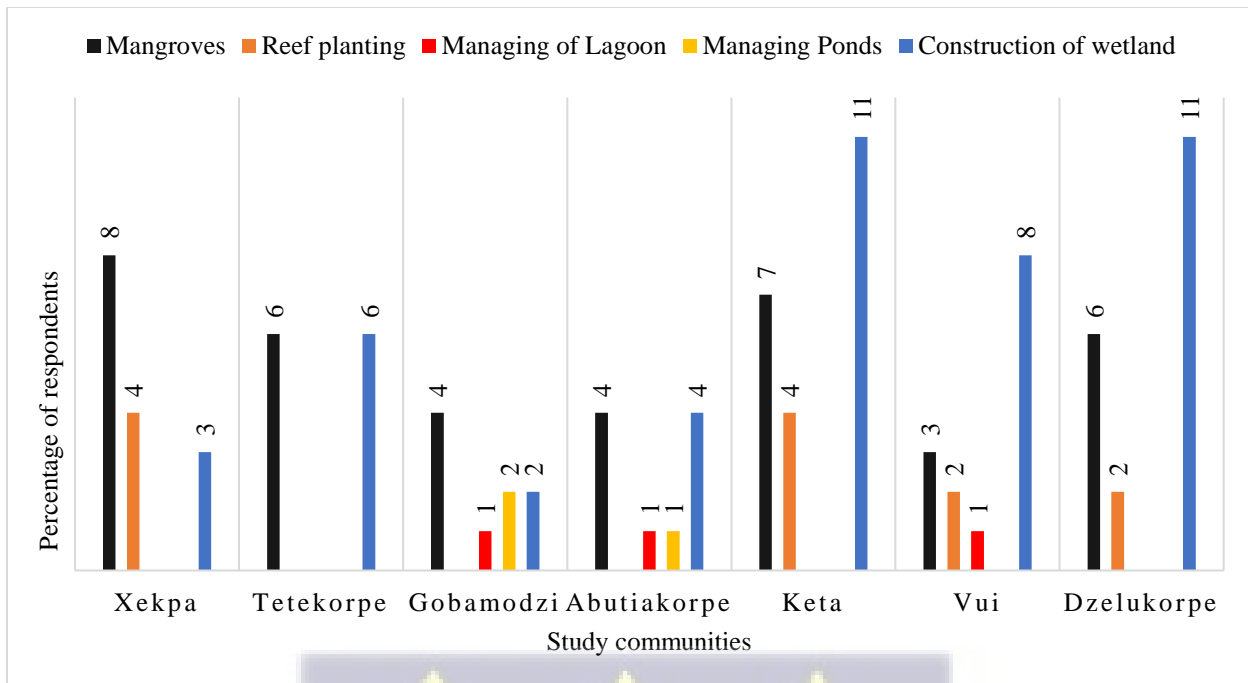


Figure 4. 23:Nature-based solutions for reducing hightide impacts in the township.

Source: Fieldwork, January-May, 2021

4.4.2.4 Nature-based solutions to reduce stormwater impacts

Results from the study show that overall, the majority of respondents in the township reported the managing of ponds (53%) as a nature-based solution to reduce stormwater impacts in the township. Managing of lagoons was also reported by 33% of the respondents followed by the planting of trees and grass (21%) to reduce stormwater impact **Figure 4.24.**

At the community level, the majority of respondents from Dzelukorpe (11%), Keta (9%), Vui (8%), and Gobamodzi (6%) reported the managing of ponds in their communities to reduce stormwater impacts in the township. The managing of lagoon in the township was also reported by respondents of Vui (6%) and Dzelukorpe (8%). The planting of trees and grass was reported most by respondents in Keta (8%).

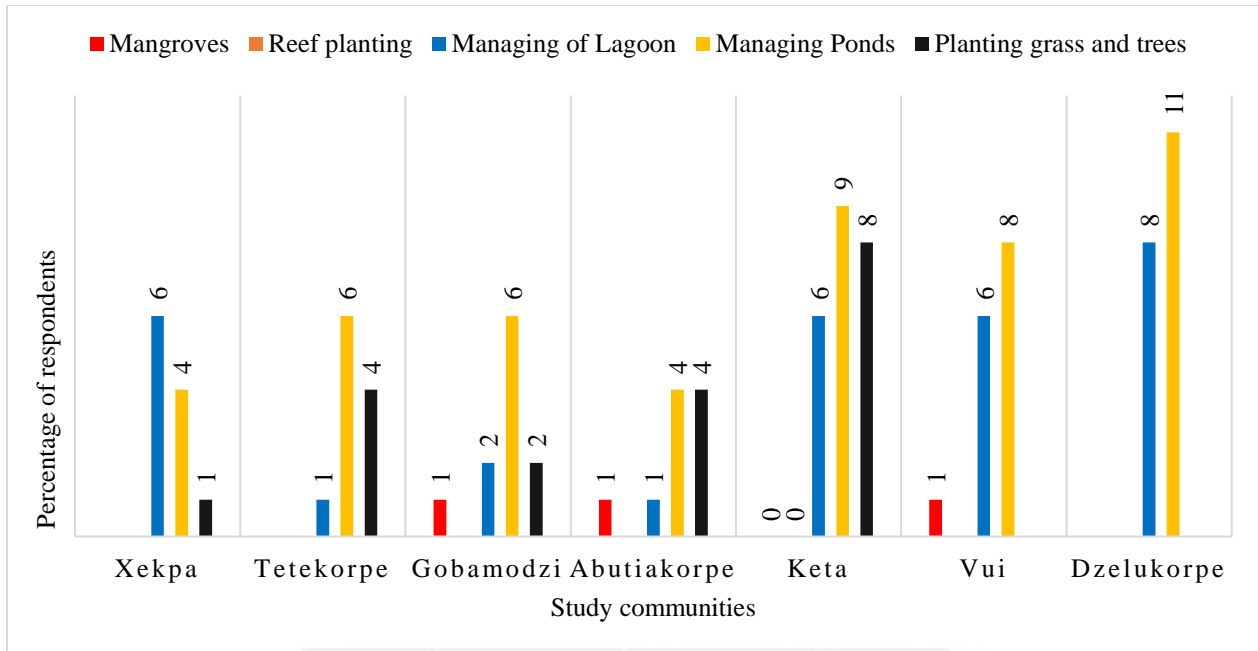


Figure 4. 24:Nature-based solutions for reducing stormwater impacts in the township.

Source: Fieldwork, January-May, 2021

4.4.3 Co-benefits of investing in nature-based solutions

The study identified certain co-benefits of investing in nature-based solutions through assessing the primary motivation of respondents' involvement in carrying out any form of NbS. Four types of nature-based solutions were investigated. These include planting trees, protecting wetlands, protecting the Keta lagoon, and managing mangroves ecosystems in the township. The following benefits were assessed; reducing erosion, providing shade, improving air quality, improving groundwater quality, providing protein, water quality regulation, flood regulation, carbon sequestration, recreation and tourism, firewood provision, and so on. **Figures 4.25 to 4.28** show pictorial representations of respondents' motivation for NbS.

4.4.3.1 Primary motivation for planting trees

In terms of assessing respondents' motivation for planting trees, four benefits (reduce erosion, provide shades, improve air quality, and improve groundwater) were assessed. The majority of

respondents from Xekpa (7%), Tetekorpe (8%), Gobamodzi (8%), Keta (11%) planted trees mostly to provide shades. Most of the respondents from Abutiakorpe (6%), Vui (8%), and Dzelukorpe (8%) also planted trees mainly for erosion reduction. The improvement of air quality was partly recognized in all communities but mostly acknowledged in Dzelukorpe (6%).

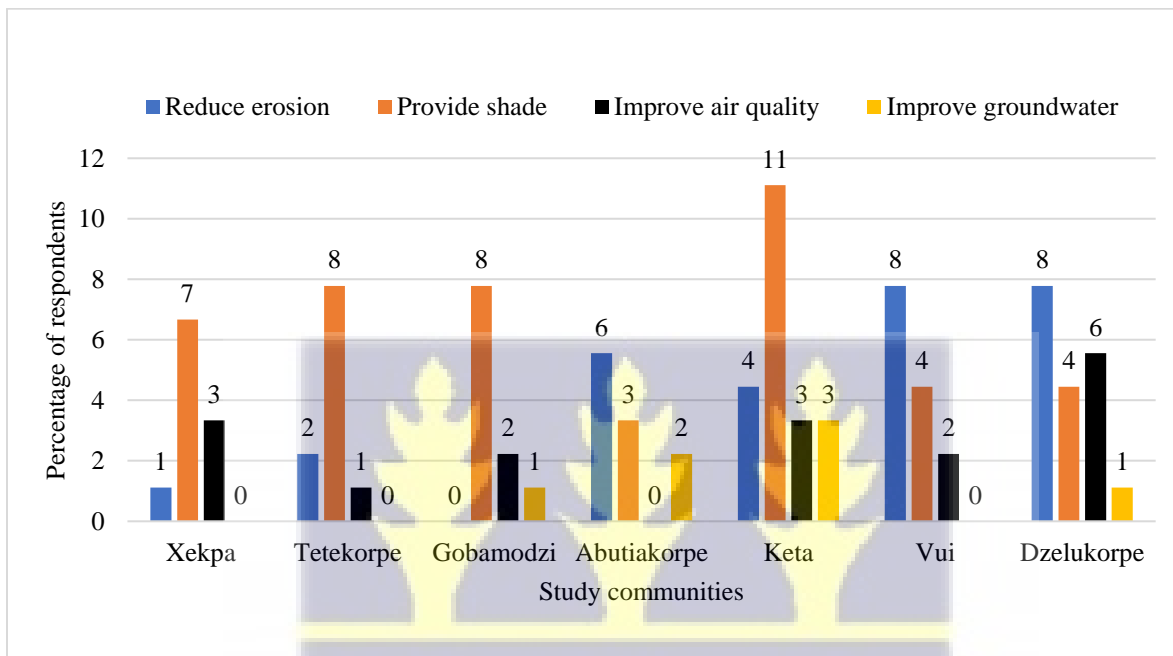


Figure 4. 25: Primary motivation for planting trees

Source: Fieldwork, January-May, 2021

4.4.3.2 Primary motivation for protecting wetlands

Wetlands in the district especially the study communities were protected for varied reasons. The provision of protein is a motivation for protecting wetlands in all the study communities (4%), Tetekorpe (6%), and Vui (9%). According to the majority of reports from respondents of Xekpa (7%), Gobamodzi (8), Keta (9%), and Dzelukorpe (10%) wetlands are mostly protected to prevent flooding in the township. Water quality regulation motivated respondents from Abutiakorpe (4%), Keta (8%), and Dzelukorpe (4%) to protect wetlands in their communities.

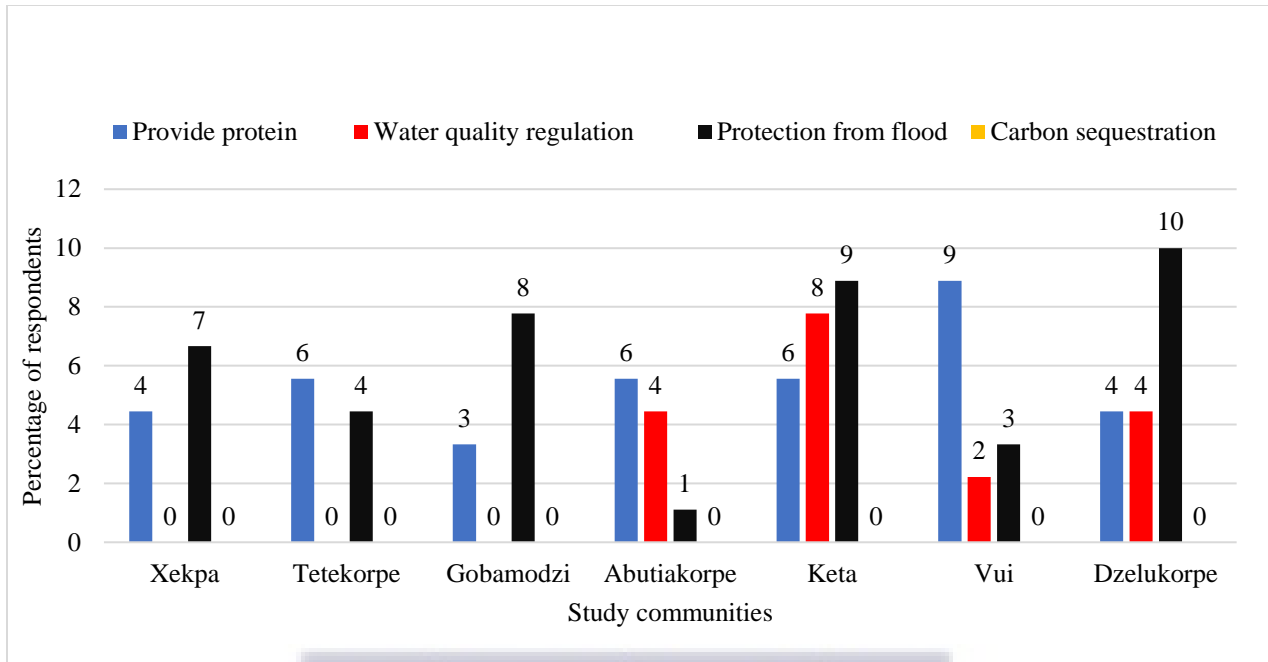


Figure 4. 26:Primary motivation for protecting wetlands

Source: Fieldwork, January-May, 2021

4.4.3.3 Primary motivation for protecting the Keta lagoon

The Keta lagoon as a nature-based solution was protected for various reasons by the study respondents. Five benefits of protecting the lagoon were assessed. The study revealed that even though all the study communities protected the Keta lagoon for the provision of food, majority of the respondents from Xekpa (7%), Abutiakorpe (6%), Keta (9%), Vui (7%), and Dzelukorpe (8%) protected the lagoon mainly for the provision of food. Recreation and tourism were the second most important reason for protecting the Keta lagoon. This was followed by the benefits of cooling the surrounding communities.



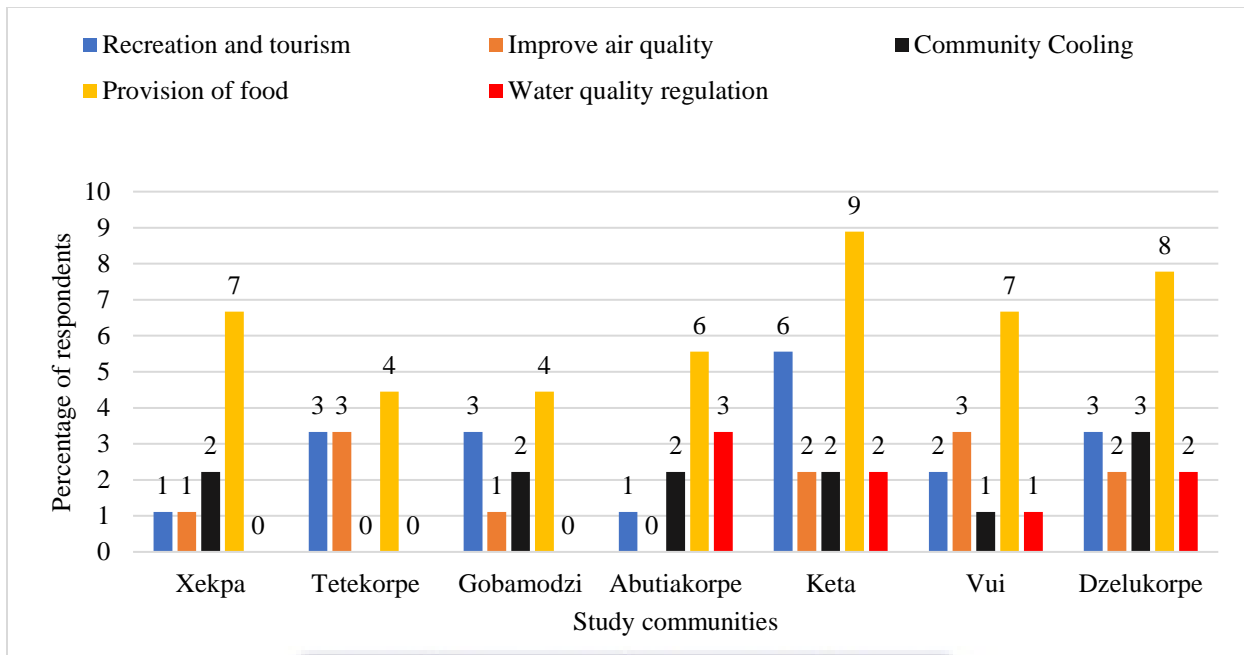


Figure 4. 27:Primary motivation for protecting the Keta lagoon

Source: Fieldwork, January-May, 2021

4.4.3.4 Primary motivation for managing mangroves ecosystem

The mangrove ecosystem provides many benefits for coastal communities. The study investigated four benefits that motivated coastal communities to manage mangrove ecosystems in their communities. The result revealed that the regulation of flood and provision of firewood were the two major reasons for managing mangroves in the study communities. The majority of respondents from Keta (13%) would manage mangroves to regulate floods in the community. Mangroves are also managed mostly for firewood by respondents from Gobamodzi (7%), Abutiakorpe (7%), Vui (8%), and Dzelukorpe (9%).



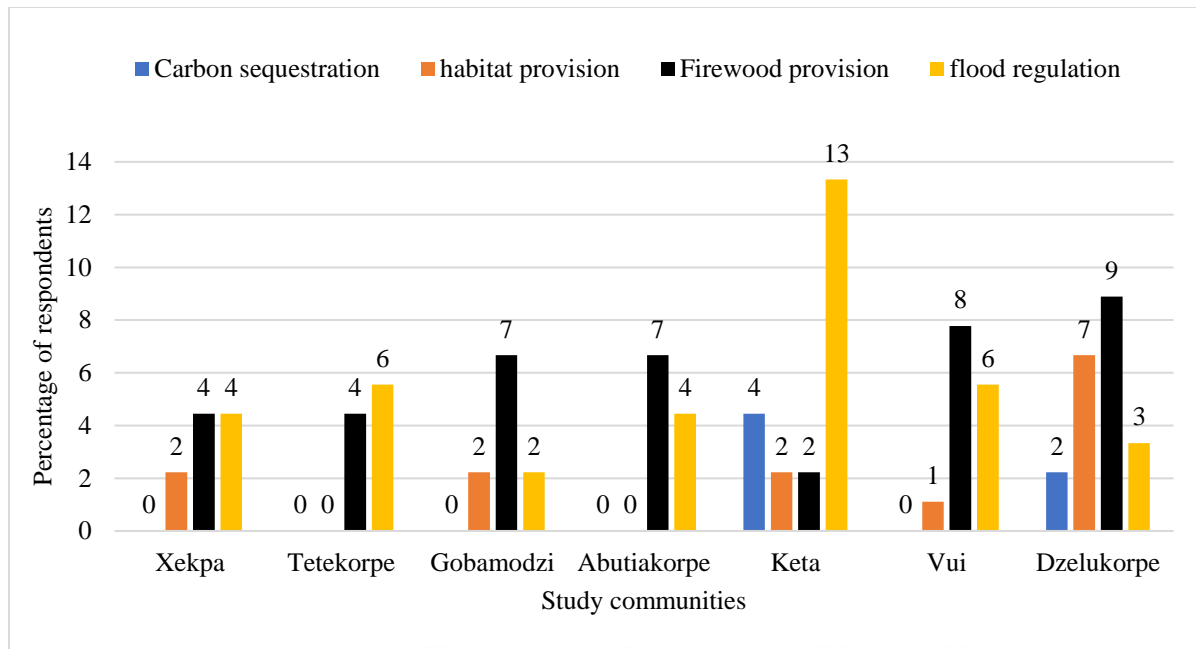


Figure 4. 28: Primary motivation for managing mangroves

Source: Fieldwork, January-May, 2021

4.5 Land use/ landcover changes and options for adapting nature-based solutions

This section of chapter four presents the findings from the land use/landcover change assessment and GIS study of the study communities within the Keta Municipality. The purpose of this section is to identify land use/land cover changes of the study area for the past ten years between 2010 to 2020.

4.5.1 Trends and magnitude of Landuse and Landcover Change (LULC)

Employing Landsat images, this section of the study mapped out coastal landuse and landcover, as well as monitored coastal landuse changes. The method entailed comparing the changes that occurred in the study region between the years 2010 and 2020. It has become obvious that there have been considerable changes in the landcover in Keta based on analysis of temporal Landsat satellite imagery, field verification, and monitoring of LULC changes.

The findings from the change analysis produced from the images for the specific periods are detailed in **Table 4.14**. **Figure 4.29** also depicts the changes in landcover for the two time periods under consideration. Except for built-up and bare surfaces, all coastal landuse/cover categories identified under this study increased in utility areas.

