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MASTER'S THESIS

THE SOCIO-ECONOMIC IMPACT OF CLIMATE CHANGE ON THE COASTAL ZONE OF THE GAMBIA

BY

JOSHUA AMUZU

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Major Supervisor:	Mr. Bubu Pateh JALLOW
Co- Supervisor:	Prof. Amos T. KABO-BAH
Director of WASCAL Program:	Dr. Sidat YAFFA

DECLARATION

I, Joshua Amuzu, the author of this dissertation, do hereby declare that except for the references, which have been duly acknowledged, the work presented in the dissertation " THE SOCIO-ECONOMIC IMPACT OF CLIMATE CHANGE ON THE COASTAL ZONE OF THE GAMBIA" is my personal work.

Student Name: Joshua AMUZU

Mat. Number: 21719405

Signature …………………………………………….. **Date** ………………………………...

This work has been submitted for examination with my approval as supervisors.

1. **Principal / Major Supervisor:** Mr. Bubu Pateh JALLOW

Department of Water Resources, 7, Marina Parade, Banjul, The Gambia

Signature …………………………………………….. **Date** ………………………………...

2. **Supervisor:** Prof. Amos T. KABO-BAH

Department of Energy and Environmental Engineering, University of Energy and Natural Resources, P. O. Box 214, Sunyani, Ghana

Signature …………………………………………….. **Date** ………………………………...

3. **Director of WASCAL Program:** Dr. Sidat YAFFA

Signature …………………………………………….. **Date** ………………………………...

ABSTRACT

Coastal systems are predominantly delicate to three key drivers related to Climate Change (CC): Sea Level Rise (SLR); ocean temperature and; ocean acidity. This study focused on the impacts realized from SLR. These variables are anticipated to increase with significant threats to the populace and structures of social, cultural or economic importance along Coastal Zones (CZ). This study seeks to: characterize the trend of annual rainfall, minimum and maximum temperatures from 1986- 2016; estimate the land at-risk of being lost to inundation under a 1m SLR scenario and the estimation of the rate of annual land loss for each coastal cell in The Gambia. This study estimates the monetary value of land to be lost and the population at risk of CC impacts in the study area. The results of the study reveal mean annual rainfall increased at a rate of 0.237mm per annum over the CZ. The annual minimum temperature showed a decreasing trend of 0.026oC while the maximum temperature showed an increasing trend of 0.028oC annually. By the end of this century, under a 1m SLR scenario, the total land to be lost due to inundation is ~12.46 km2 (1,246 ha) with a corresponding economic loss of ~US $788 Million (GMD37 Billion) over the CZ. This land loss is predicted to occur at an approximate rate of 6m annually along the CZ of The Gambia. Over 15,560 people per km2 of land are estimated to be at risk of coastal flooding events in the study area.

Keywords: Climate Change, Socio-economic Impact, Coastal Zone, Coastal Erosion, Bruun Rule, Sea Level Rise, Vulnerability Assessment, Adaptation, The Gambia

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DEDICATION

This MSc degree Thesis is dedicated to my parents, Elder Christian K. Amuzu and Dns. Grace Amuzu, my Uncle, Rev. Francis Amewondey, my siblings, Francisca and Solomon Amuzu and to all my loved ones.

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LIST OF ACRONYMS

AVVA	Aerial Videotape-Assisted Vulnerability Analysis
CBD	Convention on Biological Diversity
CC	Climate Change
CO_2	Carbon Dioxide
CS	Coastal systems
CZ	Coastal Zone
EEZ	Exclusive Economic Zone
GCM	General Circulation Models
GDP	Gross Domestic Product
GHGs	Green House Gases
GMSLR	Global Mean Sea Level Rise
ICZM	Integrated Coastal Zone Management
IPCC	Inter-Governmental Panel on Climate Change
LDC	Least Developed Countries
LECZ	Low Elevation Coastal Zone
LECZ	Low-Elevation Coastal Zones
NAPA	National Adaptation Plan of Action
NEA	National Environment Agency
PA	Protected Areas
RSLR	Relative Sea Level Rise
SAVI	Southern Africa Vulnerability Initiative
SCSY	Stabilized Commercial Shrimp Yield
SED	Socio-Economic Development
SLR	Sea-Level Rise
SST	Sea Surface Temperature
TDA	Tourist Development Area

CHAPTER ONE

1.0 Introduction

This chapter brings to light the background of the study, the Problem Statement that has raised concerns for this study, Research Objectives, Relevance of the Study and the Organization of the Study.

1.1 Background of the Study

Global Climate Change (CC) is one of the dire challenges facing the international community today of which, coastal zones are highly vulnerable to its impacts in the delivery of profoundly profitable services like tourism, fisheries, transportation, recreation and human settlements. The Coastal Zone (CZ) in this study is described as, the interface between land and ocean that incorporates shallow waters and low-lying shoreline biological systems.

The coastal zone is under continuous stress from anthropogenic activities like the establishment of human settlements and other economic developments along the coast; increasing storm intensity, temperatures and varying precipitation patterns and; surge in sea levels (Wrathall, 2016). The Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (IPCC AR5, 2014) reveals with high confidence that Coastal systems are predominantly delicate to three key drivers related to climate change: sea level rise; ocean temperature and; ocean acidity. This in result affects coastal systems in their efficient delivery its services.

Further findings from IPCC AR5 reveals with high confidence that Coastal systems (CS) and low-lying areas will increasingly experience adverse impacts of climate change such as inundation, coastal flooding, and coastal erosion due to Relative Sea Level Rise (RSLR). There has been 95% scientific certainty that human activity, increases concentrations of Green House Gases (GHGs) in the atmosphere, and has been the dominant cause of the observed warming and other climate change impacts since the mid-20th century (IPCC, 2014).

Climate change affects both biotic and abiotic elements in the ecosystem. For instance, the impacts of climate change on some biotic elements in CS include significant impacts in the amounts and distribution of fish species in the ocean. This affects the artisanal fisheries catch in the medium to long run. IPCC AR5 predicts with high confidence that among the abiotic factors affected by climate change are water temperature, salinity, nutrients, sea level, ocean dynamics, and the sea ice.

The population and assets exposed to coastal threats and human forces on coastal ecosystems will increase significantly in the coming decades due to population growth, economic development, and urbanization (IPCC, 2014). To support this claim, UN-HABITAT (2008) reports that over 25% of Africa's population live within 100 km of the coast and over 50% of Africa's total population live in Low-Elevation Coastal Zones (LECZ). This value accounts for 11.5% of the total urban population of the African continent of which The Gambia is no exception.

Further studies by Hewawasam (2002) report that over 40% of the West African populace live within coastal cities. It is estimated that the 500 km of coastline between Accra and the Niger Delta will become a continuous urban megalopolis of over 50 million inhabitants by 2020 (Hewawasam, 2002). The case is not different for The Gambia as the National Environment Agency, estimates that over 910,690 populace lives within the coastal zone equivalent to over 48.7% of the national population (NEA, 2004). These numbers keep increasing owing to the fact the coastal zone is characterized by comparatively higher: access to potable water; educational and health facilities; electricity and internet supply; fundamental infrastructural growth making these areas more enticing to migrants. The social prestige associated with settling in coastal areas, tourism and pursuance of higher income levels through the search of greener pastures has contributed to this issue. Further claims that support this argument are that most coastal countries in West Africa have their administrative and economic capitals falling within coastal areas.

Highly productive ecosystems such as mangroves, estuaries, and deltas, fall in the coastal zone of Africa (Hewawasam, 2002). The services provided by these ecosystems form the foundation for imperative economic activities such as tourism and fisheries. In the 21st century, the economic costs of not taking any adaptation action will be higher paralleled to the negative impacts climate change will pose to most developing countries (IPCC, 2014). In this light, it is imperative that prompt actions are taken to reduce vulnerability to climate change.

1.2 Problem Statement

The oceans cover over 70% of the earth's surface and play an important role in regulating the earth's climate by serving as a major sink of Carbon Dioxide (CO_2) from the atmosphere. Since the industrial era, human activities have increased CO_2 and other GHG concentrations in the atmosphere. This in effect affects the ocean's ability to provide regulatory services efficiently. Oceanic uptake of CO_2 contributes significantly to acidification of the oceans. The pH of ocean surface water has decreased by 0.1; this relates to 26% escalation in acidity (IPCC, 2014). This will apparently have a consequential effect on fisheries and marine life. This resultant effect will affect developing countries like The Gambia as its economy largely depends on the fisheries sector for over 21% of its Gross Domestic Product (GDP).

Another driver that impacts coastal zone is the increase in the surface temperature of the oceans. The acidification and surface warming of coastal waters usually fall within 0- 700m ocean depth

(IPCC, 2014). These climatic conditions will keep worsening as additional projections by IPCC states that the global mean surface temperature change for the period 2016-2035 is likely to rise by 0.3-0.7^o C. This finding implies there will be a further warming of the ocean surface with the resultant expansion of the waters exacerbating Sea-Level Rise (SLR) occurrence.

Past trends revealed a likely decrease in average annual rainfall in most parts of West Africa, with an observed drop in average annual rainfall of approximately 25–50 mm each decade from 1951–2010 (IPCC, 2014). Reduction in the rainfall likewise contributes to decrease in the freshwater received by the oceans, increasing the salinity of ocean with impact on marine life that cannot put up with such salinity ranges. This may linger with noteworthy deleterious concerns for coastal ecosystems when these threats are not well addressed in the short to long run.

The continued acceleration in the decline of polar ice sheet mass in present times raises the possibility of the future SLR of over 1 m by 2100 (IPCC, 2014). This phenomenon has been exacerbated by increasing global temperatures. The direct and indirect human-related activities in the release of CO_2 and other GHGs in the atmosphere have considerably contributed to this phenomenon. Further melting of polar ice sheets, ice from the Arctic and Antarctic regions coupled with melting glaciers adds immeasurably to SLR.

Climate change is anticipated to increase risks for people, properties, economies and ecosystems in urban areas (IPCC, 2014). As the number of people living in the coastal zone is probable to rise, there will be increased risk of these persons to impacts from SLR. With a mean surge in ocean levels of just 0.38m consolidated with populace growth situations, it is evaluated that the normal number of individuals around the entire coast of Africa at risk of floods could rise from 1 million/year in 1990 to 70 million/year in the 2080s (Nicholls *et al.,* 1999). With a 43cm rise in sea levels, over 10 million Africans will be compelled to migrate from 2000 to 2100, and the aggregated cost of damaged assets will be US$38 billion per year in the same period (Brown *et al.*, 2011). However, with climate change adaptation measures in place in most African countries, these effects can be considerably decreased to a yearly cost of US$2.2 billion (Brown *et al*., 2011).

Another issue of concern is the anticipated risk of land loss due to inundation. The Gambia, for instance, is cited among the main ten nations debilitated by SLR, due to its Low Elevation Coastal Zone (LECZ). It is predicted that about 92km² of land in the coastal zone of The Gambia will be submerged and inundated due to only 1m SLR (Jallow *et al.*, 1996). Under this scenario, The Gambia will lose its capital city, Banjul. The Gambia, like other coastal communities in West Africa, has its ports and significant tourism infrastructure exposed to SLR impacts. These areas also have a dense population with climate change threats to humans. The increment in wave activity combined with poor urban design and sand quarrying for developmental initiatives has resulted in losing land along the southern coastline of The Gambia. These joint actions have prompted the loss of vital social and cultural sites, infrastructure and nesting grounds for turtles and transient birds.

In addressing this issue, a notable action taken by The Gambia Government in past years is the beach nourishment program in 2004 along the coasts. This was aimed at reclaiming lost land in the quest to boost tourism and protect important structures from being lost. Nevertheless, concerns have been raised about whether this adaptation action has protected the coastline, as the majority of these areas has been lost again. There is the need to appraise further options and arrive at a more effective line of action to take to elude maladaptation in the coastal zone.

For the 21st century, the benefits of defending against increased coastal flooding and inundation due to submergence and erosion at the global to local scale are larger than the social and economic costs of inaction (IPCC, 2014). The study and putting into practice coastal adaptation has increased more considerably in-developed countries than in developing countries to climate-resilient and sustainable coasts (IPCC, 2014). These support the need to undertake an in-depth analysis of the socio-economic impact of climate change on the coastal zone of The Gambia to fill this research gap.

1.3 Research Questions

The study will seek to answer these research questions:

1. What is the trend of annual rainfall, minimum and maximum temperature variability in the study area from 1985- 2016?
2. What is the socioeconomic impact of climate change on marketed goods and services in the study area?
3. How many people are at risk of coastal flooding and climate change impacts in the study area?
4. How vulnerable is the coastal zone of The Gambia to climate change?
5. What will be the most appropriate adaptation options that can be taken to address the impacts identified in bullet points 2 to 4 above?

1.4 Objectives of the Study

The main objective of the study is to assess the socio-economic impacts of climate change on the coastal zone of The Gambia. The specific objectives are:

1. To characterize the trend of annual rainfall, minimum and maximum temperatures of the study area from 1985- 2016;

2. To assess the socioeconomic impact of climate change on marketed goods and services in the study area;
3. To estimate the population at risk to climate change impact in the study area;
4. To undertake a risk and vulnerability assessment of the coastal zone to climate change impacts using the Bottom-Up approach.
5. To identify, plan and implement adaptation measures that address the adverse impacts on the coastal zone.

1.5 Relevance of the Study

This study will seek to help inform stakeholders, especially decision and policymakers on sustainability measures in coping with and adapting to RSLR and its resultant effects. This owes to limited studies on this subject in The Gambia. It will add to the pool of knowledge and literature, to assist researchers in recent times and suggest a direction to fill potential research gaps.

The study will help reveal the trends of annual rainfall, annual minimum and maximum temperatures over the past 30 years. This will help farmers, fisherfolk, tourists and other stakeholders to know what the climate has been over the past years and what the situations will be in the short to medium-term. This will help in the adoption of more operational coping and adaptation strategies in the face of climate change and its variability in the study area.

The study will further reveal the trends of artisanal and industrial fisheries catch by species over the past 30 years. The study will project artisanal and industrial fisheries catch to the year 2025. The nature of the trend will expose whether this sector is approaching sustainability or not and what actions can be taken to increase the stock of fisheries in the study area.

Furthermore, the study will focus on assessing SLR impacts in recent times to be able to predict the land that is at-risk of being lost through inundation under suggested IPCC scenarios. Along with this projection, the monetary value of economic goods and services to be lost in each coastal cell in the study area will be determined. This will enlighten the public on the coastal areas that are more vulnerable to coastal erosion than others to help in making decisions that are more informed in the acquisition of land, the establishment of settlements and economic structures in the study area. The findings will further draw the attention of key players in Government institutions on areas to put up structures and infrastructural developments to avert exerting more stress on coastal ecosystems. Along with the right adaptation actions to be taken, it is possible to determine which areas will attract more revenue from tourism, fisheries, and other economic activities in the study area.

The study will reveal non-marketed goods and services along the coastal zone at risk of being lost in each coastal cell. The study will reveal the past and current trends of historical and cultural assets along the coastal zone; fish-landing sites at risk to being lost; endangered species of wildlife and biodiversity along the coastal zone and; coastal wetlands at risk to being lost.

Finally, the vulnerability assessment constituent of this study will reveal both impacts of anticipated and adaptation options in the wake of SLR. There will be suggested adaptation actions after the identification of risks and consequences of the impacts of climate change on the coastal zone from the consultation of climate change experts and key stakeholders. This will help in increasing climate-resilience in the study area. In addition, knowledge of vulnerability will enable coastal scientists, stakeholders, policy-makers and the public anticipate impacts that could emerge from SLR. It can help to prioritize management efforts to be taken to minimize risks and to mitigate possible consequences.

1.6 Organization of the Study

The study is divided into five main chapters. The first chapter covers the Background of the study; Problem Statement; Research Objectives; Relevance of the study; and the Organization of the research. The second Chapter covers a review of literature on the impacts of climate change on coastal zones from global to local levels; and a review of vulnerability assessment methods in varied studies. The third Chapter presents the Methodology of the study. This chapter explains the methods used in realizing each research objective of the study. The fourth chapter presents the Results and Discussion of the study for analysis and in-depth discussion. Finally, the Last chapter (five) brings to light findings and recommendation of the study after discussing and analyzing the results.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter summarizes international agreements and conventions ratified by The Gambia, the drivers for coastal systems and low-lying areas, climate and human-related drivers of coastal ecosystems. It also covers land loss due to coastal erosion issues, estimation of land loss due to SLR and how the issues of coastal erosion have been addressed in diverse regions. This chapter additionally looks at the link between climate change and fisheries. Finally, this chapter covers methodologies used for the assessment of climate change vulnerability.

2.1 Drivers of Coastal Systems and Low-Lying Areas

Two primary variables contribute pointedly to SLR. These are thermal expansion of ocean water because of sea surface warming and; water mass contribution of land ice mass and water repositories of land. The IPCC AR5 (2014) estimates tidal gauge valuations accessible since the late 19th century show that ocean level has ascended by an average of 1.7 ± 0.3 mm annually since the year 1950. However, over the period 1993 to 2009, the mean rate of SLR adds up to 3.3 ± 0.4 mm each year. These propositions reveal that SLR is happening at a faster rate than likely.

On one hand, thermal expansion has considerably accounted for the rise in ocean levels. This claim is reinforced by the IPCC AR5 report revealing a 25% thermal expansion in the oceans since the year 1960. For the period 1996 to 2003 sea levels have risen by over 50% due to thermal expansion (IPCC, 2014).

The overall withdrawal of ice masses and diminutive ice caps contribute to rising sea levels. To support this conception, the IPCC AR5 reveals with high confidence that the rate at which these ice masses and ice caps are melting since the 1990's, increases the likelihood of SLR occurrence sooner than predicted.

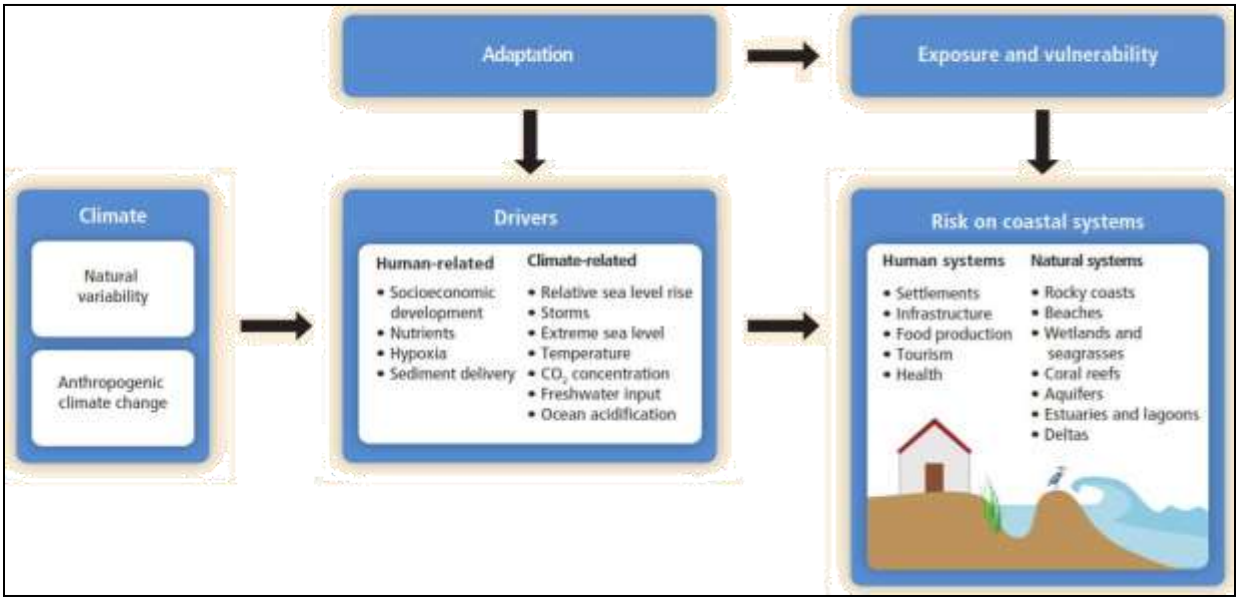
Alterations in land water reserves, resulting from the combined action of climate variability and human activities like underground water mining, irrigation, urbanization, and deforestation all contributes close to 10% of modern SLR (IPCC, 2014). This evidence calls for urgent actions to avert the consequences of the surge in ocean levels.

An agreement has been established that climate change impacts on coastal systems arise because of natural variability and anthropogenic climate change (IPCC, 2014). Figure 2.1 below divulges the human and anthropogenic drivers of coastal systems. These factors contribute directly or indirectly to observed impacts of climate change on coastal systems and low-lying areas.

The main climate change-related impacts are Relative Sea-Level Rise; severe storms; extreme sea level; temperature increase; CO_2 concentrations; Freshwater input; Ocean acidification (IPCC, 2014). Figure 2.2 below gives the main climate-related drivers for coastal systems, their trends due to climate change, and their fundamental physical and ecosystem effects.

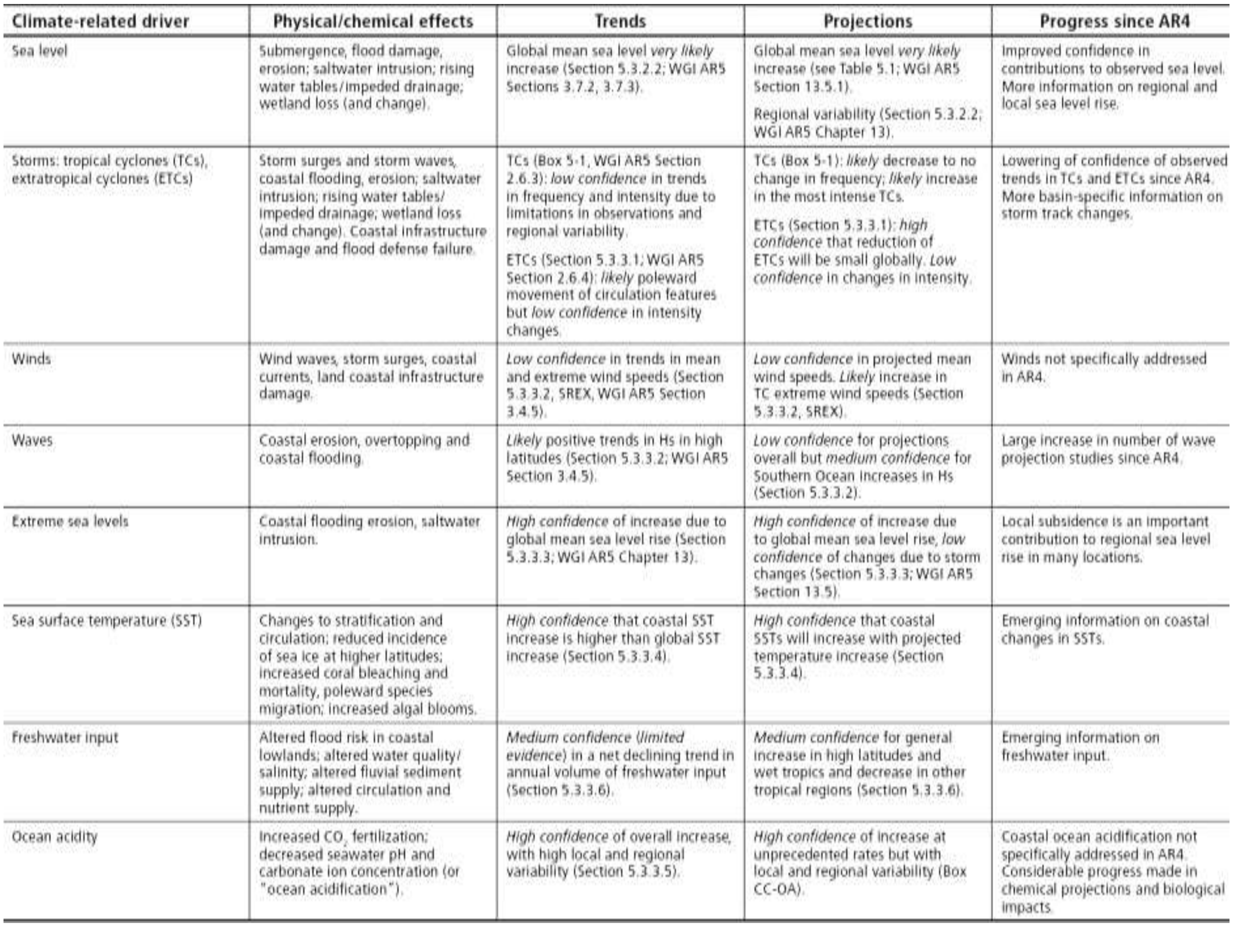
The known human-related drivers of climate change in coastal zone include Socio-economic developments along coastal systems; Nutrients; Hypoxia and Sedimentary delivery (IPCC, 2014). These drivers will be illuminated further under the forthcoming sub-sections.

