THE IMPACT OF CLIMATE CHANGE ON HYDROPOWER GENERATION: A CASE STUDY OF GHANA'S AKOSOMBO DAM

by

EZEKIEL KOJO ACQUAAH

submitted in accordance with the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in the subject

Environmental Management

at the

UNIVERSITY OF SOUTH AFRICA

SUPERVISOR: PROF. K. MEARNS
CO-SUPERVISOR: DR. A. O. AGYEPONG

OCTOBER 2021

DEDICATION

I dedicate this work to my wife Mrs Evelyn Acquaah and my children Manuella Nhyira Acquaah, Ezekiel Kobina Acquaah and Eliana Enuonyam Acquaah

DECLARATION

Name: Ezekiel Kojo Acquaah

Student number: 58545573

Degree: PhD Environmental Management

THE IMPACT OF CLIMATE CHANGE ON HYDROPOWER GENERATION: A CASE STUDY OF GHANA'S AKOSOMBO DAM

I hereby declare that the above dissertation is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

I declare further that I submitted the dissertation to originality checking software and ended up falling within the accepted requirements for originality.

I also declare that I have not previously submitted this work, or part of it, for examination at UNISA for another qualification or at any other higher education institution.

October 29, 2021

SIGNATURE DATE

ACKNOWLEDGEMENT

First and foremost appreciation of mine goes to the Almighty God for giving me life, strength, wisdom and carrying me through this journey of the PhD degree. My sincere appreciation goes to my dedicated and supportive supervisors Professor Kevin Mearns and Dr Adelaide Agyepong. I am so grateful for your support and dedication towards my PhD work. Your reviews, inputs and directions were invaluable and vital and have brought me this far. May God richly bless you.

My appreciation also goes to my research respondents for finding time in their busy schedules to attend to and answer the questionnaires and interview questions. Also, I extend my appreciation to the government institutions made up of the Energy Commission, Ghana Meteorological Agency, Water Research Institute and the Volta River Authority (VRA) for the permission granted to collect data and interview their staff.

My sincere appreciation again goes to my wife, Mrs Evelyn Acquaah and my children Manuella Nhyira Acquaah, Ezekiel Kobina Acquaah and Eliana Enuonyam Acquaah for supporting me throughout this journey of researching and learning for a PhD degree. Your love, encouragement and support were priceless.

ABSTRACT

Climate change has become one of the biggest challenges confronting the world's economic, social and environmental development efforts today. Responses to these challenges normally fall into two broad categories, namely adaptation and mitigation. Drying lakes, dams, rivers, flooding and sea level rises are some of the climate change induced threats facing humanity and their communities. Typically associated with dams is the reduction in the water level due to an increase in temperature. This is affecting energy generation, particularly within the realm of hydropower facilities. It is against this background that this study investigated both the potential and present threats of climate change to hydropower generation using Ghana's hydropower facilities through a case study of the Akosombo Dam.

In achieving this, the study set out four research objectives. To achieve the four research objectives, the study adopted sound scientific approaches including the use of a mixed-method approach to gather both qualitative and quantitative data from five government organisations and some community members living within the Akosombo Dam catchment area. The data were gathered through administering questionnaires, interviews and field observations. The data included both primary and secondary data which were subjected through sound statistical analysis using advanced Excel and "R".

As part of the findings, the research identified the challenge of a "knowledge gap" in climate change related issues amongst significant members of the community. A statistical analysis of the climate data indicated increasing temperature and sporadic rainfall patterns within the vicinity of the Akosombo Dam and its surrounding areas. The data also revealed that there are institutional climate change policies developed by the managers of the Akosombo Dam to manage the Dam and national climate change. These environmental related policies are aimed towards the management of climate change in Ghana. As part of the recommendations, the study recommended that Ghana's climate change policies should be revised to be attuned to the United Nations Sustainable Development Goals in the tackle against climate change which is aimed to be achieved by the year 2030

To enhance the management of hydropower, the study proposed the use of three novel comprehensive conceptual climate change management adaptation frameworks namely: integration and coordination network framework, adaptation framework of interaction and adaptation framework of outcomes. The study recommended the Volta River Authority to have its own climate change policy and in addition adopt the three novel climate change management adaptation frameworks to manage the Akosombo Dam in the current wave of the climate change effects