Table 4. 14: Coastal Area Landuse/Landcover distribution for 2010 and 2020

Landcover/use	2010		2020	
	Area (Km ²)	Area (%)	Area (Km ²)	Area (%)
Water body	119.4057	75.4	119.3769	75.8
Vegetation	11.1051	7.0	13.2498	8.4
Farmlands	3.3597	2.1	9.6381	6.1
Settlement	19.035	12.0	11.8665	7.5
Bareland	5.4126	3.4	3.3633	2.1
Total	158.3181	100	157.4946	100

Source: Classified Satellite images of Keta Municipal area 2010 and 2020/ CERSGIS

In 2010, the waterbody category accounted for 119.4057 Km² (75.4%) out of the 158.3181 Km² area of interest (aoi) for the study. Dense vegetation for this also accounted for 11.1051 Km² (7.0%) of the area whilst farmlands were 3.3597Km² (2.1%). On the other hand, settlement accounted for 12.0 % while bare lands accounted for 3.4% of the total area. The water body landcover occupies the largest area of 75.4% of the total area. The next largest landcover is dense vegetation followed by settlements.

The landcover distribution for the study locations for the year 2020 shows that waterbody surface category experienced a slight increase of 0.4% compared to the 2010 value out of 157.4946Km² area of interest (aoi) in 2020. The landcover for dense vegetation and farmlands also experienced a significant increase from (7.0%) to (8.4%) for vegetation and (2.1%) to (6.1%) for farmlands. There was a significant decrease in landcover for settlements and bareland from 2010 to 2020. According to the data, settlement declined from (12%) to (7.5%) while bareland also further

diminished from (3.4%) to (2.1%) for the selected study area. See **Figures 4.29 and 4.30** for visual illustration of these changes in the study area.

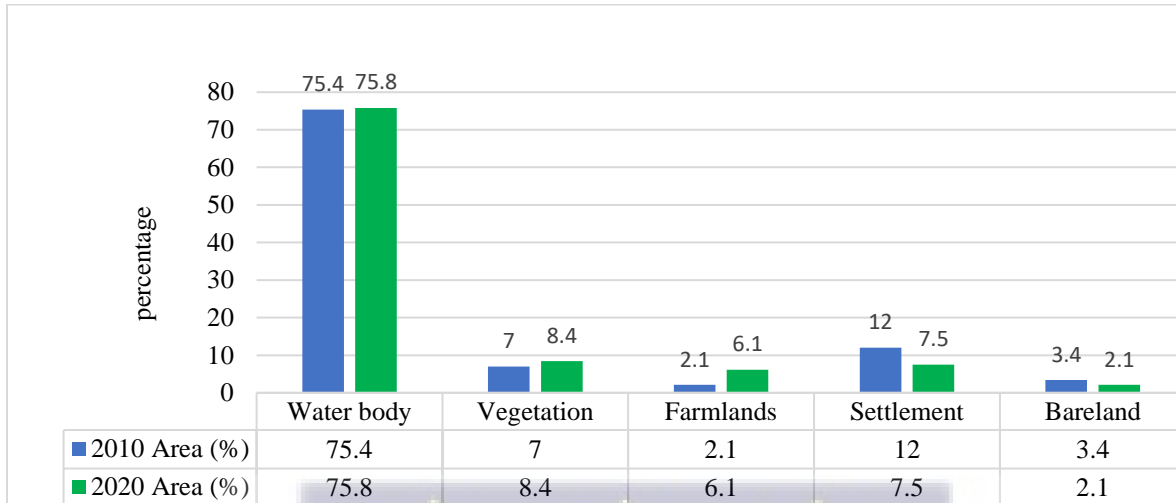


Figure 4. 29: Percentage distribution of landcover change: 2010-2020

Source: Classified Satellite images of Keta Municipal area 2010 and 2020/ CERSGIS



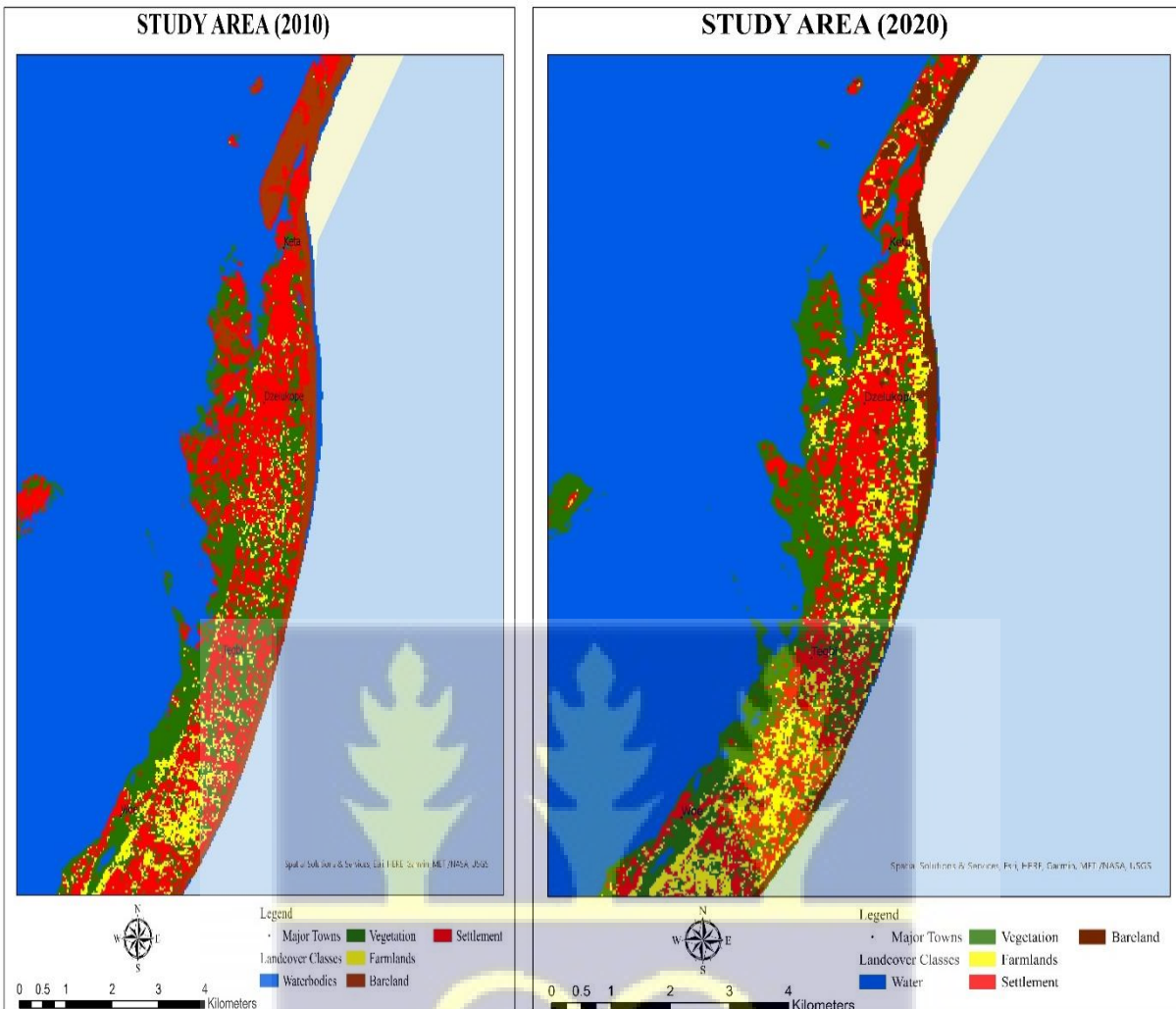


Figure 4. 30: Classified satellite images of Woe, Tegbi, and Keta.

Source: Classified Satellite images of Keta Municipal area 2010 and 2020/ CERSGIS

4.5.2 Landuse and Landcover Change Implications on climate-induced hazard

In terms of climate-induced hazard situation in the Keta township, results from the study revealed that at least one climate-induced coastal hazard (flood, erosion, high tides, and stormwater) is found in each of the study communities. The climate-induced hazard situation data was obtained through a community survey and observation. **Plate 4.8** illustrates the present situation of the different climate-induced hazards in the study area.

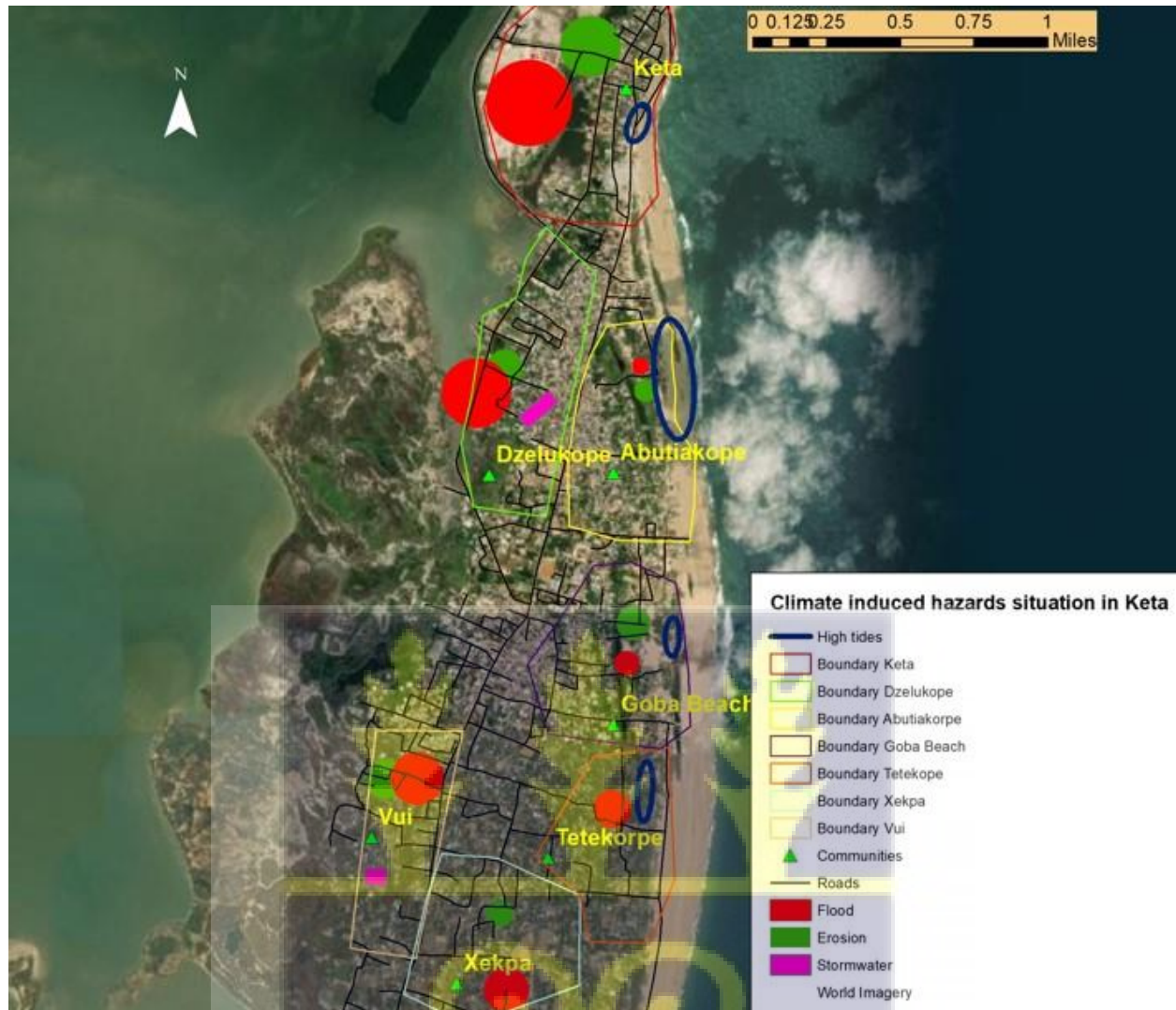


Plate 4. 8: General climate-induced hazard situation in Keta

Source: Fieldwork, January-May, 2021

4.5.2.1 Floods situation in Keta township

Keta is the most affected by floods, this is closely followed by Vui and Dzelukorpe. These lagoon communities are mostly affected by flooding from the overflow of the lagoon during high tides, heavy rains, or overflow from other tributaries. Gobamodzi and Abutiakorpe are the least affected by floods event in the township.

4.5.2.2 Erosion situation in Keta township

Erosion is the second major climate-induced challenge in the Keta township. Erosion situation analysis of Keta in Plate 4.8 shows that almost all the study communities are affected by coastal and inland erosion. The Keta community is the most affected. Erosion activities are also significant in Vui, Dzelukorpe, Xekpa, and Gobamodzi. Tetekorpe and Abutiakorpe experienced fewer erosion impacts as compared to the other communities.

4.5.2.3 High tides situation in Keta township

The impacts of high tides in Keta over the years have reduced in most of the communities. However, Tetekorpe, Gobamodzi, Abutiakorpe, and Keta were still experiencing some impacts of high tides. These were very minimal most times. The impacts of high tides were most significant in Abutiakorpe. High tides in the municipality cause an increase in the lagoon. According to most of the respondents, seawater from high tides also flooded the lagoon underground.

4.5.2.4 Stormwater situation in Keta township

Stormwater impacts and occurrence were less significant across the Keta communities. The impacts of stormwater occurred mostly within the lagoon communities (Vui and Dzelukorpe) after an overflow of the lagoon.



4.6 Institutional stakeholders’ perception of nature-based solutions

The final section of chapter four explores institutional stakeholders’ perceptions about the concept of nature-based solutions in reducing climate risk and vulnerability in the Keta municipality. The Keta lagoon complex was assessed as a nature-based solution for communities in Anloga, Woe, Tegbi, and Keta.

From the key institutional stakeholders’ interviews, a total of 13 ecosystem benefits derived from the Keta lagoon were identified and reported by the various institution as providing food (protein) (19), transportation (10), cultural value (3), recreation (6), holding water (1), firewood (13), employment (12), aesthetic value (5), habitat for wildlife (4), landing sites for migratory birds (4), tourist attraction (11), scientific purpose (3), and salt mining (9). Eight of these services were provision services, four were cultural services, and one was a supporting service. There were no regulating services identified from the lagoon (**Figure 4.31**).

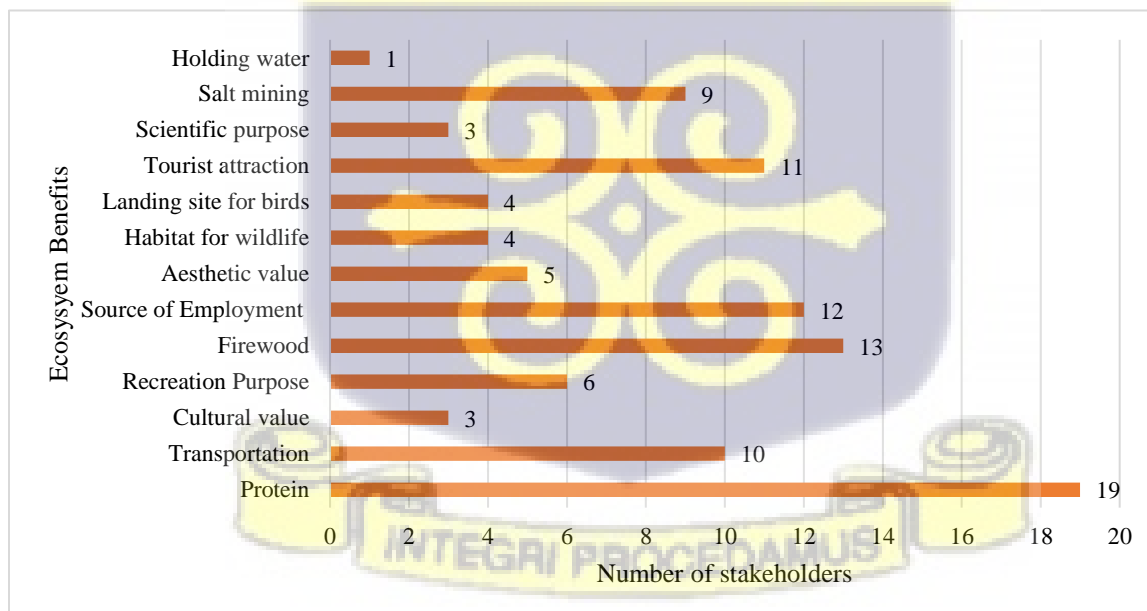


Figure 4. 31: Ecosystem benefits of the Keta lagoon complex

Source: Fieldwork, January-May, 2021

Over half, (55%) of the responses from institutional stakeholders suggest the regulation and improvement of fishing practices of the locals would improve the long-term benefits derived from the lagoon. Also, over 44% of the responses suggested frequent dredging of the lagoon as a key measure to explore the full ecosystem benefits of the Lagoon wetland. According to one of the stakeholders in a group discussion, *“The capacity of the lagoon is underexploited. This is a billion-dollar natural asset. Investments could be made to harvest a variety of fish. We can explore a variety of other livelihoods in the community, develop a mechanism to link the lagoon directly to the sea to improve the animal species of the lagoon, protect the mangroves in and around the lagoon, and treat it as a natural asset. It could even serve as a study purpose. Products from mangroves could be improved for other economic purposes aside from firewood (Keta Municipal Assembly NHIS Office, Participant from group discussion).”*

4.6.1 Institutional stakeholders understanding of nature-based solutions

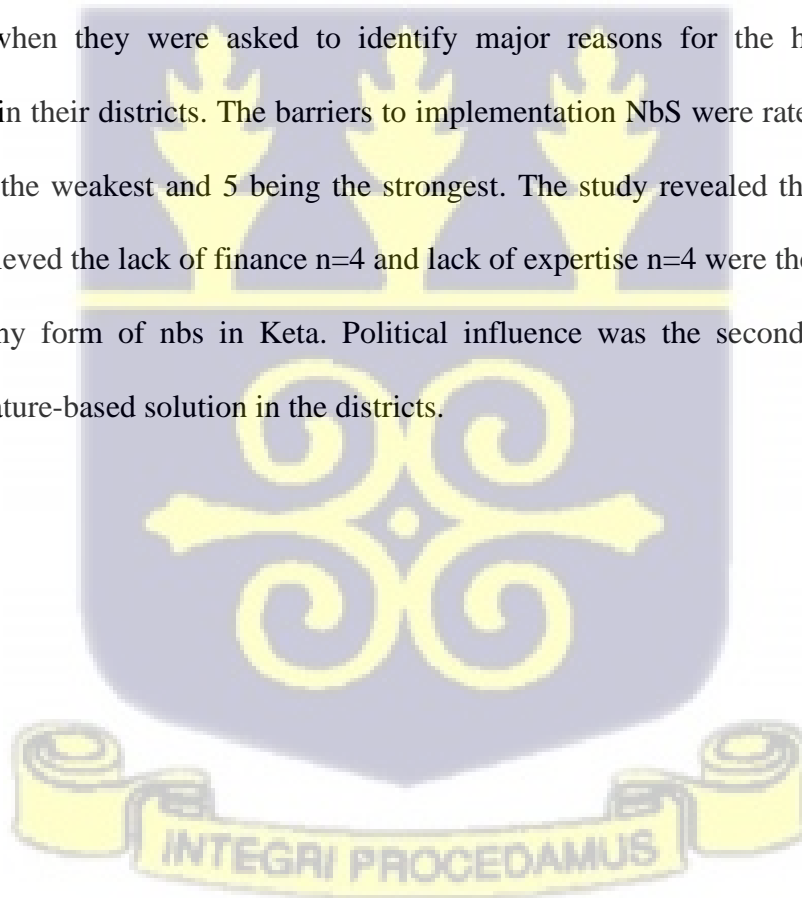
There were varied responses of how institutional stakeholders perceived the concept of NbS and actions they considered as nature-based solutions for disaster risk reduction in their communities. The assessment of stakeholders’ understanding of the concept was done through the identification of keywords and phrases of NbS found in their responses. The criteria used were from the definitional phrases of NbS: use of natural or modified ecosystems to protect, sustainably manage, restore, meet the societal challenge, using nature, inspiration from nature, and support from nature. According to some stakeholders, *“In my opinion, NbS can be described as we planting trees to protect ourselves and future generations to come including the environment. When we build a house, we pave the entire house thereby eliminating drainages in the house, water needs to sink when it rains but this is not the case which causes flooding in other areas. I mostly engage in tree*

planting because almost every house has a coconut tree” (Keta Municipal Assembly NHIS Officers group discussion).

“We need to do more tree planting around where erosion takes place and encourage the coast to have woodlocks. I have planted trees which is a very common activity here. It is believed that trees were mostly planted in honour of the dead. Collaboration between stakeholders should be improved and strengthened” (Ghana education service director of Keta Municipal assembly).

4.6.2 Barriers to implementing NbS

Figure 4.32 shows 12 institutional stakeholders’ responses from the local government administration when they were asked to identify major reasons for the hindrance of NbS implementation in their districts. The barriers to implementation NbS were rated on a scale of 1-5; with 1 being the weakest and 5 being the strongest. The study revealed that the majority of stakeholders believed the lack of finance n=4 and lack of expertise n=4 were the major barriers to implementing any form of nbs in Keta. Political influence was the second major barrier to implementing nature-based solution in the districts.