Figure 2. 1 Natural and Human Drivers of Coastal Systems



Source: Wong *et al*. (2014)

Figure 2. 2 Climate-Related Drivers, trend, and impacts on Coastal Systems



Climate-related driver	Physical/chemical effects	Trends	Projections	Progress since AR4
Sea level	Submergence, flood damage, erosion; saltwater intrusion; rising water tables/impeded drainage; wetland loss (and change).	Global mean sea level *very likely* increase (Section 5.3.2.2; WGI AR5 Sections 3.7.2, 3.7.3).	Global mean sea level *very likely* increase (see Table 5.1; WGI AR5 Section 13.5.1). Regional variability (Section 5.3.2.2; WGI AR5 Chapter 13).	Improved confidence in contributions to observed sea level. More information on regional and local sea level rise.
Storms: tropical cyclones (TCs), extratropical cyclones (ETCs)	Storm surges and storm waves, coastal flooding, erosion; saltwater intrusion; rising water tables/impeded drainage; wetland loss (and change). Coastal infrastructure damage and flood defense failure.	TCs (Box 5-1, WGI AR5 Section 2.6.3): *low confidence* in trends in frequency and intensity due to limitations in observations and regional variability. ETCs (Section 5.3.3.1; WGI AR5 Section 2.6.4): *likely* poleward movement of circulation features but *low confidence* in intensity changes.	TCs (Box 5-1): *likely* decrease to no change in frequency; *likely* increase in the most intense TCs. ETCs (Section 5.3.3.1): *high confidence* that reduction of ETCs will be small globally. *Low confidence* in changes in intensity.	Lowering of confidence of observed trends in TCs and ETCs since AR4. More basin-specific information on storm track changes.
Winds	Wind waves, storm surges, coastal currents, land coastal infrastructure damage.	*Low confidence* in trends in mean and extreme wind speeds (Section 5.3.3.2, SREX, WGI AR5 Section 3.4.5).	*Low confidence* in projected mean wind speeds. *Likely* increase in TC extreme wind speeds (Section 5.3.3.2, SREX).	Winds not specifically addressed in AR4.
Waves	Coastal erosion, overtopping and coastal flooding.	*Likely* positive trends in Hs in high latitudes (Section 5.3.3.2; WGI AR5 Section 3.4.5).	*Low confidence* for projections overall but *medium confidence* for Southern Ocean increases in Hs (Section 5.3.3.2).	Large increase in number of wave projection studies since AR4.
Extreme sea levels	Coastal flooding erosion, saltwater intrusion.	*High confidence* of increase due to global mean sea level rise (Section 5.3.3.3; WGI AR5 Chapter 13).	*High confidence* of increase due to global mean sea level rise, *low confidence* of changes due to storm changes (Section 5.3.3.3; WGI AR5 Section 13.5).	Local subsidence is an important contribution to regional sea level rise in many locations.
Sea surface temperature (SST)	Changes to stratification and circulation; reduced incidence of sea ice at higher latitudes; increased coral bleaching and mortality, poleward species migration; increased algal blooms.	*High confidence* that coastal SST increase is higher than global SST increase (Section 5.3.3.4).	*High confidence* that coastal SSTs will increase with projected temperature increase (Section 5.3.3.4).	Emerging information on coastal changes in SSTs.
Freshwater input	Altered flood risk in coastal lowlands; altered water quality/salinity; altered fluvial sediment supply; altered circulation and nutrient supply.	*Medium confidence* (*limited evidence*) in a net declining trend in annual volume of freshwater input (Section 5.3.3.6).	*Medium confidence* for general increase in high latitudes and wet tropics and decrease in other tropical regions (Section 5.3.3.6).	Emerging information on freshwater input.
Ocean acidity	Increased CO_2 fertilization; decreased seawater pH and carbonate ion concentration (or "ocean acidification").	*High confidence* of overall increase, with high local and regional variability (Section 5.3.3.5).	*High confidence* of increase at unprecedented rates but with local and regional variability (Box CC-OA).	Coastal ocean acidification not specifically addressed in AR4. Considerable progress made in chemical projections and biological impacts.

Source: IPCC (2014)

2.1.1 Relative Sea Level Rise

Relative Sea-Level Rise (RSLR) has diverse effects on coastal zones and other low-lying areas. For most countries, it poses dangers of inundation and disintegration of coastlines with the resultant destruction of economic and socio-cultural edifices. A portion of the primary factors that add to RSLR globally includes SLR owing to thermal expansions and the liquefying of ice sheets, and ice caps predominantly from areas like Greenland and Antarctica. The immense potential for SLR dwells in the West Antarctic ice sheet, particularly the portions on the continental shelf (IPCC, 2014). These ice sheets are in part gliding and halfway liquefied, and if huge separation happens, a maximum of 6 m ocean level ascent may occur. There are variations that ensue at the regional to local levels because of sea movement configurations and observed fluctuations between yearly and decadal fluctuations in the oceans (Zhang and Church, 2012; Ganachaud *et al*., 2013). More research is needed to reveal the situations at the local level.

2.1.2 Mean Sea Level Rise

It is likely that generally, worldwide mean ocean level rose at a mean rate of 1.7 mm for each year between the 1900's and 2010 and at a specific rate of 3.2 mm every year from 1993 to 2010 (IPCC, 2014). The warming of the sea and liquefying of icy masses has added over 80% to Global Mean Sea Level Rise (GMSLR) in recent times. The rise in sea levels is projected to proceed beyond 21st-century levels due to continuous emission of CO_2 (IPCC, 2014). Under low emission scenarios, CO_2 concentrations are projected to be 421 ppm by 2100 and GMSLR will be 0.24m from 2046- 2065. Under high emission scenarios, CO_2 concentrations are projected to be 936 ppm by 2100 and GMSLR will be 0.29m from 2046- 2065 (IPCC, 2014).

This notwithstanding, ascent in ocean levels will not be uniform in space and time. Although some areas will have surges in sea levels, other areas will experience a fall in sea level. Milne *et al.*, (2009) reveal, although most coastlines are encountering ascent in ocean levels, coastal areas close to icy masses and ice sheets will encounter relative fall in ocean levels. This is because the gravitational appeal of the ice sheet diminishes as it dissolves and applies less pull on the seas with the grounds ascending as the ice liquefies (Gomez *et al*., 2010). These areas experiencing a fall in sea levels, however, have the relatively low human population and infrastructural developments compared to areas facing a rise in sea levels.

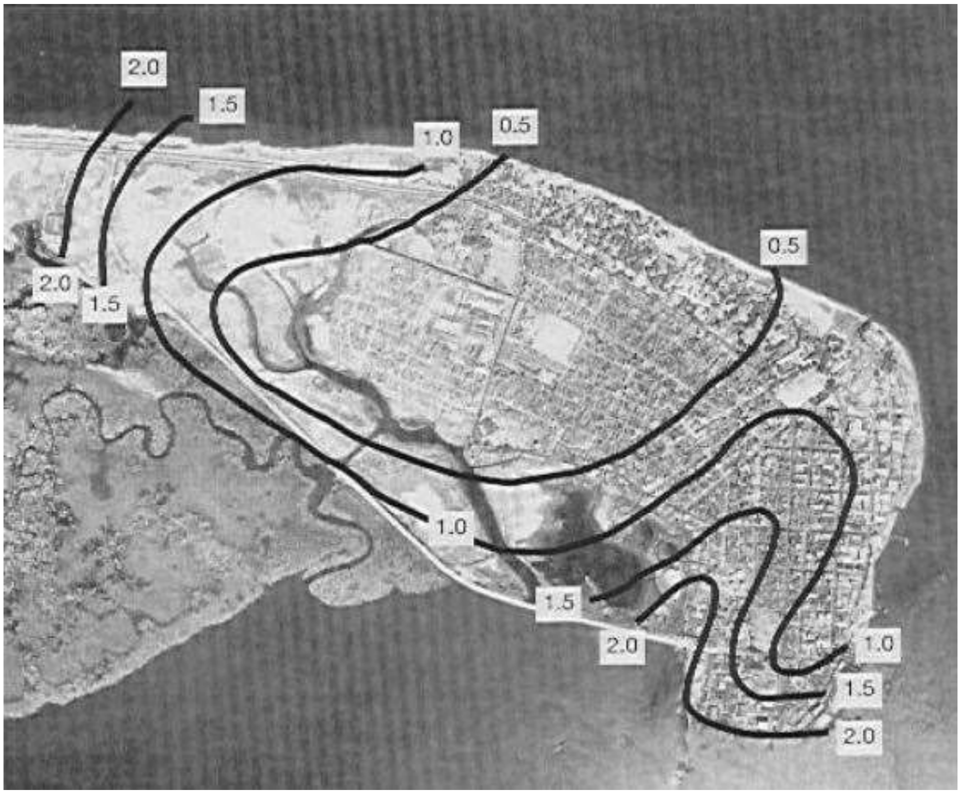
Regionally, before the end of this century, ocean level ascent will probably be 10% higher than the worldwide mean along Africa's coastlines (Schellnhuber *et al.*, 2013). This is largely because;

the African continent faces higher sensitivity and relatively low adaptive capacity to adapt to the impacts of SLR. Be as it may, the impacts of SLR will not be homogeneous over the whole continent as some areas are more sensitive and exposed to SLR than others. For instance, it is anticipated to be higher in southern Africa than in West Africa and North Africa (IPCC, 2014). One-meter ascends in ocean level is anticipated to bring about a land loss of 18,000 km^2 along the West African coast with significant economic costs (Schellnhuber *et al.*, 2013). For instance, the cost of degradation in Togo along its coastline due to erosion and economic prospect losses is projected to be about US$ 295 million, equivalent to 2.3% of the country's GDP in 2013 (World Bank, 2016). Jallow *et al.,* (1996) estimate that over US$ 217 million of land and other assets will be lost in The Gambia between Banjul and Kololi Beach Hotel under a 1m rise in sea level scenario (Figure 2.3).

At the local level, most mean SLR observed is due to subsidence. For instance, subsidence can ensue due to silt buildup and heap, which has been the case for the Mississippi River, and other deltas around the world (Törnqvist *et al*., 2008; Dokka, 2011; Marriner *et al*., 2012). Another observable instance is the Great East Japan Earthquake that occurred in 2011. The Geospatial Information Authority of Japan, Fujii *et al*., (2011) accounts that this earthquake subsided up to 1.2 m in some coastal areas of Japan. Another impact of SLR at the local level is the incidence of saline-intrusion into freshwater. This phenomenon has been observed in most rice-growing areas of The Gambia leaving many lands unproductive for cultivation.

Other variables that may affect degeneration from SLR is subject to the size and the level of the relationship of the material at the coasts; the strength of the waves; the rate of recurrence of storms; the shoreline; and the slope of the shoreline (IPCC, 2014). It is proposed that SLR will cause an unrelenting deepening of the continental shelf away from the depth of closure and result in an upsurge of effective wave heights due to the decline in bottom friction because of greater depth. These variables have a positive relationship with SLR.

Figure 2. 3 Contoured Map of The Gambia showing Banjul



Source: National Climate Committee, 2013

Among other reasons, anthropogenic causes of MSLR incorporate the combination of loads of buildings and structures along the coastline and diminishing sediment conveyance to the coast. The extraction of subsurface natural resources, like oil, gas, and groundwater also contributes to MSLR. The rate of subsidence may likewise be delicate to the rates of oil and gas evacuation and exploration (Kolker *et al.*, 2011). Loads from massive structures and other expensive developments can likewise expand residue compaction and subsidence rates (Mazzotti *et al.*, 2009).

2.2 Climate-Related Drivers of SLR

The increasing GHG intensities in the atmosphere create changes in the atmosphere framework on a scope of timescales that affect the physical condition of beaches. On shorter timescales, the physical effects of climate change on coastline include inundation; disintegration; shoreline flooding emerging from extreme storm surges; wave overtopping; and precipitation spillovers (IPCC, 2014). On longer timescales, changes in wind and wave movements due to climate change can cause changes in residual transport to or from the shorelines. This partly accounts for sediment delivery or starvation along the coastline affecting the rates of SLR incidence. Sea and air temperature change can influence the species dispersion with impacts on biodiversity along the coasts. The CO_2 absorption by the ocean leads to surges in the acidity levels of oceans with resultant effects on marine biological diversity (Menendez and Woodworth, 2010; Losada *et al.*, 2013).

An additional climate change related driver to SLR is severe storms. Serious storms, such as tropical and extratropical violent winds can produce storm surges over the shoreline in varied locations (IPCC, 2014). The gravity of these relies upon the storm pathway, local bathymetry, nearshore hydrodynamics, and the relapse rates of waves (Mazzotti *et al.*, 2009; Kolker *et al.*, 2011; Haigh *et al.*, 2010). Falling atmospheric pressures can cause storm surges and surface wind stress associated with these storms possibly changing when affected by changes in other climatic variables (Marcos *et al.*, 2009; IPCC, 2014). These storms contribute to the recession of sediments from the shoreline, exacerbating the impacts of SLR locally.

Conversely, the observed upward trends in MSL with projected increases for the end of the 21st century and beyond indicate that coastal systems and low-lying areas will increasingly exacerbate extreme sea level rise and its adverse impacts (IPCC, 2014). Other climate-related drivers of SLR are addressed in more details in the subsections to come.

2.2.1 Sea Surface Temperature and Ocean Acidification

Sea Surface Temperature (SST) has considerably warmed during the past 30 years along with over 70% of the world's coastlines (Lima and Wethey, 2012). With high confidence, IPCC AR5 reports a positive trend in coastal SSTs over the majority of coastlines. Likewise, with high confidence based on projected temperature increases, SST in coastal areas will have a positive trend over an extended period.

Increased SST has affected fisheries and marine ecosystem in the world at large and the West Africa sub-region. This phenomenon affects fisheries and other marine species in numbers and distribution in the sub-region, of which, The Gambia is no exception. For instance, in Senegal, *Sardinella sp.*, the most imperative monetary and food security species, is as of now altering its range northward because of warming water temperatures (Engelhard *et al.*, 2014).

Another driver of SLR is ocean acidification. This largely results from the additional contributions of CO_2 from human activities to the naturally occurring amounts in the atmosphere. The deposition of atmospheric nitrogen and sulphur mainly from agricultural, livestock and industrial activities also contributes to ocean acidification. The carbonate interaction from riverine waters and other water discharges into the sea also contributes to ocean acidification (Salisbury *et al.*, 2008). Additionally, the contributions of nutrients, organic matter, and the intensity of upwelling, contributes to this phenomenon (Cai *et al.*, 2011). The pH of oceans exhibits substantial temporal and spatial inconsistencies in coastal areas compared to open ocean owing to additional natural and human influences (IPCC, 2014).

Temperature variations over the land surface have impacts on the rate of SLR. Increase temperatures cause an increase in evaporation rate affecting the discharge of water bodies into oceans. The flow of water from deltas and rivers contribute to sediment delivery that lowers the rate of coastal erosion from SLR. The warming pattern observed in Sub-Sahara Africa since the 1960s is relied upon to rise by 4-6°C above present-day levels to the year 2100 (Schellnhuber *et al.*, 2013).

2.2.2 Precipitation and Freshwater Input

The trends in precipitation will vary over place and time due to changing environmental conditions. Whiles the tropics is bound to experience increases in precipitation, the sub-tropics are probable to have a decline in precipitation. The northern and southern areas of Africa are anticipated to encounter predominantly strong declines, with an anticipated decrease in yearly precipitation of 5-20% (Milano *et al.*, 2013). For a 4°C global warming, precipitations are expected to decline by 20% in North Africa and a further decline of 30% in Southern Africa contrasted with present situations (Schellnhuber *et al.*, 2013). Conversely, West Africa is estimated to have a decrease in precipitation of 15% compared to present situations under 4^{o}C global warming (IPCC, 2014).

The rate of precipitation affects the discharge of sediments into the ocean. The predicted decline in precipitation suggests a conceivable decline in sediment supply to oceans increasing future occurrence of coastal erosion from SLR. The Gambia has a Sahelian type of weather, characterized by a long dry season from November to May, and a short wet season from June to October with precipitation ranging from 850- 1,200 mm per annum (National Climate Committee, 2013).

Another factor to be deliberated in relation to the impacts of SLR is freshwater input. Freshwater input helps in reducing the salinity of oceans and the regulation of the rate of acidification of oceans. IPCC AR5 (2014) reports with medium confidence a net declining trend in freshwater input globally, although large regional variability exists. Trends in freshwater input into the oceans are subject to rainfall variations though anthropological forces on water supply may enhance descending trends (IPCC, 2014). While precipitation changes dominate freshwater flows, human pressures on these resources decreases the trends in river discharges (Dai *et al.*, 2009).

2.3 Human-Related Drivers of Coastal Systems

Coastal systems are subject to a wide range of human-related drivers that interact with climate-related drivers of climate change. The main man-made drivers of coastal erosion can be attributed to varied reasons (World Bank, 2016). The prominent ones are the construction of sea- ports along the coastal zone, legal or illegal sand mining. The improper construction of groins and breakwaters, construction of sediment- trapping upland dams; hardening of shorelines with ill-constructed sea walls. A further addition to this phenomenon is the damage to mangroves and other support systems and onshore and offshore oil explorations. Human activities towards Socio-Economic Development (SED) induce all these anthropogenic drivers driving the impacts of climate change along coastal areas in diverse ways.

Socioeconomic development impacts the number of people and the value of assets exposed to coastal erosion threats. For numerous places, population and asset exposure is rising faster than the national regular trends owing to coastward migration, coastal economic development, and urbanization (IPCC, 2014). These processes and land use variations are driven by a mixture of many social, economic, and institutional factors including taxes, subsidies, insurance schemes, the aesthetic and recreational attractiveness of the coast, and increased freedom of movement (Bagstad *et al*., 2007; Palmer *et al*., 2011). The increase in infrastructural developments along coastal areas has enticed more people to migrate to these dwellings.

The LECZ constitutes 2% of the world's land area. It encompasses 10% of the world's populace of about 600 million people (UNHCR, 2008). The LECZ correspondingly constitutes 13% of the world's urban inhabitants of about 360 million people, centred on the year 2005 evaluations (McGranahan *et al.*, 2007). About 65% of the world's cities with populations of above 5 million live in the LECZ (McGranahan *et al.*, 2007). As these populations increase, the number of people at risk and assets to be lost to coastal erosion and other climate change impacts from SLR will continue to surge.

For instance, the global population open to extreme SLR has increased by 95% from 1970 to 2010, with about 270 million people and US $13 trillion worth of assets exposed to the 1m SLR (Jongman *et al.,* 2012). Compared to other regions, Asia shows the highest exposure in population and assets with the top five nations classified by population in coastal low-lying areas being: Bangladesh, China, Vietnam, India, and Indonesia (McGranahan *et al*., 2007; Bollman *et al*., 2010; Jongman *et al*., 2012). Despite the long and undeveloped waterfront fragments of Rio Grande do Sul coastline of Brazil, approximately 33% of the state's shorelines have been affected by human actions (Esteves *et al.*, 2008). These anthropogenic activities influence nearby sand movements, which can heighten regular changes along the coastal zone and exacerbate the incidence of coastal erosion (Esteves *et al.*, 2008).

The increase in population has been linked to increased rates of socio-economic development in Africa and the world. Populace growth rates in Africa ascended from 2.3 % in 1950 to 2.6 % in 2000. It is predicted that by the year 2050 this value will increase to 1.7 billion (UNHCR, 2008). Seaside territories homes over 31% of West Africa's populace and generate over 56% of the sub-regions GDP. Around 4.5 million Senegalese (66.6% of the national populace) lives in Dakar coastal area with about 90% businesses established in this location (IPCC, 2016). In Ghana, Benin, Togo, Sierra Leone, and Nigeria, much of the commercial activity that forms the foundation of the national economies are along the coastal zone.

World Bank (2016) report reveals that shoreline floods distress an average number of 500,000 individuals in West Africa every year. The populace in The Gambia is estimated at 1.857 million with a density of 130 people per km^2, putting it among the five most densely populated nations in Africa with an annual population growth rate of 3.0% (GBoS, 2013). This estimate shows that the number of persons living in these coastal areas will continue to increase. The forerunners that move with urbanization are: extensions in power supply; communication and correspondence innovation extension; swift advancement of tourism and housing facilities, among others. Another factor that has expanded settlements along urban and peri-urban areas is the access to potable water.

Another human activity along the coast, gaining prevalence is legal and illegal sand mining. Sand mining is an open-coast expulsion of sand to support the construction industry for SED. Pilkey *et al.*, (2004) argues that the relatively cheap cost and ease of access in securing such sands from the shoreline compared to that quarried inland have heightened this menace. This makes the trade exceptionally appealing particularly to the individuals who would prefer not to work within the bounds of the law. For instance, sand mining operations along some coastlines of Ghana increased from 17.4% in 1986 to 20.8% in 1993 (Mensah, 1997). This may have quickened beachfront ecological degradation to a distressing rate in numerous parts of the country. A similar situation is noticeable with some coastal settlements of Kombo South district of The Gambia where beach sand mining is gaining predominance daily. Sand mining comes with several effects, notably the loss of land, the ruins of properties, and damage to roads. Remarkably, numerous private and group properties including houses, pathways, farmlands, burial grounds and religious structures on the coastline had been obliterated because of this activity. Given the significance of the coastal zone toward the West Africa sub-region, it is important that policymakers and key partners consider the mainstreaming of climate change into SED to avert the inevitable threats of SLR.

2.4 Land Loss Due to Coastal Erosion

Sea-level rise can stimulate two significant mechanisms that cause loss of land: erosion and inundation. Climate change is viewed as the significant natural variable stimulating seaside degeneration (Spencer, 1999). The variables that contribute to loss of land along the coast can be classified as naturally occurring or human-induced factors.

Coastal erosion characterizes the physical abstraction of sediment by a wave and action. However, the inundation component represents the long-lasting submergence of low-lying land. These impacts vary over locations chiefly subject to the geomorphology of the coastline of the locality. Wong (2003) notes that human activities that help to destroy mangroves likewise facilitate the loss of land along the coastline. Devoy (2000) reveals that if SLR occurs coupled with more prominent storms, waterfront flooding and coastal erosion issues will progress toward becoming exacerbated in delicate beach front zones. Sandy shorelines are more delicate to losing land in comparison with rocky coasts. Around 20% of the world's coastlines are sandy and supported by shoreline frontiers, ridges and other coastline protection structures (Viles and Spencer, 1995). However, these shorelines have experienced over 70% of land loss over the past decades (Viles and Spencer, 1995).

Some noteworthy human activities are the expulsion of sand and rocks from shorelines and the erection of enormous structures along the beachfront (Mensah, 1997). Along the eastern port of Lomé (Togo) harbour, a yearly erosion rate of 20 m has been recorded (Ibe et al. 1991). About

80% of the reasons for coastal erosion in Brazil can be attributed to anthropogenic forces (Muehe, 2006). The principal activities can be attributed to urbanization and obstruction in the sediment delivery flow through developing fixed structures.

As a response, coastal ecosystems undertake diverse alterations to address the peril. These natural adjustments may appear as either protected or damaging to coastal infrastructure. Some areas will experience accretion of sediments whiles other areas will experience extraction of sediments along the coastline. Seaside flooding is among the many consequences of coastal erosion. Pugh and Woodworth (2014) portray shoreline flooding as being mostly brought on by a blend of high water levels, which might be created by tides and storm surges, by waves, which can prompt overtopping of shoreline protectors and inundation of low-lying zones.

And under a projected global temperatures surge by 4°C with no modifications, it will be perceived that Egypt, Mozambique, and Nigeria will be the most affected by SLR, as far as several individuals at-risk of flooding is concerned annually (Hinkel *et al*., 2010). For the case of The Gambia, Guinea-Bissau, and Mozambique, up to 10% of the national populace will be at risk of coastal flooding from SLR (Hinkel *et al.*, 2011).

2.5 Estimation of land loss due to Sea- Level Rise

Of primary concern is to determine how much land will be lost due to sea level rise. The Bruun Rule is frequently used as a quantifiable way to predict the shoreline to be lost under given ocean level ascent on straight sandy shores (Dean, 1991; SCOR, 1991; Healy, 1997). Other studies that have used Bruun rule in its estimations of coastal erosion are Corbella and Stretch (2012) in South Africa, where 4 to 18 beach profiles were examined; Aagaard and Sorensen (2013) also used this methodology to examine the coast of Denmark. Jallow *et al*, (1996) estimated the vulnerability of the coastal zone of The Gambia and Abidjan using this rule.