Key Words: Climate Change, Akosombo Dam, Policy, Adaptation, Mitigation, Conceptual, Framework, Hydropower, Water Level, Temperature, Rainfall, Environment

Table of Content

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AP:	Annual Plan
CDM:	Clean Development Mechanism
CDP:	Carbon Disclosure Project
CFL:	Compact Florescent Lamp
CO_2:	Carbon Dioxide
COP:	Conference of Parties
COP21:	Twenty-first Conference of Parties
CPF:	Carbon Price Floor
CSIR:	Council for Scientific and Industrial Research
EPA:	Environmental Protection Agency 83
EPC:	Environmental Protection Council
GERD:	Grand Ethiopian Renaissance Dam
GHGs:	Greenhouse Gases
GMA:	Ghana Meteorological Agency
GNCCMPAPI:	Ghana National Climate Change Master Plan Action Programmes for Implementation
GPRS:	Ghana Poverty Reduction Strategy
HFO:	Heavy Fuel Oil
IEA:	International Energy Agency
INDC:	Intended Nationally Determined Contributions
IPP:	Independent Power Provider
IPCC:	Intergovernmental Panel on Climate Change
KTPP:	Kpone Thermal Power Plant
LCO:	Light Crude Oil
L I:	Legislative Instrument
MESTI:	Ministry of Environment, Science, Technology and Innovation
MM:	Millimetres
MTDP:	Medium Term Development Plans
MW:	Megawatts
NCCP:	National Climate Change Policy
NCCPC:	National Climate Change Policy Committee
NCCPF:	National Climate Change Policy Framework

NDA:	Nationally Designated Authority
NDPC:	National Development Planning Commission
PDP:	Pipeline Development Plan
PV:	Photovoltaic
REDP1:	RE Development Programme Phase 1
SAPP:	Sunon-Asogli Power Plant
SDG:	Sustainable Development Goals
STI:	Science, Technology and Innovation
TAAP:	Technology Transfer and Acquisition Plan
TAPCO:	Takoradi Thermal Power Company
TICO:	Takoradi International Company
TT1PP:	Tema Thermal Power Plant 1
TT2PP:	Tema Thermal Power Plant 2
UK:	United Kingdom
UNDP:	United Nations Development Programme
UNEP:	United Nations Environment Programme
UNFCCC:	United Nations Framework Convention on Climate Change
UNISA:	University of South Africa
USA:	United States of America
VRA:	Volta River Authority

CHAPTER 1: INTRODUCTION AND BACKGROUND

"The generation that destroys the environment is not the generation that pays the price. That is the problem." Wangari Maathai (1940 – 2011).

1.1 Introduction

The climate change related crisis is causing havoc to the lives and properties of millions of people worldwide (UNEP, 2019). Unfortunately, the generation that did the least to cause the problem are the worst affected. Not long after the world had recovered from the disaster of the 2008 financial collapse and with the pending challenges associated with the current COVID-19 pandemic, climate change management has been under key consideration in all efforts of economic recovery (Meige *et al.,* 2020; Hepburn *et al.,* 2020). The previously disputed phenomenon of climate change and its drivers is now less contentious to the extent of having been adopted during the United Nations Sustainable Development Summit in September 2015 as one of the Sustainable Development Goals (SDG 13) expected to be achieved between 2020 to 2030. Although remnants of disputes still remain, there is a broad narrowing divergence of global opinions on the management of the drivers of climate change as evidenced by the Intended Nationally Determined Contributions (INDC), a major output of the twenty first (21st) session of the Conference of Parties (COP 21) meeting in France in 2015 (United Nations, 2015) and in the Sustainable Development Goal thirteen (SDG 13).

Discussions leading to the COP21 agreements reside in the two climate change management practices, namely climate change mitigation and climate change adaptation. The climate change mitigation comprises actions taken to eliminate the anthropogenic root cause of climate change global warming, driven by an increased accumulation of atmospheric greenhouse gases (GHGs) whilst the climate change adaptation is about learning to live with the impacts of climate change (Nyong, Adesina & Elasha, 2007). The latter is important because historical factors contributing to climate change cannot be reversed, making adapting to the inevitable impacts of climate change a necessity and not an option. As a management practice, climate change adaptation considerably lags behind mitigation in the legislation, policy and practice spaces (Davidse, Othengrafen & Deppisch, 2015). However, adaptation is gaining momentum because the adverse impacts of climate change are affecting almost all the sectors of the economy including the energy