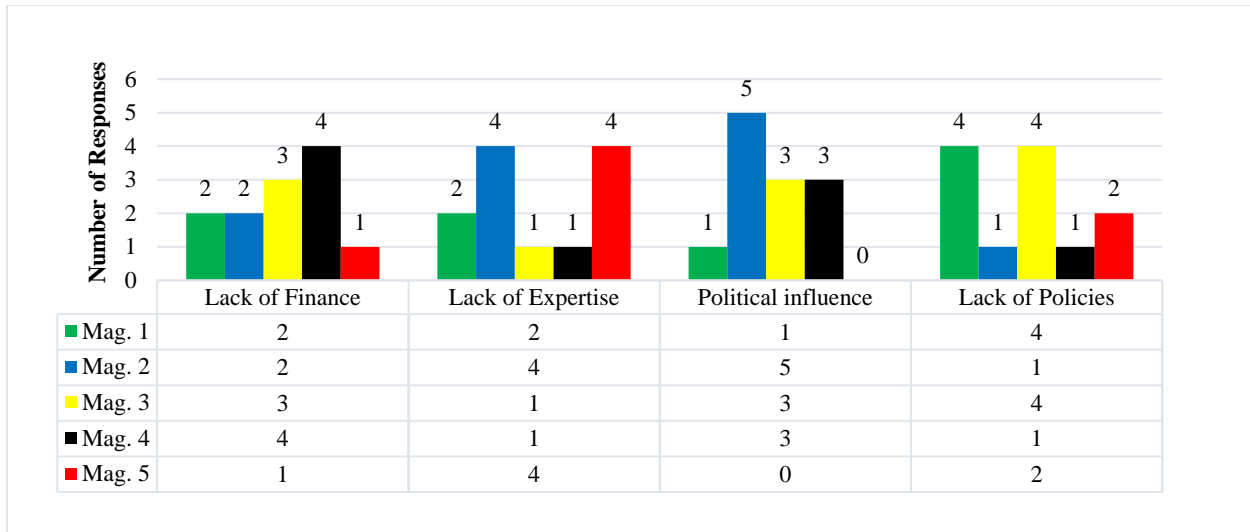


Figure 4. 32: Barriers to the implementation of NbS in Keta

Source: Fieldwork, January-May, 2021

4.6.3 Implementation of nature-based solutions in the Keta Municipality

The study assessed seven forms of nature-based solutions implementation in the study area. These NbS included pervious pavement, green roofs, green swales, ponds, constructed wetlands, tree planting, and rainwater harvesting. Key institutional stakeholders from the local government administrations of Anloga and Keta were asked to identify nature-based solutions that were or are being implemented in their communities. Twelve institutions were assessed in total, seven from Anloga and five from Keta.

Results show that (Figure 4.33) constructed wetlands and tree planting were carried out in the Keta and Anloga environments. According to institutional stakeholders' report, more ponds (n=7), constructed wetlands (n=7), tree planting (n=7), and rainwater harvesting (n=7) were done frequently in Anloga than Keta. The concept of green roofs is not common in both Anloga and Keta.

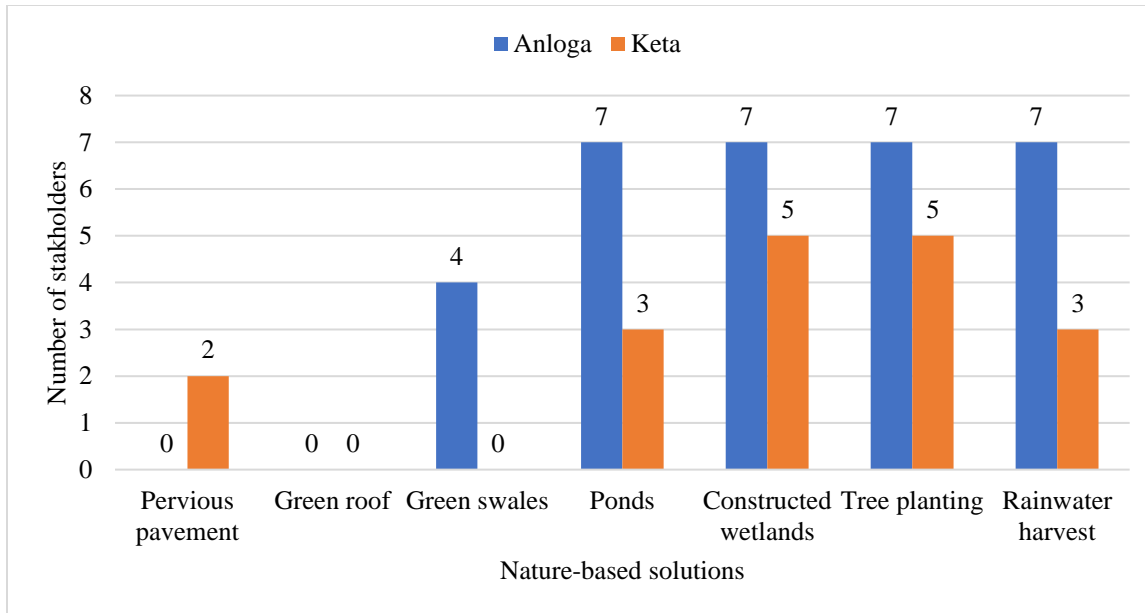


Figure 4. 33: Implemented nature-based solutions in Keta and Anloga districts

Source: Fieldwork, January-May, 2021



CHAPTER FIVE (5)

DISCUSSION

5.0 Introduction

This chapter discusses the findings from various interactions with key institutional stakeholders and communities' households. Issues under discussion in this chapter include the types, trends and impacts of climate change-induced hazards on households, existing local-level adaptation and mitigation options and evidence of nature-based solutions therein, and the Landuse/Land cover changes that has occurred in the Keta township. The study communities were purposively selected because of their geographical position in proximity to either the sea, lagoon, or both. They were selected to establish an understanding of the impacts of flood, erosion, high tides, and stormwater at different parts of the study area. In this study, the boundaries for the GIS mappings were not accurately drawn to scale or a true representation of the district data but were drawn in relation to the number of households selected from the specific communities or locations.

A systematic random sampling methodology was used in conducting the household interviews because the process was easy to construct, execute, compare, and understand. The social survey showed that a lot more females (54%) took part in the study than their male (46%) counterparts because at the time of the household interviews, the males were not available for various reasons. Out of the 90 households sampled, about 70% have stayed in the Keta township for over seven years. Over half (56%) of the study respondents lived in family homes.

5.1 Trends and impacts of climate change-induced hazards on households

For this study, the most common climate-induced coastal hazards were assessed. Trends and impacts of four hazards were reported in the Keta township by the respondents. These hazards include floods, erosion, high tides, and stormwater. Overall, flood is the most common hazard in

almost all the seven study communities. Events of flooding were experienced frequently in Vui, Dzelukorpe, Keta, Tetekorpe, and Xekpa. Erosion was reported as the next common phenomenon in almost all the study communities as several respondents from Keta, Dzelukorpe, Vui, and Gobamodzi confirmed its frequency of occurrence (**Table 4.1**). The literature on coastal hazards shows that flooding, high winds and waves, coastal erosion, storm surges, and human growth and activities near the shores contribute to coastal risks (Thior et al., 2019). The West African coastline area is complicated, as it is subjected to a variety of waves coming from various directions. As a result of the intensification of extreme climatic variables, several portions of West Africa's coastline areas are currently experiencing accelerated degradation related to coastal erosion and inundation (Thior et al., 2019; Angnuureng et al., 2020). Coastal erosion processes, particularly on sandy and muddy shores (Dada et al., 2020), is one of the most significant contributors to coastal degradation. Many coastal settlements have been endangered by rising sea levels and other climate-induced hazards in recent decades (Jonah et al., 2015). Climate change, particularly accelerated sea-level rise, is predicted to increase erosion issues (IPCC, 2014) in many vulnerable coastal nations.

The probability values calculation for the most common climate-induced coastal hazards in the Keta township shows that the likelihood ratio of floods (0.853) and erosion (0.750) occurring in the township is higher compared to high tides (0.597) and stormwater (0.144). This implies that flood and erosion activities are more likely to occur in the Keta township as a result of climate change.

The extent of these hazards was assessed from the experiences of respondents from the township. Results show that (**Figure 4.7-Figure 4.10**) the majority of respondents from Xekpa were not sure of the extent of high tides (41%) and stormwater (18%) in the community. Over half of the study

respondents from the community are however certain that the extent of floods has remained unchanged whilst erosion has increased. Xekpa shares boundaries with neither the lagoon nor the sea and is found on a much higher ground than the rest of the communities in the study area. The community has fewer drainage systems, floodwater ways, and storage systems. This is as a result of the lack of available space to construct such facilities. There is a high probability of flooding and erosion in the community.

The extent of floods and erosion were also reported as unchanged and increased over the past five years by (17%) and (25%) of respondents from Tetekorpe respectively. 12% of respondents from the community reported the extent of high tide has decreased over the period. In a similar case as Xekpa, the majority of participants from the community were uncertain about the extent of stormwater. Aside from these climate-induced coastal hazards, the respondents of Tetekorpe lamented about the menace of sand winning which they attributed to the cause of many deaths within the community. Large pits which collect water have been created from sand-winning activities. The community has fewer constructed drains. However, it has many natural waterways which collected excess rainwater. Some of its vegetation is in good condition while coconut and some palm trees have been planted along the beach. If carefully managed, the community is likely to experience fewer impacts from climate-induced hazards.

Respondents from Gobamodzi reported the extent of floods (15%), erosion (14%), and stormwater (18%) as unchanged in their community. The majority of respondents (16%) also reported high tide events have decreased over the past five years. The study observed that a large number of the respondents from Gobamodzi have knowledge of the extent of floods, erosion, and high tides in their community. The community shares boundaries with the sea and has several smaller ponds

and waterways. It also occupies many marsh areas that stored excess water whenever it rained. The respondents also reported sanding winning as a major coastal challenge in the community.

Flood, erosion, and high tides were reported as occurring frequently and in moderation respectively within the Abutiakorpe community. The community has a fish landing site and was also identified as a major hotspot area for sand winning. It has many shallow and deep creeks along the coast. It is also known to have marsh areas that collected excess water whenever it rained. The study observed that about half of the study respondents have adequate knowledge about the extent of floods, erosion, and high tides in the community.

Flood, high tides, and erosion were also identified by respondents in the Keta community. These hazards occurred in moderation and less frequently within the community respectively. Keta shares direct boundaries with the lagoon and sea. The community is the most populated in the district and accommodates some important facilities and infrastructure. This makes it highly vulnerable to the impacts of climate-induced hazards if human activities are not carefully managed. The community is interspersed with smaller ponds, lagoons, creeks, and marshy areas. Many of these natural features have been developed while many have also been contaminated by human activities. Most infrastructure along the coast has been destroyed by high tides and abundant by their occupants.

Flood, erosion, and stormwater were identified by respondents in Vui and Dzelukorpe as occurring more frequently and in moderation. The majority of respondents from the two communities believe the occurrence of high tides has a direct impact on the lagoon and its ecosystem benefits which are connected to their livelihoods. Both communities share direct boundaries with the lagoon. Due to the location of these communities, they inhabit many marshy areas and plant species. Most of the wetlands have been developed for residential purposes. Due to the occasional drying of the lagoon, new islands have emerged. According to many of the respondents, especially fishermen and

farmers, the township has experienced fewer rains over a long period. The two communities are inhabited mainly by fishermen, farmers, fish traders, and vegetable farmers.

Climate change, particularly accelerated sea-level rise, is expected to exacerbate climate and other human-induced coastal hazards (IPCC, 2014), requiring effective management strategies in dealing with the risks arising.

The probability values for the extent of these hazards varied by a very small margin. Thus, the likelihood ratios calculated show that the extent of climate-induced coastal hazards in the township will follow similar trends and impacts for flood (0.212), erosion (0.270), high tide (0.270), and stormwater (0.216).

5.2 Impacts of climate-induced hazards on households and properties

The natural and artificial driving factors have an impact on a variety of often antagonistic human socioeconomic activities that take place in coastal environments. The natural stress on coastal resources caused by wave and tidal climates is often exacerbated by human-induced factors. Coastal life and property are constantly at risk as a result of these developments. According to Boateng (2012), coastal erosion has resulted in the loss of a significant number of homes in the past, and the tendency is continuing in some regions along the coast of Ghana. According to Appeaning Addo et al. (2011) also, by 2025, roughly 85 houses in three neighborhoods of Accra's western suburbs will be lost to erosion, displacing about 2000 people. Many of Ghana's most densely inhabited coastal communities are located in low-lying coastal plains prone to coastal flooding, with key businesses, significant residential settlements, tourism and conservation areas, heritage and historical monuments all within 200 meters of the coast.

According to literature, the study district is a low-lying coastal plain while the Keta Municipality to a high degree is the most urbanized district in the Volta region.

Community study revealed that both households and properties in the Keta township are likely vulnerable to floods, erosion, and high tides (**Table 4.4- Table 4.5**). The impacts of high tides are minimal within some communities in the township while other communities are still experiencing severe impacts from high tides. The Keta Lagoon is occasionally flooded by rising tides. According to reports, the occurrence of floods (38%), erosion (18%), high tide (30%), and stormwater (14%) has caused many of the residents in Keta township to relocate from their previous residence.

Adaptation methods used by the local residents have contributed to their resilience to these hazards over the years. The Keta Sea defense has also contributed to the temporary protection from sea waves and coastal erosion in the township. Whereas this initiative has decreased coastal erosion along the Keta and Kedzi coastline, it has resulted in a 50% increase in coastal erosion in nearby villages on the down-drift coast near the Ghana-Togo border (WACA, 2007). This adds to the growing body of evidence that shore-hardening measures are not always appropriate for decreasing coastal risks (Angnuureng et al., 2013). Short-term occurrences pose a considerably larger threat to infrastructure than medium-to-long-term trends when it comes to sustainable coastal management. While natural marine processes produce a cyclic occurrence, if human actions are not well controlled, they generally produce a long-term influence (Apeaning Addo, 2013). The shoreline's rapid landward movement leads to the destruction of lives and property.

The likelihood ratio calculations of climate-induced hazards impact on the displacement of households in the township show that there is a high number of uncertainties about the displacement of households in the township. Also, the likelihood ratio of properties being

destroyed by climate-induced coastal hazards in the township was lower compared to properties not being destroyed. However, major differences occur when making a case for individual hazards and communities.

5.3 Impacts of flood and erosion in keta township

For this study, flood-driven climate-induced impacts were reported across the study communities. Overall, the majority of reports were from Keta (35%), followed by Dzelukorpe (17%), Vui (13%), and Tetekorpe (17%) for flood-driven causes of death in the township (**Figure 4.11**). The Xekpa community reported no death as a result of flood activity in the community. Tetekorpe, Keta, Vui, and Dzelukorpe reported the highest number of flood impacts in relation to the displacement of people and the destruction of farmlands. Gobamodzi has over the years not experienced many significant impacts of flood or erosion. The two lagoon communities, Vui and Dzelukorpe experience the impacts of floods in certain months of the year when the rains are much. These communities prefer flooding of the lagoon because according to the respondents, anytime the lagoon flooded, it provided many benefits for them. Death has however not occurred as a result of flooding due to heavy rains in the Vui, Dzelukorpe, and Abutiakorpe communities. The Keta and Abutiakorpe communities have experienced impacts of flooding as a result of displacing households and destroying properties. Properties that have been damaged by floods and erosion in these communities include both private and public-owned properties. Properties that were mostly destroyed were farms, homes, public toilets, schools, roads, and the only former female prison that stood in the Keta community

Literature on the erosion status in Keta reveals that sea erosion is still a serious problem for most households and towns in and around the Keta Lagoon complex (Boafo, 2018), including the study communities. The Keta lagoon erosion problem was discovered in 1907 (Akyeampong, 2001).

Over the last decade, Kporkporgbor, Fuveme, Dzita, Havedzi, and Xorvi have been among the villages most endangered by rising tidal waves that have destroyed physical infrastructure (Boateng, 2009; Boafo, 2018). Annual erosion has also had a severe impact on fishing and farming livelihood systems in villages and the Keta Municipality as a whole (Boafo, 2018).

The p-value calculations for the likelihood ratios of floods and erosion impacts show that there is a high probability of floods destroying farmlands, displacing residents, and causing death in the Keta township (**Table 4.8**). Also, erosion is more likely to destroy buildings, roads, and reduce soil quality in the township (**Table 4.12**).

5.4 Climate-induced hazards impact on biodiversity

There are different forms of plants and animal species existing across the Keta municipality. Many fish and other sea-dependent species feed on the mangroves and wetlands of the Keta Lagoon Complex Ramsar site. The Keta Lagoon has long been known for its diverse coastal and marine wildlife (Ntiamoa-Baidu and Gordon, 1991). The stretch of coastline from Fuveme to Anloga is one of Ghana's most important sea turtle nesting areas. The beaches are favored nesting sites for the leatherback (*Dermochelys coriacea*), green, and olive Ridley Sea turtle species (*Lepidochelys olivacea*). According to local sources, the mating season lasts from November to March, when sea turtles come ashore to lay their eggs in the medium grain-sized sand. The marsh had formerly been home to a variety of terns and waders. The Great White Heron (*Ardea alba*) and Pied Kingfisher (*Ceryle rudis*) are two of the most common bird species found in the wetlands today.

This study examined changes in plants and animals' species existence and their timing within the study communities of the Keta township.

According to a respondent from Xekpa, *“In the past, whenever fishermen from either the lagoon or the sea return from their fishing activities, they brought back many types of fish in very large quantity. However, unlike before, the fish catch in our community has reduced which has affected our fish trading in the district in many ways”* (A fish trader from Xekpa). The price of certain fruit crops such as pawpaw is costly as some of the respondents are unable to easily purchase them or have to travel long distances to get them for their family dietary needs.

When respondents of Tetekorpe were asked to describe some of the observed changes they have noticed in their community, varied responses were provided. A fish trader from the Tetekorpe fish landing site narrated; *“As you can see for yourself, this is the only fish I was able to get from the fishermen here today. However, today is a major fishing day where in the past, these fishermen returned with enough fish that we could buy and even take the excess on credit. Nowadays, they are returning with smaller fish and just one kind”* (A fish trader from Tetekorpe).

A group of fishermen was also interviewed about the changes they have observed in the existence and timing of certain plants and animal species in their community. According to them, *“Sometimes, we fish longer period than we did before but we end up coming back to shore with very small fingerlings. Things have changed a lot, especially with our business, the species of fish we are getting are not enough even after we have sailed long distances to find them. In the past, we caught bigger salmon, crabs, and even sea turtles. Today is a major fishing time but my colleagues and I have decided not to go fish because we will end up coming home with empty canoes. The premix fuel has also become expensive. For the plant species in Tetekorpe here, what we have noticed is that, the sea weeds we used to see around commonly are no more. The mangroves species too are not many on this side of Keta unless you visit the lagoon area. Even*

there, the people living there are harvesting the mangroves for firewood and fishing” (Fishermen from the Tetekorpe fish landing site).

A respondent from Gobamodzi who has stayed in the community for over twenty years described how the natural water bodies which provided their community many benefits were almost at the point of being destroyed. *“My grandfather owned this property I am currently on. He also owned a recreational facility like a beach bar which he named Goba beach. The community attained its name from that facility. The community has many creeks and other wetlands. When my husband and I started building this house, we used to see many reptiles. Snakes were around a lot and at times if you are up very early, you could see snakes or their trails in the sand. The water very close by used to produce different freshwater fish. However, a road was constructed through the water to link Goba beach to the main community, a lot changed. The community members have also turned the water into a refuse site. You would hardly find fish in that water anymore because it has become stagnant and even smells at night.”* (Respondent of Gobamodzi)

The Abutiakorpe community has a fish landing site. Sand winning was also a common activity in the community as other communities along the beach. According to the respondents, sea turtles at some time of the year in the past were commonly found on the beach. In those seasons, they came to lay their eggs and mate. Over the years, some of the residents and young men who engaged in sand winning harvested these sea turtles for food. In recent times, the residents do not easily come across these beach animals.

The Keta community is a fast-developing community with many land-use activities taking place daily. Wetlands that accommodate important plants and animal species are being developed. According to some of the respondents, in the past the Agama lizards and certain snake species

especially the water-snakes were common in the community. However, these reptiles were not easily seen in the community as before.

The majority of respondents from the lagoon communities revealed there has been a significant reduction in the number of mangroves species of the lagoon. Most of the respondents attributed this reduction of mangroves to the decrease in fish caught from the lagoon. The mangrove plants are mostly used for firewood by most of the residents living around the lagoon. Fishermen on the lagoon used these mangrove plants for fishing. They create fishing traps using a local fishing method called 'blocking' with mangrove plants. A significant reduction in worldwide mangrove coastlines has been recorded, according to a Food and Agriculture Organization (FAO) estimate, from 198,000 km in 1980 to 146,530 km in 2000.

As narrated by a respondent from Keta; *“After the construction of the dam, the floods resided and starved the lagoon of water and fish. This has dwindled the fish stocks in the lagoon causing major food security problem for most people in Keta. The grasscutter and rat species are not easily seen in the community.”*

The p-values data for the impacts of climate-induced hazards on biodiversity in the township (**Table 4.10 and 4.11**) show that there has been a significant change in plants and animal species existence with a likelihood probability value of (0.464) for the township. There has also been a significant change in the timing of these plants and animal species with an LRPV of (0.659) in the township.

5.5 Local level adaptations and mitigations options and evidence of nature-based solution.

Coastal adaptation is more than just a technical problem (Gopalakrishnan, Landry, and Smith 2018). It is also an economic concern regarding a society's readiness to utilize precious resources

for adapting and enhancing coastal protection at its core. Decisions about which adaptation measures to apply and how much to implement need costly trade-offs (Johnston, Makriyannis, and Whelchel 2018). Several opportunities exist in leveraging on traditional knowledge of using the natural environment to reduce a society's vulnerability to climate change.