The notion, proposed by Bruun (1962), states that a marine shoreline maintains an equilibrium profile with a depth and slope determined by the current and wave regime. This basic model expresses that the shoreline profile is an illustrative capacity whose parameters are controlled by the mean water level and the sediment estimate. This rule is opposite for a shoreline of unconsolidated sand, with coasts deprived of rock layers. Bruun (1962) reveals all things being equal, a typical coast will adjust to ocean level ascent naturally. The coast must keep pace with ocean level ascent, raising its profile regarding the ocean level. But to do this, a residue budget is established.

In synopsis, when ascent in ocean levels occurs, the shoreline withdraws and another proportional profile will be created at the new shoreline position by moving residue to further areas. The beach profile is moved to an upward and landward location (Bruun, 1962). Although the Bruun Rule has been used extensively in research it has several weaknesses. Care must be taken when utilizing this tool to anticipate the coastline reaction to ocean level ascent. In using the Bruun rule these assumptions to be established:

1. The coasts must be a soft-sediment coast, which should be typically sandy and not a rocky coast;
2. All the eroded sediment is reallocated along the profile in the cross-profile sequence;
3. The coastal erosion is wholly due to SLR excluding other factors.

2.6 Addressing Coastal Erosion Issues

Several approaches have been used to address coastal erosion and inundation threats in various countries. According to Clifton *et al*, (2013), some prospective actions embraced in addressing these issues can be assembled into four classes:

1. Policy development, advancement and Capacity building
2. Hard Engineering measures
3. Soft Engineering measures
4. Regulatory measure

2.6.1 Policy Development, Advancement and Capacity building

This involves mainstreaming climate change into all developmental agenda from the national to the local levels. For instance, the establishment of early-warning systems to help provide timely information on extreme climate events like floods, severe storms, and drought. There should be effective communication and easy access to this information to end-users. The capacity of the end-users should be built and developed to allow them to take more precautionary measures in reducing their vulnerability to climate change threats from SLR. Likewise, in the long-term, resilience actions should be an all-encompassing way from national to local levels as activities in one sector can affect other sectors elsewhere.

2.6.2 Hard Engineering Measures

Some hard engineering alternatives include the utilization of stone, wood, concrete and other nearby materials to shield the coastline from wave battering and other erosive strengths. Some of the structures include seawalls; gabions; Groynes; flood banks; rock armouring and; revetments (Wong, 2003). The hard engineering approaches involve the use of the above-listed structures to push the ocean backwards, to reduce the strengths of waves that hit the coastline, eroding cliffs, and accumulation of sediments. Wong (2003) noted that hard designed structures are the most widely acknowledged responses to shoreline erosion and inundation in most countries lying along the coast.

2.6.3 Soft Engineering Measures

Using soft-engineering structures involves the utilization of bio-designing strategies to settle coastal banks and to control groundwater seepage and surface overflows. This approach is relatively cheaper than the hard engineering options and requires relatively less expertise.

Remains and Duncan (1997) listed some of the soft engineering approaches as:

1. **Mangrove Restoration**- this involves planting mangroves in wetlands and estuaries to help trap sediments. This helps in slowing down the rate of erosion along the coast and protect biodiversity.
2. **Mega-foods**- this is an excess of sand put into the normal areas along the coast and expected these areas would be redistributed alongshore and into the ridges, through the regular characteristic action of waves, tides, and wind.
3. **Beach nourishment**- this involves the extraction of sediments lost from the ocean floor onto the coastline to reestablish previous levels.
4. **Dune re-contouring**- this involves adjustment of a ridge profile, usually through mechanical means using structures that form a mould of sand.
5. **Sand fencing**- this involves the erection of a wall to trap and collect wind-blown sand and help trap sediments.
6. **Dune grass planting**- this involves the adjustment of exposed sand rise surfaces with highly resistant grasses, which will likewise trap sand carried by wind-action.
7. **Setback**- this involves evacuation of seaside structures inland to allow steady expansion of a shoreline naturally. This considers relocating structures away from areas that are more vulnerable to the impacts of SLR to areas that are less vulnerable.

2.6.4 Regulatory Measures

This involves taking regulatory measures to address anthropogenically induced causes of SLR. Some measures are land-use management; Impacts Assessments along the coast; Enforcement of prohibition on sand mining and; decentralization of the SED to aid in reducing human migration to coastal areas. The enforcement of land-use measures will ensure proper planning and development of suitable structures that will not increase pressure on coastal resources and pose potential threats under conditions of coastal erosion. The prohibition of sand mining along the coast will help reduce sediment withdrawal and reverse the trends for sediment accretion. Restructuring socio-economic advances in countries will aid in dipping human exodus to coastal cities with its consequential effect on coastal resources.

2.7 Fisheries and Climate Change

Nadje (2012) accounts that West Africa has over 6,069 km of coastal zone and an Exclusive Economic Zone (EEZ) of 2,016,900 km^2 which support fishing and other economic activities. The fisheries sector is a vital source of overseas exchange and a fundamental source of income for the financial and social advancement in most part of the world.

As at 2015, the world marine fisheries capture was 81,164,685 tonnes with a net increase of 1.7% from the previous year (FAO, 2017). The top 10 leading producer countries of fisheries resources in a decreasing order range from; China, Indonesia, United States of America, Peru, Russian Federation, India, Japan, Vietnam, Norway and Philippines (Table 2.1). In the West Africa Sub-Region, the top 10 leading producer countries of fisheries resources in a decreasing order are Senegal, Nigeria, Ghana, Sierra Leone, Guinea, Cote d’Ivoire, The Gambia, Togo, Cape Verde and Benin (Table 2.5).

The marine fisheries sector alone contributes to a net worth of over US $3 billion from an estimated annual catch of 1.6 million tons (FAO, 2014). The value added by the fisheries subdivision in 2011 was evaluated at more than US $24 billion, corresponding to 1.26% of the GDP of every single African nation (Table 2.2). The total value added from fishing and aquaculture alone in Africa is over US $17.4 billion (FAO, 2014). In the year 2013, the total contributions of fisheries to GDP in The Gambia was 5.7%, whiles in Senegal the value is estimated at 13.45% (Table 2.4).

In recent decades, artisanal fisheries in West Africa have extended enormously with the provision of over 27% of food protein and income streams (Allison *et al*., 2005). Fisheries divisions are a notable wellspring of primary and secondary occupations. The total employment from fisheries in Africa is estimated to be over 1.9 million people with total Inland fisheries accounting for 40.4%, whiles total marine artisanal fisheries contributing 32.9% and total marine industrial fisheries contributing 0.36% (Table 2.3). Among the most imperative landing of marine fishes in the sub-region are herrings (*Clupea sp.*), sardines and pilchards (*Sardinops sp.*), and anchovies (*Engraulis sp*.). These species of fisheries develop at an early stage and are short-lived.

Table 2. 1 Marine Capture Production Showing Major Producer Countries

Country	**2014 (Tonnes)**	**2015 (Tonnes)**	**Variation (%) 2014- 2015**
China	14,811,390	15,314,000	3.4
Indonesia	6,016,525	6,028,260	0.2
United States of America	4,954,467	5,019,399	1.3
Peru	3,548,689	4,786,551	34.9
Russian Federation	4,004,242	4,172,073	4.2
India	3,727,088	3,497,284	-6.2
Japan	3,610,892	3,427,300	-5.1
Viet Nam	2,513,833	2,607,214	3.7
Norway	2,301,376	2,293,290	-0.40
Philippines	2,032,763	1,948,136	-4.20
Chile	2,175,486	1,786,633	-17.9
Korea, Republic of	1,727,329	1,639,860	-5.1
Thailand	1,488,280	1,496,450	0.5
Malaysia	1,458,126	1,486,050	1.9
Morocco	1,350,147	1,349,637	0.00
Iceland	1,076,558	1,317,148	22.3
Mexico	1,396,176	1,315,787	-5.8
Myanmar	1,118,020	1,090,060	-2.5
Taiwan (Province of China)	1,068,381	987,767	-7.5
Spain	1,055,496	967,240	-8.4
Denmark	745,019	868,892	16.6
Canada	835,196	823,155	-1.4
Argentina	815,355	795,415	-2.4
Total 23 major countries	63,830,834	65,017,601	1.9
Total other 172 countries	15,973,728	16,147,084	1.1
World total	79,804,562	81,164,685	1.7
Share 23 major countries	80.00%	80.10%	

Source: FAO, 2017

Table 2. 2 Fisheries and Aquaculture Contribution to GDP in Africa by Subsector

	Gross Value Added (US$ millions)	**Contribution to GDP (%)**
Total GDPs for African Countries	1,909,514	
Total Fisheries and Aquaculture	24,030	1.26
Total Marine Artisanal Fisheries	8,130	0.43
Total Marine Industrial Fisheries	6,849	0.36

Source: FAO, 2014

Table 2. 3 Fisheries Employment by Subsector

	No. of Employees (Thousands)	**Share Subsector (%)**
Total Employment	12,269	
Total Inland Fisheries	4,958	40.4
Total Marine Artisanal Fisheries	4,041	32.9
Total Marine Industrial Fisheries	2,350	19.2

Source: FAO, 2014

Table 2. 4 Contribution of fishing and Post-Harvest to GDP

Country	**Fishing GDP (%)**	**Post-Harvest GDP (%)**	**Total Fisheries GDP (%)**	**Post-Harvest Share in Fisheries GDP (%)**
Benin	1.76	1.24	3	41.3
Burkina Faso	0.2	0.1	0.3	33.3
Cameroon	0.9	0.8	1.7	47.1
Cape Verde	1.28	2.66	3.94	67.5
Cote d'Ivoire	0.76	0.76	1.52	50
Senegal	11.15	2.3	13.45	17.1
Gambia	1.75	3.95	5.7	69.3

Source: FAO, 2014

Table 2. 5 Production of Marine Fisheries in West Africa (in tonnes)

Country	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
G-Bissau	5 445	5,526	6,850	5,757	6,240	6,540	5,997	5,885	6,408	6,404	6,404
Liberia	7,285	6,039	6,464	6,364	9,795	8,002	6,198	12,367	6,950	7,070	7,070
Benin	5,400	7,472	9,888	10,676	10,537	8,678	10,999	5,387	6,822	7,779	7,908
Cape-Verde	10,557	8,601	8,077	8,049	10,336	21,581	24,554	18,328	23,698	16,828	19,500
Togo	16,822	17,324	15,262	22,007	20,754	21,498	18,761	14,312	17 684 F	20,988	21,208
Gambia	5,640	0,192	42,083	33,136	28,422	28,410	30,667	35,523	35,569	38,366	39,489
Cote d'Ivoire	68,439	65,149	46,948	46,295	48,525	28,370	46,988	42,901	44,499	37,474	63,929
Guinea	86,758	00,193	87,342	114,845	88,550	98,566	94,489	70,823	81,240	81,000	82,000
Sierra Leone	55,571	58,979	62,606	74,908	112,477	123,410	126,995	123,218	178,564	175,185	175,007
Ghana	363,732	357,930	286,665	302,362	313,953	304,599	280,472	233,999	265,020	223,575	251,947
Nigeria	283,466	269,911	255,258	262,798	251,232	248,247	288,670	274,354	273,936	281,200	290,780
Senegal	355,087	356,435	322,388	398,152	379,356	343,885	314,174	351,292	364,802	378,619	350,769
Grand Total	**1,284,202**	**1,283,751**	**1,149,831**	**1,285,349**	**1,280,177**	**1,241,786**	**1,248,964**	**1,188,389**	**1,305,192**	**1,274,488**	**1,316,011**

Source: FAO, 2014

The leading producers of fisheries in West Africa are; Mauritania, Ghana, Senegal, and Nigeria. However, Gambia is ranked as the sixth most productive fishing area in the world (UNECA, 2016). Most African countries benefit from fishing agreements of the European Union (EU) regarding industrial fishing in territorial waters. For instance, the EU pays Mauritania 86 million euros annually, which relates to approximately a third of Mauritania's national income (Lee *et al*., 2009).

Regardless of the operations of artisanal fishers in The Gambia, they contribute 90% of the aggregate national fish utilization in the country. They supply around 80% of throughput in the modern fisheries management plants of The Gambia. The artisanal fishers in this study allude to those fisherfolk with low capital, and fish utilizing little gear and innovation like canoes. With The Gambia, artisanal fishers likewise incorporate the women oyster and oyster collectors who largely work inside the estuarine ranges.

Industrial fishing in The Gambia, for instance, represents as meagre as 10% of the aggregate national fish utilization, and about 20% of the locally treated fisheries (National Climate Committee, 2013). This fishing segment involves the use of high-cost fish generation frameworks with fishing trawlers chiefly focused along the Atlantic shoreline.

Climate change is likely to cause an increase in acidification and a surge in ocean temperatures (IPCC, 2014). This incident will lead to potential effects on fisheries numbers and distribution. Another issue of concern is that marine biological systems, including coral reefs and the fisheries that rely upon them, are anticipated to be amid the regular frameworks influenced by climate change in the shortest time (Drinkwater *et al*., 2010; Brander, 2007).

As the rate of evaporation of the oceans increases under increasing temperature and low precipitation, salinity levels of oceans are expected to increase. Under increased salinity conditions, the survival of some marine resources will likewise be at-risk (IPCC, 2014). These incorporate biophysical impacts on the productivity of marine and freshwater fisheries stock.

At large, fisheries resources are transboundary with no restrictions at the regional to the local level in maritime space. This makes it easy for them to relocate towards more favourable areas for their survival and reproduction. Managing adequate access to fish under climate change will entail the reception of actions intended to ensure the preservation of specific fish species in danger of extinction in particular regions (Cinner *et al*., 2012). The impacts of climate change correspondingly have social and security ramifications. For instance, in The Gambia, stock shortage and technological advancements have induced more artisanal fishers to go over 200 nautical miles seaward in the areas allocated to foreign vessels. This incidence has led to several confrontations between foreign and local fishers raising safety concerns at sea.

Some actions that have been incorporated in varied locations include expansion of aquaculture to help increase the population of fisheries from freshwater sources; increased support for creative research and technological developments in innovative and more sustainable fishing. There is also the need to protect more wetlands and introduce more adaptive species of mangroves that can better withstand areas with high salinity. With this in place, fisheries nesting grounds will be increased to help produce and care for juvenile fisheries resources before they migrate to the deeper waters at maturity.

2.8 Methodologies for Assessing Climate Change Vulnerability

Methods and tools for evaluating risks and vulnerability to climate change impacts on coastal systems are in the formative stages of development. This study defines Vulnerability as “the degree, to which a system is susceptible to and unable to cope with, adverse effects of climate change, including climate variability and extremes” (IPCC, 2014). Vulnerability assessment also depends on the intended use of the assessment results, which may range from an intention to inform international and national policy or to spur community-level action (Moret, 2014). Macro-level interventions typically include measures at the country level, with international and regional policy applications (Moret, 2014). This level typically uses the top-down approach to assess vulnerability. Meso level interventions typically include measures at the subnational level (Moret, 2014). This level uses the top-down, bottom-up or a combination of these approaches in vulnerability assessment. The micro-level measures target individuals and households where vulnerability is more frequently assessed using participative and qualitative measures for programs targeting. Though each level possesses unique requirements for analysis, they intersect in important ways; this study focuses on mixed methods between the meso and micro levels.

At the macro level, the IPCC first developed the guidelines for assessing impacts of climate change called the ‘common methodology’ using the top-down approach (Carter, Parry, Harasawa, & Nishioka, 1994). Ever since the IPCC ‘common methodology‘ was developed in 1991, there have been numerous attempts to use or adapt this methodology, but the focus has remained on sea-level rise as the most important issue of coastal zone vulnerability assessment (Harvey, Clouston, & Carvalho, 1999). The seven stages of IPCC ‘common methodology’ are:

Stage 1. Delineate case study area and specify accelerated sea-level rise and climatic change conditions.

Stage 2. Produce an inventory of study area characteristics.
Stage 3. Identify relevant development factors.
Stage 4. Assess physical changes and natural system responses.
Stage 5. Formulate response strategies, identifying potential costs and benefits.
Stage 6. Assess the vulnerability profile and interpret the results.
Stage 7. Identify future needs and develop a plan of action (IPCC CZMs, 1992).

This approach is most useful as an initial, baseline analysis for country-level studies where little is known about coastal vulnerability (Kay *et al*., 1996; Waterman, 1993). The focus of the 'common methodology' was on obtaining monetary valuations of vulnerable areas so a cost-benefit test could assess the best response option (Harvey *et al.*, 1999). The adaptation component of the 'common methodology' focused on three generic options: retreat, accommodate or protect. This study defines adaptation as "the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (Parry *et al.*, 2007). The 'common methodology' was deficient in assessing a wide range of technical, institutional, economic and cultural elements present in different localities (Kay *et al*., 1996; Waterman, 1993). The concept of vulnerability did not consider the resilience of coastal systems to various stresses like increase in temperature, flood intensity, on coastal systems. The 'common methodology' received criticism at the World Coast Conference in 1993 and some noted that if coastal vulnerability assessment supported Integrated Coastal Zone Management (ICZM) it would need revision and expansion (Bijlsma *et al*., 1993).

Later, three agencies, the United States Country Studies Program (USCSP) (Benioff *et al.*, 2012), the Netherlands climate change studies assistance program and UNEP country case studies on climate change impacts and adaptation assessment (O'Brien, 2000) conducted studies in different parts of the world. The UNEP methodology, for instance, establishes a generic framework for vulnerability assessment and response to the threats posed by sea level rise and climate change. The USCSP methodology also extended from the assessment of the impacts of climate change on coastal recourses to other sectors like agriculture, livestock, water resources, human health, terrestrial vegetation, wildlife and fisheries (Younus, 2017). Since these methods are based on the IPCC 'common methodology' with a single-stressor approach (Klein & Nicholls, 1999), the conceptual ideas behind these methods do not tackle these weaknesses either. The Southern Africa Vulnerability Initiative (SAVI) framework was developed in 2004 to emphasize the interconnections of multiple stressors (O'Brien *et al*., 2009). It draws on the vulnerability literature originating in the disciplines of anthropology/sociology, economics, and disaster management. Because it focuses on root causes than suggested adaptive responses, assessments utilizing the SAVI framework are more complicated, resource-intensive, and demands complex and long-term research (Casale *et al*., 2010; O'Brien et al., 2009).

The focus shifted to a bottom-up approach at the micro level where the main focus has been to understand the community members' actions, practices, and strategies for community-based vulnerability, adaptation and coping strategies to climate change impacts (Younus, 2017). Younus (2017), for example, used the bottom-up approach in the prioritization of Vulnerability and Adaptation issues at the community level using weighted indices in coastal regions of Bangladesh. His study modified the Participatory Vulnerability Analysis method in the vulnerability and adaptation assessment. Another method used at the micro level is the Household Economy Approach (HEA). This is a livelihoods-based analytical framework developed based on multi-level analysis (Boudreau et al., 2008). It was initially developed to predict food emergencies at the national level, but has since been adapted to assess an array of shocks at the local level

(Frankenberger *et al.*, 2005; Petty & Seaman, 2004). A limitation associated with this method is that it is resource intensive and time-consuming (Boudreau et al., 2008; Petty & Seaman, 2004).

At the meso level, most of the vulnerability assessments are suitable for economic strengthening interventions like poverty reduction, food security and sustainable livelihoods. They have features that are not generalizable for adoption in climate change vulnerability and impact assessments (Chiwaka & Yates, 2005; Moret, 2014). An example is the Local Vulnerability Index (LVI) (Naudé *et al.*, 2008), Household Vulnerability Index (HVI) (Hahn *et al.*, 2009; Moret, 2014; Wen-Jian & Hai-Shan, 2013) and the Participatory Vulnerability Analysis (PVA) (Chiwaka & Yates, 2005; Younus, 2017). Another example is the Household Livelihood Security Analysis (HLSA). Though the HLSA is useful in creating a comprehensive baseline and incorporates mixed methods, including participatory methods, the qualitative approach used is not generalizable outside the economics, sociology and anthropology frameworks (Cannon *et al.*, 2003; Frankenberger *et al.*, 2002; Frankenberger et al., 2005; Lindenberg, 2002; Rahman & Akter, 2010). Another method is the Risk and Vulnerability Assessment Methodology Development Project (RiVAMP). The RiVAMP is intended for vulnerability assessment in Small Island Developing States with a focus on coastal areas affected by tropical cyclones and their secondary effects (Estrella et al., 2010). This makes the RiVAMP not suitable for assessments in West Africa. There is the need for a method that incorporates a bottom-up approach which is more consistent with coastal zone management at the sub-national level (Harvey et al., 1999; Waterman, 1993). This led to the development of the vulnerability and risk management framework by researchers in the Australian Greenhouse Office (AGO) in 2006 (AGO, 2006). This method has been used in the development of climate change risk and vulnerability assessments in Australia and Canada (Brundell *et al.*, 2010; Cobon et al., 2009). The method employs a multi-stressor approach with fewer resources and, training time requirements in assessments (Brundell et al., 2010; Cobon et al., 2009). It also identifies a more comprehensive variety of adaptations characteristically explored by researchers to deliver a simple, hands-on and representative assessment of risk and vulnerability (Abuodha & Woodroffe, 2006; Brundell et al., 2010; Cobon et al., 2009; Howden et al., 2007; Stokes *et al.*, 2008). We argue that a framework that considers the full process of vulnerability and adaptation will better integrate adaptation to climate change at the meso and micro levels for effective coastal zone management. This study seeks to fill this research gap by adapting the AGO methodology using the bottom-up approach at the meso level with qualitative measurements. Despite the strengths associated with this methodology, germane literature must be consulted to establish a common understanding or direction where views made from expert judgement are opposing (IPCC, 2014).

CHAPTER THREE

METHODOLOGY

3.0 Introduction

This chapter presents the methods used in data analysis to achieve each objective of the study with the expected outcomes embedded. It further covers the types and sources of data used in the study. This chapter covers the description of the study area, and finally the scope and limitations of the study.