sector. An increase in population and changes in the climate are expected to have an adverse impact on the demand and supply of energy, especially non-renewable energy which could run out of supply against increasing demand. As such, the need exists for countries to start putting in place structures to accommodate renewable, clean but sustainable energy technologies of which the source may not run out and also to possibly reduce or stop the emission of greenhouse gases into the atmosphere. According to the International Renewable Energy Agency (IREA, 2019), renewable energies could supply four-fifths of the world's electricity by 2050, massively cutting carbon emissions and helping to mitigate climate change because they do not emit greenhouse gases. One such renewable energy is hydropower, which is the focus of this study. Hydropower is a clean, renewable, and environmentally friendly source of energy that could serve as both climate change mitigation and adaptation source (Berga, 2016). It serves as a climate change mitigation source in that it significantly helps to avoid greenhouse gas emissions. It also serves as an adaptive measure because regulated basins with large reservoir capacities could be resilient to water resource changes (Ibid). Under favourable conditions such as the required water level and the requisite managerial processes, hydropower becomes a viable option in the face of emerging climate change. Figure 1 shows the layout of a hydropower process.

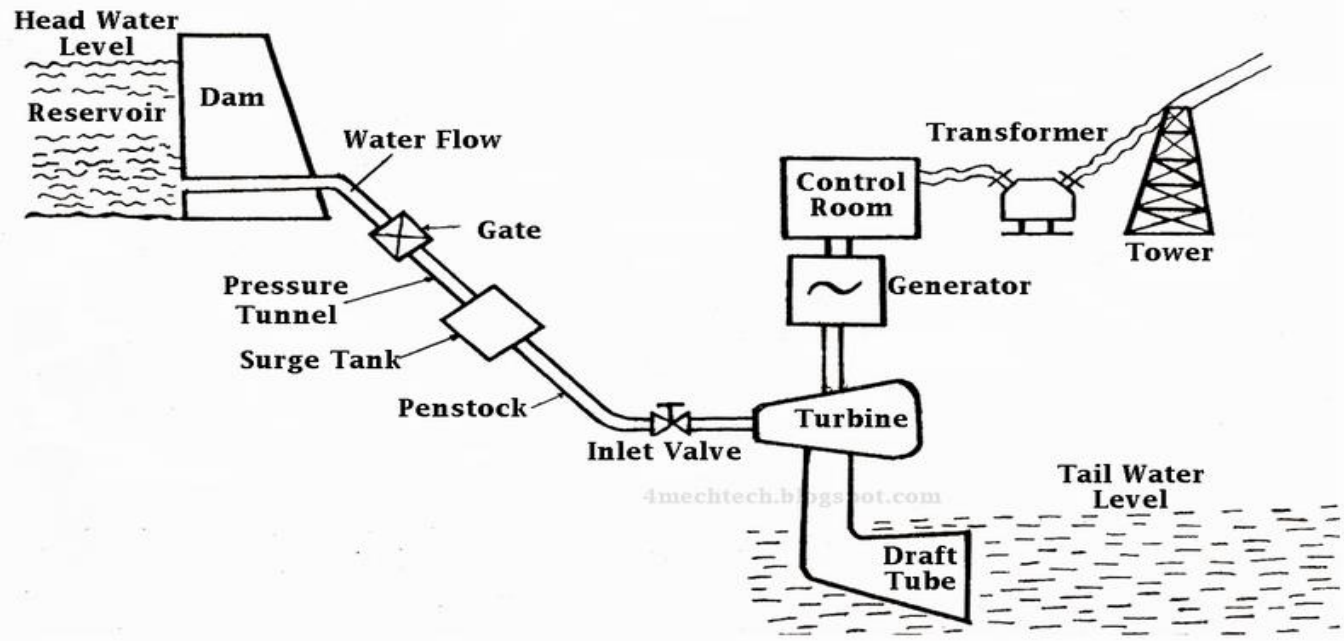

Figure 1: Layout of a hydropower plant
Source: Singh, Raghuvanshi & Sharma, 2007

The required water level is needed for a hydropower dam to run on its full number of turbines to generate its full megawatts of power. The right management is also needed for the necessary maintenance of a dam to ensure it runs adequately during its full lifespan. Within this realm, this study explored how climate change is affecting power generation in hydropower facilities and subsequently proposed a framework to enhance the adaptation management of the hydropower facilities in order to ensure sustainable power generation in the face of the emerging climate change. The research involved a case study of the Akosombo Dam, a hydropower facility in Ghana. The study drew on other scientific studies through a literature review coupled with views sampled through semi-structured surveys with stakeholders within the hydropower and water management sectors. They included managers of the Volta River Authority (in-charge of the operations of the Akosombo Dam), managers of the Energy Commission, Ghana Meteorological Agency and Water Research Institute. The survey also sought views from the local community members to assess the level of their awareness and knowledge on climate change issues. The expert opinions of the managers provided an inside perspective of the management and strategic planning practices of the hydropower. The study uses these opinions to propose a framework that could enhance the management of hydropower facilities within the Ghanaian context.