The Keta Lagoon is the first point of adaptation for many of the community members in dealing with several challenges including flooding in the Keta township. The majority of respondents believe that dredging of the lagoon will reduce flooding and improve other ecosystem benefits provided by the lagoon resource such as food, water, shelter, fresh air, and so on. The lagoons are the primary drainage basins for the township. The Keta, Angaw, Agbatsivi, Logui, Nuyi, and Klomi are among the major lagoons in the municipality. However, according to the majority of respondents, the level of water in these lagoons has decreased drastically in recent years, resulting in the formation of numerous islands in the Keta, Angaw, and Agbatsivi lagoons. Seva and Dudu, the largest of the islands, are partially populated. There exist no single evidence of mainstreaming or upscaling these natural water basins as adaptations and nature-based solution options into the district policy and plans in managing coastal hazards for the township. Secondly, the options of building reservoirs to collect and store floodwaters are increasingly limited for the township because of the lack of available lands. Therefore, the protection of these natural forms of water storage is environmentally sustainable to reduce climate-induced hazards in Keta.

The study assessed three types of adaptation options for reducing erosion; planting trees and grass, planting mangroves, and building seawall (**Figure 4.16**). The result showed that the respondents also proposed the filling of their compounds with sea sand (22%) in reducing erosion within the communities. Tree planting is a common activity in the Keta township as over half of households preferred the planting of trees and grass in place of pavement to reduce the impacts of erosion.

Respondents around the lagoon believe that the planting of mangroves will improve other benefits of the lagoon such as increasing fish stock and other aquatic life, providing shade for fishermen, and reducing the rate of evaporation of the lagoon. These methods by the local community are opportunities to encourage the use of the natural environment to reduce erosion.

Several instances of tree planting exist within the township, especially in all the study communities. Field observations showed that over 90% of the households studied have at least a tree on their compound. Other households had either a garden or grass or both on their facilities. These plant-based adaptation methods reduced erosion in many ways. Most of the residents along the lagoon, especially some vegetable farmers have trees on their farmlands. These tree plants hold the soil together and improve soil moisture which supports plants growth for most of these farmers. The palm, coconut, and mango trees were mostly found in the lagoon communities. Coconut and some mango trees were found mostly along the coast.

The communities that share direct boundaries with the sea; Tetekorpe, Gobamodzi, Abutiakorpe, and Keta have adopted different means to adapt to the impacts of high tide in their communities. According to the majority of respondents, adaptation to certain coastal hazards such as high tides is expensive and more technical. However, many residents have found different means to survive the impacts of high tides in their communities. In the past, whenever tides were high the residents would move inland to other communities farther away from the beach. Many of these residents have also constructed some of their apartments with inexpensive materials and non-permanent structures. These techniques were found mainly in Tetekorpe, Gobamodzi, and Abutiakorpe communities.

The Keta municipality as a whole is one of the driest on Ghana's coast. The rainy season lasts from March to July, with September and November often having the lowest rainfall in the area. With a

hot environment and high evapo-transportation, the average daily temperature is generally about 30° Celsius. Stormwater runoff is mostly caused by heavy rainfall that runs over land or impermeable surfaces, such as paved roadways, parking lots, and building rooftops, rather than soaking into the earth. Respondents from the study communities were assessed on the methods of reducing stormwater impacts through the reduction of paved surfaces, construction of bigger drains, and stormwater storage facilities (**Figure 4.18**). The filling of compound with sea sand is again a method the locals have relied on and preferred over the years to address the issue of stormwater in the communities. Some communities also proposed dredging of the Keta lagoon to accommodate more rainwater and floodwater in the district. In most of the study communities, the availability of land to undergo certain projects is a challenge. Hence, only a few smaller drainage systems were found in the Keta community itself. However, the methods used by the local community to reduce stormwater impact over the years could be redesigned and upscale for use by most residents in the district.

Respondents from the lagoon communities reported the adoption of reducing paved areas, construction of bigger drains, dredging of the lagoon, filling compound with sea sand and stormwater storage facilities to reduce the impact of stormwater in their communities. Results about the types of hazards experienced by the entire township and the challenges in managing them showed very little impact from stormwater as a result of heavy rainfall. This is due to the reduction of rainfall in the district over the years.

In light of the various respondents' preferences to managing coastal hazards in their communities, the study further sought to assess what households would consider as key when choosing adaptation measures (**Figure 4.19**). In recent years, the private sector has worked with households to plant along the Keta and other lagoon banks to decrease evaporation and siltation of the resource.

To deal with the consequences of high tides, communities are increasingly establishing coconut groves and planting trees along the coast. Some youth organizations for example have been involved in tree-planting efforts in the Keta township. In several localities, woodlots with indigenous trees are being developed. There is an opportunity for the local government to take up and improve collaboration with households in designing and implementing adaptations and NbS options.

5.6 Factors affecting households' reliance on NbS and existing adaptation strategies

There is widespread agreement that adaptation to the effects of climate change is unavoidable and that preparatory effort should begin immediately. However, if it becomes obvious that a major rethink of current coastal policy is required, the question of which activities are most suited for dealing with the long-term effects of climate change arises. The study assessed four factors that respondents would consider when choosing an adaptation or coping mechanism. The study sought to understand how cost, availability of space, availability of material, and severity of the climate-induced hazards affected respondents' choice of adaptation (**Figure 4.19**). Several challenges were reported by respondents and key institutional stakeholders as affecting the adoption of nature-based solutions for addressing the impacts of climate-induced hazards in the Keta township.

Firstly, at the household level, the study revealed that the cost of adopting and managing various nature-based solutions was a major challenge for about (84%) of households in the Keta township. The respondents reported that materials and infrastructure needed to manage climate-induced hazards such as floods were expensive. The cost of raising an existing building level was also expensive as this required a redesign of their entire properties. Key institutional stakeholders also attributed the lack of implementing NbS to inadequate finance to carry out these projects.

According to the literature (Somarakis et al., 2019), technically feasible solutions that can be used to solve a variety of problems are minimal, underdeveloped, and, in many cases, costly.

Secondly, respondents of the township reported the availability of space as a major challenge to support the implementation of NbS in the Keta township. Lands needed to strategically site NbS for the communities were not easily accessible due to several reasons according to the key institutional study. Families that own large tracks of land are not ready to give such lands for NbS. Due to the scarcity of lands in the township, natural habitats such as marsh areas, swamps, waterways, and many mangroves island on the Keta lagoon are being developed for settlement purposes. According to (Davis et al., 2015), certain kinds of NbS necessitate a large amount of land for implementation, which can be expensive and difficult for planners and local governments to consider, particularly in urban areas. This makes choosing NbS over conventional engineered approaches all the more unlikely, particularly if the broader environmental and social benefits aren't factored into decision-making.

The availability of material or resources was reported as the third major challenge to adopting NbS and adaptation strategies in the Keta township. According to the institutional stakeholders' study, the human and material resources needed to design, implement, and manage NbS for the district were available. According to literature (Somarakis et al., 2019), decision-makers and practitioners should have the knowledge and skills needed to effectively overcome potential trade-offs and make the best use of available technological solutions which the municipality as a whole was lacking to a large extent. Also, the lack of ready-to-use technology, as well as ready-to-apply research findings and principles to reduce the impacts of climate-induced hazards were not available for the study area. However, at the community level, households relied on the natural environment and

their traditional beliefs such as filling their compounds with sea sand, planting trees in honour of the dead, and so on to reduce their vulnerability to coastal hazards.

Fourthly, there was a lack of collaboration between households and the institutional stakeholders in charge of planning and implementing environmental projects for the township. This lack of collaboration among respondents constitutes a major challenge for the implementation of NbS in the township. Many other challenges of adopting NbS can be traced to lack of collaboration according to (Somarakis et al., 2019). The study also revealed that there were limited collaborations even amongst the key institutional stakeholders in the township. This greatly hinders the adoption of approaches such as the bottom-to-up approach of environmental management for the township.

5.7 Community perception of nature-based solutions in keta township

There is a strong agreement amongst the majority of respondents that when they put in place measures and approaches that rely on, work with, and enhance the natural environment to reduce their societal challenges to climate-induced hazards of the coast, can be classified as nature-based solution. The study further questioned respondents on the benefits they derived from the Keta lagoon and whether they considered the Keta lagoon resource as the most important source of nature-based solution (**Figure 4.20**). The majority of respondents confirmed seven ecosystem services provided by the keta lagoon complex. According to reports, the lagoon provided respondents with protein, water for construction, leisure, while protecting them from floods, improving air quality, cooling of the communities, and water quality regulation. However, the level and number of participations from households in the design, planning, implementation, and management of nature-based solutions in the township are very minimal. According to most of the study respondents, households were not engaged by the municipal assembly in the design and

implementation of most environmental projects concerning them. Most projects involving local community members were initiated by either NGOs or some private organizations.

In assessing respondents' understanding of the co-benefits of investing in NbS, four types of nature-based solutions were investigated with eleven benefits presented in the survey (**Figure 4.25- Figure 4.28**). Households' motivations for planting trees were more for the provision of shades and to reduce erosion in almost all the study communities. In addition, wetlands in the township were protected primarily for the benefit of providing protein and protection from floods. Thirdly, the majority of the respondents were motivated in protecting the Keta lagoon primarily for the provision of food and for the purpose of recreation and tourism. Finally, the mangroves ecosystem was managed for the provision of firewood and regulation of floods in the township. The local community is well aware of the benefits of managing the natural environment. However, in the absence of regulations and monitoring of these natural ecosystems, they stand at risk of being overexploited and mismanaged.

5.8 Land use/ landcover change trends in keta and options for adapting nature-based solutions

Results from the Landuse and Landcover Change assessment of the municipality reveal that at least one climate-induced hazard was identified in each study community. Overall, the hazard situations are almost synonymous with all the study communities irrespective of the diverse natural habitats in the study area (**Plate 4.8**). High tides were experienced in all the communities that share direct boundaries with the sea at different magnitudes. Over the years, the most impacts of high tide have occurred in Abutiakorpe and Keta communities resulting in occasional flooding of the lagoon. Several properties have been damaged and many households have relocated as a result.

Erosion and its impacts occurred in all the study communities with Keta community being the most affected. There are still instances of coastal erosion as a result of high waves and heavy rainfall in the township. Floods can also be associated with all the study communities with Keta again having the highest impacts. The lagoon communities are also flooded due to several factors; heavy and prolonged rainfall and flooding from other tributaries. Stormwater impact was almost not occurring in the district as many of the study communities were not experiencing stormwater. Over the years, according to the majority of the respondents, rainfall patterns and intensity have changed. The township was experiencing lesser rainfall even in the rainy seasons.

5.9 Landuse/cover change assessment in keta

Results from Landuse/ Landcover Change of 2010 and 2020 show that (**Table 4.14**) there was rapid loss of settlement cover in the study area. This may be explained by an array of interwoven factors, which includes the loss of residential cover to hazards such as floods and high tides, and the conversion of residential cover into farmlands. The seemingly insignificant increase in the size of waterbody still represents a major increase in water cover because a large proportion of the district is covered by waterbodies such as lagoons, ponds, and the Keta Lagoon. This increase in water cover occurred mainly around the lagoon leading to the loss of residential cover (displacement of households) and farmlands. A major decrease in waterbodies occurred around the coastline, overtaken by more residential and bareland cover. A study of the classified landcover/use map in **Figure 4.29** indicates rapid development of settlements in the Keta community. Significant conversion of bareland to settlements and farmlands occurred in the community. This phenomenon has increased the community vulnerability to climate-induced hazards such as flooding, erosion, and occasional hightide. Vegetation cover is seen to have

increased generally across the entire Keta township. The reasons could be as a result of the increase in cultivable lands and the township beliefs and habits of commonly planting trees.

An unusual pattern shown in this study is the increased conversion of settlement cover into farmlands and other landuse such as cemetery, and so on. Bare lands along the coast have also been converted to pockets of settlements and more farmlands. The increased rate at which this conversion is occurring requires an urgent plan of action to protect the biological diversity of the coasts. The observed pattern of landcover change has several environmental, economic, and social implications for the study area's adaptation against climate-induced coastal hazards.

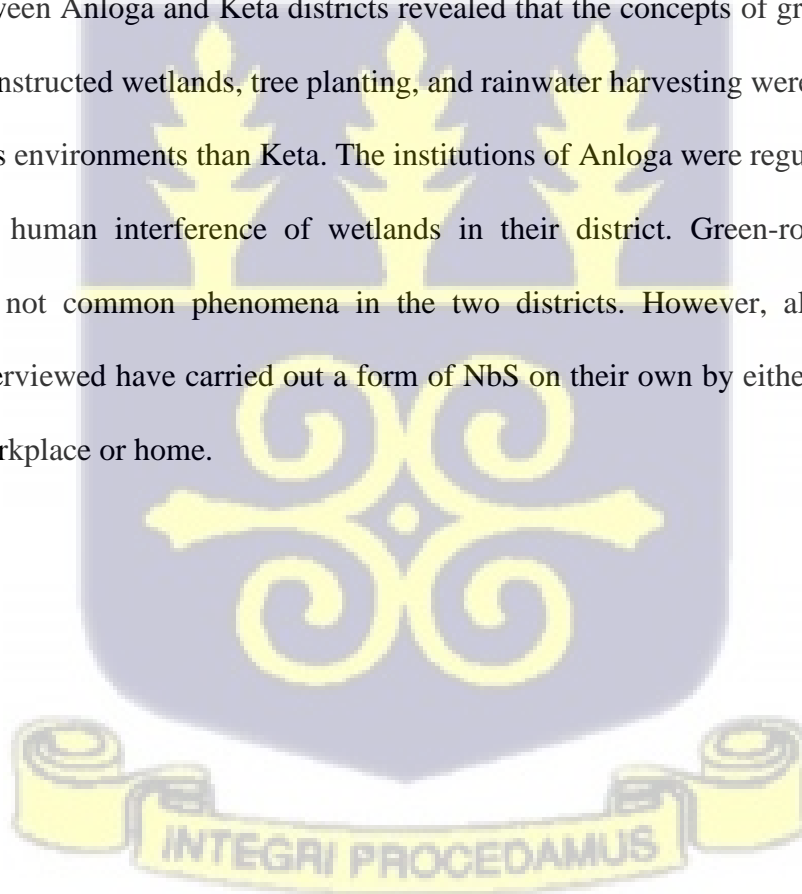
5.10 Assessment of institutional stakeholders' perception of NbS

Key institutional stakeholders' interviews were conducted to assess their perception of the Keta lagoon complex as a nature-based solution to reduce the impacts of climate-induced challenges they were struggling to manage. In addition, the study identified challenges and barriers in planning and implementing NbS. There is high awareness about the types of ecosystem benefits provided by the Keta lagoon among key stakeholders ranging from provisioning, supporting, and cultural services. According to key stakeholders, the majority believe that putting in place regulations, improving fishing practices, and frequent dredging of the lagoon would improve the benefits derived from the lagoon. The impacts of erosion, floods, and high tides were hazards that all the institutional stakeholders were struggling to manage in the districts especially the municipal assembly. In terms of their understanding of NbS and how they perceived the concept of hazard reduction in their communities, varied responses were obtained. The study also revealed that the majority of key stakeholders believe when the natural or modified ecosystem (pond, mangroves, lagoon, planting trees and grass, and marshes) is used to protect themselves and the environment,

the idea was understood as NbS. However, a few of the stakeholders thought these natural or modified habitats should be sustainably managed and restored to meet societal challenges.

In addition, the study revealed barriers and challenges of implementing NbS in the districts (**Figure 4.32**). The majority of stakeholders from the municipal administration believe inadequate finance and lack of expertise were the major barriers to implementing any form of NbS projects in the district. It can also be confirmed that the lack of collaboration between the key stakeholders and local community households posed major challenges to successfully implementing NbS.

In terms of what had been achieved or implemented in the form of NbS (**Figure 4.33**), a comparison between Anloga and Keta districts revealed that the concepts of green swales, ponds management, constructed wetlands, tree planting, and rainwater harvesting were being done more in Anloga and its environments than Keta. The institutions of Anloga were regularly seeing to the management of human interference of wetlands in their district. Green-roofs and pervious pavement were not common phenomena in the two districts. However, almost all the key stakeholders interviewed have carried out a form of NbS on their own by either planting trees or grass at their workplace or home.



CHAPTER SIX (6)

CONCLUSIONS AND RECOMMENDATIONS

6.0 Introduction

This chapter of the study focuses on summaries of key findings, conclusions, and recommendations. The first part summarizes major findings of the study with regard to the types and trends of climate-induced coastal hazards, local-level adaptation and perceptions of nature-based solutions, and landuse/landcover Change situations of the study area. The second section discusses the conclusions derived from the study whilst the final section presents the study recommendations.

6.1 Summary of key findings and conclusions

During the period between January and May, 2021, a series of studies of key institutional stakeholders' interviews and household surveys were conducted in Keta and its township to assess the trends and impacts of climate change-induced coastal hazards with existing and possible adaptation options. The study uncovered the following findings:

6.1.1 Types and trends of climate-induced coastal hazard

- Results from the entire study reveal that for objective one, the trends in floods (51%), erosion (28%), and high tides (18%) were reported as the major climate-induced coastal hazards the Keta township was struggling to manage. These hazards over the period have differed in frequency and intensity. The most affected is the Keta community with the highest impacts of floods (24%) and erosion (28%).
- Over the past five years, according to the household survey, the frequencies and intensities of these hazards have either increased, decreased, remained unchanged, or respondents were unsure of the hazards. Many of the study respondents are of the opinion that rainfall

patterns in the township are changing which is having fewer impacts from stormwater occurrence in the township. Although coastal erosion in the Keta township has been minimal over the years due to the Keta Sea defense structure, it has increased coastal erosion and flooding in surrounding communities. Inland flooding and erosion are still major problems for many residents in the township because of limited drainage systems, the development of wetlands, waterways, sand winning activities, and so on.

- The identified hazards have had several impacts on the environment and community livelihoods sources. According to the study's socioeconomic demography, fishing, crop farming, and trading are the three most common occupations of the district. This reveals that a large proportion of the population relies on natural environments such as lagoons, ponds, sea, soil, and so on for their daily needs. These natural habitats are impacted by climate-induced coastal hazards in many ways. The study revealed that the impacts of floods (38%) and high tides (30%) have displaced many residents. Coastal erosion in Keta has had very minimal impacts on households (18%) over the years due to the presence of the Keta Sea defense. Community observations and household's surveys also revealed that many properties both private and public have been destroyed by floods (44%), erosion (32%), and high tide (46%) in the township over the years. Floods have destroyed and disrupted many crop farms along the lagoon communities. The impacts of floods and erosion were due to the absence of constructed drainage system and the development of waterways and marshlands in the township. The occurrence of erosion has destroyed many roads in the study communities and reduced soil quality for most farmers. The impacts on biodiversity over the years have been significant. Many plants and animal species that

provided for a large number of the residents have become scarce. This has affected the cost of living for many and also reduced the nutritional needs of many families.

6.1.2 Existing Local adaptation and mitigation options

- Results for objective two for this study show that communities and households have adopted several practices over the years to reduce their vulnerability to coastal hazards both natural and human-induced. The most common practice that has been in existence and employed by the majority of respondents to reduce flooding and erosion in Xekpa (26%), Tetekorpe (16%), Gobamodzi (21%), and Keta (21%) has been the filling of their compounds with sea sand collected from the beach. This has been the normal practice in the township for many years. This can be likened to traditional knowledge for coastal hazards reduction. In light of very little effort from local government institutions in managing these hazards, the residents rely on this method to address several issues in their environment. Tree planting is the second most commonly used method by households to reduce not only erosion but for shades, foods, and protection of their properties in many ways. A large number of the respondents have planted trees on their properties and their communities (**Figure 4.14**). The third local adaptation measure employed by most of the study respondents to reduce floods is the creation of holes in their walls and buildings. Some of the residents along the coast have put up buildings with non-permanent materials to reduce the impacts from high tides. During several cases of high tides in the past, affected residents moved away from the impacted communities onto higher grounds. Many of these activities of the local communities in reducing their vulnerabilities to coastal hazards are embedded in the concept of using the natural environment to solve societal challenges.

- For preferred adaptation measures against hazards such as flooding in the Keta township (**Figure 4.15-Figure 4.18**), floodwater transfer (37%) and floodproofing of buildings (26%) were preferred more. In addition to these measures, the majority of respondents equally suggested dredging the lagoon and filling their compounds with sea sand. The planting of trees and building seawalls were also preferred for reducing erosion. A large number of the respondents also selected filling of compounds with sea sand to reduce erosion. The construction of small dikes and flood gates were preferred most to reduce high tides. For stormwater reduction, the majority of respondents chose to reduce paved areas by equally filling their compounds with sea sand. Construction of bigger drains was given equal attention in reducing stormwater. It was revealed that either cost, severity of hazards, availability of space, or availability of materials were the key considerations that influenced respondents' choice of adaptation measure. The cost of adaptation, the severity of hazards, availability of materials, and space were all factors that affected choices of adaptation measures. These concerns are evident in the literature on adaptation and mitigation to climate hazards.