3.1 Method of Data Analysis

3.1.1 Characterizing the Trend of Annual Rainfall, Minimum, and Maximum Temperature

Trend analysis is used in achieving the first objective of the study. To describe the trend of annual Rainfall in The Gambia from 1985- 2016, a line graph is drawn to show the trend of Rainfall (in mm), minimum and maximum temperature (in ^{o}C) respectively. The growth rate over the period can be estimated using the simple linear regression model below (Equation 3.1);

$$\mathbf{Y_t = \beta_o + \beta_i\, T + e_i} \qquad 3.1$$

Where:

$\mathbf{Y_t}$ = Annual Rainfall (in mm) or Minimum / Maximum Temperature (in ^{o}C)
$\boldsymbol{\beta_o}$= Intercept,
$\boldsymbol{\beta_i}$ = Growth rate / Trend,
T = Time (1985- 2016)
$\mathbf{e_i}$ = Error term

To describe the trend of Minimum and Maximum Temperature in The Gambia from 1985- 2016, a line graph is drawn to show the trend of minimum and maximum temperature (in ^{o}C) respectively. The growth rate over the period can be estimated using the simple linear regression model below (Equation 3.2);

$$\mathbf{Y_t = \beta_o + \beta_i\, T + e_i} \qquad 3.2$$

Where:

$\mathbf{Y_t}$ = Minimum / Maximum Temperature (in ^{o}C)
$\boldsymbol{\beta_o}$= Intercept,
$\boldsymbol{\beta_i}$ = Growth rate / Trend,
T = Time (1985- 2016)
$\mathbf{e_i}$ = Error term

3.1.2 Estimation of Future Land Loss due to Inundation and Coastal Erosion

To achieve the second objective of the study, the mathematical expression of Bruun Rule (1962) is used to estimate future land loss rate due to coastal erosion under varied IPCC scenarios. Jallow *et al.*, (1996) used the Aerial Videotape-Assisted Vulnerability Analysis (AVVA) in the delineation of the study area into nine coastal cells. The Bruun rule is given in Equation 3.3 below;

$$\mathbf{R = G \times S\, [W/\,(H + d^*)]} \qquad 3.3$$

Where:

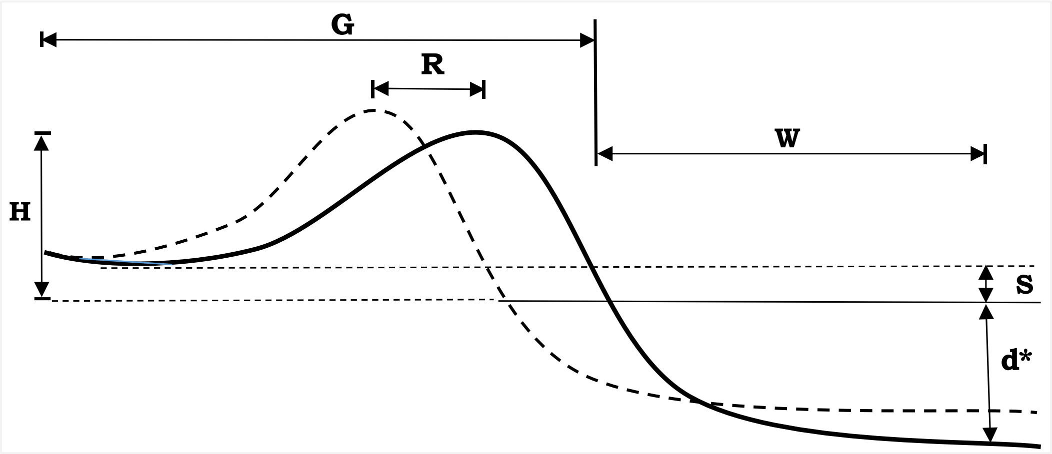
R =Shoreline retreat (erosion) due to SLR,
G = Overfill ratio of the materials being eroded,
W = Width of the active profile. This ranges from the dune to the depth of closure
H = Dune/Cliff Height,
d* = Depth of closure,
S = Projected SLR Scenarios,

For the case of The Gambia, the value of G is assumed to be a uniform value of 1.0 as the coastal zone is mainly characterized by fine sand erodible materials (Jallow *et al.*, 1996). The depth of closure, d* is the most difficult variable to estimate as largely varies with timescales (Lüdeling &

Kytö 1996; Jallow *et al.*, 1996). The longer the time under study, the larger the value for the depth of closure with resultant positive impact on the rate of coastal erosion from sea level rise. To get the depth of closure over the 100 years' timescale, a low and high estimate of this variable is created, d_{L1} and d_{L100} respectively. The low estimate is determined from field measurement using the bathymetric map of The Gambia along the respective cells that make up the coastal zone of The Gambia. Nicholls and Leatherman (1994) related estimating the high estimate of the depth of closure over 100 years given the low estimate of the depth of closure; this is given as Equation 3.4. The bathymetric map is further used in the estimation of the width of the active beach profile. The coastline is divided into segments based on the width and cliff height similarities, and the Bruun Rule is applied. Figure 3.1 below illustrates the parameters integrated into the Bruun rule to estimate the future erosion rate due to SLR. Table 3.1 gives the aprior expectation of the variables in Equation 3.3 in relation to the rate of shoreline retreat.

$$\mathbf{d_{L100} = 1.75 \times d_{L1}} \qquad [3.\ 4]$$

Figure 3. 1 Illustration of the parameters of Bruun Rule



Source: Author, 2017

Table 3. 1 A prior Expectation

Variable	Definition	A Prior Expectation
G	Overfill ratio of eroding materials	+
W	Width of the active profile	+ / -
H	Dune/Cliff Height	+
*d**	Depth of closure	+

Source: Author, 2017

The direct inundation concept is applied to estimate the land loss due to Inundation. Using the contoured topographic map of the coastal strip of The Gambia, the area of land that falls within the 1m contour line in the study area is shaded. A transparency paper with a graduated mess of 1cm by 1cm (the 1cm is converted to the scale of the map) is placed on the shaded area of the map. The number of boxes that fall within the shaded area is counted and conversions made with the scale of the map. The total area recorded gives the area to be inundated under a 1m SLR scenario.

3.1.3 Characterizing the Trend of Artisanal Fisheries

To describe the trend of artisanal fisheries catch by species in The Gambia from 1986- 2016, a line graph is drawn to show the trend of Fisheries (in MT). The growth rate over the period can be estimated using the simple linear regression model below (Equation 3.4);

$$\mathbf{Y_t = \beta_o + \beta_i T + e_i} \qquad [3.4]$$

Where:

$\mathbf{Y_t}$ = Artisanal Fisheries Catch by Species (in MT)

$\boldsymbol{\beta_o}$= Intercept,

$\boldsymbol{\beta_i}$ = Growth rate / Trend,

T = Time (1985- 2016)

$\mathbf{e_i}$ = Error term

3.1.4 Assessing the effects of temperature on the productivity of riverine fisheries resources.

The model developed by Welcomme (1979) is used in estimating the annual productivity of the River Gambia based on its average stream width, biogenic capacity, average annual temperature, acidity or alkalinity and the fish population present in the river. The area covered ranges from the mouth of the river to Bamba Tenda/ Yelli Tenda crossing point. This can be estimated using Equation (3.5).

$$K = B \times L \times (K_1 \times K_2 \times K_3) \qquad [3.5]$$

Where:

K= Annual Productivity (kg/km)

L= Average width of the river (m) = 4,900m.

This value is estimated from the bathymetric map of the river Gambia.

B = Biogenic Capacity = 6

(B = 1-3 for waters with little fish food, B = 4-6 for waters with average fish food, and B = 7-10 for waters rich in fish food). In the case of The Gambia, the River Gambia has average fish food (MOA, 2015); the value of the Biogenic capacity, B is taken as 6 for the study.

k_1 = annual average temperature.

k_2 = acidity or alkalinity of the water = 7.16.

This is the average pH of the River Gambia from the mouth of the river to the Bamba Tenda/ Yelli Tenda crossing point.

k_3 = the fish population present.

The value for **k_3** can be estimated based on the percent of rheophic (fast flowing water) and limnophilic (slow flowing water) species in the fish community of the river.

$$\mathbf{k_3 = (2L + R)/100}$$

L = percentage of the fish community comprising limnophilic species.
R = percentage of the fish community comprising rheophilic species.

The values of L and R in the study are taken as 95% and 5% respectively for the river Gambia (Jallow, 1997) as most part of the river is flowing with more community of limnophilic species. The General Circulation Models (GCM) used are the Canadian Climate Center Model (CCCM199), Geophysical Fluid Dynamics Laboratory (GFDL90) and the Australian model is used (BMRC95). These three GCMs are the ones with the highest correlation coefficients (r) with the baseline climatic data extracted from the SCENGEN climate model used in this study. The data for 1981- 2010 are baseline climate. This secondary data is sourced from The Gambia's first national communications report (National Climate Committee, 2013) and available in Appendix (A).

3.1.5 Assessment of the Effects of Temperature Changes on Shrimp Yield

To assess the effects of different temperature scenarios on the yield of shrimps in the sheltered coast of The Gambia, the Regier *et al*., (1990) model is adopted. The correlation coefficients (r) for the model used is 58%. This is given by Equation (3.6);

$$\mathbf{Log_e\, SCSY_{\mathit{i}} = 52.0 - 14312\ (1/T_{\mathit{i}})} \qquad [3.\ 6]$$

Where:

SCSY = Stabilized Commercial Shrimp Yield (kg/ha of intertidal vegetation)
T= Mean annual Temperature (^{o}K)

3.1.6 Estimating Population at Risk to Coastal Flooding

The IPCC mathematical definition of Population at Risk is used in estimating the number of people exposed to coastal erosion and flooding in each coastal cell of the study area. This is given as Equation 3.7 whiles Table 3.2 presents the expected outcome of the variables of this equation.

Population at Risk = PD * PC [3. 7]

Where:

PD= Population Density

PC= Probability of Coastal Flooding in each coastal cell

Table 3. 2 A prior Expectation

Variable	Definition	A Prior Expectation
PD	Population Density	+
PC	Probability of Coastal Flooding	+

Source: Author, 2017

3.1.7 Assessment of Non- Marketed Goods and Services along the Coastal Zone

An appraisal of literature is done to reveal the historical assets in the study area. An inventory is undertaken from field observations to know the status of these assets in recent times. The non-marketed goods and services assessed include:

- Historical and Cultural assets along the coastal zone;
- Fish-landing sites that fall within risk zones to inundation in the study area;
- Endangered Species of Wildlife and Biodiversity along the coastal zone;
- Coastal wetlands at risk of being lost.

3.1.8 Vulnerability and Impact Risk Matrix for the Coastal Zone of The Gambia

Some categories of uncertainty are possible to quantify in probabilities while others are not. In the guidelines for the Fifth Assessment Report of the IPCC (2014), two metrics for the communication of the degree of certainty are proposed, with one metric comprising quantified measures of uncertainty in a finding that can be expressed probabilistically. This is expressed based on statistical analysis of observations, model results or expert judgment. The other metric for the degree of certainty is expressed qualitatively and comprises confidence in the validity of a finding, based on the type, amount, quality, and consistency of evidence and the degree of agreement (IPCC, 2014; Mastrandrea *et al.*, 2010). The latter metric is used in this study.

A workshop was organized for the development and validation of the impact risk and vulnerability matrix for the study area. Later, stakeholder consultations were made for further information to support the results. There are various methods to involve stakeholders, like cognitive mapping, expert judgement, brainstorming or checklists, interviews and surveys (Ziervogel & Zermoglio, 2009). When quantitative data are not available, expert opinions of key stakeholders can offer alternative sources of information on coastal systems (IPCC, 2014; Malone & Engle, 2011; Mastrandrea et al., 2010; Salter *et al.*, 2010; Younus, 2017; Ziervogel & Zermoglio, 2009). A purposive expert sampling technique was used in selecting respondents for the study. To minimize the error associated with this sampling technique, a quota of 20 experts were selected from each institution for the workshop. A total of 100 experts were engaged in the workshop. The steps of this study were officially communicated to the heads of the institutions. This information was later relayed to other staff members for 2 weeks, to ensure familiarization with the steps to be used for the workshop. The heads of the institutions selected the experts based on their level of expertise in climate change and their willingness to participate in the workshop. The institutions consulted are; the Department of Water Resources, Coastal and Marine Environment Unit of the National Environment Agency, Department of Parks and Wildlife Management, Department of Agriculture, Ministry of Environment, Climate Change and Natural Resources.

Thirteen (13) principal steps were used in completing the risk and vulnerability matrix during the workshop and stakeholder consultative meetings. This includes:

Step 1: Definition of the Area of Interest and Timescale Boundaries

Step 2: Identification of Important Climate Change Variables
Step 3: Assigning likely Changes in Climate Change Patterns
Step 4: Identification of Elements of the Sector
Step 5: Completion of the Framework of the Impact Risk Matrix
Step 6: Description of the Climate Change Impacts
Step 7: Determination of the Likely Category for the Impact
Step 8: Determination of the Consequence Category for the Impact
Step 9: Assigning Impact Risk in the Impact Risk Matrix
Step 10: Description of Adaptation Response
Step 11: Determination of Adaptive Capacity
Step 12: Assigning Level of Vulnerability
Step 13: Preparing a Risk/Vulnerability Statement.

The themes for each step is translated into the research questions for the study. For instance, in step 2-Identification of Important Climate Change Variables. The experts were asked to list 5 important climate change variables that impact the coastal zone of The Gambia. The stakeholders then went through the IPCC document, identified and listed out the 5 most important climate change variables that will impact the study area. The 5 commonest variables selected by the respondents were then ranked collectively from 1 (the most important to the study area) to 5 (the least important). These steps are expanded below:

Step 1: Definition of the Area of Interest and Timescale Boundaries

The geographical boundary was defined as the entire open coast of The Gambia (Figure 3.2) within the scale limits of 2100 (IPCC, 2014). This timeframe adopted formed the baseline climate and socio-economic scenarios for this study.

Step 2: Identification of Important Climate Change Variables

The workshop participants identified five vital variables of climate change with a momentous impact on the coastal zone of The Gambia. Although not thorough, the list provides a useful vulnerability and risk assessment of the coastal zone of The Gambia. These key climate change variables selected and the level of confidence in projection were identified from a review of the IPCC (2014) report (Table 3.3). Table 3.3 below provides the identified imperative climate change variables relevant to the coastal zone sector of The Gambia. The first column ranked the climate change variables from one to five, where one is the most significant and five is the least significant for the sector. The third column shows the level of confidence scientists placed in the projection for each climate variable using color codes described in Table 3.4 below.

Figure 3. 2 Map of the Study Area, the Coastal Zone of The Gambia.

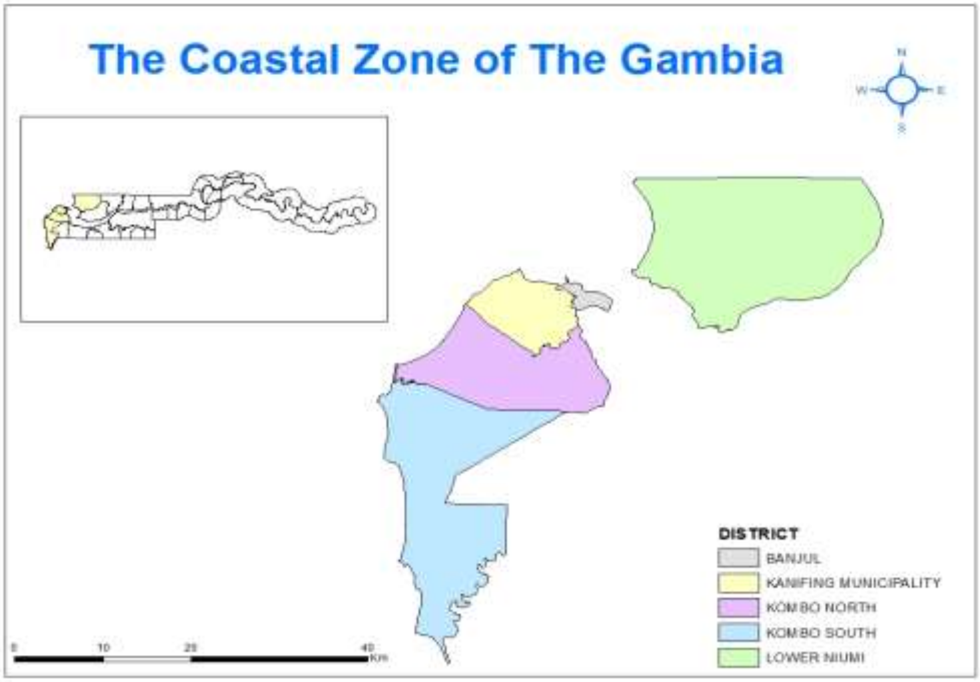


Table 3. 3 List of Climate Change Variables and the Level of Confidence in Projections.

Priority Level	Climate Change Variables	Level of Confidence Using Color Code
1	Increased Temperature	🟥
2	Sea Level Rise	🟥
3	Elevated Carbon Dioxide (CO_2) levels	🟥
4	Increased Flood Severity	🟧
5	Reduced Rainfall frequency and Intensity	🟧

Source: IPCC, 2014.

Table 3. 4 Confidence and Likelihood of the Coastal Zone experiencing the CC Variables in Table 3.3.

Level of Confidence	Likelihood of the Outcome	Equivalent Priority Level	Color Code
Virtually Certain	99–100% probability	1	🟥
Extremely Likely	95–99% probability	2	🟥
Very Likely	90–95% probability	3	🟧
Likely	66–90% probability	4	🟨

Source: IPCC, 2014.

Step 3: Assigning Of Likely Changes in Climate Change Patterns

By assigning likely changes in each climate change pattern identified in step 2, the IPCC (2014) report was reviewed to expose the level of confidence in each climate change projection. Four levels of confidence were assigned to the 2100 projections to the climate change variables (Table 3.4), namely: *virtually certain*; *extremely likely*; *very likely* and; *likely*. The reviewed literature exposing the projections in the climate change variables are discussed in the subsections below.

Increased Temperature

IPCC (2014) reveals air temperatures surged by over 0.5 °C throughout last 50–100 years over most parts of Africa. It is *virtually certain* that globally the troposphere has warmed since the mid-20th century. Temperatures in Africa are projected to rise faster than the global average increase during the 21st Century. In West Africa, a temperature rise of 3–6 °C is predictable by the end of the 21st century as of the late 20th Century baseline (IPCC, 2014). These forthcoming projections in temperature over the West Africa Sub-region will occur one to two decades earlier than the projected global average. This is due to the relatively small natural climate variability in the sub-region engendering a narrow climate limits that can be easily outshined by comparatively slight changes in climatic variables (IPCC, 2014). At the local level, The Gambia has recorded temperature increases of 0.5 °C per decade from the year 1940 and it is predicted that temperatures will increase from the current levels of 28 °C to 31.5 °C by 2100 (IPCC, 2014).

Sea Level Rise (SLR)

The IPCC (2014) envisages with *virtual certainty* that SLR will advance further than 21st-century levels owing to continuous emissions of CO_2 from both natural and anthropogenic sources. Under Low emissions scenario, sea levels are anticipated to increase to 0.26–0.55 m by 2100 while increases in the range 0.52–0.98 m are recorded in High emissions scenario (IPCC, 2014). The

IPCC (2014) forecasts with *virtual certainty* that near-surface permafrost size at high northern latitudes will diminish as the global mean surface temperature rises, with the size of permafrost near the surface (upper 3.5 m) projected to decrease by 37–81%. This will contribute to surge in sea levels from global to local levels. At the regional level, before the end of the 21st century; ocean level ascent is probably to be 10% Higher along Africa's coastlines than the worldwide mean (Schellnhuber et al., 2013).

Elevated Carbon Dioxide Levels

The IPCC (2014) predicts with very high certainty that elevated CO_2 levels with other GHG emissions in the atmosphere have resulted in an *extremely likely* cause of the observed warming since the mid-20th century. It is *extremely likely* that the increase in anthropogenic sources of CO_2 and other anthropogenic GHG concentrations triggered over 50% of the observed surge in global average surface temperature from 1951 to 2010. These anthropogenic sources of CO_2 have increased since the pre-industrial era, driven largely by economic and population growth through the burning of fossil fuels, and cement manufacturing processes, among others.

Increased Flood Severity

It is *very likely* that since 1951 there have been statistically significant increases in the number of heavy precipitation events in more regions than there have been statistically significant decreases (IPCC, 2014). This phenomenon has caused varied impacts like floods from regional to local levels (IPCC, 2014). Coastal systems and Low-lying areas will increasingly experience submergence, flooding, and erosion throughout the 21st century and beyond, due to SLR (IPCC, 2014). The contemporary detection of increasing trends in extreme precipitation besides discharges in some catchments denotes greater risks of flooding on a regional scale (IPCC, 2014).

Increased Rainfall Frequency and Intensity

The frequency and intensity of heavy precipitation events have *likely* increased over most parts of Africa while continents like North America and Europe have experienced *very likely* increases (IPCC, 2014). It is *very likely* that global near-surface and tropospheric air specific humidity has increased since the 1970s. This has contributed to an increase in the frequency and intensity of rainfall, although the rainfall amounts have shown a downward trend over most parts of Sub-Sahara Africa. This is largely observed at the local level. For instance, forecasts over The Gambia point to at least 20% decrease in rainfall by mid-century with an increase in its intensity and frequency (National Climate Committee, 2013).

Step 4: Identification of Elements of the Sector

The sector elements identified are issues that affect production, natural resources, social or lifestyle aspects, particularly agricultural production, fisheries, tourism and human health and well-being in the study area (Table 3.5). Amongst the elements that affect production dynamics in the sector are: Land Use/Cover Changes; Infrastructure Development; Population Dynamics and; Fisheries Productivity (National Climate Committee, 2013). The other sector elements that formed natural resource drivers of the coastal zone comprise: Mangroves and Wetland; Fisheries; Agricultural Land; Mining Operations; Habitat, and Biodiversity loss (National Climate Committee, 2013). In this study, coastal wetlands comprise salt marshes, mangroves and intertidal areas excluding other biogenic features like coral reefs. Lastly, the sector elements that form the social or lifestyle drivers of the coastal zone include Employment; Health; Poverty; Cultural and Religious Issues and; Population Dynamics (National Climate Committee, 2013). The workshop participants identified and ranked five vital elements with a momentous impact on the coastal zone of The Gambia. Overall, five elements were selected for the vulnerability assessment. The top two ranking sector elements that form the production drivers are; natural resource drivers and social or livelihood drivers. These elements are ranked from one (the highest rank) to five (lowest rank).

Table 3. 5 Elements of the sector that are affected by Climate Change.

Drivers of the Sector	Elements	Priority
Production Drivers	Land Use/Cover Change	1
	Infrastructure Development	2
	Population Dynamics	3
	Fisheries Productivity	4
Natural Resources Drivers	Mangroves and Wetland	1
	Fisheries	2
	Agricultural Land	3
	Mining, e.g, Sand, and ilmenite	4
	Habitat and Biodiversity	5
Social or Lifestyle Drivers	Employment	1
	Health	2
	Poverty	3
	Cultural and Religious Issues	4
	Population Dynamics	5

Source: Author’s Computation, 2017.

Step 5: Completion of the Framework of the Impact Risk Matrix

The experts in the workshop completed each cell of the impact risk matrix independent of each other. This was done by deliberations and the establishment of an accord on the anticipated impact of each climate change variable on each key sector element identified in step 4. The impact risk matrix framework comprises the climate change variables on the vertical axis while the key sector elements are on the horizontal axis.

Step 6: Description of the Climate Change Impacts

The participants of the workshop came to a verbal agreement and values were recorded on the anticipated impacts, whether positive or negative of each climate change variable for each principal element in the coastal zone. Varied literature sources were consulted to complement and substantiate the claims made from the expert judgement. This helps in reducing individual biases.

Most impacts of the climate change element on the key sector elements were negative. These descriptions were imputed into the risk matrix, independent of each other and without external influences.

Step 7: Determination of the Likely Category for the Impact

The likelihood of each climate change event happening was determined from one of the five categories either as almost certain, likely, possible, unlikely, or rare (Table 3.6). The likelihood of each event occurring was determined for each key sector element independent of each other in the impact risk matrix development. The frequency of occurrence of the climate change event is also considered as some will occur once in the year, while others may occur more than once in a year (AGO, 2006).

Table 3. 6 Likelihood Categories Describing the Occurrence of Each climate change Impact.

Rating	Recurrent Events	Single Event
Almost Certain	Could occur several times per year.	More likely than not. Probability greater than 50%.
Likely	May arise about once per year.	As likely as not. 50/50 chance of happening.
Possible	May arise once in 10 years.	Less likely than not but still appreciable. Probability less than 50% but still quite High.
Unlikely	May arise once in 10 years to 25 years.	Unlikely but not negligible. Probability Low but noticeably greater than zero.
Rare	Unlikely during the next 25 years.	Negligible. Probability very small, close to zero.

Step 8: Determination of the Consequence Category for the Impact

The consequences of the impact of the climate change risk are considered for each sector element independent of each other and range from ‘catastrophic’ to ‘minor’ impacts (AGO, 2006). The consequence category for the impact of the climate change variables on each key sector element was determined from one of the five categories as either catastrophic, severe, major, moderate or minor.

Step 9: Assigning Impact Risk in the Impact Risk Matrix

After the likelihood and the consequence category of the impacts were determined, Table 3.7 was used to combine the likelihood (step 7) and the consequences (step 8) categories in developing the level of impact risk. These values were documented for each significant sector element in completing the impact risk matrix. The overall impact of climate change for each key sector element of the coastal zone was derived by adding each cell in the specific column and communally arriving at unanimity on the overall impact (as either positive or negative). An overall impact matrix is developed and shown with shading of each cell with color codes. The darker the brown color, the greater the negative impact of the climate change variable on the key sector elements of the coastal zone of The Gambia.

Table 3. 7 Level of Impact (Impact Risk) for Describing Negative Consequences.

Likelihood	**Consequence**				
	Minor	**Moderate**	**Major**	**Severe**	**Catastrophic**
Rare	Low	Low	Low	Low	Low
Unlikely	Low	Low	Medium	Medium	Medium
Possible	Low	Medium	Medium	High	High
Likely	Low	Medium	High	High	Extreme
Almost Certain	Low	Medium	High	Extreme	Extreme

Source: AGO, 2006.

Step 10: Description of Adaptation Response

After developing the impact risk matrix (step 9), the climate change professionals used their expert judgment to identify key adaptation responses likely to reduce the risks associated with each climate change impact on each sector element. This was then validated with the review of pertinent literature. The climate change variables and their corresponding key sector elements of the impact risk matrix are then transferred to develop the vulnerability matrix.

Step 11: Determination of Adaptive Capacity

The level of adaptive capacity for each cell is then determined to complete the vulnerability matrix. Adaptive capacity in this study is defined as “the ability or potential of a system to adjust successfully to climate change, to moderate potential damages, to take advantage of opportunities, and/or to cope with the consequences” (IPCC, 2014). The coastal zone of The Gambia has a low adaptive capacity in addressing issues of climate change (NAPA, 2007; National Climate Committee, 2013), the reason for the low adaptive capacity option selected for all cells. A modified form of the AGO (2006) description of adaptive capacity is used: Low-this level of adaptive capacity implies it is very demanding and expensive for the coastal zone sector to actualize adaptation actions that are effective. Medium-this level of adaptive capacity identifies trouble and cost implications in actualizing change; however, it is conceivably possible within the study area. High-this level of adaptive capacity implies there is ease in adopting options placing adjustments as doable and useful.