Research indicates that a hydropower facility is the most widely used form of renewable energy accounting for 16% of global electricity generation of 3,427 terawatt-hours of electricity generated in 2010 (Worldwatch Institute, 2012). This output is expected to increase by about 3.1% per annum over a 25-year period beginning in 2012 (Worldwatch Institute, 2012). Globally, hydropower is produced in about 150 countries, with the Asia-Pacific region generating 32% of global hydropower (International Energy Agency, IEA. 2015). In 2010, China was the largest hydropower producer, producing about 721 terawatt-hours of hydropower (IEA, 2015). In Central America and sub-Saharan Africa over half of all electricity generated is from hydropower sources (Anderson, Pringle & Rojas 2006). Hydropower is often the most preferred renewable energy because of its cost efficiency. The cost per unit of generated hydroelectricity is lower than that of other sources (renewable and non-renewable) including coal gas and oil among others (GyauBoakye, 2001). For instance, in the United States of America (USA), hydropower is produced at an average cost of 0.85 USD per kilowatt-hour (kwh). Under the same condition, this is about 50% the cost of producing power from nuclear and 25% the cost of using natural gas to generate power (Worldwatch Institute, 2012). In addition, hydropower facilities have a longer life span compared to other established electricity generation facilities (Ibid). Given sufficient water

levels and flows, the facilities are also fairly reliable sources of energy. More important and relevant to this study, is the fact that hydropower contributes significantly to preventing greenhouse gas emissions, which otherwise would increase the level of global warming leading to climate change (Kaunda, Kimambo & Nielsen, 2012). While relatively lower polluting than fossil fuels and thus desirable for climate change mitigation, hydropower facilities have some levels of vulnerability to the adverse impacts of climate change. This is because climate change impacts water resources, which are the backbone of these facilities. Indications are that, in future, climate change will affect the availability of water, particularly in Africa due to decreasing rains and rising temperatures in some areas. However, the nature, intensity, and frequency of these changes vary per region. The decreasing rains and rising temperature will in turn affect the operations of hydropower generation in many African countries as they are expected to face climate change induced dryer conditions in the future (Aronica & Bonaccorso 2013).

Until the late 1990s, the main source of electricity generation in Ghana has been hydropower, after which other forms of generation plants, most notably thermal power plants, were introduced to augment the hydropower generation industry (Barry *et. al.,* 2005). Table 1 shows Ghana's energy distribution as at the 2020-year end. The table indicates the various types of power plants, their installed capacity, which represents the maximum capacity they are designed to run at, the dependable capacity representing the load-carrying ability of the power plant, the capacity at peak which is the highest amount of power they can produce at the highest level of demand and the fuel type used at the plants as the source of energy to generate electricity.

Table 1: Ghana energy distribution as at 2020

Plant	Installed Capacity (MW)	Dependable Capacity **(MW)**	Capacity at Peak (MW)	Fuel type
Akosombo Dam	1020	900	900	Hydro
Kpong Dam	160	140	140	Hydro
TAPCO (T1)	330	300	300	LCO/Gas
TICO (T2)	340	320	320	LCO/Gas
TT1PP	110	100	100	LCO/Gas
TT2PP	87	70	70	Gas
KTPP	220	200	200	Gas/ Diesel
VRA Solar Plant	2.5	1.75	0	Solar