6.1.3 Perceptions and challenges of Nature base solutions

- As their obligation, very little has been done by the local government with the engagement of the local community in the design of NbS to reduce climate-induced coastal hazards in the districts. In addition to this, there were several challenges raised by key institutional stakeholders in planning, implementing, and managing the Keta lagoon, ponds, mangroves, and other wetlands as nature-based solutions to reduce the impacts of climate hazards. The lack of finance to implement NbS and expertise to

design and manage NbS projects in the districts are the major hindrances to adopting NbS.

- As the biggest users of the natural environment, community households pointed out several reasons as motivations for implementing NbS in the township. The study revealed that; the planting of trees was done to provide shade and reduce erosion, protection of wetlands was for the benefits of providing protein and protection from floods, and managing of mangroves was done primarily to obtain firewood and flood regulations. The provision of food, recreation and tourism, and community cooling were major reasons for protecting the Keta lagoon as a nature-based solution in the district. This study concludes that the limitless co-benefits of investing and implementing NbS are not well known to both key institutional stakeholders and the local communities.

6.1.4 Trends and magnitude of Landuse and Landcover Change

- The landuse/landcover change assessment of the Keta municipality conducted for the years of 2010 and 2020 reveals that an increase in landcover occurred in waterbody, vegetation, and farmlands between 2010 and 2020 within the study area. An unusual decrease in settlement cover and bareland occurred between the same periods. However, massive settlement is identified to have taken place in the Keta community which used to be dominated by barelands. Vegetation has improved significantly across the study area. Waterbody appears to be the biggest landcover for the districts and therefore any small change in waterbody will have significant implications on other landcover. Visual representation from the classified satellite images shows that the lagoon communities are the most affected. It is worth noting that a lot of

misclassifications might have occurred between the settlement, bare land, and farmland cover types. This could be attributed to the similar reflectance values that exist between the three classes which are sometimes difficult to distinguish.

- The current climate-induced hazard situation of the study area reveals that the most common climate-induced coastal hazards in the study area were flooding and sometimes erosion. At least one climate-induced hazard was found in each of the study communities. Flood impacts and frequencies have remained unchanged in about five of the study communities while it has seen an increase in Vui and Dzelukorpe. About half of the study communities have seen an increase in erosion while the other half have seen no change in erosion impacts and frequencies. The event of high tides has decreased in almost all the study communities. Finally, the majority of study communities are not sure of the impacts and frequencies of stormwater in the district. This could either be a result of a lack of knowledge of the hazard or a misinterpretation of the term.

6.1.5 Key institutional stakeholders' perceptions of Nature-based solutions

- Key institutional stakeholders' study revealed a series of challenges among stakeholders with the management of climate-induced coastal hazards in the districts. In addition, their knowledge and actions towards the protection and use of the natural environment confirmed a series of literature about the concept of NbS. The key stakeholders identified floods, erosion, and high tides as major hazards their institutions were struggling to manage. Most of these hazards were attributed to climate change and human-landuse activities. Across all the institutions, adequate knowledge of the ecosystem benefits provided by natural resources such as lagoon, ponds, mangroves, and so on was identified.

Thirteen ecosystem benefits in total were listed by stakeholders with a majority of these being provisioning and cultural services. There is still a lack of knowledge among majority of the stakeholders about regulating and supporting services of many natural ecosystems of the district.

- Barriers to implementing nature-based solutions in the district revealed that there is little to no engagement amongst the various stakeholder groups when designing and implementing NbS projects in the district. Most times, the local community members were left out of projects planning and design. In addition, very little has been done by the local government authorities to implement NbS in their various communities. Apart from the lack of collaborations, the stakeholders attributed these challenges mainly to a lack of finance and inadequate expertise for such projects. As to what NbS were implemented in the districts, a comparison between Keta and Anloga revealed that more NbS were being implemented in the Anloga district compared to the Keta Municipality.

6.2 Study recommendations

Recommendations for this study have been made under the following headings and subheadings.

6.2.1: Stakeholders and community engagement

- *Involvement of all stakeholders and the local community in all stages of coastal hazards management.*

This study revealed that there is little to no engagement between the local government institutions, local communities, and other institutional stakeholders in managing coastal hazards in the district.

The local communities and other non-government institutions' concerns about the participation of coastal hazards management are essential to the sustainable management of hazards and increase

resilience in the district. Local resentment towards community projects which may result from not being part of the planning processes can have adverse impacts on its outcome and benefits to the communities. Local residents should be involved in all stages of the planning and decision-making process about hazards they were experiencing and struggling to manage. Techniques and measures should also be put in place for communities to benefit directly from hazard management strategies and citing. The successful implementation of community engagement will conversely ensure that local residents are given the responsibility to implement, manage and protect management projects in the township.

An example of some community engagement in local-level planning and management of hazards is the Tasman region of Mapua and Ruby Bay, which have a variety of planning and natural hazard challenges. They were vulnerable to coastal inundation and erosion, as well as freshwater flooding as a result of climate change. The size of the hazard area, future urban growth, risk management for existing properties, upkeep of current public protection systems, and service provision all required decisions. The Tasman District Council (TDC), the Mapua and Districts Community Association, landowners, residents, and other community stakeholders concerned about issues such as coastal access and archaeological site protection were among the partners involved, as were planning consultants and a joint CRI (GNS Science, NIWA, AGResearch) project that conducted a survey and provided good background information on Mapua/Ruby Bay communities (e.g. climate change attitudes, trusted sources of information, expectations of local government, acceptable costs for remedial activity). A workshop was organized with Councillors to present current natural hazard risk forecasts, expenses involved with maintaining public protection works, and alternatives for the Council's response in the worst-case situation. The public engagement process began with discussion documents that gauged public opinion on the problems. TDC

employees attended Community Association meetings monthly. Open days were held for people who chose to speak with staff one-on-one about their concerns. TDC's own risk analysis and work on several solutions were merged into a draft structure plan, along with substantial feedback. The structure plan's ideas were refined and incorporated into a draft plan change later. To date, the project has raised awareness and created a vision for managing growth and natural hazard risk in the area. The project revealed that people had varying levels of comprehension of the natural hazard risk, as well as often erroneous assumptions about how easy it would be to provide mitigation (Stewart et al., 2010).

There should also be an increase in governance infrastructure and resources for the management of climate-related coastal hazards. The increased infrastructure resource should be accompanied by trained staff and community representatives to oversee issues of disaster and hazards management.

6.2.2 Coastal hazards and Nature-based solutions

- *Management of climate-induced hazards in the district.*

The study revealed that different climate-induced hazards are occurring within communities of the township. It also revealed that both climate and human challenges are contributing to these occurrences while very little is being done by stakeholders and local communities to address the situation. Most of the existing approaches by the local communities are short-lived and unsustainable. Coastal sand winning is causing other challenges apart from increasing coastal erosion in the district. Mangroves harvesting along the coast and lagoon is reducing the biodiversity benefits provided by the resource. In addition, increased farming activities within the

district are increasing the size of bare lands which can increase erosion impacts in the district. Development of wetlands and marsh areas are on the increase posing greater risks for flooding activities. In some years to come, the Keta Sea defense would outlive its purpose as climate change persists. This study is therefore proposing the following measure to address the above-mentioned challenges.

The citizens' financial situation is linked to their reliance on community-level structural protection mechanisms, with these communities being primarily financially impoverished. Despite their willingness to do so, a lack of financial means has hampered their ability to better prepare, such as moving out of extremely dangerous locations and making their homes safe. If the communities are to be better prepared, they must improve their financial situation. As a result, financial incentives might be identified as a useful approach for enabling preparedness. On a more fundamental level, this emphasizes the significance of financially empowering vulnerable populations through programs such as vocational training, self-employment, and microbusiness chances, among other things.

During the stakeholder's interview, some community leaders discussed the shortcomings of current measures and, more significantly, how they may be improved. It is also worth noting that several steps were discovered to be in place to lessen catastrophe susceptibility in the township, including structural and other measures. In interactions with local policymakers, initiatives that address or seek to address community issues were discussed. Local policymakers recognized the need for new initiatives as they were identified.

In addition, the participatory technique can be used to gather measures that community members believe could reduce the risk of climate-related disasters. Using the cards technique, community members should write practical risk-reduction strategies on huge multi-colored paper cards of

various shapes and sizes that can be viewed by the entire group. Community members who are unable to write should be assisted by others in the community, but facilitators should exercise caution to avoid undue influence. Following the presentation of cards, community members should be encouraged to engage in conversations for explanations, which will lead to the identification of new measures.

The construction of the Akosombo Dam, which is located upstream on the Volta River, has been blamed for several recent biological changes in the wetlands, including silting and blocking of the channels that interconnect the many lagoons. This is said to have changed the normal drainage pattern, causing significant portions of the lagoon and marshlands to dry up in the dry season and severe flooding in the wet. About 90% of the study respondents including key institutional stakeholders have called for seasonal dredging of the lagoon to improve the ecosystem benefits to the district and communities.

Priority should be given to the allocation of fundings concerning environmental projects aimed at reducing climate-induced coastal hazards in the township. Study observations revealed that well-drafted plans are carried out annually within the local government institutions about targets on environmental and hazards management in the township, however, funds allocation to these projects do not come in on time or are hardly available. This was very common at the Keta municipal assembly.

- *Proposed nature-based solutions to managing coastal hazards in the district*

Natural coastal habitats serve a critical role in protecting coastal areas from storm surge to floods and so on. However, many of these ecosystems have been lost or degraded, diminishing their potential to serve as natural flood defenses. Natural ecosystems can be devastated by storm events

and other factors once they have been degraded, posing an additional hazard to these systems. Mangroves, tree and grass ecosystems, sand dune and associated sandy beach systems, salt marshes, and coral reefs (non-biogenic reefs) are all proposed for this study.

Salt marshes are wetlands along the coast that are filled and drained by tide-driven saltwater. Because the soil may be made up of deep muck and peat, they are marshy. Peat is squishy, soggy, and root-infested. Salt marshes can be found throughout the world, but they are more common in the medium to upper latitudes. They are a common habitat in estuaries, where they thrive along protected shorelines. Salt marshes can be found on every coast in the United States. The Gulf Coast is home to over half of the country's salt marshes. More than 75 percent of fishery species, including shrimp, blue crab, and numerous finfish, rely on them for food, refuge, or nursery habitat. By buffering wave action and retaining sediments, salt marshes also protect shorelines from erosion. They maintain water quality by filtering runoff and metabolizing excess nutrients, and they minimize flooding by delaying and absorbing rains (NOAA, n.d).

Coral reefs were first discovered in Ghana's waters in 2012 and located on the western coast near the border with Côte d'Ivoire. It is revealed to be about 400 metres deep in deep waters. It is also said to be about 1.4 kilometers long and 70 meters high (Africafeeds.com). As the major source of livelihoods related activities of the township, fishing activities are faced with numerous challenges related to both climate and human activities. The citing of coral reefs structures has the potential to address many challenges relating to foods security and hazards reduction. The structure of coral reefs protects shorelines from waves, storms, and floods, reducing the risk of death, property damage, and erosion. When reefs are damaged or destroyed, the lack of a natural barrier to protect coastal settlements from normal wave action and heavy storms can compound the damage. Coastal development and polluted runoff from coastal areas, on the other hand, have the potential to harm

coral reefs in the long run. As a result, coral reef health is dependent on long-term coastal development methods that safeguard delicate coral habitats and the species that live there. (NOAA, n.d).

Mangrove forests were once thought to be muddy wasteland. Planners, biologists, and coastal residents have all come to appreciate them for what they are: incredibly diverse and vital ecosystems. Mangroves, seagrass beds, and coral reefs all work together to maintain the health of coastal zones. Thousands of species rely on mangroves for their survival. They also safeguard the land and the people who live there from waves and storms by stabilizing shorelines and preventing erosion. In addition to the seasonal dredging of the lagoon ecosystem as proposed by a majority of the study respondents, the citing of mangrove ecosystems and protection of existing mangroves along the lagoon can reduce the impacts of extreme occasional floods and drought in the district. Managing of exiting mangroves along the lagoon and coastline has the potential to provide many other benefits. The mangrove ecosystem supports a diverse range of fauna, including numerous fish, crab and shrimp species, mollusks, and mammals such as sea turtles. A variety of nesting, breeding, and migratory birds use the trees as homes. When mangrove trees are cut down, significant habitat is lost, putting the survival of a variety of species and societal livelihoods at jeopardy. *“If there are no mangrove forests, then the sea will have no meaning. It is like having a tree with no roots, for the mangroves are the roots of the sea.” (Fisherman, Trang Province, southern Thailand)*

Climate change implications in the Keta district necessitate a rethinking of long-term infrastructure solutions. Coastal nature-based solutions, according to studies, can alleviate flood, erosion, and storm damage more effectively and are more resilient than gray infrastructure alone. As a result,

the study proposes the following nature-based remedies and map in **Plate 6.1** for reducing the impacts of climate-related coastal risks in the Keta township.

Within Keta, Abutiakorpe, and Gobamodzi, the restoration of wetlands, mangroves, and marshes, as well as the installation of living shorelines (plants and natural components designed to maintain and protect coasts), can help to lessen wave impacts and coastal erosion during storms. Along the lagoon communities, mangroves, wetlands, and marshes can help decrease overflowing during the rainy season and catastrophic dryness during the dry season.

The planting of trees and grass along major roads in the district can reduce the impact of erosion from heavy rains. This solution will be the most appropriate because of the lack of available lands to site adequate drainage systems. Pervious pavement should be encouraged in place of only grey infrastructure within most of the public institutions such as the hospitals, schools, and the assemblies. Small-holder farmers along the lagoon and coast should incorporate agroforestry as part of their farming practices to help reduce the impact of soil erosion, improve soil quality, and reduce deforestation from farming activities in the township. An agroforestry system will also improve soil moisture and water quality. This will help reduce the devastating effects of increased farming activities.

Rainwater harvesting is still in its infancy within most parts of the township. The practice was found in a few households within Xekpa and Keta. This practice should be redesigned and encouraged in almost all parts of the districts. As population and infrastructure demand increases within the district, the rely on grey infrastructure solutions for water security will not be the most sustainable. Harvested rainwater could be used for domestic and farming purposes.

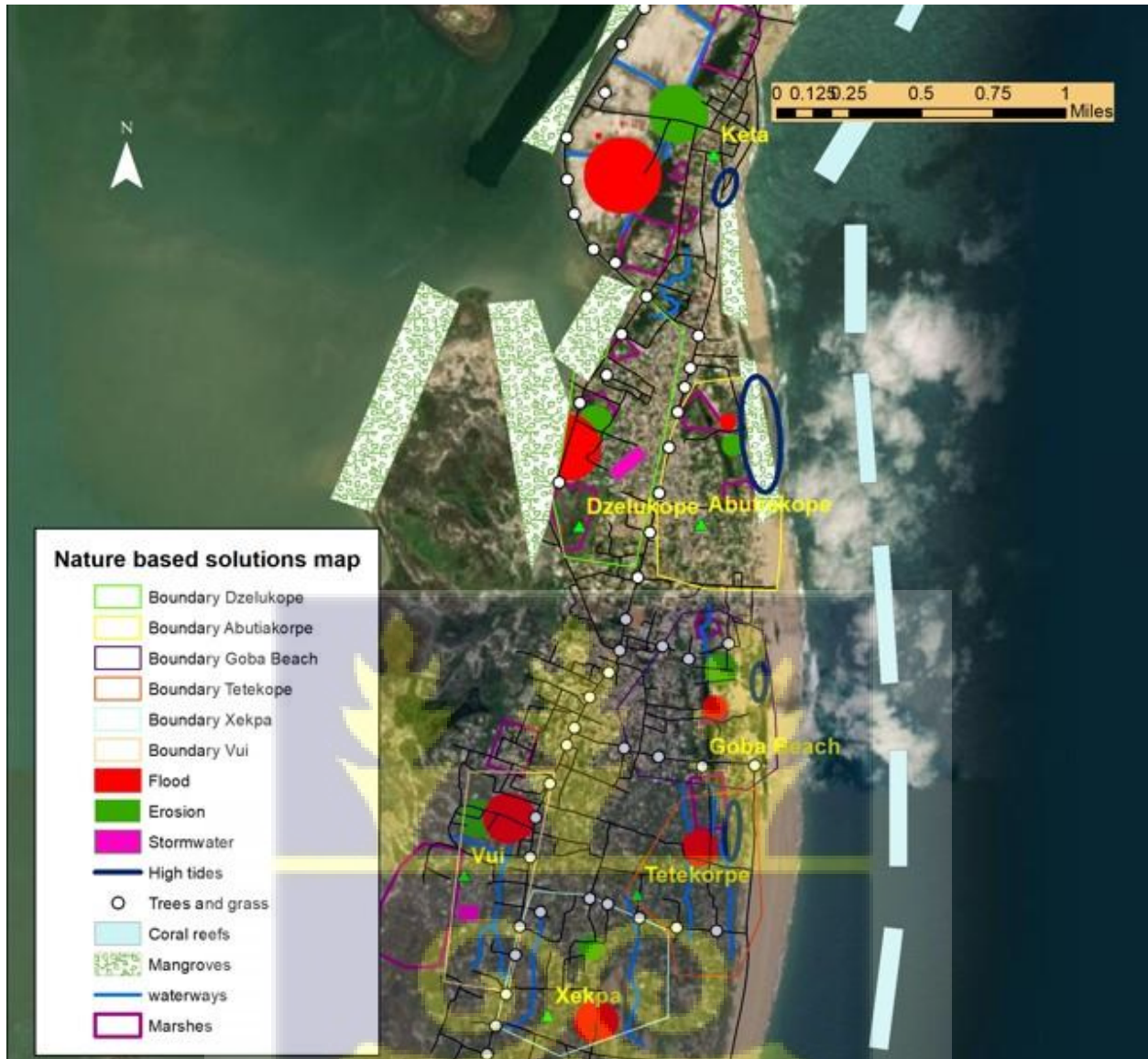


Plate 6. 1:NbS map for reducing coastal climate induced hazard

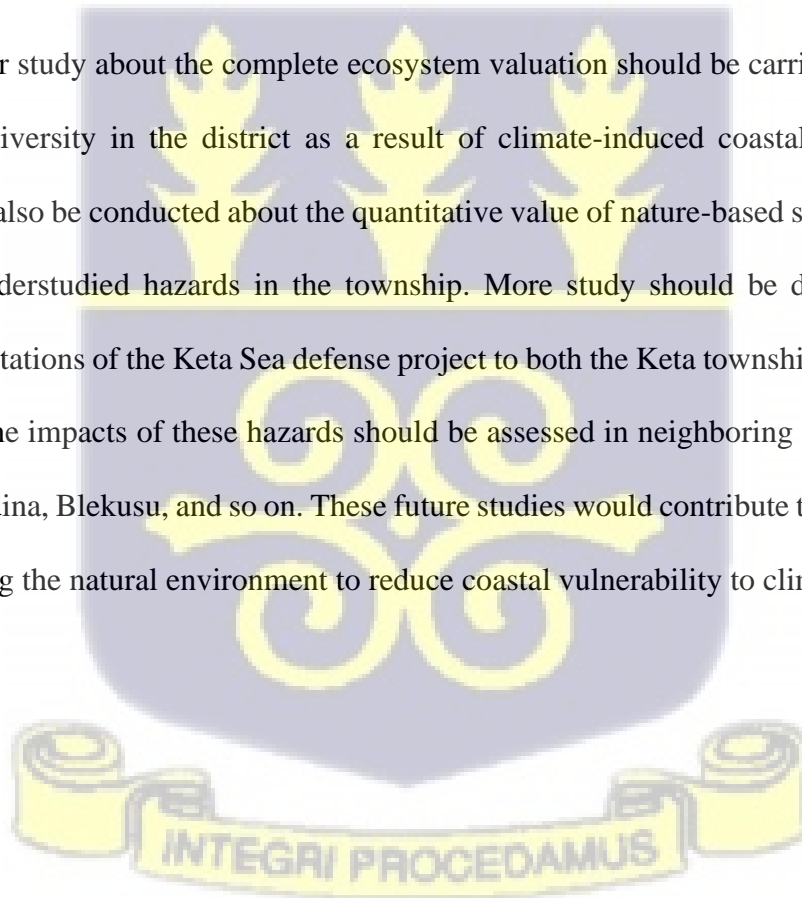
Source: Fieldwork, January-May, 2021

6.2.3 Recommendation for further study

Ghana's economic growth over the last decade has come at a cost, especially to the country's coastline. In addition to coastal agriculture and fishing, around 80% of its industrial activities, such as oil and gas production, port operations, and the generation of thermal and hydroelectric energy,

are focused along the shore. According to Appeaning Addo, K. (2014), unregulated human activities have greatly accelerated the problem of coastal erosion, a natural ongoing process by which coastlines adapt to varying sea levels, the energy levels of the tides and currents, sediment supply, and the existing topography over hundreds of years. The study's focus was on climate-induced coastal hazards along a coastal district in the eastern coastline. Although other factors contributing to coastal hazards were identified in the township, this study is recommending a complete analysis of the human causes of coastal hazards such as floods, erosion, stormwater, and high tides in the study area. Further study should be conducted on the degradation of the natural ecosystem by human activities and how this degradation can reduce coastal resilience.