Step 12: Assigning Level of Vulnerability

In assigning the level of vulnerability of each climate change variable on the key sector element, Table 3.8 is used to cross-reference the risk determined from the impact risk matrix with the adaptive capacity determined in step 11. These values were recorded and used in developing the Vulnerability Matrix. The Vulnerability Matrix describing the Adaptation responses for the key elements of the coastal zone of The Gambia is completed with shading of each cell with color codes (Table 4.13). The darker the pink color, the greater the vulnerability of the key sector elements to the climate change variables in the study area.

Table 3. 8 Level of Vulnerability Derived From Combining Impact Risk and Adaptive Capacity.

Impact	Low	Medium	High
Extreme	High	High	Moderate
High	High	Moderate	Moderate
Medium	Moderate	Moderate	Low
Low	Low	Low	Low

Source: AGO, 2006.

Step 13: Preparing a Risk or Vulnerability Statement

The Risk or Vulnerability statement was prepared to expose the nature and level of risk or vulnerability of the coastal zone to anticipated climate change impacts, the necessity for scheduling of the response and the nature of useful adaptation responses. This helps in revealing how the identified risks can be potentially addressed in the short to long-term.

3.2 Type and Sources of Data for the Study

The types and sources of data used for the study include:

1. **Department of Lands and Surveys:** the data type sourced from this department is the Contoured Topographic Map of the Coastal Zone of The Gambia for the year 1977.
   This data gives the conditions of the coast in the year 1977, from which measurements of the beach land is taken. The scale of this map used is 1: 10,000.
2. **Gambia Ports Authority:** the data type sourced from this department is:
   The bathymetric map of The Gambia for the year 1977.
   This shows the depths of the sea along the coastal strip and the River Gambia in the year 1977.
3. **Department of Water Resources:** The data sourced from this department include meteorological time series data from 1985- 2016 on Annual Rainfall and; Minimum and Maximum Temperature. Also, General Circulation Model (GCM) giving temperature climatic scenarios from 2010 to 2100 is sourced and used in the assessment of the impact of temperature on stabilized commercial shrimp yield and the productivity of river Gambia in support of fisheries resources.

This data is used in characterizing the trends of some climatic variables over a 30-year period in the study area.

4. **Gambia Bureau of Statistics:** The data sourced from this department include Gambia Population data for each coastal cell.

   This is used in the estimation of the population at risk to coastal flooding (Equation 3.8) in the study area.

5. **Department of Parks and Wildlife:** The data sourced from this department include the number and size of Protected Areas including Biodiversity and Wetland habitats in The Gambia. Further data on Historical and Cultural Assets along the coast is likewise sourced from this department.

   This is used to access the impacts of climate change on non-marketed goods and services in the study area.

6. **Department of Fisheries:** the data sourced from this department include Time series Data on Artisanal Fisheries Catch by Species from 1985- 2016.

   This is used to characterize the trends of artisanal fisheries catch by species (Equation 3.4) in the study area.

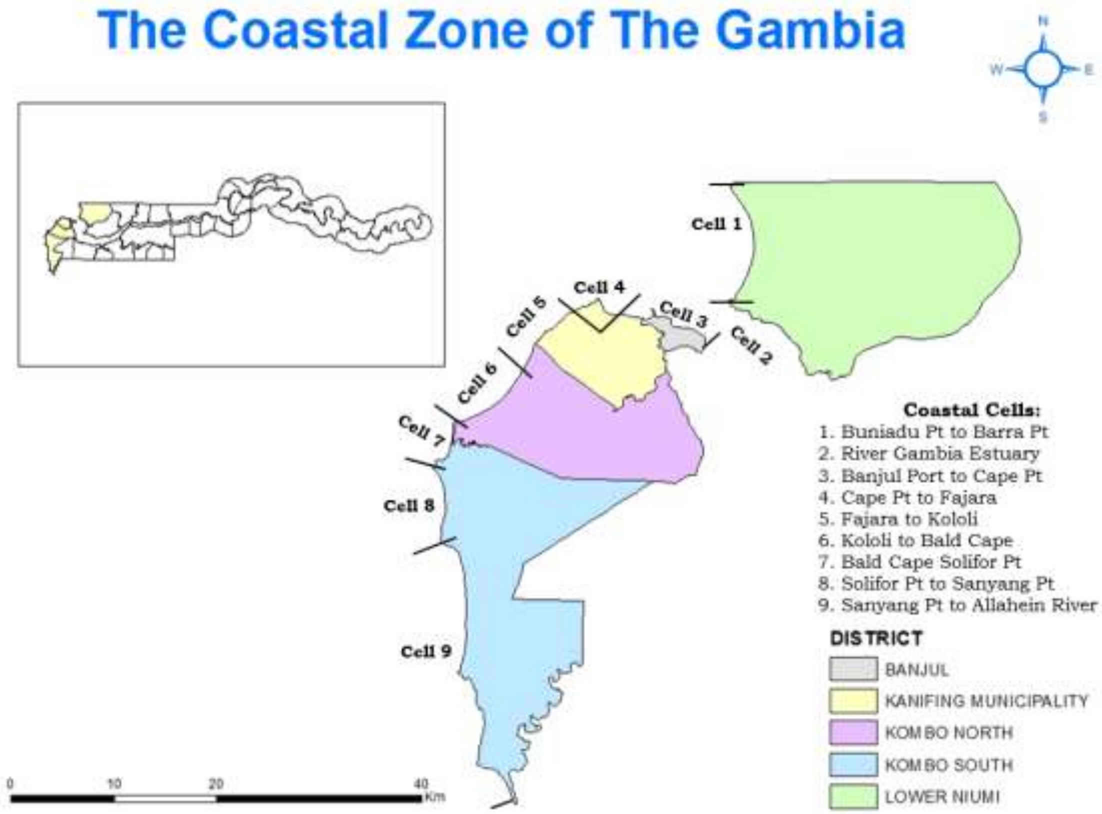
7. **Primary Data:** This will be sourced from measurements along each coastal cells in the study area to compute the coastal retreat due to SLR scenarios (Equation 3.3). Still photographic images will be taken in the fields to reveal the damages caused by coastal erosion.

3.3 Description of Study Area

The Gambia, lying between latitudes 13 and 14^0 North and longitudes 17 and 12^0 West, is the smallest nation on mainland African. It has an aggregate territory of around 11,300 km^2 of which 10,000 km^2 is land and 1,300 km^2 is water (National Climate Committee, 2013). The Gambia has an aggregate land limit of 740 km, which is surrounded by the Republic of Senegal on all three sides except for the western territories bounded by the Atlantic Ocean.

The Gambia has 80 km of open coastline circumscribing the Atlantic Ocean and over 200 km of protected coastline along The Gambia River. The open coast is described by low-inclination sandy shorelines. Broad mangrove frameworks of over 66,900 ha and mud flats overwhelm the shielded coast (Jallow *et al*., 1996). The waterfront zone of The Gambia out spreads 80 km from Buniadu Point and the Karenti Bolong in the north, to the mouth of the Allahein River in the south (Figure 3.3). The coastal zone of The Gambia is alienated into nine cells coastal based on geomorphological characteristics, (Figure 3.3). Each coastal cell is auxiliary divided into unique profiles.

Figure 3. 3 Map of The Gambia showing the Coastal Cells



Source: Author, 2017

3.4 Scope and Limitation of the Study

The study narrowed its scope principally to the impacts of SLR on socio-economic activities in the open and sheltered coasts of The Gambia. This covers an area of about 80km of open coast and over 200km of sheltered coast.

There are few challenges in studying the socioeconomic impacts of climate change on coastal zones. Most challenges from this study are principally due to financial and time constraints. It is assumed that potential inundation and coastal flooding in the study area will chiefly result from SLR, however, other incidence like landslide can similarly contribute to this observed phenomenon.

The study does not account for other socioeconomic impacts from saltwater intrusion, riverine flooding and changes in the levels of the water table. This study does not also access the impact of climate change on human health.

Concerning the population at risk to coastal flooding, it is assumed all the people will be affected equally with less emphasis on individual differences. However, individual variations exist due to variations in the level of exposure, sensitivity and adaptive capacities. With the estimation of the value of land to be lost to inundation, the study omitted estimations of the monetary values of properties like buildings and roads over the land area lost. Finally, the secondary data sourced from the departments had gaps that may contribute to the error margins captured in the trend analysis (Equations 3.1, 3.2, 3.4, and 3.5).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents results and discussions of the trends in annual rainfall, and minimum and maximum temperatures over the period 1986 - 2016. And the results of the estimation of future land losses due to inundation and coastal erosion are presented in this chapter. This chapter further presents the trend of annual artisanal and industrial fisheries catch over the period 1986- 2016. This chapter presents the results and discussions from the estimation of people at risk and the assessment of non-marketed goods and services at risk to coastal erosion. Finally, a vulnerability and risk matrix is developed for the coastal zone of The Gambia.

4.1 Trend of Annual Rainfall, Minimum and Maximum Temperature

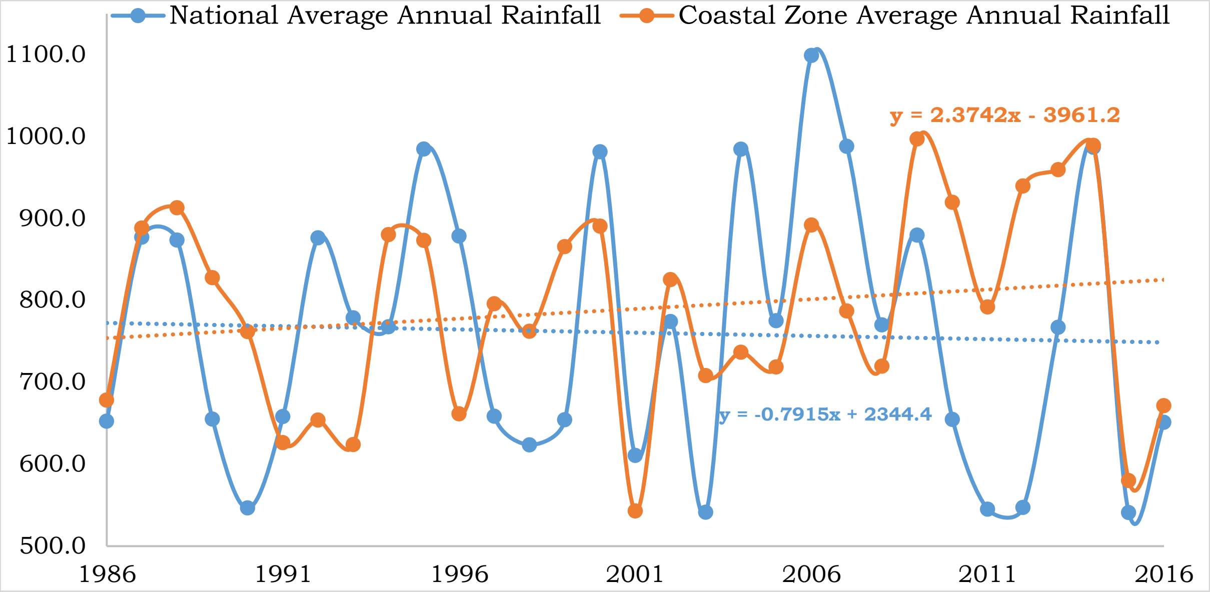
Figure 4.1 shows the trend of annual rainfall over the whole Gambia and the coastal zone of The Gambia from 1986 - 2016. From the graph, the annual rainfall over the past 30 years has been decreasing by 0.79mm annually over the whole country (Table 4.1)**.** These values were obtained from analysis of secondary data from all the 10 meteorological stations in The Gambia. This recorded value is much lower than the 3mm decrease in annual rainfall amount reported by Urquhart (2016) from 1950 to 2000 in The Gambia. This might result from improvements in meteorological equipment in recent times giving more precision in measurement relative to the past fifty years. The decrease in rainfall over the whole Gambia has become evident as the length of the rainy season is decreasing. The R-square value of 67% obtained from the linear regression model reveals that variations in the rainfall values around the mean are largely explained by 67% of its corresponding number of years (Table 4.1). The decrease in the annual rainfall over the study area agrees to the IPCC AR5 (2014) report with other studies supporting this assertion (Fatato, 2010; FAO, 2013; Yaffa and Durand, 2016; IFRC, 2009).

However, the 0.79mm annual decline in rainfall is much higher in value, in contrast to the 15% value observed over the West Africa sub-region (IPCC, 2014). Since The Gambia falls within the Sudano-Savanna zone of Africa it is characterized by relatively low rainfall amounts, likely leading to the observed variation. The Gambia is characterized by a short wet season and a long dry season with six to seven months without active rains (Jaiteh and Sarr, 2010). The observed trend in the study area may be because of the decrease in the number of rain-generating synoptic circumstances rather than a decline in the rainfall intensity received annually (Hutchinson, 1985). Although there has been a steady decrease in the rainfall received over the past 30 years, there have been observed increases in the last decade like; 2006, 2009, 2012 and 2014. The decrease in annual rainfall amounts has implications for small-scale farming, artisanal fisheries and livestock raising activities in The Gambia. With The Gambia, most agricultural activities are rainfall-dependent decrease in its amounts largely constrains farming activities with resultant impact on the nation's food security needs.

For instance, The Gambia experienced a meteorological drought in 2011; this led to crop failures with resultant food security issues. This informed the Government of Gambia's to officially declare a nation-wide drought emergency in the year 2012. The Lives and livelihood of people were affected as over 40% of the populace encountered hunger situations leading to humanitarian appeals as crops failed over one-third of production compared with 2010 (ActionAid, 2012; FAO, 2013). A decrease in the rainfall will cause the salinity levels of the ocean to increase; this in effect will influence the number and distribution of fisheries resources in The Gambia affecting artisanal fisheries catch. Reduced rainfall will also reduce the recharge of streams and other water reservoirs and cause drying of these streams and reservoirs. This will affect fisheries productivity because fish do not spawn in the main river; they spawn in streams and reservoirs.

Conversely, the annual trend of rainfall over the coastal zone of The Gambia revealed a positive trend of 0.237mm from 1986 – 2016 (Table 4.2). These values were obtained from analysis of secondary data from five meteorological stations (Banjul, Yundum, Sibanor, Kerewan and Jenoi) within the coastal zone of The Gambia. Relatively higher humidity and lower temperatures characterize coastal zones in comparison with areas hinterland (IPCC, 2014; Mohamed, 2010). This may have led to the observed positive trend in rainfall amount received annually. This trend has been observed in other coastal areas of Africa. For instance, Mohamed (2010) accounts that the Mediterranean coastal zone of Egypt experienced a consecutive increase in annual rainfall throughout the last 30 years with a 0.76 mm annual trend over the area. A similar positive trend of 3mm is observed in Rainfall over the western coastal zone of Egypt annually (Mohamed, 2010). Similarly, coastal areas like islands in the North- East part of Sri Lanka recorded a negative annual trend over the 30 year period under review (CRACP, 2011).

Figure 4. 1 Trend of Annual Rainfall from 1986- 2016 (Average Annual Rainfall in MM against number of years)



Source: Author, 2017

Table 4. 1 Estimated Growth Model of Average Annual Rainfall of The Gambia from 1986-2016

Variable	Coefficient	Standard Error	
Trend (T)	-0.79	1.21	
Intercept (C)	2344.41	1121.43	
R- Square	0.67	F-statistics	0.057
Adjusted R-Square	0.42	Prob (F-statistics)	0.813

Table 4. 2 Estimated Growth Model of Average Annual Rainfall of the coastal zone of The Gambia 1986- 2016

Variable	Coefficient	Standard Error	
Trend (T)	2.37	1.21	
Intercept (C)	-3961.21	1121.43	
R- Square	0.78	F-statistics	0.905
Adjusted R-Square	0.53	Prob (F-statistics)	0.349

Source: Author's Computation, 2017

Figure 4.2 shows the trend of annual minimum and maximum temperatures from 1986 - 2016 over the coastal zone of The Gambia. These values were obtained from analysis of secondary data from five meteorological stations (Banjul, Yundum, Sibanor, Kerewan and Jenoi) within the coastal zone of The Gambia. From the graph (Figure 4.2), annual minimum temperature over the past 30 years showed a decreasing trend rate of 0.025 ^{o}C each year over the study area (Table 4.3). The R-square value of 62% obtained from the linear regression model reveal variations in the annual minimum temperature values around the mean are largely explained by 62% of its corresponding annual values (Table 4.3).

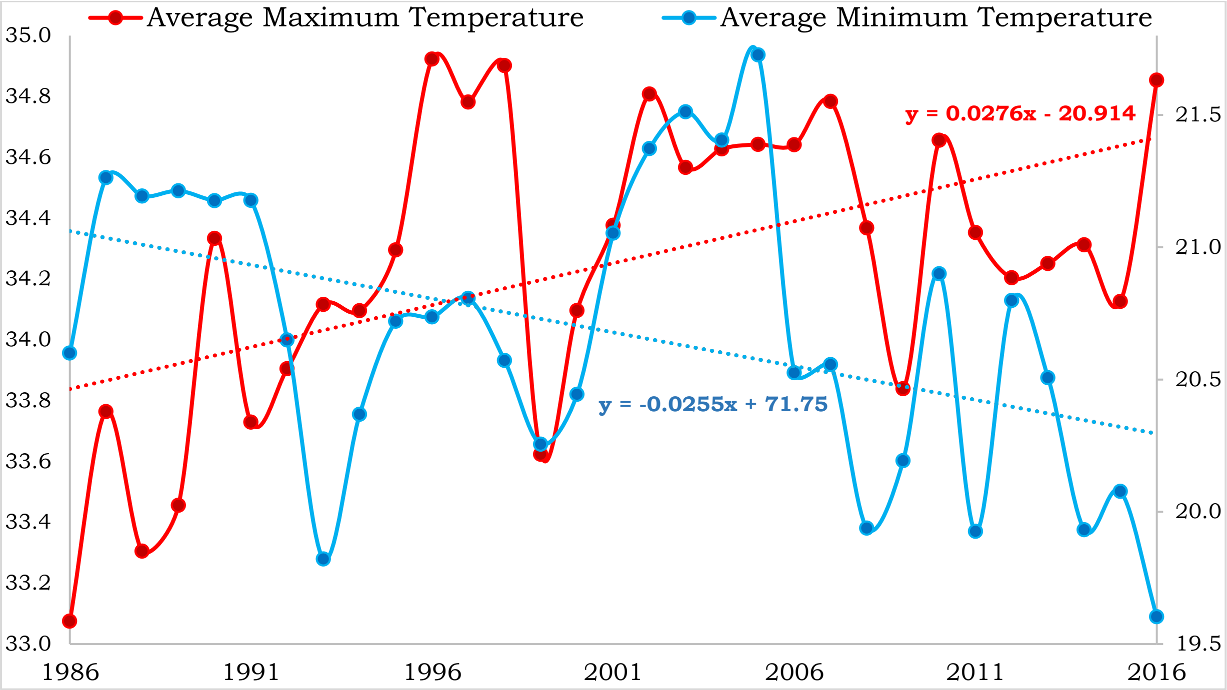
The yearly maximum temperature showed an increasing trend rate of 0.027 ^{o}C in the coastal zone of The Gambia over the past three decades (Table 4.4). The R-square value of 54% attained from the linear regression model reveal variations in the average maximum temperature values around the mean are largely explained by 54% of its corresponding yearly values (Table 4.4). The temperature value, 28.2^{o}C was the highest recorded since the year 1947 in the history of The Gambia, since then, the temperature records keep changing as the temperature rises over the coastal zone of The Gambia (Touray and Jammeh, 2013). This observed increase agrees with the IPCC (2014), Lima and Wethey (2012) studies. On one hand, granting there has been a steady decrease in the minimum temperature, the trend over the last decade reveals increases in the years; 2009, 2010, and 2014. With a steady increase in annual maximum temperature, there have been cases of variations to this trend over the years 2008, 2009, 2011, 2012 and 2015.

The observed increases in the annual maximum temperature and decreases in the minimum temperatures will have both positive and negative impacts on some crop species and biological diversity in the study area. On one hand, most crops have a temperature envelope within which they can thrive; one’s these limits are exceeded most fail due to excessive climatic stress. A cash crop like groundnut has a relatively large temperature envelop making it able to withstand large climatic stresses in comparison with crops like maize, cassava, rice and cowpea (MOA, 2015).

With increases in the maximum temperatures over the study area, the food security potentials in the coastal regions of The Gambia may be hurt pragmatic actions must be taken to enable farmers to adapt suitably. Increase in maximum temperatures will increase the rate of evapotranspiration, which in effects increases salinity levels of water bodies affecting the productivity of fisheries and land for agricultural purposes.

On the other hand, with decreasing minimum temperatures, artisanal fisheries catch in the coastal zone may increase, as cooler night temperatures enhance fishing activities and fish catches (NAPA, 2007; National Climate Committee, 2013).

Figure 4. 2 Trend of Average Annual Minimum and Maximum Temperatures (in ^{o}C) of the coastal zone from 1986- 2016.



Source: Author, 2017

Table 4. 3 Estimated Growth Model of Annual Minimum Temperature of the Coastal Zone of The Gambia from 1986- 2016

Variable	**Coefficient**	**Standard Error**	
Trend (T)	-0.026	0.01	
Intercept (C)	71.75	11.22	
R- Square	0.62	F-statistics	6.35
Adjusted R-Square	0.51	Prob (F-statistics)	0.001

Table 4. 4 Estimated Growth Model of Annual Maximum Temperature of the Coastal Zone of The Gambia from 1986- 2016

Variable	**Coefficient**	**Standard Error**	
Trend (T)	0.021	0.01	
Intercept (C)	-20.91	12.59	
R- Square	0.54	F-statistics	8.067
Adjusted R-Square	0.41	Prob (F-statistics)	0.002

Source: Author's Computation, 2017

4.2 Estimation of Past and Future Land Loss due to Inundation and Coastal Erosion

4.2.1 Land Loss Due to Inundation

Table 4.5 presents the land to be lost due to inundation from a 1m surge in sea levels. It also presents the economic value of land to be lost in Gambian Dalasi (D) and its dollar equivalence. The result of the study reveals that the total land to be lost to inundation is 12,460,000m^2 (1,246 ha) with a corresponding economic loss of ~US $788Million (D37, Billion) at the November, 2017 exchange rate of US $1 equivalent to about D47.45 (Table 4.5).

Detailed analysis of the bathymetric and topographic maps of The Gambia reveals coastal cell 7 (from Bald Cape to Solifor Point) has the largest area falling below the 1m contour line (2,790,000 m^2) has the highest risk of inundation with an economic loss of US $176.4 Million. This is followed by coastal cell 3 (Banjul to Cape Point) and Coastal cell 9 (from Sanyang Point to Allahein River); this corresponds to a land area of 2,240,000 m^2 and 2,160,000 m^2 respectively. The coastal cell 9, for instance, is an area where legal and illegal sand mining operations take place. With the rate of land loss due to this anthropogenic forcing, it is expected that the rates estimated from this analysis may occur at a faster rate than anticipated. However, Coastal cell 5 (from Fajara to Kololi) has most of its areas above the 1m sea level contour line with the least land loss to inundation owing to surge in ocean levels. This area houses the highest point on the coast, 11 meters above mean sea level (Jallow and Barrow, 1997). Cliffs and higher grounds 1m above mean sea levels characterize this area accounting for the least rate of land loss from inundation. The description of each coastal cell with pictorial proves showing structures at risk to threats from SLR are given further below.

Table 4. 5 Land loss due to Inundation from 1m Sea Level Rise

Coastal Cells	**(m^2)**	**(million Dalasi)**	**(USD)**
1 (Buniadu- Barra Point)	810,000	2,430	51,211,802
2 (River Gambia Estuary)	-	-	-
3 (Banjul Port- Cape Point)	2,240,000	6,720	141,622,760
4 (Cape Point- Fajara)	1,000,000	3,000	63,224,447
5 (Fajara- Kololi)	620,000	1,860	39,199,157
6 (Kololi- Bald Cape)	880,000	2,640	55,637,513
7 (Bald Cape- Solifor Point)	2,790,000	8,370	176,396,207
8 (Solifor Point- Sanyang Point)	1,960,000	5,880	123,919,916
9 (Sanyang Point- Allahein River)	2,160,000	6,480	136,564,805
Total	**12,460,000**	**37,380**	**787,776,607**

Source: Author's Computation, 2017

The Exchange Rate used was the US \$1 ≡ D47.45, accessed from www.cbg.gm on 1st November, 2017. The monetary values of land in the Coastal zone were valued at D3, 000 per square metre (m^2) of land in the coastal zone sourced from the Department of Lands and Surveys, Gambia.