AMERI	250	230	230	Gas
Bui Dam	404	360	360	Hydro
CENIT	110	100	100	LCO/Gas
SAPP 161	200	180	180	Gas
SAPP 330	360	340	340	LCO/Gas
KAR Power	470	450	450	Gas
AKSA	370	350	350	HFO
BXC Solar	20	14	0	Solar
Meinergy Solar	20	14	0	Solar
Trojan	44	39.6	39.6	Diesel/Gas
Genser	89.5	18	18	Gas
CEN Power	340	340	340	LCO/Gas
Amandi	190	190	190	LCO/Gas
TOTAL	5,137.0	4657.35	4627.6	

Source: Government of Ghana 2020 Energy Report

The source of energy distribution in Table 1 indicates that Ghana relies heavily on hydropower, contributing 30% of the country's total electricity output. This points to the fact that hydropower energy sources in Ghana cannot be downplayed and ought to be given the required attention by taking enhanced mitigating and adaptive climate actions to prevent and avert any adverse climate change related impacts on the Akosombo Dam.

The Akosombo Dam has been the cornerstone of Ghana's electricity supply since its construction in 1966 (Gyau-Boakye, 2001). The Dam is located in the Volta River Basin, which has a catchment area of over 400,000 square kilometres (km^2) (Barry *et al.,* 2005). Other dams located in the basin include the Bagre and Kompienga dams, which are both located in Burkina Faso, and are both solely used for the purpose of generating hydropower. Over the years, population growth and economic development have continued to stretch the hydropower supply to the point that Ghana is experiencing power supply deficits. The challenge of declining water inflows into the dam has also compelled the Government of Ghana to consider building other sources of power generation including an additional hydropower with the aim of ensuring that these facilities meet both current and future electricity demands. Table 2 shows some of Ghana's power generation projects planned for construction to commence between the years of 2016 and 2020. The table indicates

the installed capacity representing the maximum capacity they are designed to run, the dependable capacity representing the load-carrying ability of the power plant, the proposed timing for the installation and construction of the power plants and the type of fuel to power the plants to generate electricity.

Table 2: Ghana's planned additional electricity generation projects

Project Description	Installed Capacity	Dependable Capacity	Proposed Timing	Fuel type
Osonor/TT1PP Expansion - VRA/IPP	110 MW	100 MW	2016	Gas
Takoradi 3 (T3) - (Phase 2)	132 MW	120 MW	2016	LCO/Gas/Diesel
Domunli thermal project	450 MW	450 MW	2016	Gas
Pwalugu hydroproject	60 MW	48 MW	2020	Hydro

Source: Author's compilation 2021

In the context of a country with a dominant hydroelectricity industry, which is in the process of adding another hydropower facility with 60 MW of installed capacity, it is imperative that the concerned authorities pay due attention to the various threats that could adversely impact this industry. Against this background, this study investigated both the potential and present threats of climate change to Ghana's hydropower facilities through a case study of the Akosombo Dam. Understanding the various aspects of this threat provides opportunities to inform the appropriate adaptation policies and practices relating to the management and operation of the Dam. Broadly, this can add impetus to efforts seeking to enhance Ghana's climate change management policy and practice efforts. More important is that lessons learned from the Akosombo Dam can inform policy and practice in other hydropower facilities in Ghana and beyond.

1.2 Research problem

Climate change is impacting the lives of almost all of earth's flora and fauna. One of the current and future antithetical impacts of climate change is reduced precipitation resulting in moisture stress that adversely affects agriculture and forests among other sectors (Bonan, 2008). At the extreme, this can lead to a severely limited quantity of water flowing into hydropower facilities such as dams and lakes consequently adversely affecting both the social and economic contributions of such reservoirs. Most notable and of relevance to this study is the fact that water shortages reduce the capacity and efficiency of hydropower generating water reservoirs (Aronica

& Bonaccorso, 2012). This means that as the climate change phenomenon firmly establishes itself, countries that are heavily reliant on hydropower are at risk of power supply deficits and reliability. Ghana is one such country.

Presently, Ghana faces an electricity supply deficit, which is adversely affecting the country's economic and social development and growth objectives. The electricity deficit is largely attributable to the supply side capacity, which has not grown to match demand. Part of the supply side challenges are linked to problems at the Akosombo Dam, Ghana's largest source of electricity since its independence in 1963 (Barry *et. al.,* 2005). Generating electricity at the facility, like at all other hydropower facilities, depends on the level of water in the dam. In general, the higher the level of water the higher the generating capacity of the dam. The Akosombo Dam faces the challenge of inconsistent water levels. Most recently, the Dam has been undergoing a consistent drop in its water levels leading to a reduction in its electricity generating capacity. This in turn has resulted in electricity supply deficits and inconsistencies all of which have had adverse economic and social implications for the country. In the economic sphere, the inadequate and unreliable power supply has led to lost production and in some cases even to the closure of some firms resulting in the loss of jobs (Ghana Statistical Service, 2015).