Secondly, further study about the complete ecosystem valuation should be carried out to quantify the loss of biodiversity in the district as a result of climate-induced coastal hazards. Further research should also be conducted about the quantitative value of nature-based solution benefits to reducing the understudied hazards in the township. More study should be done to reveal the benefits and limitations of the Keta Sea defense project to both the Keta township and neighboring communities. The impacts of these hazards should be assessed in neighboring communities such as Salakorpe, Adina, Blekusu, and so on. These future studies would contribute to the foundational literature of using the natural environment to reduce coastal vulnerability to climate change.



REFERENCES

- Adger W.N. (2006): Vulnerability. *Global Environmental Change* 16(3) 268-281.
- Afsara Binte Mirza, Anika Binte Razzaque, S. R. R. (2020): Nature-based solutions by people of nature | Dhaka Tribune. <https://www.dhakatribune.com/climate-change/2020/12/13/nature-based-solutions-by-people-of-nature>
- Akyeampong, E. K. (2001): *Between the Sea and the Lagoon: An Eco-social History of the Anlo of Southeastern Ghana*. Ohio University Press Athens Ohio
- Akumu, C.E., Pathirana, S., Baban, S.M.J, Bucher, D.J (2010): Monitoring coastal wetland communities in north-eastern NSW using ASTER and Landsat satellite data. *Wetland Ecological Management*. 2010,18, 357–365
- Al-Nasrawi, A. K. M., Hopley, C. A., Hamylton, S. M., and Jones, B. G. (2017): A Spatio-Temporal Assessment of Landcover and Coastal Changes at Wandandian Delta System, Southeastern Australia. <https://doi.org/10.3390/jmse5040055>
- Al-Nasrawi, A.K., Jones, B.G., Hamylton, S.M (2016): “GIS-based modelling of vulnerability of coastal wetland ecosystems to environmental changes: Comerong Island, southeastern Australia.” *J. Coast Res.* 2016,75,33–37.
- Allison, I., Bindoff, N.L., Bindshadler, R.A., Cox, P.M., Noblet, N.d., England, M.H., Francis, J.E., Gruber, N., Haywood, A.M., Karoly, D.J., Kaser, G., Quéré, C.L., Lenton, T.M., Mann, M.E., McNeil, B.I., Pitman, A.J., Rahmstorf, S., Rignot, E., Schellnhuber, H.J., Schneider, S.H., Sherwood, S.C., Somerville, R.C.J., Steffen, K., Steig, E.J., Visbeck, M., Weaver, A.J., 2009. The Copenhagen Diagnosis, (2009): *Updating the World on the Latest Climate Science*. University of New South Wales, Climate Change Research Centre, Sydney.
- Al-Tahir, R, Ali, A. (2004): Assessing land cover changes in the coastal zone using aerial photography. *Surv. Land Information Science*. 64(2):107–112.
- Alves, B., Angnuureng, D. B., Morand, P., & Almar, R. (2020): A review on coastal erosion and flooding risks and best management practices in West Africa: what has been done and should be done. *Journal of Coastal Conservation*, 24(3). <https://doi.org/10.1007/s11852-020-00755-7>
- Aman A, Tano R.A, Toualy E, Silué F, Appeaning Addo K, Folorunsho R. (2019): “Physical forcing induced coastal vulnerability along the Gulf of Guinea”. *Journal of Environmental Protection* 10:1194–1211
- Angnuureng D.B, Appeaning A.K, Wiafe G. (2013): Impact of sea defense structures on Downdrift coasts: the case of Keta in Ghana. *Journey of Environmental Science* 1(6):104–121
- Angnuureng D.B, Jayson-Quashigah P-N, Almar R, Stieglitz TC, Anthony EJ, Aheto DW, Appeaning AK (2020): “Application of shore-based video and unmanned aerial vehicles (drones): complementary tools for beach studies”. *Remote Sens* 12(3):394.
- Appeaning Addo, K. (2014): “Coastal Vulnerability Index to Sea Level Rise in Ghana Coastal Vulnerability Index to Sea Level Rise in Ghana. January”. <https://doi.org/10.12966/cmr.01.01.2014>

- Appeaning Addo, K. (2011): “Changing Morphology of Ghana’s Accra Coast”. *Journal of Coastal Conservation* 15(4): 433–443. doi:10.1007/s11852-010-0134-z.
- Armah, A.K. and Amlalo, D.S., (1998): “Coastal Zone Profile of Ghana. Gulf of Guinea Large Marine Ecosystem Project. Accra, Ghana: Ministry of Environment, Science and Technology”.
- Arsanjani, J.J. (2011): *Dynamic Land Use / Cover Change Modelling: Geo-simulation and Agent-Based Modelling*. Vienna: University of Vienna; 2011.
- Beaumont, N.J., Austen, M.C., Atkins, J.P., Burdon, D., Degraer; S., Dentinho; T.P., Derous, S., Holm, P., Horton, T., van Ierland, E., Marboe, H., Starkey, D.J, Townsend, M., and Zarzycki, T., (2007): Identification, definition and quantification of goods and services provided by marine biodiversity: implications for the ecosystem approach. *Marine pollution bulletin*, 54, 253-265
- Beck, M.W., Heck, K.L., Able, K.W., Childers, D.L., Eggleston, D.B., Gillanders, B.M., Halpern, B., Hays, C.G., Hoshino, K., Minello, T.J., Orth, R.J., Sheridan, P.F., Weinstein, M.P., (2001): The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. *Bioscience* 51 (8), 633.
- Beck, M. W. (2014): *Coasts at Risk An Assessment of Coastal Risks and the Role of Environmental Solutions*. The Nature Conservancy (TNC) and the Coastal Resources Center (CRC) at the University of Rhode Island Graduate School of Oceanography.
- Bender, M.A., Knutson, T.R., Tuleya, R.E., Sirutis, J.J., Vecchi, G.A., Garner, S.T., Held, I.M., (2010): Modeled impact of anthropogenic warming on the frequency of intense Atlantic hurricanes. *Science* 327, 454e458
- Benefits of Coastal Landscaping | Mass.gov. (n.d.). Retrieved April 1, 2021, from <https://www.mass.gov/service-details/benefits-of-coastal-landscaping>
- Benefits of marine and coastal ecosystems to human wellbeing | GRID-Arendal. (n.d.). Retrieved April 1, 2021, from <https://www.grida.no/resources/5612>
- Berkes, F. (2012): *Sacred Ecology*, 3rd ed. Routledge, New York
- Bewket, (2002): Farmers' participation in soil and water conservation activities in the Chemoga Watershed, Blue Nile basin, Ethiopia. <https://doi.org/10.1002/ldr.492>
- Bird, E. C. F. (1985): *Coastline changes; A Global Review*. Wiley, Chichester (1985).
- Boafo, Y.A. (2018): *Safeguarding the Keta Lagoon Complex Ramsar Site (KLCRS) for Sustained Socio-ecological Benefits*. Integrated Research System for Sustainability Science (IR3S), The University of Tokyo
- Boateng, I. (2006): *Shoreline management planning: Can it benefit Ghana? A case study of UK SMPs and their potential relevance in Ghana*. Promoting Land Administration and Good Governance, 5th FIG Regional Conference, Accra, Ghana, March 8–11, 2006.
- Boateng, I. (2012): An application of GIS and coastal geomorphology for large scale assessment of coastal erosion and management: a case study of Ghana. *Journal of Coast Cons* 16:383–397

- Boateng, I. (2009): Development of integrated shoreline management planning: a case study of Keta, Ghana. Paper presented at the Proceedings of the Federation of International Surveyors Working Week 2009-Surveyors Key Role in Accelerated Development
- Borsje, B. W., Van Wesenbeeck, B. K., Dekker, F., Paalvast, P., Bouma, T. J., Van Katwijk, M. M. & DE Vries, M. B. (2011): How ecological engineering can serve in coastal protection. *Ecological Engineering*, 37, 113-122.
- Bridges, T.S., Burks-Copes, K.A., Bates, M.E., Collier, Z.A., Fischenich, J.C., Piercy, C.D., Russo, E.J., Shafer, D.J., Suedel, B.C., Gailani, J.Z., Rosati, J.D., 2015. Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience. US Army Engineer Research and Development Center, Environmental Laboratory, Coastal and Hydraulics Laboratory.
- Burton, I, Kates R, and White G. (1993): The environment as hazard. (*Guildford Press, New York*).
- Burton, I., E. Diringier and J. Smith. 2006. Adaptation to Climate Change: International Policy Options. Pew Center on Global Climate Change. Arlington, Virginia, USA.
- Bulkeley, H., Bracken, L., Almassy, D., Pinter, L., Naumann, S., Davis, M., Reil, A., Hedlund, K., Hanson, H., Dassen, T., Raven, R., & Botzen, W. (2017). State of the Art Review: Approach and Analytical Framework (Deliverable 1.3: Part I). NATURVATION project funded by the EU Horizon 2020 research and innovation programme under grant agreement No. 730243
- Cazenave, A and Llovel W. (2010): Contemporary Sea level rise. *Annual Review of Marine Science* 2(1), 145-173
- Chakilu, G.G., Moges M.A. (2017): Assessing the Land Use/Cover Dynamics and its Impact on the Low Flow of Gumara Watershed, Upper Blue Nile Basin, Ethiopia. *Hydrol Current Res* 7: 268. doi: 10.4172/2157-7587.1000268
- Chapman, M. G. & Underwood, A. J. (2011): Evaluation of ecological engineering of “armoured” shorelines to improve their value as habitat. *Journal of Experimental Marine Biology and Ecology*, 400, 302-313
- Cho, H.Y, Lakshumanan, C., Usha, N. Coastal wetland and shoreline change mapping of Pichavaram, southeast coast of India using satellite data. In Proceedings of the Geospatial Application Papers, Map Asia Conference, Beijing, China, 26–29 August 2004
- Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., Maginnis, S., Maynard, S., Nelson, C. R., Renaud, F. G., Welling, R., & Walters, G. (2019): Core principles for successfully implementing and upscaling Nature-based Solutions. *Environmental Science and Policy*, 98(February), 20–29. <https://doi.org/10.1016/j.envsci.2019.04.014>
- Cohen-Shacham, E., Walters, G., Janzen, C., Maginnis, S. (Eds.), (2016): Nature-Based Solutions to Address Global Societal Challenges. IUCN International Union for Conservation of Nature.
- Costanza, R., D’Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., et al. (1997): The value of the world’s ecosystem services and natural capital. *Nature* 387, 253–259.
- Costanza, R., Perez-Maqueo, O., Luisa Martinez, M., Sutton, P., Anderson, S.J., Mulder, K., (2008): The value of coastal wetlands for hurricane protection. *AMBIO* 37, 241–248.

- Cooper, J.A.G and McLaughlin S. (1998): Contemporary multidisciplinary approaches to coastal classification and environmental risk analysis. *Journal of Coastal Research* 14(2) 512-524.
- Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003): Social Vulnerability to Environmental Hazards. *Social Science Quarterly*, 84(2), 242–261.
- Cutter S.L. (1996): Vulnerability to environmental hazards. *Progress in Human Geography* 20(4) 529-539.
- Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D. & Yan, J. (2007): ‘The impact of sea-level rise on developing countries: A comparative analysis’, World Bank Policy Research Working Paper 4136,1(1), viewed 28 June 2012
- Davis, M., Krüger, I., & Hinzmann, M. (2015): Coastal protection and SUDS – Nature-Based Solutions.
- Deshmukh, B. (2017): Unit 9 Ground Truth Data Collection. 45–64.
- de Vries D.H. (2011): Temporal vulnerability in hazardscapes: flood memory-networks and referentiality along the North Carolina Neuse River (USA). *Global Environmental Change* 21(1) 154-164
- Dethier, M. N., and Harbor, F. (2011): Classes of Nearshore Coasts. In *Treatise on Estuarine and Coastal Science* (Vol. 1). Elsevier Inc. <https://doi.org/10.1016/B978-0-12-374711-2.00105-4>
- Duedall, W., Maul G.A. (2005): Demography of Coastal Populations. in *Encyclopedia of Coastal Science*, *Encyclopedia of Earth Sciences Series*, edited by M.L. Schwartz, Springer, the Netherlands. p. 368-374.
- Du Bois, R. A *Natural Hazards Assessment of the Coastal Area of Saint Lucia, West Indies* (Washington, D.C.: Organization of American States, 1985).
- Dudley, N., Stolton, S., Belokurov, A., Krueger, L., Lopoukhine, N., MacKinnon, K., Sandwith, T., Sekhran, N. (2010): *Natural Solutions: Protected Areas Helping People Cope with Climate Change*. IUCN WCPA, TNC, UNDP, WCS, The World Bank and WWF, Gland, Switzerland, Washington DC and New York, USA. *Millennium Ecosystem Assessment (MEA). 2003. Ecosystems and human well-Being: A Framework for Assessment*. Washington, D.C., USA: Island Press.
- Dwyer, A. Z., Nielsen, C., Day, S., et al. (2004): Quantifying social vulnerability: A methodology for identifying those at risk to natural hazards. *Geosciences Australia Record*, 14, 20004.
- Eakin H. and Luers A.L. (2006): Assessing the vulnerability of social-environmental systems. *Annual Review of Environment and Resources* 31 365-394.
- EC (European Commission) (2015): *Horizon. Work Programme 2016–2017: 12. Climate action, environment, resource efficiency and raw materials*. European Commission Decision C (2016) 1349 of 9 March 2016
- EC (2015): *Towards an EU Research and Innovation policy agenda for Nature- Based Solutions & Re-Naturing Cities*. Final Report of the Horizon 2020 Expert Group on 'Nature-Based Solutions and Re-Naturing Cities' (full version).

- Eggermont, H., Balian, E., Azevedo, J.M.N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P., Reuter, K. (2015): Nature-based solutions: new influence for environmental management and research in Europe. *GAIA-Ecological Perspectives for Science and Society* 24, 243–248.
- Elliott, M., Dewailly, F. (1995): The structure and components of European estuarine fish assemblages. *Netherlands Journal of Aquatic Ecology* 29, 397–417 (1995). <https://doi.org/10.1007/BF02084239>
- Ellis, M.Y. (1978): Coastal Mapping Handbook (Washington, D.C.: U.S. Geological Survey and Office of Coastal Zone Management, 1978).
- European Commission (2018): European Commission Webpage on Nature-based Solutions. <https://ec.europa.eu/research/environment/index.cfm?pg=nbs>
- Faivre, N., Fritz, M., Freitas, T., de Boissezon, B., Vandewoestijne, S. (2017): Nature-Based Solutions in the EU: innovating with nature to address social, economic and environmental challenges. *Environ. Res.* 159, 509–518
- Fabrice G. Renaud, Karen Sudmeier-Rieux and Estrella Marisol, The Role of Ecosystems in Disaster Risk Reduction (Tokyo: UNU Press, 2013).
- Frantzeskaki, N., McPhearson, T., Collier, M. J., Kendal, D., Bulkeley, H., Dumitru, A., Walsh, C., Noble, K., Van Wyk, E., Ordóñez, C., Oke, C., & Pintér, L. (2019): Nature-based solutions for urban climate change adaptation: Linking science, policy, and practice communities for evidence-based decision-making. *BioScience*, 69(6), 455–466 <https://doi.org/10.1093/biosci/biz042>
- Frechette, A., Ginsburg, C. & Walker, W. (2018): A Global Baseline of Carbon storage in a collective land: indigenous and local community contributions to climate change mitigation. Washington D.C., rights and resources initiative (RRI), Woods Hole Research Center, World resources institute.
- Füssel H.M. (2007): Vulnerability: a generally applicable conceptual framework for climate change research. *Global Environmental Change* 17(2) 155-167.
- Gallopín G.C. (2006): Linkages between vulnerability, resilience and adaptive capacity. *Global Environmental Change* 16(3) 293-303.
- Gallopín G.C, Gutman P. and Maletta H. (1989): Global impoverishment, sustainable development and the environment: a conceptual approach. *International Social Science Journal* 121 375-397.
- GESAMP, (2005): A Sea of Troubles 2001 #70 (40p.) Publisher(s): UNEP. *Journal Series Reports and Studies*.
- Gornitz, V. (2000): Impoundment, Groundwater Mining, and other Hydrologic Transformations. In Sea Level Rise: History and Consequences; Douglas, B.C., Ed.; *Academy Press*: Fletcher, NC, USA, 2000.
- Goodchild, M. F. (2004): Geographic Information Systems. In Encyclopedia of Social Measurement (pp. 107–113). Elsevier Inc. <https://doi.org/10.1016/B0-12-369398-5/00335-2>

- Gopalakrishnan, S., C. E. Landry, and M. D. Smith. (2018): “Climate Change Adaptation in Coastal Environments: Modeling Challenges for Resource and Environmental Economists.” *Review of Environmental Economics and Policy* 12: 48–68. [Crossref], [Web of Science ®], [Google Scholar]
- Ghana Statistical Service, (2010): 2010 Population and Housing Census Provisional Results Summary of Findings, <http://www.ghana.gov.gh/census/phc2010.pdf> (Assessed on 20/03/2011)
- Haack, B. (1996): Monitoring wetland changes with remote sensing: An East African example. *Environ. Manag.* 1996,20, 411–419.
- Han, W., Meehl, G.A., Rajagopalan, B., Fasullo, J.T., Hu, A., Lin, J., Large, W.G., Wang, J.w., Quan, X.-W., Trenary, L.L., Wallcraft, A., Shinoda, T., Yeager, S. (2010): Patterns of Indian Ocean sea-level change in a warming climate. *Nat. Geosci.* 3, 546e550 IPCC, (2013). Climate Change, The Physical Science Basis: Summary for Policymakers, s.l.: s.n.
- Hanson, H. I., Wickenberg, B., & Alkan, J. (2020): Land Use Policy Working on the boundaries — How do science use and interpret the nature- based solution concept? 104302. <https://doi.org/10.1016/j.landusepol.2019.104302>
- Hanley, M.E., S.P.G. Hoggart, D.J. Simmonds, A. Bichot, M.A. Colangelo, F. Bozzeda, H. Heurtefeux, et al. (2014): “Shifting Sands? Coastal Protection by Sand Banks, Beaches and Dunes.” *Coastal Engineering* 87: 136–46
- Hegazy, I.R. and Kaloop, M.R. (2015): Monitoring Urban Growth and Land Use Change Detection with GIS and Remote Sensing Techniques in Daqahlia Governorate Egypt. *International Journal of Sustainable Built Environment*, 4, 117- 124. <https://doi.org/10.1016/j.ijbsbe.2015.02.00>
- Heltberg R, Siegel P.B, and Jorgensen S.L. (2009): Addressing human vulnerability to climate change: towards a ‘no-regrets’ approach. *Global Environmental Change* 19(1) 89-99
- He D, Zhou J, Gao W, Guo H, Yu S, Liu Y. (2014): An integrated CA-markov model for dynamic simulation of land use change in Lake Dianchi watershed. *Beijing Daxue Xuebao (Ziran Kexue Ban)/Acta Scientiarum Naturalium Universitatis Pekinensis*. 2014; 50(6):1095–105.
- Hinkel, J., Brown, S., Exner, L., Nicholls, R.J., Vafeidis, A.T. & Kebede, A.S. (2011): ‘Sealevel rise impacts on Africa and the effects of mitigation and adaptation: An application of DIVA’, *Regional Environmental Change*, viewed 22 August 2011, from <http://www.springerlink.com/content/v25561n65501lk3n/>, <http://dx.doi.org/10.1007/s10113-011-0249>
- Hoang L. and Fenner R.A. (2016): System interactions of stormwater management using sustainable urban drainage systems and green infrastructure, *Urban Water Journal*, 13:7, 739-758, DOI: 10.1080/1573062X.2015.1036083
- Holling C.S. (1973): Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4(1) 1-23.
- Holl, K.D. (2017): Restoring tropical forests from the bottom up. *Science* 355 (6324), 455–456. <https://doi.org/10.1126/science.aam5432>

Hurni et al. (2005): The Implications of Changes in Population, Land Use, and Land Management for Surface Runoff in the Upper Nile Basin Area of Ethiopia. *Mountain Research and Development* May 2005: 147–154

Ilieva, R.T., McPhearson, T. (2018): Social-media data for urban sustainability. *Nat. Sustain.* 1, 553–565 (2018). <https://doi.org/10.1038/s41893-018-0153-6>

Intergovernmental Panel on Climate Change, Climate Change (2014): Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge and New York: Cambridge University Press, 2014).

Inter-Governmental Panel on Climate Change (IPCC) (n.d.). The earth's greenhouse - CO₂ and IPCC climate modeling. Global Warming Science.

http://appinsys.com/globalwarming/gw_part5_greenhousegas.

IPCC, (2021): Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3–32, doi:10.1017/9781009157896.001.

IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. In [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp (Vol. 9781107025). <https://doi.org/10.1017/CBO9781139177245.003>

IUCN (2010): Coastal Ecosystem-based Adaptation

IUCN (2014): Nature-based solutions. Available via http://www.iucn.org/about/union/secretariat/offices/europe/european_union/key_issues/nature_based_solutions. Accessed 30 Apr 2016

IUCN (n.d.) Pioneering nature's solutions to global challenges. Available via https://cmsdata.iucn.org/downloads/iucn_english_brochure.pdf. Accessed 30 Apr 2016

Jonah, F. E., D. Adjei-Boateng, A. E. Mensah, N. W. Agbo, and R. E. Edziyie. (2015): Assessment of sand and stone mining along the coastline of Cape Coast, Ghana. *Annals of GIS*, doi:10.1080/19475683.2015.1007894

Jonah, F. E., Jonah, F. E., Mensah, E. A., Edziyie, R. E., Agbo, W., Adjei-boateng, D., Ekow, F., Mensah, E. A., & Esi, R. (2016): Coastal Erosion in Ghana : Causes , Policies , and Management Coastal Erosion in Ghana : Causes , Policies , and Management. November 2018. <https://doi.org/10.1080/08920753.2016.1135273>

Johnston, R. J., C. Makriyannis, and A. W. Whelchel. (2018): “Using Ecosystem Service Values to Evaluate Tradeoffs in Coastal Hazard Adaptation.” *Coastal Management* 46: 259–277. [Taylor & Francis Online], [Web of Science ®], [Google Scholar]

Jurik, J., Schneider-Roos, K., Gaullier, N., Kolokotsa, D., Nikolaidis, N., Lilli, K., Lilli, M., van

- Rompaey, S., Goni, E., Stagakis, S., Mink, E., Lemaitre, F., & Bailly, E. (2018): Report on Dialogue Steering Statement Papers and Dialogue Outcomes for Sustainable Urbanisation in Cities (Deliverable 4.1). ThinkNature project funded by the EU Horizon 2020 research and innovation programme under grant agreement No. 730338.
- Kabat, P., Fresco, L. O., Stive, M. J. F., Veerman, C. P., van Alphen, J. S. L. J., Parnet, B. W. H., et al. (2009): Dutch coasts in transition. *Nat. Geosci.* 2, 450–452. doi: 10.1038/ngeo572
- Kabisch N. et al. (2017): Nature - based Solutions to Climate Change Adaptation in Urban Areas Linkages between Science , Policy and practice.
- Kaiser, G (2006): Risk and vulnerability analysis to coastal hazards- an approach to integrated assessment. PhD thesis, Christian Albrecht University, Kiel, Germany.
- Kildow J.T. and McIlgorm A. (2010): The importance of estimating the contribution of the oceans to national economies, *Marine Policy*, 34, (3), 367-374
- Kockelman, W.J., and Brabb, E.E. (1979): "Examples of Seismic Zonation in the San Francisco Bay Region" in E.E. Brabb (ed.), *Progress on Seismic Zonation in the San Francisco Bay Region*, Circular 807 (Reston, Virginia: U.S. Geological Survey, 1979)
- Koch, E. W., J. D. Ackerman, J. Verduin, and M. Keulen, (2006): “Fluid Dynamics in Seagrass Ecology—from Molecules to Ecosystems.” In *Seagrasses: Biology, Ecology and Conservation*, 193–225. Berlin/Heidelberg: Springer-Verlag.
- Krauze, K., and Wagner, I. (2019): From classical water-ecosystem theories to nature-based solutions — Contextualizing nature-based solutions for sustainable city. *Science of The Total Environment*, 655, 697–706. doi:10.1016/j.scitotenv.2018.11.187
- Kurt, S., A. Karaburun, and A. Demirci (2010): Coastline changes in Istanbul between 1987 and 2007. *Scientific Research and Essays* 5 (19):3009–3017.
- Laïbi, R.A, Anthony, E.J, Almar, R, Castelle, B, Sénéchal, N, Kestenare, E (2014): Longshore drift cell development on the human-impacted Bight of Benin sand barrier coast, *West Africa. J Coast Res* 70(SI): 78–83
- Lambin, E. F., Geist, H. J., Lepers, E. (2003): Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources*, 28, 205–241. <https://doi.org/10.1146/annurev.energy.28.050302.105459>
- Lindgren, D. (2011). *Form and Functions of Coastal Areas*.
- Liping, C., Yujun, S., & Saeed, S. (2018): Monitoring and predicting land use and land cover changes using remote sensing and GIS techniques—A case study of a hilly area, Jiangle, China. 13(7), e0200493. <https://doi.org/10.1371/journal.pone.0200493>
- Low S.M. and Altman I. (1992): Place attachment: a conceptual inquiry. In: *Place attachment*, edited by Altman I and Low S (Plenum Press, New York) 1-12.
- Lo, V. (2016): Synthesis Report on Experiences with Ecosystem-based Approaches to Climate Change Adaptation and Disaster Risk Reduction. Technical Series No.85. Secretariat of the Convention on Biological Diversity, Montreal 106 pages

- Luna, P. M., and Young, P. S. (2019): Coastal flood hazard assessment of Ghana.
- Ly, C.K. (1980): The Role of the Akosombo Dam on the Volta River in Causing Coastal Erosion in Central and Eastern Ghana (West Africa). *Marine Geology*, 37, 323-332.
- McGranahan, G. Balk, D., Anderson, B. (2007): Rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environ. Urban.* 19:17
- McConnell W.J (2015): Land Change: The Merger of Land Cover and Land use Dynamics A2—Wright, James D. *International Encyclopedia of the Social & Behavioral Sciences* (Second Edition). Oxford: Elsevier; 2015. p. 220–3
- Mentzer, A.P. (2021): Where Are the Temperate Zones Located? *sciencing.com*. Retrieved from <https://sciencing.com/temperate-zones-located-5882122.html>
- Millennium Ecosystem Assessment (MEA), (2005): Ecosystems and Human Well-being: Synthesis. *Island Press*, Washington, DC.
- Möller I. (2019): Applying Uncertain Science to Nature-Based Coastal Protection: Lessons From Shallow. 7(April). <https://doi.org/10.3389/fenvs.2019.00049>
- Mukhopadhyay, A., Dasgupta, R., Hazra, S., & Mitra, D. (2012): Coastal hazards and vulnerability: a review. 2(1), 57–69.
- Myint S.W., Wang L. (2006): Multicriteria decision approach for land use land cover change using Markov chain analysis and a cellular automata approach. *Can J Remote Sens.* 2006; 32(6):390–404. <https://doi.org/10.5589/m06-032>
- Nadzirah H., Hitoshi N., and Amran H. (2020): Adaptation to Climate Change: Does Traditional Ecological Knowledge Hold the Key? Received: 25 December, 2019; Accepted: 15, January 2020; Published: 16 January, 2020.
- National Academies of Sciences, Engineering, and Medicine. (2018): Understanding the Long-Term Evolution of the Coupled Natural-Human Coastal System: The Future of the U.S. Gulf Coast. Washington, DC: The National Academies Press. doi: <https://doi.org/10.17226/25108>.
- National Academies of Sciences, Engineering, and Medicine. (2018): Understanding the Long-Term Evolution of the Coupled Natural-Human Coastal System: The Future of the U.S. Gulf Coast. Washington, DC: The National Academies Press. <https://doi.org/10.17226/25108>.
- Nicholls, R.J. and Tol, R.S.J. (2006): 'Impacts and responses to sea-level rise: A global analysis of the SRES scenarios over the twenty-first century', *Philosophical Transactions of the Royal Society A*, 364(1841), 1073–1095.
- Nicholls, R.J., P. P. Wong, V. R. Burkett, J. O. Codignotto, J. E. Hay, R. F. McLean, S. Ragoonaden, and C. D. Woodroffe. (2007): Coastal systems and low-lying areas. In *Climate Change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, 315–356. Cambridge, UK: Cambridge University Press.
- Ntiama-Baidu Y. and Gordon C. (1991): Coastal wetlands management plans: Ghana. Report to the World Bank, Department of Zoology, University of Ghana, Legon

oas.org. (n.d.). Chapter 6 multiple hazard mapping. Retrieved April 27, 2021, from <http://www.oas.org/dsd/publications/unit/oea66e/ch06.htm>

OmniSci. (n.d.). What is Spatial Temporal? Definition and Related FAQs. Retrieved April 5, 2021, from <https://www.omnisci.com/technical-glossary/spatial-temporal>

Ozesmi, S.L.; Bauer, M.E (2002): Satellite remote sensing of wetlands. *Wetl. Ecol. Manag.* 2002,10, 381–402

Perry, C. T., P. S. Kench, M. J. O’Leary, K. M. Morgan, and F. Januchowski-Hartley (2015): “Linking Reef Ecology to Island Building: Parrotfish Identified as Major Producers of Island-Building Sediment in the Maldives.” *Geology* 43, no. 6: 503–6.

Pontee, N. (2016): Nature Based Solutions: lessons from around the world. May. <https://doi.org/10.1680/jmaen.15.00027>

Raymond, C., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M.R., Geneletti, D., Calfapietra, C. (2017): A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environ Sci Policy* 77, 15–24.

Rodríguez Guerra, Y., Valdés Sáenz, M. A., Hernández Ramos, H., and Soria Re, S. (2019): Guía metodológica para estudio etnobotánico de especies forestales en comunidades amazónicas y afines. In *Revista Cubana de Ciencias Forestales* (Vol. 7, Issue 1).

Roshier, D.A.; Rumbachs, R.M (2004): Broad-scale mapping of temporary wetlands in arid Australia. *Journal Arid Environ.* 2004,56, 249–263

Rumson, A. G., Hallett, S. H., and Brewer, T. R. (2017): Coastal risk adaptation: the potential role of accessible geospatial Big Data. *Mar. Policy* 83, 100–110. doi: 10.1016/j.marpol.2017.05.032

Sauka, S. (2020): Policy Insights Resilient Ecosystems and Disaster Risk Reduction: Opportunities for Coastal Cities in Africa. March.

Scyphers, S. B., A. P. Powers, K. L. Heck, and D. Byron (2011): “Oyster Reefs as Natural Breakwaters Mitigate Shoreline Loss and Facilitate Fisheries.” Edited by H. Browman. no. 8: e22396.

SDGs (UN Sustainable Development Goals) (2017): <https://sustainabledevelopment.un.org/sdgs>.

Sewnet, Amare (2015): “Land Use/Cover Change at Infrac Watershed, Northwestren Ethiopia” *Journal of Landscape Ecology*, vol.8, no.1, 2015, pp.69-83. <https://doi.org/10.1515/jlecol-2015-0005>

Setegn, S. G., R. Srinivasan, B. Dargahi, and A. M. Melesse (2009): Spatial delineation of soil erosion vulnerability in the Lake Tana Basin, Ethiopia, *Hydrol. Processes*, 24, 357– 367. Web of Science@Google Scholar

Small C. and Nicholls R.J (2003): A global analysis of human settlement in coastal zones. *Journal of Coastal Research* 19(3) 584-599.

Somarakis, G., Stagakis, S., and Chrysoulakis, N. (2019): ThinkNature Nature Based Solutions Handbook. ThinkNature Project Funded by the EU Horizon 2020 Research and Innovation Programme, 730338, 1–226.

Sohl T.L, Claggett P.R. (2013): Clarity versus complexity (2013): Land-use modeling as a practical tool for decision- makers. *Journal of Environmental Management*. 2013; 129:235–43. <https://doi.org/10.1016/j.jenvman.2013.07.027>. <https://doi.org/10.1016/j.jenvman.2013.07.027> PMID: 23954777

South African National Biodiversity Institute and Department of Environmental Affairs, Strategic Framework and Overarching Implementation Plan for Ecosystem-Based Adaptation (EbA) in South Africa 2016–2021 (Pretoria: SANBI and DEA, 2018)

Spalding, M. D., Ruffo, S., Meliane, I., Hale, L. Z., Lacambra, C. C. C., and Beck, M. W. (2014): The role of ecosystems in coastal protection: adapting to climate change and coastal hazards. *Ocean Coast. Manag.* 90, 50–57. doi: 10.1016/j. ocecoaman.2013.09.007

Stewart, C.; Becker, J.S.; Blackett, P.; Coomer, M.A.; Reese, S.; Hume, T. (2010): Coastal residents' views on climate change. p. 55 In: Stewart, C. (ed.) 4th Australasian Hazards Management Conference: from warnings to effective response and recovery, Te Papa, Wellington, New Zealand, 11-12 August 2010. GNS Science miscellaneous series 33

“Temperate zone.” Merriam-Webster.com Dictionary, Merriam-Webster, <https://www.merriam-webster.com/dictionary/temperate%20zone>. Accessed 15 Mar. 2021.

Tewabe, D., and Fentahun, T. (2020): Assessing land use and land cover change detection using remote sensing in the Lake Tana Basin, Northwest Ethiopia. *Cogent Environmental Science*, 6(1), 1778998. <https://doi.org/10.1080/23311843.2020.1778998>

The National Academies Press. (n.d.). Performance of Coastal Risk Reduction Strategies Reducing Coastal Risk on the East and Gulf Coasts. Retrieved April 8, 2021, from <https://www.nap.edu/read/18811/chapter/5#75>

Thior M, Sané T, Dièye E-HB, Sy O, Cissokho D, Ba B.D, Descroix L. (2019): Coastline dynamics of the northern lower Casamance (Senegal) and southern Gambia littoral from 1968 to 2017. *J Afr Earth Sci* 160:103611. <https://doi.org/10.1016/j.jafrearsci>.

Toro J, Duarte O, Requena I and Zamorano M. (2012): Determining vulnerability importance in environmental impact assessment: the case of Colombia. *Environmental Impact Assessment Review* 32(1) 107-117.

Turner II B. (2010): Vulnerability and resilience: coalescing or paralleling approaches for sustainability science? *Global Environmental Change* 20(4) 570-576.

United Nations Framework Convention on Climate Change (UNFCCC), UNFCCC, (1992).

United Nations Environment Programme (2004): Annual evaluation report 2004

UNESCO. (2003c). Draft recommendation concerning the promotion and use of multilingualism and universal access to cyberspace (Document 32 C/27). Paris, France: UNESCO.

UNFCCC, 1992: United Nations Framework Convention on Climate Change. United Nations, FCCC/INFORMAL/84 GE.05-62220 (E) 200705, Secretariat of the United Nations Framework Convention on Climate Change, Bonn, Germany, 24 pp., unfccc.int/resource/docs/convkp/conveng.pdf.

Van Ham C. (2014): Pioneering nature-based solutions. Available via www.biodiversa.org/673/download. Accessed 30 Apr 2016

Vasseur, L., Horning, D., Thornbush, M., Cohen-Shacham, E., Andrade, A., Barrow, E., et al. (2017): Complex problems and unchallenged solutions: bringing ecosystem governance to the forefront of the UN sustainable development goals. *Ambio* 46, 731–742. doi: 10.1007/s13280-017-0918-6

Visbeck, M. et al. (2014): Securing blue wealth: the need for a special sustainable development goal for the ocean and coasts and for future ocean spatial planning. *Mar. Policy* 48, 184–191 (2014).

WACA (2007): West Africa Coastal area management | 2007 report

Ward J.K, Antonovics J, Thomas R.B, Strain B.R. (2000): Is atmospheric CO₂ a selective agent on model C₃ annuals? *Oecologia* 123: 330– 341. *CrossrefCASPubMedWeb of Science®Google Scholar*.

Wheeler, D., Tan, S., Pontee, N., Pygott, J. (2008): Alkborough scheme reduces extreme water levels in the Humber Estuary and creates new habitat. floodrisk 2008 - The European conference on flood risk management research in to practice 30 September - 2 October 2008 Keble College, Oxford, UK.

Wong, P. P., Losada, I. J., Gattuso, J.-P., Hinkel, J., Khattabi, A., McInnes, K., Saito, Y., & Sallenger, A. (2013): Chapter 5: Coastal Systems and Low-Lying Areas. *Ipcc Wgii Ar5*, October 2013, 1–85.

Woodroffe, C.D. (2003): *Coasts: Form, process and evolution*, Cambridge University Press, Cambridge.

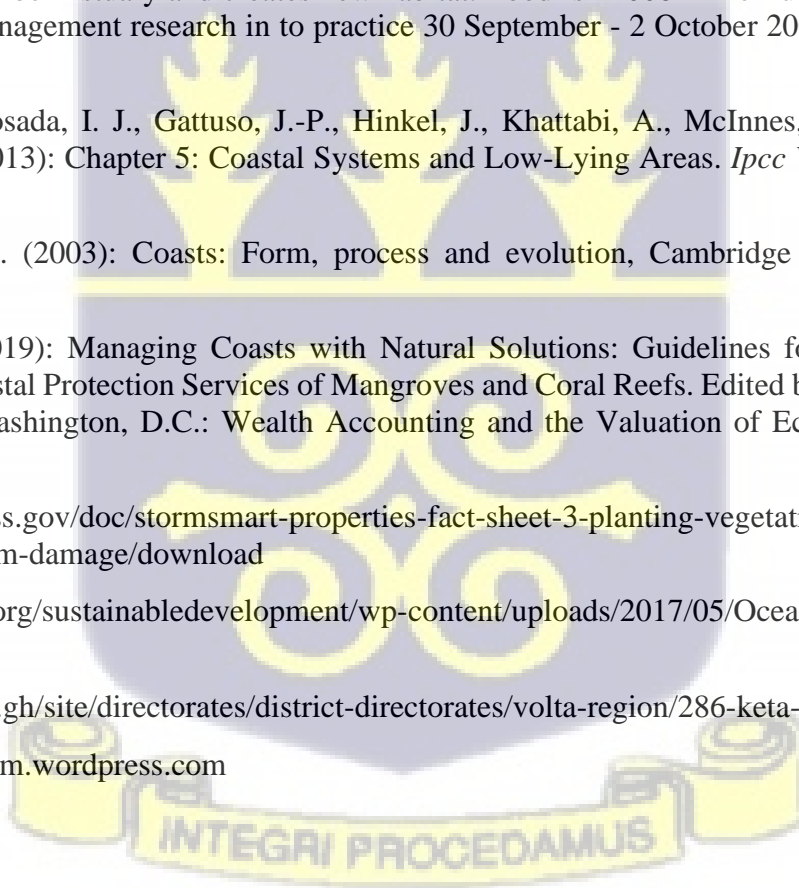
World Bank (2019): *Managing Coasts with Natural Solutions: Guidelines for Measuring and Valuing the Coastal Protection Services of Mangroves and Coral Reefs*. Edited by M.W. Beck and G-M. Lange. Washington, D.C.: Wealth Accounting and the Valuation of Ecosystem Services Partnership.

<https://www.mass.gov/doc/stormsmart-properties-fact-sheet-3-planting-vegetation-to-reduce-erosion-and-storm-damage/download>

<https://www.un.org/sustainabledevelopment/wp-content/uploads/2017/05/Ocean-fact-sheet-package.pdf>

<https://mofa.gov.gh/site/directorates/district-directorates/volta-region/286-keta-municipal>

<https://ketatourism.wordpress.com>



**APPENDIX 1: QUESTIONNAIRES
LOCAL COMMUNITY SURVEY**

CENTRE FOR CLIMATE CHANGE AND SUSTAINABILITY STUDIES

UNIVERSITY OF GHANA, LEGON

MPHIL CLIMATE CHANGE AND SUSTAINABLE DEVELOPMENT

QUESTIONNAIRE SURVEY

This is neither a government survey nor a profit-oriented project. Information will be aggregated with those from similar interviews with other people and will be used for academic purposes in **Mr. Gontorwon Saye Lah** master’s thesis at the University of Ghana, Legon. This is in partial fulfillment of the award of a Master of Philosophy degree in Climate Change and Sustainable Development with the thesis topic *“Trends and impacts of climate change-induced coastal hazards in Keta, and existing adaptation options with nature-based solutions therein”*. The following objectives are to be investigated in this part of the study

1. Assess the trends and impacts of climate change-induced hazards on households within coastal communities.
2. Identify existing local-level adaptation and mitigation options for climate change-induced hazards and examine evidence of nature-based solutions therein.
3. Conduct a spatio-temporal assessment of nature-based solutions for climate change-induced coastal hazards in the Keta Municipal.

All the information collected during this interview is confidential and no direct references will be made to individual respondents. Your support and contribution would be very much appreciated

Background Information

Name of Community:

1. Gender

a. Male []

b. Female []

Age:

2. Occupation

a. Fishing []

b. Crop farming []

c. Artisan []

d. Salt mining []

e. Formal []

e. Other (specify).....

3. How long have you lived in this community (in years)?

- a. less than 1 b. 1 – 3 c. 4 – 6 d. 7 – 9
e. 10 and above

4. What is the status of your house/residence?

- a. Tenant [] b. House/Land Owner [] c. Family Occupation []

Section A: Impacts of climate change-induced hazards on households within coastal communities.