4.2.1.1 Buniadu Point to Barra Point (Coastal Cell 1)

This coastal cell is a 12km area ranging from Buniadu Point, the Senegal boundary to the rocky cliffs at Barra Point and to the ferry terminal. The land in most part of this coastal cell is underdeveloped and under relatively low agriculture pressure. There are no noteworthy financial, social or cultural resources in danger aside few eco-resort developments along the coast. The wetland and town of Kajata with its populace are far away from the drift with less risk of coastal erosion. However, the full length of the shoreline is experiencing slight disintegration from coastal erosion (Figures 4.3 and 4.4), with significant disintegration at Buniadu Point as the shoreline realigns, given changing waterfront forms (Coates & Manneh, 2014).

Figure 4. 3 Some buildings at risk to coastal erosion

Figure 4. 4 Some buildings at risk to coastal erosion

Source: Author, 2017

4.2.1.2 River Gambia Estuary (Coastal Cell 2)

The river Gambia is approximately 11 km wide-ranging between Cape St. Mary and Buniadu Point and around 4 km wide between Banjul and Barra. It contracts down to almost 1.5 km at Carrol's Wharf. This river Gambia is flanked by an extensive mangrove system and mud flats providing substantial breeding and spawning support systems for aquatic species like fishes and shrimps. The dense mangrove systems also support the growth of oysters while the nearby low marshy lands are further used for rice cultivation; all serving as a means of livelihood to local community members.

4.2.1.3 Banjul Port to Cape Point (Coastal Cell 3)

This coastal cell has a 13.5km stretch of land ranging from Banjul, the capital city of The Gambia to the Cape Point. Few people reside in this area as a considerable lot of the public and other institution workers ply this area daily for work engagements or as a transit point to other parts of the country. Some significant structures of economic, social or cultural benefit include the President’s State House, The Gambia National Assembly, Ministry buildings, the national port, the Banjul Christian cemetery, Gambia National Museum, Banjul fish-landing site, hotels, among other structures. The Ministry of foreign affairs building under construction is also located less than 300m from the coastline. The lowest regions are as of now shielded from tidal flooding by a bund worked through the mangrove wetlands, yet they are liable to general water flooding amid summer storms because of poor drainage.

The beach nourishment exercise in 2004 was a short-term adaptation measure taken to protect structures like the highway and other more valuable shorefront properties (Haskoning, 2004). Other measures taken was the construction of the groyne system from the trunks of royal palm trees (Figure 4.5). The 2004 beach nourishment has also seen success as the T head groyne built immediately east of the Bakau fish landing beach which has supported in sustaining a high tide beach along its west side (Figure 4.8). This notwithstanding, threats of destruction are being posed to infrastructure and businesses along the coast in recent times. For instance the destruction of the Old Wharf at the Banjul port due to coastal erosion and wave action and other structures exposed to coastal erosion (Figures 4.6 and 4.7).

Figure 4. 5 Groyne system destroyed by coastal erosion and wave action

Figure 4. 6 Old Wharf destroyed by coastal erosion and wave action

Source: Author, 2017

Figure 4. 7 Some structures at Risk to Coastal Erosion

Figure 4. 8 The ‘T’ Head Groyne Providing Sustenance of the Beach

Source: Author, 2017

4.2.1.4 Cape Point to Fajara (Coastal Cell 4)

The coastal cell that stretches over a distance of 3.5km is characterized by feebly dissolving bluffs and restricted pocket shorelines running west from Cape Point to the Ocean View Apartment complex. The upper layer of sandstone is liable to disintegration by stormwater spillover, and, where uncovered, the underlayer is liable to disintegration by wave action. The precipices front a line of high esteem private properties, overseas organizations, consulates, some lower and mid-esteem tourism offices, the Bakau fish-landing site, among others. Besides threats of coastal erosion, this area is also prone to frequent flooding from a stream opening in this coastal cell (Figure 4.9). There are other considerable damages to hotels, residential buildings along the shoreline of this coastal cell (Figures 4.11 and 4.12) besides the overtopping of a sea-wall constructed in the 1980s (Figure 4.10).

Figure 4. 9 The Opening of the Stream along the Coastal Cell

Figure 4. 10 Seawall Over-topped by SLR and coastal erosion

Source: Author, 2017

Figure 4. 11 Some Structures at Risk to Coastal Erosion

Source: Author, 2017

Figure 4. 12 Some Structures at Risk to Coastal Erosion

Source: Author, 2017

4.2.1.5 Kotu Point to Kololi Point (Coastal Cell 5)

The shoreline of this coastal cell has a total span of 2.5km. It is wide and chiefly uninterrupted towards the north while the southern part is narrow and mostly overdeveloped. Tourist-related infrastructure and the demarcated Tourist Development Area (TDA) mainly characterize this area. The area is also prone to frequent river flooding from the ingress of the Kotu creek beside coastal erosion. Farmland along Kotu Creek will probably experience the ill effects of expanded immersion and saline interruption, lessening profitability in these coastal areas. Although there are embankments along some part of the coastline (Figure 4.14), other areas are still exposed and likely to be at risk to coastal erosion in the short-term (Figure 4.13).

Figure 4. 13 Some Structures at Risk to Coastal Erosion

Source: Author, 2017

Figure 4. 14 Some Structures at Risk to Coastal Erosion

Source: Author, 2017

4.2.1.6 Kololi Point to Bald Cape (Coastal Cell 6)

This coastal cell spans 11km from Kololi point through Senegambia to Bald Cape. Many hotels, resorts and tourism infrastructure characterize this area similar to coastal cell 5. This area benefited from the beach nourishment in 2004 to safeguard key structures along the coast. During the beach nourishment, 1,000,000 m^3 of sand was dredged from neighbouring Kololi Point with a placed 10 – 15 years life expectancy. Bijl (2011) accounts this life expectancy of the beach nourishment was not reached as the beach returned to its original state after about 5 years leading to considerable regrets as approximately US $8,000,000 was spent on this project. Without a positive administrative design, the shoreline will keep on deteriorating (Figures 4.15 and 16). This may force hotel and resort owners to undertake short-term and small-scale unsustainable interventions in safeguarding the shoreline in anticipation of attracting more tourist and vacationers.

Figure 4. 15 Coastal Erosion along the Cell

Source: Author, 2017

Figure 4. 16 Eroding Cliffs along the coastline

Source: Author, 2017

4.2.1.7 Bald Cape to Solifor Point (Coastal Cell 7)

This cell spans 4.5km from the Tanji angle-landing site in the South with its broad sand shoreline to Solifor Point characteristic by low laterite precipices. This area has few land used for agricultural purposes with several wind turbines for energy generation. There are few structures at risk of coastal erosion with the fish-landing site the most predominant of them (Figures 4.17 and 4.18).

Figure 4. 17 Some Socio-economic activities at Tanji fish-landing site

Figure 4. 18 Other Socio-economic activities at Tanji fish-landing site

Source: Author, 2017

4.2.1.8 Solifor Point to Sanyang Point (Coastal Cell 8)

This coastal cell extends 7.5km from Solifor point to Sanyang point where there are relatively low tourism and infrastructure developments. Generally, properties are well distant from the shoreline with less threat of destruction from coastal erosion in the short-term.

4.2.1.9 Sanyang Point to Allahein River (Coastal Cell 9)

This coastal cell extends over a distance of 24km from Sanyang point to the Allahein River. South of Sanyang Point an expansive fish-landing site is supported by tidal ponds and mangrove wetlands at the convoluted mouth of the River Benifet (Figures 4.19 and 4.20). Past the stream mouth, the shoreline is undeveloped and sponsored by hills similarly to the headland at Bator Sateh where there are another extensive fish-landing site, vacationer lodges, and mangrove wetland. Most hotels and eco-resorts like the Sandele Eco-retreat, Nemasu Eco-lodge along the coast are distant from the shoreline posing less risk to the threats of coastal erosion. The sand mining operations in this area may likely expose this area to potential threats from SLR if a more sustainable approach is not adopted as most land resources are been lost at a rate alarming rate (Figure 4.21). This was realized during field visits to this site.

Figure 4. 19 Tidal Pond created after high tide

Source: Author, 2017

Figure 4. 20 Tidal Pond and Mangrove wetland around River Benifet

Source: NEA, 2016

Figure 4. 21 Some Sand-mining activities in Karthong

Source: NEA, 2016

4.2.2 Land Loss Due to Coastal Erosion

Table 4.6 gives the results of using the Bruun rule to estimate the rate of coastal erosion along the coastline of The Gambia owing to a one-meter SLR scenario. This indicates the rate at which the estimated loss of land due to inundation will occur over the coastal zone of The Gambia by the period of a century. The rate of coastal erosion along the entire coastline of The Gambia is estimated to be ~6m per year. The areas along Sanyang Point to the Allahein River (coastal cell 9) is estimated to have the highest rate of coastal erosion in the study area followed by areas covering Solifor Point to Sanyang Point (coastal cell 8); this corresponds to 2 and 1m per year. The areas from Banjul Port to Cape Point (coastal cell 3) recorded the least rate of coastal erosion of 0.14m per year followed by the 15m per year value recorded for areas falling within Buniadu to Barra Point (coastal cell 1).

Table 4. 6 Application of the Bruun Rule to project the rate of coastal erosion along the coastal zone of The Gambia due to Sea level rise.

Coastal Cell	Overfill Ratio, G	SLR Scenario, S (m)	Active Profile Width, W (m)	Dune or Cliff Height, H (m)	Depth of Closure, d* (m)	Retreat, R=G×S[W/(H+ d*)], (m)
1	1.0	1.0	100	1.2	5.3	15
2	-	-	-	-	-	-
3	1.0	1.0	180	1.7	10.7	14
4	1.0	1.0	560	2.8	3.7	86
5	1.0	1.0	400	1.6	6.3	50
6	1.0	1.0	200	2.4	5.4	25
7	1.0	1.0	130	0.7	0.7	92
8	1.0	1.0	210	1.0	1.1	100
9	1.0	1.0	680	1.5	1.6	219
Total						**601**

Source: Author’s Computation, 2017

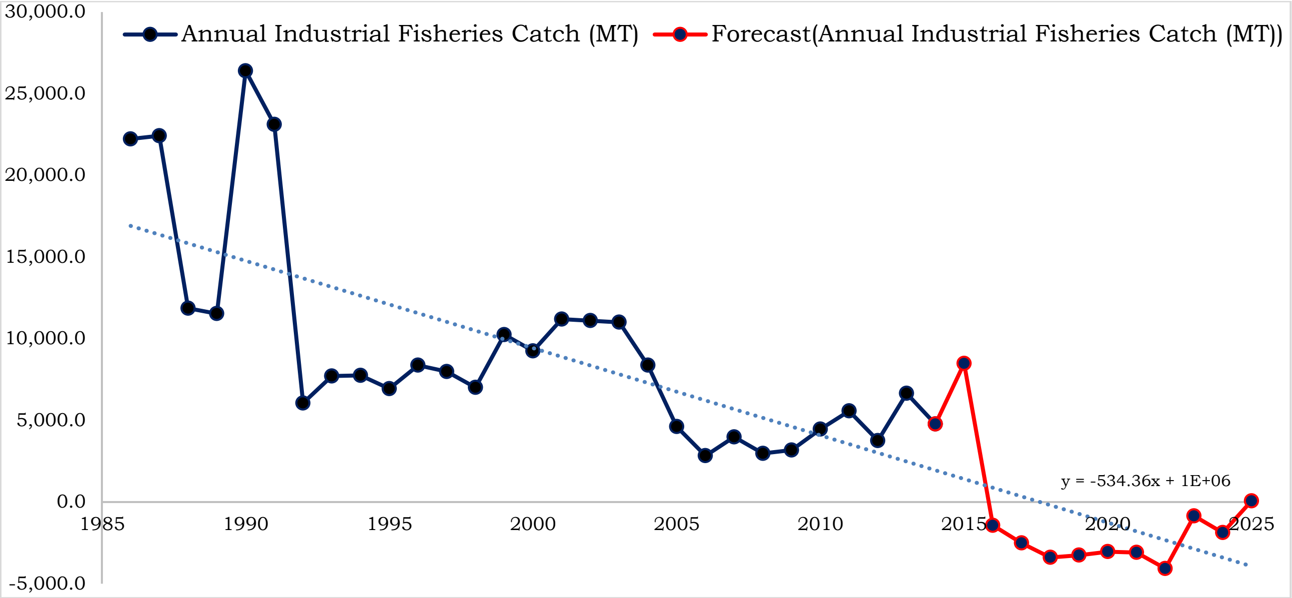
4.3 Trend of Annual Artisanal and Industrial Fisheries Catch

Figure 4.22 shows the trend of annual industrial fisheries catch from 1986- 2014 and its forecast values from 2015- 2025 over the study area. From the graph (Figure 4.22), annual industrial fisheries catch over the past three decades shows a decreasing trend at an approximate rate of 534 MT annually in the study area (Table 4.7). The R-square value of 51% obtained from the linear regression model reveal that variations in the annual industrial fisheries catch values around the mean are largely explained by 51% of its corresponding annual values (Table 4.7).

Among the factors that may have contributed to the decrease in the annual industrial fisheries catch are; the rigorous process vessels must go through to obtain and renew their fishing licence. And other industrial fishing vessels are engaged in some practices like under-declaration of fisheries resources caught at various landing sites. There has also been a ban on beach seine net and importation and use of monofilament nets, which are non-biodegradable; all these measures are aimed towards sustainable fishing (GoG, 2010). Although annual industrial fisheries catch experienced a decreasing trend, over the last decade there has been observed increases in some years like; 2001, 2007, 2009, 2010, 2011, and 2013. In some years, tax incentives were increased besides the facilitation of acquiring and renewing the fishing licenses (GoG, 2010). The Government of The Gambia placed a ban on industrial fishing over the years 2015 through 2016, this accounts for the lapse in the data on these years.

With 95% confidence interval and a Mean Absolute Percent Error (MAPE) of 3%, the study predicts that the observed decline in the fisheries resources from the industrial catches will persist to the year 2022 and then there will be a sturdy increase to the year 2025. There may be a decrease from 4,770 MT in 2014 to 66.7 MT by the year 2025 if urgent actions are not engaged to reverse this predicted trend.

Figure 4. 22 Trend of Annual Industrial Fisheries Catch (in MT) from 1986- 2014 (number of years) and Forecast values from 2015- 2025



Source: Author, 2017

Table 4. 7 Estimated Growth Model of Annual Industrial Fisheries Catch from 1986- 2014

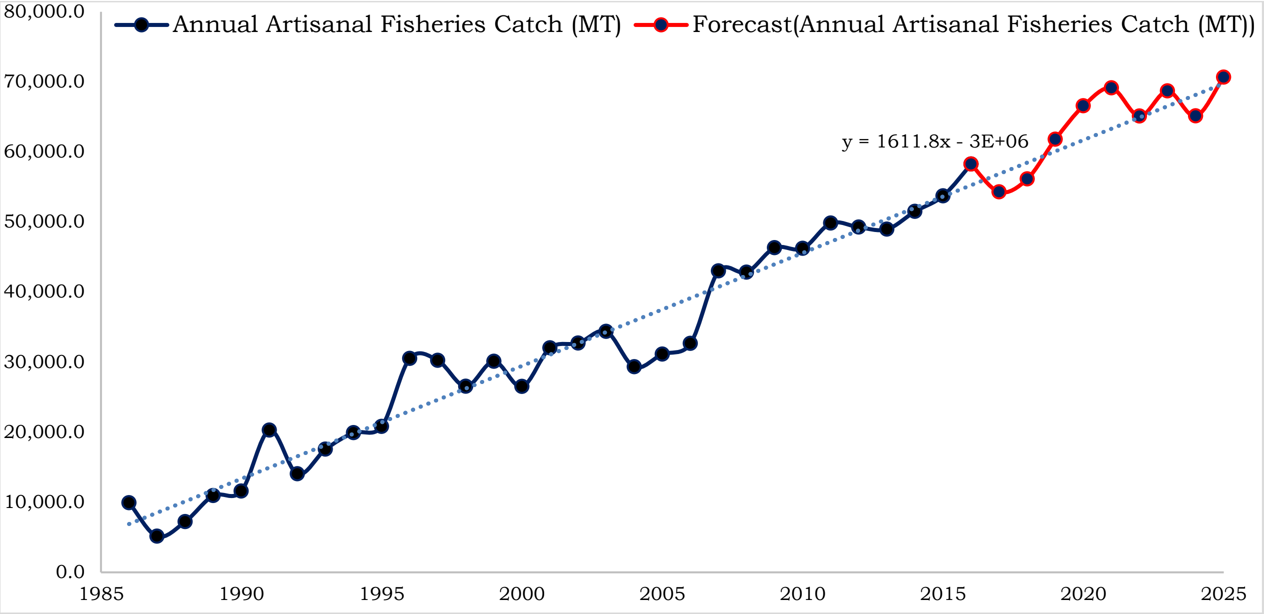
Variable	Coefficient	Standard Error
Trend (T)	-534.36	101.02
Intercept (C)	1,078,142.76	202034.46
R- Square	0.51	F-statistics 27.98
Adjusted R-Square	0.49	Prob(F-statistics) 0.0001

Source: Author's Computation, 2017

Figure 4.23 shows the trends of annual artisanal fisheries catch from 1986- 2016 and its forecast values from 2017- 2025 over the study area. From the graph (Figure 4.23), annual artisanal fisheries catch over the past three decades has been increasing at an approximate rate of 1,611 MT per annum in the study area (Table 4.8). This trend reveals that the fisheries resources in the study area are under-utilized. The R-square value of 95% obtained from the linear regression model revealed that the variations in the annual artisanal fisheries catch values around the mean are largely explained by 95% of its corresponding yearly values (Table 4.8).

Although annual artisanal fisheries catch experienced an increasing trend, over the last decade there has been observed decreases in some years like; 2008, 2010, 2012, and 2013. With 95% confidence interval and a MAPE of 6%, it is predicted that the observed increase in artisanal fisheries catch will persist to the year 2025. The 2016 value of 58,261.6 MT is predicted to increase to 70,651.8 MT by 2025. By the year 2020, the study predicts that the artisanal fisheries catch will increase by 14% (66,563.2 MT) paralleled to the 58,261.6 MT in 2016.

Figure 4. 23 Trend of Annual Artisanal Fisheries Catch (MT) from 1986- 2016 (number of years) and Forecast values from 2017- 2025



Source: Author, 2017

Table 4. 8 Estimated Growth Model of Annual Artisanal Fisheries Catch from 1986- 2016

Variable	**Coefficient**	**Standard Error**
Trend (T)	1,611.82	67.39
Intercept (C)	-3,194,187.11	134,851.79
R- Square	0.95	F-statistics 572.04
Adjusted R-Square	0.94	Prob(F-statistics) 0.0000

Source: Author's Computation, 2017

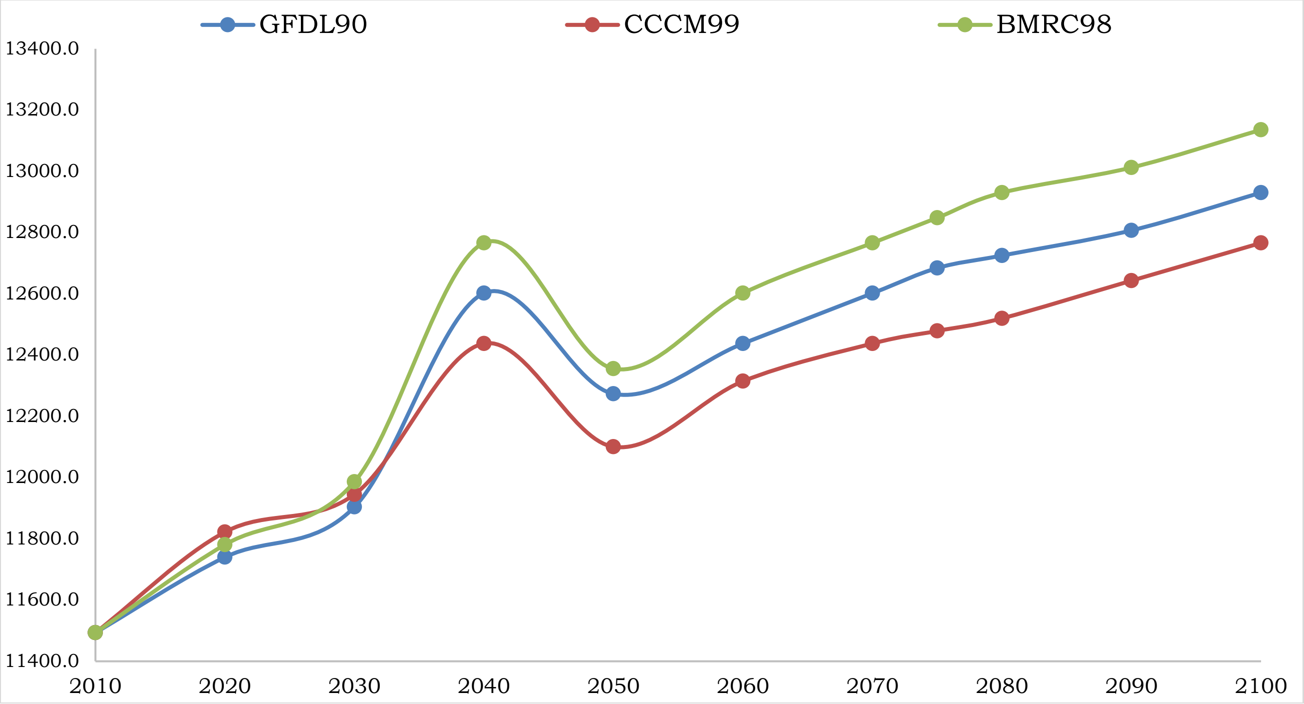
4.3.1 Assessing the Effects of Temperature on Productivity of Riverine Fisheries Resources

Figure 4.24 shows the annual productivity of the river Gambia to support riverine fisheries as estimated for mean annual water temperatures. The baseline (1981- 2010) productivity of the River Gambia based on a temperature of 28.0^0C is estimated at 11,493.5 MT/km. In synopsis, the results of the analysis revealed an increase in this value by 9% in 2060 and a sturdy increase of 13% by the year 2100 under the varied GCM scenarios. Randall *et al*., (1995) work supports the result of the study, showing a positive trend in the productivity of rivers to support fisheries resources in contrast with lakes. And Acreman (2010) support this result showing a positive trend in the productivity of the Senegal River to support fisheries resources. Predictions by Rutherford and Houde (1993) reveals a positive trend in the productivity of rivers regarding fisheries resources, supporting the result.

In elucidation, by the year 2020, it is predicted that the productivity of the river to support fisheries will increase by a maximum value of 3% (CCCM199) with at least 2% increase (BMRC98 and GFDL90). By the year 2030, it is predicted that productivity will increase by a maximum value of 4% (CCCM199 and BMRC98) with a minimum increase of 3% (GFDL90). Through the year 2040, it is predicted that productivity of the river will increase by a maximum value of 9% (BMRC98) with a minimum increase of 5% (GFDL90). By the year 2050, it is predicted that productivity will increase by a maximum value of 7% (BMRC98) with a minimum decrease of -1% (CCCM199). By the year 2060, it is anticipated that productivity will rise by a maximum value of 9% (BMRC98) with a minimum increase of 7% (CCCM199).

Through the year 2070, it is forecasted that productivity will surge by a maximum value of 10% (BMRC98) with a minimum increase of 8% (CCCM199). By the year 2075, it is predicted that productivity will increase by a maximum value of 11% (BMRC98) with a minimum increase of 8% (CCCM199). Through the year 2080, it is predicted that productivity will increase by a maximum value of 11% (BMRC98) with a minimum increase of 8% (CCCM199). By the year 2090, it is predicted that productivity will increase by a maximum value of 12% (BMRC98) with a minimum increase of 9% (CCCM199). Finally, by the year 2100, it is predicted that productivity will increase by a maximum of 13% (BMRC98) with a minimum increase of 10% (CCCM199).