The consistent drop of the Dam's water level has been attributed to the climate change reduced precipitation within the Dam's catchment area. However, this has not been ascertained through research. Also, changes in the water levels in the Dam may be attributable to other factors, such as the siltation of the reservoir thus reducing the Dam's water carrying capacity, and the building of reservoirs and increased water harvesting upstream from the Dam. This study seeks to investigate and determine the extent and form to which climate change has contributed to the reduction of water levels in the Akosombo Dam. Simultaneously, it will also identify other factors that might have been the cause of the reduction of water levels in the Dam. Findings from the research may contribute to the management of current and planned hydropower facilities in Ghana and beyond. The findings may also shed light on the prudence of Ghana's focus on hydro energy sources of power.

1.3 Purpose: research questions, aim and objectives

This section encompasses the purpose of the study, which will be achieved by answering the research questions, aim and objectives. Three research questions were covered in the course of the study, namely

(i) what are the literature gaps and theories regarding the phenomenon of climate change and its effects on the generating of hydropower?

(ii) what is the nature and extent of climate change linked variations on rainfall quantities and temperature patterns within Akosombo (the location area of the Dam) and the surrounding areas and its effects on the Dam's electricity generating capacity?

(iii) how is climate change related institutions and policy regime responding to the climate change impacts in Ghana?

Broadly, the aim of this study was to determine the extent to which climate change has contributed to changes in the Akosombo Dam's electricity generation capacity, and how different relevant authorities are responding to the management of climate change impacts. The study also aimed to develop some climate change adaptation frameworks that can be used in managing hydropower. To answer the research questions and achieve the study's aim, the study advanced the following four objectives, namely

(i) to examine the theoretical concept of the phenomenon of climate change and its effects on hydropower generations

(ii) to determine the nature and extent of climate change linked variations on rainfall quantities and temperature patterns within Akosombo and the surrounding areas and its effects on the Dam's electricity generation capacity

(iii) determine how the climate change adaptation institutions and policy regime are responding to the management of climate change in Ghana

(iv) develop comprehensive conceptual management adaptation frameworks that enhance climate change adaptation management of hydropower within the Ghanaian context.

1.4 Study area

The focus of the study is Ghana, a country located on West Africa's Gulf of Guinea. The Akosombo Dam is the study site and is used as the case study. This Dam is located within the south-eastern part of Ghana in the Akosombo gorge and forms part of the Volta River Authority.

Figure 2 shows the location area of the Akosombo Dam whilst Figure 3 shows the outlook of the Dam.