5. Which of the following do you consider to be the most frequent climate-induced hazard in your community?

- (a) Flood
(b) Erosion
(c) High tides
(d) Stormwater

6. What is your opinion about the extent of flood in your community in the past 5 years?

- I Have increased
II Have decreased
III Unchanged
IV Unsure

7. What is your opinion about the extent of erosion in your community in the past 5 years?

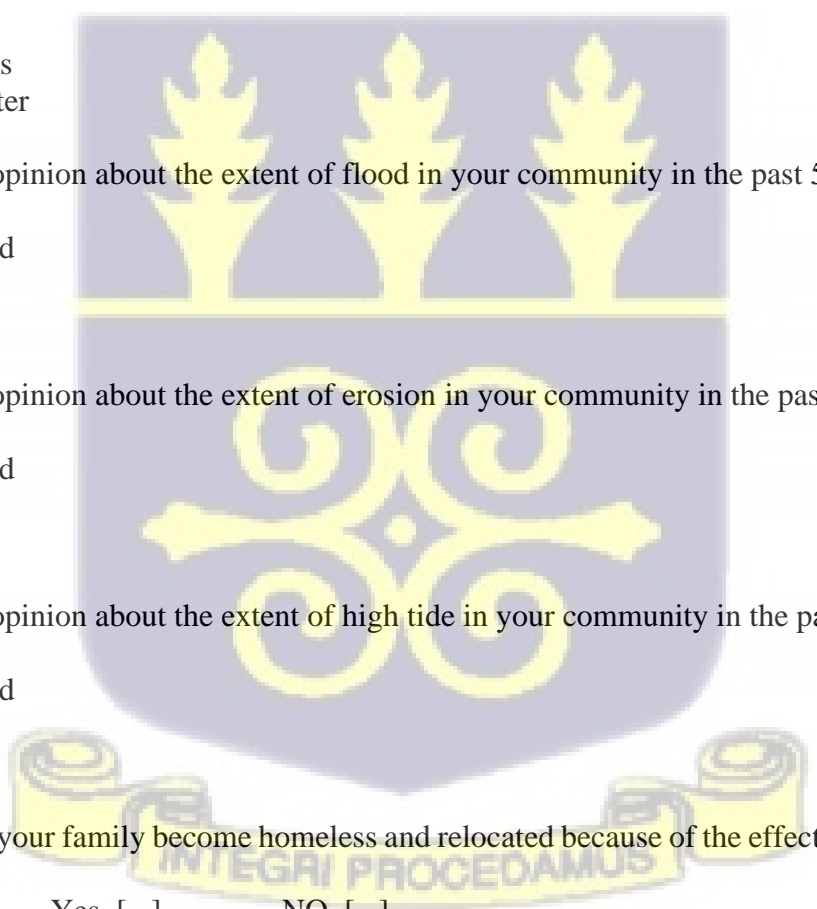
- I Have increased
II Have decreased
III Unchanged
IV Unsure

8. What is your opinion about the extent of high tide in your community in the past 5 years?

- I Have increased
II Have decreased
III Unchanged
IV Unsure

9. Have you and your family become homeless and relocated because of the effect of the following hazards?

- | | | |
|----------------|---------|--------|
| (a) Flood | Yes [] | NO [] |
| (b) Erosion | Yes [] | NO [] |
| (c) High tides | Yes [] | NO [] |
| (d) Stormwater | Yes [] | NO [] |



10. Have you had any of your properties been damaged by the following hazards?

a) Flood Yes [] NO []

If Yes, name any.....

b) Erosion Yes [] NO []

If Yes, name any.....

c) High tides Yes [] NO []

If Yes, name any.....

d) Stormwater Yes [] NO []

If Yes, name any.....

11. Can you say that the occurrence of floods in your community has caused the following?

a) Destroyed farmlands Yes [] NO []

b) Displaced residents Yes [] NO []

c) Caused death Yes [] NO []

12. Can you say that the occurrence of erosions in your community has caused the following?

a) Destroyed building Yes [] NO []

b) Destroyed roads Yes [] NO []

c) Reduced soil quality Yes [] NO []

13. Can you describe some major impacts of high tides in your community?

.....

14. How have the following hazards impacted your livelihood systems?

Livelihood system	Severity of impacts			
	<i>1=Insignificant</i>	<i>2= minor</i>	<i>3=moderate</i>	<i>4=major 5=catastrophic</i>
	Flood	Erosion	Hightide	Storm water
Fish catch				
Fish trading				
Small-scale farming				

Tourism services					
Salt mining					

15.a) Have you noticed any changes in plant or animal species' existence in your community?

Yes [] NO []

b) Can you describe any of the observed changes?

.....

c) How has this observed change impacted you?

.....

16) Have you noticed any changes in the timings of certain crops or animal species in your community?

Yes [] NO []

b) Can you describe the change you have observed?

.....

Section C: Local level adaptation and mitigation options for climate change-induced hazards (examine evidence of nbs therein)

17. Have your local community put in place any measures to reduce the impacts of the following hazards?

- (a) Flood Yes [] NO [] Unsure []
- (b) Erosion Yes [] NO [] Unsure []
- (c) High tides Yes [] NO [] Unsure []
- (d) Stormwater Yes [] NO [] Unsure []

18. If Yes, please explain the measures which have been put in place to reduce the impacts of the following hazards over the years?

- (a) Flood
-
- (b) Erosion
-
- (c) High tides
-
- (d) Stormwater
-

19. What specific adaptation/coping measures have you been using to address the following hazards (answer as applicable)

Hazards	Adaptation measures
Flood	
Erosion	
Storm surge	
High tides	

20. Which of the following adaptation/coping measures would you prefer most for reducing flood?

- a) Flood water transfer
- b) Floodproofing of buildings
- c) Floodwater storage
- d) Other (specify).....

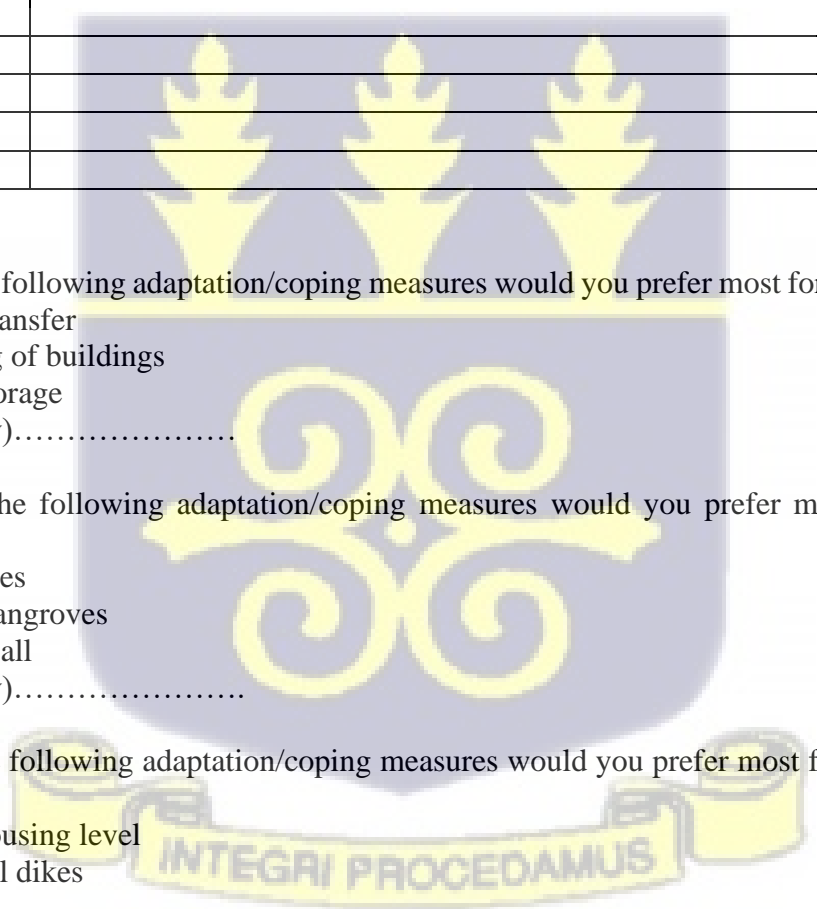
21. Which of the following adaptation/coping measures would you prefer most for reducing erosion?

- a) Planting of trees
- b) Planting of mangroves
- c) Building seawall
- d) Other (specify).....

22. Which of the following adaptation/coping measures would you prefer most for reducing high tide?

- a) Raising the housing level
- b) Building small dikes
- c) Flood gates
- d) Other (specify).....

23. Which of the following adaptation/coping measures would you prefer most for reducing stormwater?



- a) Reducing paved areas
- b) Stormwater storage facilities
- c) Constructing bigger drains
- d) Other (specify).....

24. Do you think that modification in the coastline here has added to the risk of coastal hazards?

- Yes []
- NO []
- Unsure []

If yes, please explain:.....

25. Do you think that modification in the coastline here has reduced the risk of coastal hazards?

- Yes []
- NO []
- Unsure []

If yes, please explain:.....

26. What are some of your key considerations when choosing a coping/adaptation measure?

- a) For flood
- b) For erosion
- c) For high tide
- d) For storm

Section D: Nature-based solutions to reduce climate change-induced coastal hazards in the Keta Municipal

27. When we put in place measures and approaches that rely on, work with, and enhances the natural environment to reduce our societal challenges to climate-induced hazards of the coast.

1=strongly disagree, 2=disagree, 3=agree, 4=strongly agree

28. What benefits do you get from the Keta lagoon?

.....
.....
.....

29. Do you believe the Keta lagoon provides you the following services?

- a) Protein Yes [] NO [] Unsure []

- b) Water Yes [] NO [] Unsure []
- c) Protection from flood Yes [] NO [] Unsure []
- d) Leisure Yes [] NO [] Unsure []
- e) Improve air quality Yes [] NO [] Unsure []
- f) Community Cooling Yes [] NO [] Unsure []
- g) Water quality regulation Yes [] NO [] Unsure []

30. Do you agree that the Keta lagoon is the most important nature based solution of your community?

1=strongly disagree, 2=disagree, 3=agree, 4=strongly agree

31. Please indicate your level of participation in managing the following hazards in your community as either [High], [Low], or [None]

- a) Flood [High] [Low] [None]
- b) Erosion [High] [Low] [None]
- c) High tide [High] [Low] [None]
- d) Storm water [High] [Low] [None]

32. Please indicate your level of participation in the designing, planning, and implementation of NBS to reducing the following coastal hazards in your communities?

- a) Flood [High] [Low] [None]
- b) Erosion [High] [Low] [None]
- c) High tide [High] [Low] [None]
- d) Storm water [High] [Low] [None]

33. Which of the following natural solutions best qualifies as a flood reduction mechanism for your community?

- a) Construction of wetland
- b) Mangroves
- c) Planting grass in place of pavement

34. Which of the following natural solutions best qualifies as an erosion reduction mechanism for your community.

- a) Forest restoration
- b) Mangroves

c) Planting grass in place of pavement

35. Which of the following natural solutions do you believe when implemented would reduce your risk of high tide?

a) Reef planting

b) Mangroves

c) Construction of wetlands

36. Which of the following natural solutions best qualifies as a stormwater regulation in your community?

a) Planting grass and trees

b) Ponds

c) lagoon

Section E: Co-benefits of investing in nature-based solutions

37. What will be your primary motivation for planting trees in your community?

a) Reduce erosion

b) Provide shade

c) Improve air quality

d) Improve groundwater

38. What will be your primary motivation for protecting coastal wetlands?

a) Provide protein

b) Water quality regulation

c) Protection from flood

d) Carbon sequestration

39. What will be your primary reason for protecting the Keta lagoon of your community?

a) Recreation and tourism

b) Improve air quality

c) Community Cooling

d) Water quality regulation

40. What will be your primary motivation for managing mangrove ecosystems in your community?

a) Carbon sequestration

b) habitat provision

c) Firewood provision

d) flood regulation

Spatio-temporal assessment of coastal hazards

41. Can you identify some communities suffering from any of the following climate-induced coastal hazards?

a) Flood [communities:
Frequency [1, 2, 3, 4]

b) Erosion [communities:
Frequency [1, 2, 3, 4]

c) High tides [communities:
Frequency [1, 2, 3, 4]

d) Stormwater [communities:
Frequency [1, 2, 3, 4]

Participant observation checklist

a) Participant resides close to:
coast/beach
pond
lagoon
mangroves
marshes

b) Household has trees:
(Yes No)
Number of trees ()

c) Household contain greenspace: (Yes No)

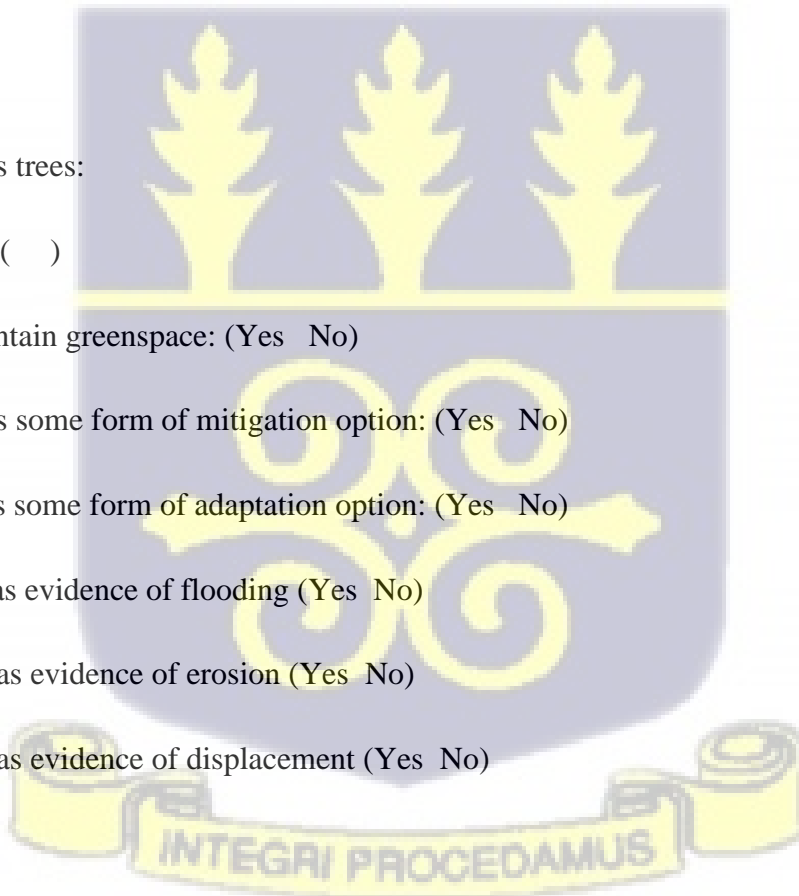
d) Household has some form of mitigation option: (Yes No)

e) Household has some form of adaptation option: (Yes No)

f) Community has evidence of flooding (Yes No)

g) Community has evidence of erosion (Yes No)

h) Community has evidence of displacement (Yes No)



KEY INSTITUTIONAL STAKEHOLDERS' INTERVIEWS

Regional government/administration (District office, Municipal office, Chiefs)

INTERVIEW GUIDE

Location/Community:

Affiliation:

Role/Position:

Section A: Benefits of Keta Lagoon Complex

How would you describe the Keta Lagoon Complex?

What benefits would you say the Keta Lagoon complex provides to meeting the existing human and coastal challenges in Keta?

What would you suggest as measures to explore the full benefits of the Keta Lagoon Complex?

What would you say are the major factors deteriorating the ecosystem benefits of the Lagoon complex?

Section B: Climate-induced hazards

My municipality/district/community suffers from managing the following

Hazard	Yes	No
Flood		
Erosion		
High tides		
Stormwater		

Which of these hazards would you say are the major coastal challenges/hazards within the Keta Municipal?

How would you describe the magnitude and frequencies of these challenges/hazards?

Hazards

Frequency and Magnitude

- a) Flood Frequency [1, 2, 3, 4, 5] Magnitude [1, 2, 3, 4, 5]
- b) Erosion Frequency [1, 2, 3, 4, 5] Magnitude [1, 2, 3, 4, 5]
- c) High tides Frequency [1, 2, 3, 4, 5] Magnitude [1, 2, 3, 4, 5]
- d) Stormwater Frequency [1, 2, 3, 4, 5] Magnitude [1, 2, 3, 4, 5]

What would you say are the causes of these coastal hazards?

What impacts would you say these hazards have had on the affected communities?

Section C: Nature-based Solutions

As a stakeholder, what is your understanding of nature-based solutions?

What would you consider or describe as a nature-based solution?

What role are you likely to play in contributing to a successful NbS concept?

Which other sectors are you collaborating with to promote NBS?

The Keta Lagoon Complex is the most important NbS.

1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree.

Co-creation project is effective as compared to a traditional retro-fitted plan concerning NBS implementation?

1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree.

Which of the following NbS IS/ARE been implemented in your municipality/district/community?

NbS	Yes	No
Pervious pavement		
Green roof		
Green swales		
Ponds		
Constructed wetlands		
Tree planting		
Rainwater harvesting		

Does your municipality/ district/ community have plans to implement NbS?

- Yes []

- No []
- Not sure []

What is the main reason for the lack of NbS implementation in your area? (scale of 1-5; 1 being the weakest and 5 being the strongest)

- (a) Finances [1, 2, 3, 4, 5]
- (b) Expertise [1, 2, 3, 4, 5]
- (c) Politics [1, 2, 3, 4, 5]
- (d) Lack of policy [1, 2, 3, 4, 5]

What do you consider to be the most important knowledge gap in terms of monitoring and assessing the effectiveness of Keta Lagoon Complex as an NBS?

What do you consider to be the most important knowledge gap in terms of designing, implementing, and maintaining of **Keta Lagoon Complex as an NBS?**

What do you consider to be the most important knowledge gap in terms of quantifying (including economic valuation) the benefits and co-benefits of ecosystem services provided by **Keta Lagoon Complex?**

Local authorities (Schools and Hospitals)

INTERVIEW GUIDE

Location/Community:

Affiliation:

Role/Position:

Section D: Benefits of Keta Lagoon Complex

The existence of the Keta Lagoon Complex has a direct impact on our lives and wellbeing.

1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree.

What benefits would you say the Keta Lagoon complex provides to reduce human and coastal challenges in Keta?

How can we explore the full benefits of the Keta Lagoon Complex?

What are the major factors deteriorating the ecosystem benefits of the Lagoon complex?

Section E: Climate-induced hazards

My municipality/district/community suffers from managing the following.

Hazard	Yes	No
Flood		
Erosion		
High tides		
Stormwater		

How would you describe the magnitude and frequencies of these challenges/hazards?

Hazards Frequency and Magnitude

- a) Flood Frequency [1, 2, 3, 4, 5] Magnitude [1, 2, 3, 4, 5]
- b) Erosion Frequency [1, 2, 3, 4, 5] Magnitude [1, 2, 3, 4, 5]
- c) High tides Frequency [1, 2, 3, 4, 5] Magnitude [1, 2, 3, 4, 5]
- d) Stormwater Frequency [1, 2, 3, 4, 5] Magnitude [1, 2, 3, 4, 5]

Section F: Nature-based Solutions

How would you describe your background in the awareness of Nature-Based Solutions?

Have you heard of the following Nature-based Initiatives?

NbS	Yes	No
Pervious pavement		
Green roof		
Green swales		
Ponds		
Constructed wetlands		
Tree planting		
Rainwater harvesting		

What would you say are the significant gaps in research which are hindering NBS propagation?

What will be your motivations for implementing NbS?

What Nature-Based Solutions have you implemented in your institution?

Which of the following NbS do you think could be implemented in your municipality/area/

NbS	Yes	No
Pervious pavement		
Green roof		
Green swales		
Ponds		
Constructed wetlands		
Tree planting		
Rainwater harvesting		

Co-creation project is effective as compared to a traditional retro-fitted plan concerning NBS implementation?

1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree.

The Keta Lagoon Complex is the most important NbS.

1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree.

Are there any other sectors you would want to collaborate with to promote NBS?

What role are you likely to play in contributing to a successful NbS concept?

(Churches, NGOs)

INTERVIEW GUIDE

Location/Community:

Affiliation:

Role/Position:

Section G: Benefits of Keta Lagoon Complex

The existence of the Keta Lagoon Complex has a direct impact on our lives and wellbeing.

1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree.

What benefits would you say the Keta Lagoon complex provides to reduce human and coastal challenges in Keta?

How can we explore the full benefits of the Keta Lagoon Complex?

What are the major factors deteriorating the ecosystem benefits of the Lagoon complex?

Section H: Climate-induced hazards

My municipality/district/community suffers from managing the following

Hazard	Yes	No
Flood		
Erosion		
High tides		
Stormwater		

How would you describe the magnitude and frequencies of these challenges/hazards?

Hazards	Frequency and Magnitude	
a) Flood	Frequency [1, 2, 3, 4, 5]	Magnitude [1, 2, 3, 4, 5]
b) Erosion	Frequency [1, 2, 3, 4, 5]	Magnitude [1, 2, 3, 4, 5]
c) High tides	Frequency [1, 2, 3, 4, 5]	Magnitude [1, 2, 3, 4, 5]
d) Stormwater	Frequency [1, 2, 3, 4, 5]	Magnitude [1, 2, 3, 4, 5]

Section I: Nature-based Solutions

The Keta Lagoon Complex is the most important NbS.

1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree.

Have you heard of the following Nature-based Initiatives?

NbS	Yes	No
Pervious pavement		
Green roof		
Green swales		
Ponds		
Constructed wetlands		
Tree planting		
Rainwater harvesting		

What will be your motivations for implementing NbS?


What Nature-Based Solutions have you implemented in your institution/area?

Which of the following NbS do you think could be implemented in your municipality/area?

NbS	Yes	No
Pervious pavement		
Green roof		
Green swales		
Ponds		
Constructed wetlands		
Tree planting		
Rainwater harvesting		

What role are you likely to play in contributing to a successful NbS concept?

Which other sectors would you want to collaborate with to promote NBS?

The Nature-based Solutions		
Pervious pavement	YES	NO
		
Green roof	YES	NO



Green swales

YES

NO



Ponds

YES

NO



Constructed wetlands

YES

NO



Tree planting

YES

NO



Rainwater harvesting

YES

NO