Figure 4. 24 Annual Productivity of Fisheries in the River Gambia (MT/Km) against Scenarios (Years)



Source: Author, 2017

4.3.2 Assessment of the Effects of Temperature Changes on Shrimp Yield

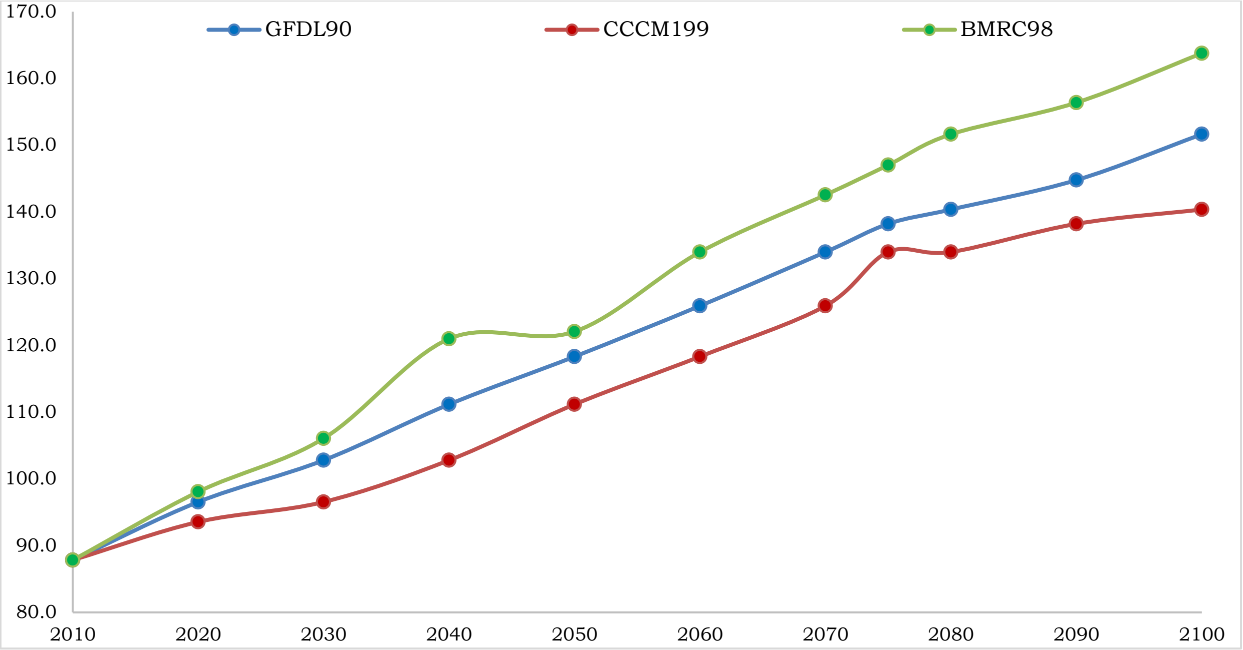
Figure 4.25 shows the stabilized commercial shrimp yield (Kg/Ha) of the river Gambia as estimated with the mean air temperature under the GCM varied scenarios. The baseline (1981-2010) Stabilized Commercial Shrimp Yield (SCSY) of the River Gambia based on a temperature of 28.0^{0}C is estimated at 87.8Kg/Ha. In synopsis, the results of the analysis revealed an increase in this value by 34% in 2060 and a sturdy increase of 46% by the year 2100 under the varied GCM scenarios. This result is supported by Turner (1977) and reveals a positive trend in the current and future projections of Penaeid shrimp yield over varied mean air temperature.

In elucidation, by the year 2020, it is predicted that SCSY of the river Gambia will increase by a maximum value of 10% (BMRC98) with a minimum increase of 6% (CCCM199). By the year 2030, it is anticipated that SCSY of the river Gambia will increase by a maximum value of 17% (BMRC98) with a minimum increase of 9% (CCCM199). By the year 2040, it is predicted that SCSY of the river Gambia will increase by a maximum value of 34% (BMRC98) with a minimum increase of 15% (CCCM199). By the year 2050, it is foreseen that SCSY of the river Gambia will increase by a maximum value of 28% (BMRC98) with a minimum increase of 21% (CCCM199). By the year 2060, it is anticipated that SCSY of the river Gambia will increase by a maximum value of 34% (BMRC98) with a minimum increase of 26% (CCCM199).

By the year 2070, it is predicted that SCSY of the river Gambia will increase by a maximum value of 38% (BMRC98) with a minimum increase of 30% (CCCM199). By the year 2075, it is predicted that SCSY of the river Gambia will increase by a maximum value of 40% (BMRC98) with a minimum increase of 34% (CCCM199). By the year 2080, it is predicted that SCSY of the river Gambia will increase by a maximum value of 35% (BMRC98) with a minimum increase of 30% (CCCM199). By the year 2090, it is predicted that SCSY of the river Gambia will increase by a maximum value of 44% (BMRC98) with a minimum increase of 36% (CCCM199). Finally, by the year 2100, it is predicted that SCSY of the river Gambia will rise by a maximum value of 46% (BMRC98) with a minimum increase of 37% (CCCM199).

The observed positive trend in stabilized commercial shrimp yield under varied temperature may be because of the inclination and flexibility of shrimps to warm waters. Shrimps are likewise fit for living amid the chilly season in cool waters not dipping under 18^0C (National Climate Committee, 2013). And their feeding activity is primarily diurnal and relocation is moulded by temperature varieties of its natural surroundings with their spawning period mainly in the rainy season. The post-hatchling phase of shrimps floats into the stream through tides into the mangroves amid the blustery season and the adolescent shrimp relocate to the fundamental channel of the waterway where it forms into sub-grown-ups and moves to the estuary where saltiness is low. This is characteristic of The Gambia sheltered coast increasing its suitability for commercial shrimp production in the river Gambia.

Figure 4. 25 Stabilized Commercial Shrimp Yield (Kg/Ha) against Scenarios (Years)



Source: Author, 2017

4.4 Population at Risk of Coastal Flooding

Table 4.9 shows the number of people at risk to coastal flooding events in the study area. The results show a total of 15,560 people at risk to flooding events per square kilometre. The coastal cell 6 (Kololi- Bald Cape) is recorded to have the largest number of people at risk to flooding followed by coastal cell 3 (Banjul Port- Cape Point); this corresponds to 6,249 and 2,955 respectively. The coastal cell with the least number of people exposed to flooding incidence because of a surge in sea levels is cell 1 (Buniadu- Barra Point) with about 738 people per square km of land area.

Table 4. 9 Estimation of Population at Risk to Coastal Flooding Events

Coastal Cell	**Population Density (Number per Km^2)**	**Probability of Coastal Flooding Event**	**Population at Risk of Coastal Flooding**
1 (Buniadu- Barra Point)	2,461	0.3	738
2 (River Gambia Estuary)	-	-	-
3 (Banjul Port- Cape Point)	5,768	0.7	2,955
4 (Cape Point- Fajara)	2,933	0.5	1,467
5 (Fajara- Kololi)	4,634	0.2	927
6 (Kololi- Bald Cape)	15,623	0.4	6,249
7 (Bald Cape- Solifor Point)	1,148	0.9	1,033
8 (Solifor Point- Sanyang Point)	1,461	0.7	1,023
9 (Sanyang Point- Allahein River)	1,460	0.8	1,168
Total			**15,560**

4.5 Vulnerability and Impact Risk Matrix for the Coastal Zone of The Gambia

Table 4. 10 Impact Risk Matrix

Climate Variable	**Coastal Zone Sector Elements**				
	Land Use/ Cover Change	**Infrastructural Development**	**Mangroves and Wetlands**	**Employment**	**Health**
Elevated CO_2 Levels Level of Confidence: *Virtually Certain*	Impact: *Negative* Likelihood: *Likely* Consequence: *Major* Impact Risk: *High*	Impact: *Negative* Likelihood: *Possible* Consequence: *Moderate* Impact Risk: *Medium*	Impact: *Negative* Likelihood: *Likely* Consequence: *Major* Impact Risk: *High*	Impact: *Negative* Likelihood: *Possible* Consequence: *Minor* Impact Risk: *Low*	Impact: *Negative* Likelihood: *Possible* Consequence: *Minor* Impact Risk: *Low*
Increased Flood Severity Level of Confidence: *Virtually Certain*	Impact: *Negative* Likelihood: *Likely* Consequence: *Major* Impact Risk: *High*	Impact: *Negative* Likelihood: *Likely* Consequence: *Major* Impact Risk: *High*	Impact: *Negative* Likelihood: *Possible* Consequence: *Minor* Impact Risk: *Low*	Impact: *Negative* Likelihood: *Possible* Consequence: *Major* Impact Risk: *Medium*	Impact: *Negative* Likelihood: *Likely* Consequence: *Major* Impact Risk: *High*
Sea Level Rise Level of Confidence: *Extremely Likely*	Impact: *Negative* Likelihood: *Likely* Consequence: *Moderate* Impact Risk: *Medium*	Impact: *Negative* Likelihood: *Likely* Consequence: *Major* Impact Risk: *High*	Impact: *Negative* Likelihood: *Likely* Consequence: *Major* Impact Risk: *High*	Impact: *Negative* Likelihood: *Possible* Consequence: *Moderate* Impact Risk: *Medium*	Impact: *Negative* Likelihood: *Unlikely* Consequence: *Minor* Impact Risk: *Low*
Increased Temperature Level of Confidence: *Very Likely*	Impact: *Negative* Likelihood: *Likely* Consequence: *Major* Impact Risk: *High*	Impact: *Negative* Likelihood: *Unlikely* Consequence: *Minor* Impact Risk: *Low*	Impact: *Negative* Likelihood: *Likely* Consequence: *Major* Impact Risk: *High*	Impact: *Negative* Likelihood: *Unlikely* Consequence: *Minor* Impact Risk: *Low*	Impact: *Negative* Likelihood: *Likely* Consequence: *Major* Impact Risk: *High*
Reduced Rainfall frequency and Intensity Level of Confidence: *Very Likely*	Impact: *Negative* Likelihood: *Possible* Consequence: *Moderate* Impact Risk: *Medium*	Impact: *Negative* Likelihood: *Rare* Consequence: *Minor* Impact Risk: *Low*	Impact: *Negative* Likelihood: *Likely* Consequence: *Major* Impact Risk: *High*	Impact: *Negative* Likelihood: *Unlikely* Consequence: *Minor* Impact Risk: *Low*	Impact: *Negative* Likelihood: *Likely* Consequence: *Moderate* Impact Risk: *Medium*
Overall Risk Estimate	**High**	**High**	**High**	**Low**	**High**

Table 4. 11 Impact Risk Matrix describing the impacts of the key elements of the coastal zone of The Gambia to Climate Change

Climate Change Variables	Land Use/ Cover Change	Infrastructural Development	Mangroves and Wetlands	Employment	Health
Elevated CO_2 Levels	Major Reduction in land use/cover changes (Afrane *et al*, 2005; Chase *et al*., 2001; Lawrence & Vandecar, 2015; *****)	Reduction in Infrastructure Development (Ribeiro et al, 2007; *****)	Major increase in algal blooms affecting wetland and mangrove systems (Lawrence & Vandecar, 2015; McKee, 2006; *****)	Slight negative impact on Employment (Olsen, 2009; Vergara *et al*., 2013; Wei & Chatterjee, 2013; *****)	Major Reduction in Health Issues (Lawrence & Vandecar, 2015; WHO, 1996; Zhong *et al*., 2017; *****)
Increased Flood Severity	Severe impact on land use/cover changes (Brebante *et al*, 2017; Luce, 2005; Mutiibwa *et al*., 2014; Ometto *et al*., 2013; Schultz,1995; *****)	Major damage to facilities of economic, social or cultural importance due to floods (Deshmukh *et al*, 2011; Project *et al*.,2011; *****)	Slight changes in mangroves and wetland ecosystem (Alongi, 2008; MESCAL, 2013; Short *et al*., 2016; *****)	Major decrease in productivity of employees (Koen, 2014; MESCAL, 2013; Wei & Chatterjee, 2013; *****)	Severe health challenges like injuries, death (Luber, 2011; Vellinga, P. 2015; *****)
Sea Level Rise	Major Reduction in land use / Land cover changes (Balukkarasu *et al*., 2009; Mani & Dinesh, 2015; Mutiibwa *et al*., 2014; Nicholls, 2003; Ometto *et al*., 2013; *****)	Major damage to Infrastructure and tourism facilities (Almeida & Mostafavi, 2016; Assessment *et al*, 2010; Flanagan, 2016; *****)	Severe Impact on wetland and decrease in mangrove survival (Blankespoor *et al*., 2014; Ellison, 2015; Garner *et al*., 2015; McIvor *et al*., 2013; Pramanik, 2016; *****)	Major drop in employment opportunities owing to destruction of some infrastructure (Asuncion & Lee, 2017; Deshazo,2017; Heberger, 2012; *****)	Minor Health Challenges (Nicholls, 2003; Vellinga, P. 2015; WHO, 1996; *****)
Increased Temperature	Severe heat stress on crops, livestock, and biodiversity (Babalola & Akinsanola, 2016; Faqe, 2017; Mutiibwa *et al*., 2014; Nduati *et al*., 2013; Omran, 2012; Rasul & Ibrahim, 2017; Wen-Jian & Hai-Shan, 2013; *****)	Minor reduction in infrastructural development (Ware, 2016; Wei & Chatterjee, 2013; *****)	Major reductions in water quality due to increased growth of nuisance algae which further Lowers oxygen levels (Alongi, 2008; Jaiteh & Sarr, 2010; Spalding *et al*., 2014; Williams *et al*., 1999; *****)	Deleterious impact on Employment due to increased cost of cooling (Alleng, 2014; Heal & Park, 2016; UNEP 2008; *****)	Severe health challenges from heat stress (EPA, 2016; USHHS, 2016; *****)
Reduced Rainfall frequency and Intensity	Major Reduction in land use / Land cover changes (Babalola & Akinsanola, 2016; Mwaniki, 2015; Pielke *et al*., 2007; *****)	Minor reduction in infrastructural development (Bradbury *et al*., 2015; *****)	Major reduction in water quality due to changes in freshwater supply and runoff (Jaiteh & Sarr, 2010; Webb *et al*., 2013; *****)	Slight negative impact on Employment (Koen, 2014; Olsen, 2009; *****)	Major Reduction in Health Issues (*****)
Overall Risk Estimate	Major Reduction in land use/cover changes (Babalola & Akinsanola, 2016; Dia, 2012; Mutiibwa *et al*., 2014; Mwaniki, 2015; Ometto *et al*., 2013; Wen-Jian & Hai-Shan, 2013; Youneszadeh *et al*., 2015; *****)	Major Reduction in Infrastructure Development (Almeida & Mostafavi, 2016; Assessment *et al*, 2010; Ware, 2016; *****)	Severe Impact on wetland and mangrove survival (Alongi, 2008; DSE, 2013; Gilman *et al*., 2006; Sandilyan, 2014; Williams *et al*., 1999; *****)	Minor Reduction in Employment Opportunities (Alleng, 2014; Asuncion & Lee, 2017; Koen, 2014; Olsen, 2009; *****)	Severe health challenges (Doocy *et al*., 2013; Hassan, 2009; Vellinga, P. 2015; WHO, 1996; *****)

LEVEL OF CONFIDENCE IN PROJECTIONS

🟥	*Virtually Certain*
🟥	*Extremely Likely*
🟧	*Very Likely*
🟨	*Likely*

LEVEL OF NEGATIVE IMPACT

	Consequence				
Likelihood	***Minor***	***Moderate***	***Major***	***Severe***	***Catastrophic***
Rare	Low	Low	Low	Low	Low
Unlikely	Low	Low	Medium	Medium	Medium
Possible	Low	Medium	Medium	High	High
Likely	Low	Medium	High	High	Extreme
Almost Certain	Low	Medium	High	Extreme	Extreme

(*****) *Based on Expert Opinion. Values in parenthesis are references sourced to support the expert opinion.*

Table 4. 12 Vulnerability Matrix

Climate Change Variables	**Coastal Zone Sector Elements**				
	Land Use/ Cover Change	**Infrastructural Development**	**Mangroves and Wetlands**	**Employment**	**Health**
Elevated CO_2 Levels Level of Confidence: *Virtually Certain*	Impact Risk: *Medium* Adaptive Capacity: *Low* Vulnerability: ***Moderate***	Impact Risk: *High* Adaptive Capacity: *Low* Vulnerability: ***High***	Impact Risk: *Medium* Adaptive Capacity: *Low* Vulnerability: ***Moderate***	Impact Risk: *Low* Adaptive Capacity: *Low* Vulnerability: ***Low***	Impact Risk: *Low* Adaptive Capacity: *Low* Vulnerability: ***Low***
Increased Flood Severity Level of Confidence: *Virtually Certain*	Impact Risk: *High* Adaptive Capacity: *Low* Vulnerability: ***High***	Impact Risk: *High* Adaptive Capacity: *Low* Vulnerability: ***High***	Impact Risk: *Low* Adaptive Capacity: *Low* Vulnerability: ***Low***	Impact Risk: *Medium* Adaptive Capacity: *Low* Vulnerability: ***Moderate***	Impact Risk: *High* Adaptive Capacity: *Low* Vulnerability: ***High***
Sea Level Rise Level of Confidence: *Extremely Likely*	Impact Risk: *Medium* Adaptive Capacity: *Low* Vulnerability: ***Moderate***	Impact Risk: *High* Adaptive Capacity: *Low* Vulnerability: ***High***	Impact Risk: *High* Adaptive Capacity: *Low* Vulnerability: ***High***	Impact Risk: *Medium* Adaptive Capacity: *Low* Vulnerability: ***Moderate***	Impact Risk: *Low* Adaptive Capacity: *Low* Vulnerability: ***Low***
Increased Temperature Level of Confidence: *Very Likely*	Impact Risk: *High* Adaptive Capacity: *Low* Vulnerability: ***High***	Impact Risk: *Low* Adaptive Capacity: *Low* Vulnerability: ***Low***	Impact Risk: *High* Adaptive Capacity: *Low* Vulnerability: ***High***	Impact Risk: *Low* Adaptive Capacity: *Low* Vulnerability: ***Low***	Impact Risk: *High* Adaptive Capacity: *Low* Vulnerability: ***High***
Reduced Rainfall frequency and Intensity Level of Confidence: *Very Likely*	Impact Risk: *Medium* Adaptive Capacity: *Low* Vulnerability: ***Moderate***	Impact Risk: *Low* Adaptive Capacity: *Low* Vulnerability: ***Low***	Impact Risk: *High* Adaptive Capacity: *Low* Vulnerability: ***High***	Impact Risk: *Low* Adaptive Capacity: *Low* Vulnerability: ***Low***	Impact Risk: *Medium* Adaptive Capacity: *Low* Vulnerability: ***Moderate***
Overall Vulnerability Estimate	**Moderate**	**High**	**High**	**Low**	**High**

Table 4. 13 Vulnerability Matrix describing the Adaptation responses for the key elements of the Coastal Zone of The Gambia

Climate Change Variables	Land Use/ Cover Change	Infrastructural Development	Mangroves and Wetlands	Employment	Health
Elevated CO_2 Levels	Improving crop and grazing land management for increased land cover and soil carbon storage; Reduction in using fossil-based fertilizers and pesticides; Increase afforestation and reforestation programs. (Besada & Sewankambo, 2009; OECD, 2015; Raymond *et al*., 2014; USAID, 2012; *)	Promotion of more energy efficient electric heating and cooling appliances with renewable energy sources like solar energy; Improvement of insulation. (Change, 2009; Chinowsky *et al*., 2015; EPA, 2011; NRC, 2010; USAID, 2012; *)	Training of community members principally oyster harvesters on sustainable use of mangrove resources; Provision of alternative livelihood support system to community members like sinking boreholes for irrigation water supply for horticulture throughout the lean season to tolerate effective fallow of mangroves and wetland ecosystem. (Boer, 2010; CBD, 2009; EPA, 2013; European Commission, 2009; Murdiyarso & Kauffman, 2011; Powell *et al*., 2007; *)	Awareness raising on climate change risks, impacts, and adaptation with its mainstreaming into strategic and annual businesses plans; More research, investment, and development of Clean energy; Use of renewable energy sources like solar energy; creation of green jobs. (Ahmed, 2015; Camarsa *et al*., 2015; Maunsell, 2009; Pettengell, 2010; TUC, 2009; UNEP, 2008; *)	Mass Transit, pollution controls, and Public Education; Alternative energy generation from sources like Solar, Biomass, Geothermal, wind. (Benjamin, 2005; Camarsa *et al*., 2015; Dimitrios *et al*., 2014; McIver *et al*., 2016; *)
Increased Flood Severity	Improve regulations for restricting agriculture and livestock grazing activities to improve land cover; Engaging inhabitants in analyzing possibilities for relocation from flood-prone areas. (Change, 2009; NRC, 2010; OECD, 2015; Raymond *et al*., 2014; *)	Improve regulations for restricting coastal development; Engaging inhabitants in analyzing Possibilities for relocation; Maintenance of natural and beneficial functions of floodplains; Construction of flood-proof housing. (Alston, 2015 ; Chinowsky *et al*., 2015; EPA, 2011; NRC, 2010; UNFCCC, 2007; *)	Mangrove Restoration and Rehabilitation of affected areas; Introduction of more flood-tolerant mangrove species. (Besada & Sewankambo, 2009; Murdiyarso & Kauffman, 2011; EPA, 2013; Maunsell, 2009; *)	Economic diversification in sectors to reduce dependence on climate-sensitive resources in the coastal zone like basket weaving, calabash design, bead-making to support the local tourism industry; Development of effective flood response plans at the corporate level. (TUC, 2009; Alston, 2015; CESP, 2008; UNEP, 2008 Martinez-Fernandez *et al*., 2011, NRC, 2010; Pettengell, 2010; USAID, 2012; *)	Strengthening of Early-warning system; Building flood-shelters; Integrated emergency services and Stakeholder response to flood events. (Benjamin, 2005; Berry *et al*., 2014: Change, 2009; Dimitrios *et al*., 2014; Luber, 2011; McIver *et al*., 2016; *)
Sea Level Rise	Protection of key Economic Infrastructures like fish landing and tourism attraction sites; Consolidation in using integrated coastal zone management. (Change, 2009; EPA, 2013; Maunsell, 2009; Raymond *et al*., 2014; UNFCCC, 2007; *)	Improve regulations for restricting coastal development; Engaging inhabitants in analyzing Possibilities for relocation; Routine monitoring of the coast, improving coastal defence through afforestation; Increase in shoreline setbacks. (Besada & Sewankambo, 2009; EPA, 2011; Maunsell, 2009; NRC, 2010; UNDP-UNEP, 2010; *)	Use of appropriate agricultural and forestry practices to increase the water retention capacity; Allowance for coastal wetlands to migrate inland using setbacks; Incorporation of wetland protection into regional and local infrastructure development planning. (Boer, 2010; CBD, 2009; European Commission, 2009; UNDP-UNEP, 2010; NRC, 2010; Powell *et al*., 2007; *)	Employee training on climate risks and disaster management; Development and subscription of employees to insurance policies against impacts of climate change. (Camarsa *et al*., 2015; Change, 2009; TUC, 2009; Martinez-Fernandez *et al*., 2011; Pettengell, 2010; UNFCCC, 2007; *)	Construction of Sea walls and revetments. (ADB, 2011; Berry *et al*., 2014; Change, 2009; Dimitrios *et al*., 2014; UNFCCC, 2007; USAID, 2012; *)

Increased Temperature	Increase Crop Diversification and Rotation to reduce total Crop failure; Switching to drought-tolerant crop and animal species; Changes to more heat tolerant livestock like the shift from cattle to goat rearing; More appropriate, accessible and reliable seasonal and weather forecasts. (Change, 2009; EPA, 2013; Maunsell, 2009; OECD, 2015; *****)	Changes in Urban housing design like green roofing and more vents for improved ventilation. (Camarsa *et al*., 2015; Change, 2009; Chinowsky *et al*., 2015; USAID, 2012; *****)	Use of appropriate agricultural and forestry practices to increase the water retention capacity; Education and Awareness Creation; Identification and protection of ecologically significant areas like areas of High species diversity, nursery and spawning grounds; Management of Invasive species and restoration of native species. (CBD, 2009; Boer, 2010; Maunsell, 2009; UNDP-UNEP, 2010; Murdiyarso & Kauffman, 2011; *****)	Development and subscription of employees to insurance policies against impacts of climate change; Use of renewable energy sources for cooling, lighting or heating purposes. (Besada & Sewankambo, 2009; CESP, 2008; UNEP, 2008 Martinez-Fernandez *et al*., 2011; US-EPA, 2009; *****)	Construction of buildings with more vents for improved ventilation; Green Roofing to reduce Urban-Heat-Island effect. (ADB, 2011; Benjamin, 2005; Camarsa *et al*., 2015; Dimitrios *et al*., 2014; Luber, 2011; *****)
Reduced Rainfall frequency and Intensity	Increase Crop Diversification and Rotation to reduce total crop failure; Educational and outreach programmes on conservation agriculture and improved pasture and graze-land management; use of water conservation technique like the Zai technique adopted from Burkina Faso. (Besada & Sewankambo, 2009; GIZ, 2013; NRC, 2010; UNFCCC, 2007; *****)	Rainwater harvesting techniques incorporated in building designs. (Besada & Sewankambo, 2009; EPA, 2011; NRC, 2010; US-EPA, 2009; USAID, 2012; *****)	Incorporation of wetland protection into infrastructure planning; Promotion of community-based conservation programmes; Education and Awareness Creation. (Besada & Sewankambo, 2009; CBD, 2009; European Commission, 2009; Powell *et al*., 2007; *****)	Rainwater harvesting techniques incorporated in building designs. (Besada & Sewankambo, 2009; TUC, 2009; Change, 2009; EPA, 2013; Pettengell, 2010; *****)	Watershed Management and water treatment; Public Education; Changes in Urban housing design. (ADB, 2011; Berry *et al*., 2014; Dimitrios *et al*., 2014; Luber, 2011; McIver *et al*., 2016; *****)

LEVEL OF CONFIDENCE IN PROJECTIONS

🟥	*Virtually Certain*
🟥	*Extremely Likely*
🟧	*Very Likely*
🟨	*Likely*

LEVEL OF VULNERABILITY TO CLIMATE CHANGE

Impact	***Low***	***Medium***	***High***
Extreme	High	High	Moderate
High	High	Moderate	Moderate
Medium	Moderate	Moderate	Low
Low	*Low*	*Low*	*Low*

(*****) *Based on Expert Opinion. Values in parenthesis are references sourced to support the expert opinion.*

4.5.1 Impact Risk

The writings in the impact risk matrix show the direction and the impact of the climate change variables on the key sector elements in the study area (Table 4.11). The shaded areas indicate impact of the climate change variables on the key sector elements. The deeper the shade of brown, indicates the impact of climate change on the sector elements in each cell of the impact risk matrix (Table 4.11).