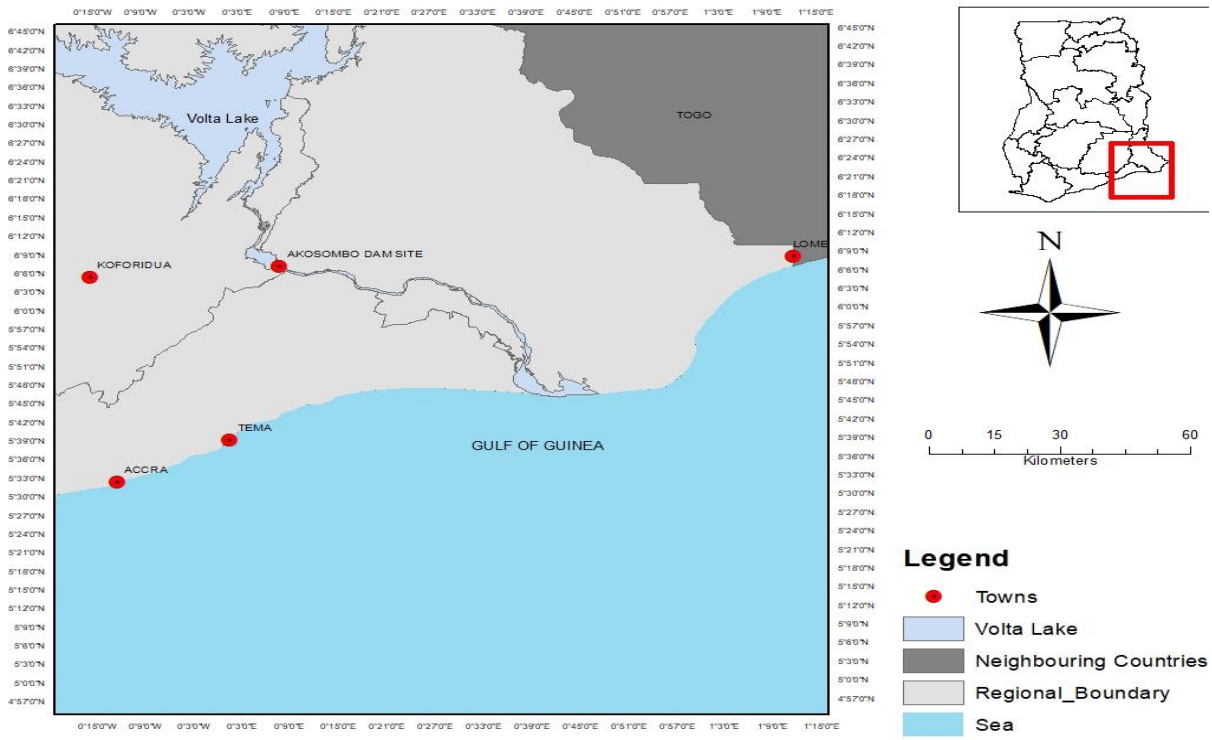

Figure 2: Area of location of the Akosombo Dam.
Source: Author, 2021

Figure 3: Outlook of the Akosombo Dam and its outflow
Source: Field picture taken by author, 2021.

1.5 Research methodology

Restricting this study to a single region and seeking that the findings inform policy and practice here and elsewhere, the research adopts the case study design. Yin (2006) states that case study research is an approach to research that facilitates exploration of phenomenon in bounded systems within its contexts using a variety of data sources. According to Stake (1995) and Yin (2003), there are different types of case study research, some of which include:

i. Exploratory case study. This type investigates distinct phenomena characterised by a lack of detailed preliminary research and/or by a specific research environment that limits the choice of methodology.
ii. Explanatory case study. This type of case study is used when a researcher is seeking to answer a question that will explain presumed casual links in real-life interventions that are too complex for the survey strategies.
iii. Multiple-case studies. These studies enable the researcher to explore differences within and between cases. iv. Single case study. This type of case study design is used when there is only one subject matter under investigation.

The paucity of research in hydropower facilities adaptation to climate change in Ghana and beyond renders the exploratory single case study approach acceptable for this study. This exploratory single-case study made use of the mixed method strategy to collect data that address the research objectives. The mixed method approach involves collecting and analysing a mix of qualitative and quantitative data in a single study or series of studies (Creswell & Plano Clark, 2011). The gathering and analysis of both qualitative and quantitative data provide a better understanding of the research problem than either data types (Creswell & Plano Clark, 2011).

1.6 Significance and contribution of the study to body of knowledge

Climate change is an interrelated global issue and therefore the significance of this study borders on a diverse range of issues. As the study deals with the impact of climate change on hydropower facilities, the significance of the study affects the following areas by helping to enhance their existence and making them more profitable. These areas include water conservation, energy conservation and tourism as the Akosombo Dam site serves as excursion and tour site to the general public, especially students. Beyond this, the study addresses four of the United Nations Sustainable Development Goals. The United Nations has set 17 priority goals to be achieved in the world by the year 2030 as indicated in Figure 4.

Figure 4: United Nations Sustainable Development Goals
Source: UNDP (2015)

The four SDG goals addressed in this study are: SDG goal 7 (access to affordable, reliable, sustainable and modern energy for all), SDG goal 13 (climate action), SDG goal 14 (life below water) and SDG goal 17 (partnership for goals). Hydropower is known to be the cheapest source of renewable energy and by working towards enhancing its efficiency, the SDG goal 7 (access to affordable, reliable, sustainable and modern energy for all) is addressed. SDG goal 13 (climate action) is addressed as the study covered the impact of climate change on hydropower. The Dam water carries biological life and by working towards enhancing and maintaining the appropriate water level, life below the water is protected and this satisfies SDG goal 14 (life below water). By engaging the stakeholders in the energy sector (management of the Volta River Authority, Energy Commission, Ghana Meteorological Agency and the Water Research Institute), SDG goal 17 (partnership for goals) is addressed.