All the cells in the impact matrix recorded a negative impact on the key sectors of the coastal zone of The Gambia (Table 4.11). The impact of the climate change variables recorded range from ‘High’ to ‘Low’. 11 (44%) cells in the matrix recorded a ‘High’ impact, 6 (24%) cells recorded a ‘Medium’ impact while 8 (32%) of the cells recorded a ‘Low’ impact on the key sector elements in the coastal zone. The anticipated ‘High’ impact of climate change on the coastal zone indicates the High level of exposure of the sector element as it has a relatively Low adaptive capacity to address these impacts in The Gambia (NAPA, 2007; National Climate Committee, 2013; Camara, 2013; Yaffa, 2013).

The climatic variables; increased flood severity and increased temperature recorded the highest impact on the coastal zone. The increase in temperature will likely have deleterious impacts across the sector elements like: the increase in heat stress on crops, livestock and biodiversity; reduction in water quality due to increased growth of nuisance algae, which will lower oxygen levels, among others. Although increased temperature could have detrimental effects on the study area, other areas like the tourism sector can benefit from this climate change impact until a particular threshold of temperature is achieved. Increased temperature may provide prospects for the outdoor tourism activities like historical and cultural site visits, increased exposure of tourists to the ‘sun’ with shopping activities (ADB, 2014).

Increased flood severity will likely have deleterious impacts across the sector elements like impacts on land use/ cover changes; damage to facilities of economic, social or cultural importance owing to floods; mangrove and wetlands survival; major drop in employment opportunities due to destruction of infrastructure and; changes with health of individuals.

The key elements in the coastal zone that recorded an overall ‘High’ impact consist of: land use/cover changes; infrastructural development; wetlands and mangroves and; Health concerns. The Employment key sector nonetheless recorded a Low climate change impact on the coastal zone of The Gambia. With the overall High impact of the climate change variables on land use/cover changes, it is likely there will be observed impacts like severe heat stress on crops, livestock, and biodiversity within the coastal zone. Yaffa (2013) and NAPA (2007) study further supports this claim.

The overall High impact of the climate change variables on infrastructural development will likely lead to impacts like major damage to facilities of economic, social and cultural importance owing to flood events. Sem (2009) argues that the negative impacts of climate change could create a new group of refugees, who may migrate into new settlements to seek new livelihoods, which will create additional demands on infrastructure. This may account for the observed high impact of climate change on infrastructure development in the study area.

The overall High impact of the climate change variables on Mangroves and wetlands will likely lead to impacts like changes in their ecosystem, increase in algal blooms affecting their very survival beside affecting water quality and reduction in oxygen levels, reduction in water quality attributed to changes in freshwater supply and runoff. Sustainable survival of wetlands and mangrove ecosystems requires that the evapotranspiration rate runs parallel to the rate of water supply with rainfall or from streamflow (Ceesay *et al*., 2017; IPCC, 2014). Increase in temperature and decrease in rainfall amounts is likely to alter this balance beside anthropogenic activities like deforestation, and damming of waterways (NAPA, 2007; National Climate Committee, 2013). Some factors increase the exposure of wetland and mangrove ecosystem may account for the observed high impact of climate change on this key sector element in the study area.

The overall High impact of the climate change variables on Health is likely to cause an increase in cases of malaria, injuries and other threats to lives owing to floods, heat stress, among others. But the employment sector recorded an overall low impact of anticipated climate change events. This is likely to cause a major decrease in productivity of employees due to fatigue from increased temperature, dip in employment opportunities owing to the destruction of infrastructure from flood risks, among others. The overall impact risk for each impact risk is assessed through stakeholder consultation with developing the appropriate adaptation responses in addressing these risks in the study area.

4.5.2 Vulnerability and Adaptation Assessment

The writings in the vulnerability and adaptation matrix (Table 4.13) show some responses agents in the areas of climate change, agriculture, water resources, parks and wildlife management, tourism can take in addressing some of the climate change impacts identified from the impact risk matrix. This list is not considered as thorough or relevant to all businesses in the coastal zone of The Gambia. The shades of pink in the table gives a measure of vulnerability to climate change incorporating climatic impacts and adaptive capacity. The deeper the shade of pink, indicates the vulnerability of climate change on the sector elements in each cell of the adaptation and vulnerability matrix (Table 4.13).

The result of the adaptation and vulnerability matrix reveals each sector element within the coastal zone of The Gambia experienced varied levels of vulnerability to climate change impacts. 10 (40%) cells in the matrix recorded 'High' vulnerability, 7 (28%) recorded 'Moderate' vulnerability and 32% (8) recorded 'Low' vulnerability to the anticipated climate change impacts in the coastal zone. The coastal zone sector is highly vulnerable to increased flood severity and increased temperature.

The key elements in the coastal zone that recorded an overall High vulnerability to climate change comprise infrastructural development; wetlands, and mangroves. The land use/cover changes key sector element recorded an overall Moderate vulnerability with employment issues recording an overall Low vulnerability to the anticipated impacts of climate change in the coastal zone of The Gambia. The key sector elements that recorded High vulnerability requires transformational changes in the adaptation option to ensure potential reduction of its elements to imminent impacts of the principal climate change variables under study.

With the overall High vulnerability of the infrastructural development, there is the need to undertake adaptation responses like the promotion of more energy efficient electrical, heating and cooling appliances with renewable energy sources; improvement of insulation. This has become necessary as energy will continually power industrialized processes, trade and agriculture and support the delivery of resources in the health, education and water and sanitation sectors (UNDP, 2012; Ceesay *et al*., 2017). The accessibility of a reliable energy supply system that is effectual, reasonably priced and environmentally friendly is fundamental for advancement in all three-facet of sustainable development and a condition for a shift to a green economy (UNDP, 2012). For instance, an institution like The Gambia Renewable Energy Centre (GREC) was established in The Gambia to promote the development of technologies and the encouragement of its use at the national to local levels. And some adaptation responses could be the improvement in regulations for restricting coastal development; engaging inhabitants in analyzing possibilities for relocation; maintaining the natural and beneficial functions of floodplains; and changes in the urban housing design like green roofing and more vents for improved ventilation, among others.

The key sector element wetlands and mangroves recorded an overall High vulnerability to the climate change variables in the study area. Some measures taken at the national level like the Banjul Declaration in 1977 for the preclusion of the national flora and fauna endowment including wetlands and its ecosystem has achieved minimum success (UNDP, 2012). And the National Disaster Management Act of The Gambia is silent on vulnerability factors with less exposition on effective adaptation measures to reduce anticipated impacts of climate change (UNDP, 2012). This among other reasons may have contributed to the observed high vulnerability to climate change impacts in the study area. But there is the need to undertake adaptation responses to overcome the challenges faced in the areas. Some of the adaptation actions that can be used comprise the training of community members principally oyster harvesters on sustainable use of mangrove resources; provision of alternative livelihood support system to community members to allow for effective fallow of mangroves and wetland ecosystem. There is the need for mangrove restoration and rehabilitation of affected areas; the introduction of more flood tolerant mangrove species; incorporation of wetland protection into regional and local infrastructure development planning, among others.

Per the overall Moderate vulnerability of the land use/cover changes, there is the need to undertake adaptation responses like improving crop and grazing land management for increased land cover and soil carbon storage; reduction in using fossil-based fertilizers and pesticides; increase afforestation and reforestation programs (Table 4.13). The continuous pressure from anthropogenic activities in wetland areas in the study area may likely increase their vulnerability to the varied impacts of climate change. NEA (2014) report divulges the rate of deforestation is far beyond the rate of mangrove restoration. This emanates from practices like some wetland areas like the Tanbi and Bao Bolong reserves for rice cultivation during the wet season and vegetable crop production during the dry season (NEA, 2014). Others also harvest the mangroves for household energy and construction needs, mainly credited to poverty; this has a resultant impact on local and commercial fishing and oyster population. Effectively implementing the adaptation response requires a stronger partnership among the public, private sector and community members (NEA, 2014).

At the international level, The Gambia is a signatory to international conventions like the Convention on Biological Diversity (CBD), the Ramsar Convention, Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). At the regional level, The Gambia is a signatory to the Convention for the Cooperation in the Protection and Development of the Marine and Coastal Environment of the West and African Region (Abidjan Convention), among others. There is the need to look deep into the underlying and more pragmatic actions taken at the local level as more threats to wetlands and mangrove ecosystems occur at this level (NEA, 2014; UNDP, 2012). This will help in driving results that are more positive at the national to regional levels with using some of the adaptation options.

Further adaptation responses identified include the improvement of regulations for restricting agriculture and livestock grazing activities to improve land cover and; engagement of inhabitants in analyzing possibilities for relocation from flood-prone areas. There is also the need for protection of key economic infrastructure like fish landing and tourism attraction sites; consolidation in using integrated coastal zone management; increase crop diversification and

Rotation to reduce total crop failure. An adaptation response like the encouragement of farmers to undertake crop diversification at the local level may be met with concerns like poverty restraining the diversification options available to them (Sem, 2009; UNDP, 2012). Microfinancing and other social wellbeing nets and social welfare allowances may serve to improve adjustment to present future stun and stresses and assist in beating such limitations if upheld by indigenous institutional plans for long-term sustainability (Chigwada, J. 2005).

The key sector element, employment noted an overall Low vulnerability to the climate change variables in the study area. The Agriculture sector is a key contributor to Greenhouse Gases (GHGs), accounting for over 13.5% of global greenhouse gas emissions (IPCC, 2007). Increase in employment in this sector can be associated with a resultant increase in activities releasing more GHGs exacerbating climate change impacts. Nshimyumuremyi *et al*., (2017) accounts that over 62.8% of the employed populace in The Gambia is in the non-agricultural informal sector and other forms of vulnerable occupations. The non- agriculture informal sector may contribute less GHG emissions relative to regions with more employment in the agricultural informal sector. This may account for the observed low vulnerability of the employment sector elements to the anticipated impacts of climate change in the coastal zone. This notwithstanding, there is the need to undertake adaptation responses like raising more awareness on climate change risks, impacts, and adaptation with its mainstreaming into strategic and annual business plans. And more research, investment, and development of clean energy and other renewable energy sources like solar energy with the significant creation of green jobs; development of flood response plan at the corporate level. Among other adaptation responses are the encouragement of employee training on climate change risks and disaster management with the subscription of employees to insurance policies in the face of anticipated climate change impacts.

4.5.3 Risk Statement

It is helpful while educating administrators, and key policymakers regarding dangers and vulnerabilities to portray them as risk statement. The risk statement synthesises highlights from the impact, vulnerability and adaptation matrix In this paper. A case in point of a risk statement describing the risk of increased flood severity to the coastal zone of The Gambia is:

> *The High risk to the coastal zone of The Gambia to increased flood severity of land cover/ use change, infrastructural development, and health could cause severe impact on land use /cover changes, major damage to infrastructure of economic, social or cultural importance owing to floods besides severe health threats from injuries, death, among others. This level of risk requires an immediate response from the most senior levels of leadership, agency management, policy development and government representatives beside individuals in the sector. This risk can be potentially be addressed through improved regulations for restricting agriculture and livestock grazing activities to improve land cover; Engaging inhabitants in analyzing possibilities for relocation from flood-prone areas; Strengthening of the Early-warning system; Building flood-shelters; Integrated emergency services and Stakeholder response to flood events.*

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.0 Introduction

This chapter provides relevant conclusions from the study and based on the findings from the study, a number of recommendations are made.

5.1 Conclusion

The results of the trend analysis revealed rainfall decreased at 0.79mm annually over the whole Gambia in the past 30 years. Conversely, the coastal zone of The Gambia alone showed a positive trend of 0.237mm per annum for rainfall amount received during the same period. The annual minimum temperature over the past 30 years showed a decreasing trend rate of 0.025 ^{o}C each year while the yearly maximum temperature showed an increasing trend rate of 0.027^{o}C in the coastal zone of The Gambia over the past three decades.

By the end of this century, under a 1m SLR scenario, the total land to be lost due to inundation is 1,246 ha (12,460,000m^2) with a corresponding economic loss of ~US $788Million (GMD37 Billion) over the coastal zone. This land to be lost is predicted to occur at an approximate rate of 6m annually along the coastline of The Gambia owing to the effects of coastal erosion. The estimated total number of people at risk of being affected by coastal erosion and flooding events from SLR are 15,560 per km^2 of land area. The areas ranging from Bald Cape to Solifor Point (coastal cell 7) had the largest area of land, 279ha to be lost under 1m SLR scenarios with an estimated economic loss of US $176.4 Million. The areas along Sanyang Point to the Allahein River (coastal cell 9) is estimated to possibly have the highest rate of coastal erosion with a value of 2m each year under a 1m SLR scenario. The areas from Kololi- Bald Cape (coastal cell 6) is recorded to have the largest number of people at risk to flooding followed by areas from Banjul Port to Cape Point (coastal cell 3); this corresponds to 6,249 and 2,955 respectively.

The results of the trend analysis revealed that annual industrial fishery catches in The Gambia showed a decreasing trend of 534 MT per annum over the period 1968- 2014. This observed negative trend is predicted to persist with a noteworthy decrease from 4,770 MT in 2014 to 66.7 MT by the year 2025.

The artisanal fisheries sector of The Gambia revealed a positive trend of 1,611 MT of fisheries resources from 1986- 2016. It is predicted that the observed increase in artisanal fishery catches will persist to the year 2025. This corresponds to an increase of 21% from by the year 2025.

The analysis of the effects of temperature changes on shrimp yield in The Gambia showed a potential increase of 46% by the year 2100.

The analysis of the effects of temperature on the productivity of the fisheries resources of the River Gambia revealed a potential increase of 13% by the year 2100. This result reveals that The Gambia maritime space, and the River Gambia ranges, will continue to be productive in the support of shrimp and other artisanal fisheries resources under the anticipated climate change impacts over the coastal zone in the short-long term.

The findings of the study reveal that by the end of the 21st century, the climatic variables likely to have the highest impact on the coastal zone of The Gambia are increased flood severity and increased temperature. The coastal zone of The Gambia showed the highest vulnerability to these climate change variables. The increase in flood severity may cause: severe impact on land use/cover changes; major damage to facilities of economic, social or cultural importance; and impacts like; severe health challenges from injuries or death. The increase in temperature may cause: severe heat stress on crops, livestock and biodiversity; major reductions in water quality due to increased growth of nuisance algae that further lowers oxygen levels, and; severe health challenges from heat stress.

5.2 Recommendations

- The adaptation measures recommended for each coastal cell are integrated into the results and discussion segment of this paper. The recommendations ranged from non-structural methods like the preparation, implementation, and enforcement of regulations governing land use planning, and sand mining operations in the coastal zone, among others. Other structural adaptation methods recommended include the use of protective methods like constructing long longitudinal coastal defence structures like seawalls, embankments, besides active protection methods like constructing Groynes and breakwater structures.
- To help reverse the trend in the industrial fishery catches, it is imperative for the Government of The Gambia to set-up and substantively build the capacity of more patrol vessels to regulate Illegal, Unreported and Unregulated fishing in the coastal zone of The Gambia. There should be the facilitation in the process of obtaining and renewing industrial fishing licenses. The establishment of a deep-marine fishing port will increase the number of industrial fisheries landings in The Gambia to increase revenue and meet local market supply needs of this sector.
- Although the artisanal fisheries sector revealed a positive trend, there should continuous monitoring and enforcement of laws and regulations against unsustainable fishing operations like blast fishing or use of dynamite in fishing. The study suggests there should be more programs and partnerships with financial institutions to give artisanal fisherfolk easy access to operating funds, instruction of more Gambian youth in sustainable fishing

operations and repair and maintenance of mechanized fishing gears. It is also imperative that the number of premixed fuel stations within the country is increased and its pricing regulated for easy access and purchase for artisanal fishing operations. The study also suggests more monitoring and reporting of favourable areas for artisanal fisheries.

- It is suggested that there should more expansion in Infrastructure development from the hinterlands and project sites to upgrade meeting standards for ease of production and export of shrimp fisheries products. There should be afforestation programs to increase the population of mangroves in local wetlands and the introduction of more adaptable species of mangroves that can better withstand areas with high salinity owing to sea-level rise impacts. With this in place, fisheries nesting grounds will be increased to help produce and care for juvenile fisheries resources before they migrate to the deeper waters at maturity besides increasing the productivity of the River Gambia to support more fisheries resources.
- There is the need to build and develop the capacity of various stakeholders in the coastal zone sector in order to facilitate the mainstreaming of the adaptive responses identified in this study into plans, policies, and strategies at all levels to increase resilience to climate change impacts.

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LIST OF PUBLICATIONS

1. **Amuzu, J.,** Kabo-Bah, A. T., Jallow, B. P., & Yaffa, S. (2018). Households' Livelihood Vulnerability to Climate Change and Climate Variability: A Case Study of the Coastal Zone, The Gambia. *Journal of Environment and Earth Science*, *8*(1), 1–12.

2. **Amuzu, J.,** Jallow, B. P., Kabo-Bah, A. T., & Yaffa, S. (2018). The Climate Change Vulnerability and Risk Management Matrix for the Coastal Zone of The Gambia. *Hydrology*, *5*(1), 1–22. http://doi.org/10.3390/hydrology5010014

3. **Amuzu, J. (2018).** The Socio-economic Impact of Climate Change on Marine and Freshwater Fisheries Resources in the Coastal Zone of the Gambia, *6*(1), 1–12. http://doi.org/10.13189/nrc.2018.060101

Joshua AMUZU, MSc

Post Office Box, 7123, Accra North. Ghana
Mobile: (+233) 0543 121 834 / 0243 821 320
Email: joshua.amuzu@yahoo.com / joshe2002@yahoo.com

PERSONAL STATEMENT & AREAS OF EXPERTISE

Conduct environmental research on topics such as Climate Change Adaptation, Mitigation, Vulnerability Assessment and Livelihood improvement at the household to the regional level. Carry out research on climate change and its variability (i.e. drought and flooding) as it affects crop and animal husbandry in West Africa. Conduct climate change education and environmental protection through a weekly radio program. Conduct consultancy services for institutions and published four research articles in international peer-reviewed journals like mdpi.org. Student-advise undergraduate courses and supported students in their thesis work with further online publications. Have a rich background in diverse fields including professional, academic and social areas. Honest, diligent and trustworthy. Able to manage own time effectively and prioritize workload. Experienced at working to tight deadlines and under considerable pressure. Friendly and approachable with excellent interpersonal and customer relations skills. Team Player and highly adaptable to change, a regular user of Microsoft Office; Excel, Word and PowerPoint. Highly organized and efficient, professionally mannered and give high level of attention to detail.

PROFESSIONAL EXPERIENCE AND RESPONSIBILITIES

Jan. 2016-Present

Freelance Consultant

Provide technical and strategic assistance for project activities, including planning, monitoring and site operations, and assuring quality control of interventions. Maintaining relationship with external organizations and partners. Overseeing Monitoring and Evaluation activities

June 2016-Feb. 2018

Student Advisor for Undergraduate students.

Supported students in their Thesis work and online publication of research articles during and after graduation

Sept. 2015 – Nov. 2015

Economic Census Enumerator, Ghana Statistical Service

World Bank funded Project, Integrated Business Establishment Survey (IBES) II.

Sept 2013-Aug. 2015

Research and Teaching Assistant, University of Ghana, Legon.

The core responsibilities of this role include; undertaking research, managing the head of department's diary, creating PowerPoint presentations and organizing board level meetings. I assist in teaching courses, questionnaire design, administration, data entry, analysis using statistical software's as well as write reports on information gathered. I organized and taught students during tutorials session fortnightly. Aided in lecture material gathering and delivery to ensure lectures were timely and more effective.

During my time in this role, three students dissertation were published online by the department as a result of monitoring and motivating students to meet standards.

Sept 2010-2015

Voluntary Internship, Ministry of Food and Agriculture, Pokuase- Accra

The core responsibilities of this role include; Reporting and record keeping, risk assessment of seeds, ensuring standards are met in- terms of moisture content and level of infestation, quality and quality assurance checks. Additional oversight responsibilities on human resources, seed production and marketing operations. During my time in this role, I reorganized data recording and reporting on an online system, which gives ease to accessing information by anyone at any time.

2011-2013 **Tutor, Institute of Business Management, Madina.**
Taught Mathematics; both core and elective mathematics for remedial students preparing them for the WASSCE examination. Ensured students grasped the brass tucks and concepts of the various topics in both fields of study.

EDUCATIONAL BACKGROUND

March 2016-March 2018 **MSc. Climate Change and Education,** University of The Gambia
Fully funded Scholarship by Germany Government and WASCAL- West Africa Science Service Center on Climate Change and Adapted Land Use.
Thesis: Socio-economic Impact of Climate Change on the Coastal Zone of The Gambia.

2009- 2013 **BSc. Agricultural Economics, University of Ghana, Legon**
Thesis: Economic Analysis of Maize Production in Ghana; a case study of farmers in the Gomoa East District.

2005- 2008 **WASSCE, Ebenezer Senior High School, Accra**

LIST OF PUBLICATIONS

1. **Amuzu, J. (2018).** The Socio-economic Impact of Climate Change on Marine and Freshwater Fisheries Resources in the Coastal Zone of the Gambia, *6*(1), 1–12. http://doi.org/10.13189/nrc.2018.060101

2. **Amuzu, J.,** Jallow, B. P., Kabo-Bah, A. T., & Yaffa, S. (2018). The Climate Change Vulnerability and Risk Management Matrix for the Coastal Zone of The Gambia. *Hydrology*, *5* (1), 1–22. http://doi.org/10.3390/hydrology5010014

3. **Amuzu, J.,** Kabo-Bah, A. T., Jallow, B. P., & Yaffa, S. (2018). Households' Livelihood Vulnerability to Climate Change and Climate Variability: A Case Study of the Coastal Zone, The Gambia. *Journal of Environment and Earth Science*, *8* (1), 1–12.

OTHER POSITIONS AND RESPONSIBILITIES

2012- 2013 **President, Ebenezer Past Students Association, Legon Branch.**
Organizing old students at the University of Ghana and briefing them on issues that concern our alma mater. Seeking Sponsorship to finance some of our school's project. Creating platforms for past students to interact motivate and share past experiences with past students. Achievement: Liaised for the school to get a Bus and helped raised funds for the renovation of the science laboratories with modern equipment

2010- 2011 **Member, Ghana Association of Agricultural Students, GAAS.**
Member, organizing team and participant; Poverty Alleviation through Good Leadership and Financial Management Conference- organized by GAAS, Legon in collaboration with UNDP.

Key Interest Solve problems, research, reading and practical application of knowledge gained.

Languages
English- Speak (fluent), Write (fluent), Read (fluent), Twi, Ewe, Hausa, Ga, Fante
French- Speak (basic), Write (basic), Read (medium)

Computer Skills I am familiar with most Microsoft Office applications (MS Word, Excel, PowerPoint, and Outlook). I can execute SPSS, STATA, EVIEWS and most of the Biophysical Models used in Vulnerability and Adaptation, IPCC Inventory Software and Climate Change Mitigation Assessments

Referees:

1. Prof. Sidat YAFFA, Director- WASCAL, University of The Gambia.
   Email: syaffa@utg.edu.gm, Mobile #: (+220) 3650028
2. Mrs. Theresa Aneigyei- Bonsu. Email: aniagyei-bonsu.t@wascal.org, Mobile #: +233244975698.
3. Prof. (Mrs.) Irene S. Egyir. Email: ireneegyir@yahoo.com, Mobile: +233240 932768
4. Prof. John Kuwornu. Email: jkuwornu@gmail.com, Mobile: +233245 131807