This study also contributes to the body of knowledge through the development of a conceptual climate change adaptation framework that is expected to enhance climate change adaptation management of hydropower within the Ghanaian context. The study also informs climate change adaptation strategies in the management of the Akosombo Dam. By extension, lessons drawn

from the study can be applied in the wider African context since the challenges within the African continent are similar.

1.7 Ethical consideration

An application for ethical clearance for this study was sought from UNISA's ethics committee. After satisfying all requirements pertaining to the conduct of the surveys and interviews, the committee granted the approval for the conduct of the study in March 2, 2017. The approval is with reference number 2017/CAES/037 (Appendix 1). During the surveys and the interviews, individual informed consent forms (Appendix 2) from the College of Agriculture and Environmental Science was used to seek the written consent of participants involved in the research. The informed consent forms explained the details of the study and assured participants that information gathered for the study would be used only for the purposes of the study.

In cases where engagements needed to be recorded electronically, the consent of the participants was sought prior to recording. All voice and/or visual records were only accessible to the principal researcher. The vocal records were kept in a locked drawer in the office of the principal researcher. The voice and visual records will be destroyed after 5 years of completing this study. The reporting of the study findings was in a way such that respondents would not be identifiable. Participants were informed that participation was voluntarily and that it was their right to withdraw participation consent at any time during the course of the study.

1.8 Thesis outline

The outline of the final thesis is as follows:

Chapter 1:

This chapter contains the introduction and background to this study. It explains the importance of the study and spells out the research problem, research questions, aim and the objectives of the study.

Chapter 2:

This chapter reviews available literature on climate change theories and concepts, answering the first research objective. Greater emphasis is placed on climate change adaptation and identification of literature gaps within the area of this study. The chapter is divided into four sections. The first section presents a broad discussion of the climate change phenomenon stating

its drivers, impacts and risks. The second section discusses climate change management. The third section locates the climate change in hydropower plants in general whilst the fourth section provides the chapter conclusions.

Chapter 3:

Chapter 3 provides the research design and methodology employed in this study. It describes and explains the rationale behind the choice of the study area, the research design and data collection instruments used in the study. It also indicates the sources of the data and the mode of questionnaire administration and how all results were obtained in general. The chapter further discusses the ethical considerations, the research limitations encountered and the ways in which the limitations are dealt with to augment the quality of the research process.

Chapter 4:

Chapter 4 aims to identify the impact on the power generation capacity of the Akosombo Dam and any physical changes it might have undergone due to climate change-linked variations over the years. The chapter focuses on climate change-linked variations in relation to rainfall and temperature patterns within Akosombo (the location of the Dam) and its surrounding areas and how these variations might have affected the Dam's electricity generation activities. Specifically, the chapter also addresses the second and the third research objectives. This is done in four sections where the first section discussed issues relating to the changing rainfall quantities and patterns, followed by the examination of climate change linked temperature patterns, evidence of physical changes on the Akosombo Dam and its impact on hydropower generation and the last section contains the chapter conclusion.

Chapter 5:

This chapter connects the physical issues that relate to the impacts of climate change in and around the Akosombo Dam to the national climate change policy and legislation regime in Ghana. It presents, analyses and discusses how the policy and legislation regime in Ghana is affecting practices that seek both mitigation of and adaptation to climate change. It did so by examining and discussing the range of Ghana's policies, programmes and legislation relating to managing of climate change. The chapter specifically addresses the fourth research objective. This is done by first focusing on the broad policy and legislation terrain, followed by the focus on the climate

change challenge and its management. This is followed by a discussion on how government implementing agencies apply the management of climate change.

Chapter 6:

Chapter 6 focuses on this study's contribution to the body of knowledge, which addresses research objective four. The chapter proposes a comprehensive conceptual management adaptation framework to enhance climate change adaptation management of hydropower within the Ghanaian context. The frameworks were built based on gaps identified in the literature, views expressed during the interviews and borrowing of theories from literature. The chapter is divided into three main sections. The first section discusses the need and choice of framework, the second section discusses three frameworks which the study proposes as its contribution to the body of knowledge, and the third section concludes the chapter.

Chapter 7:

The final chapter summarises the findings, gives the shortcomings and the limitations encountered in the study, placement of the study within the literature, the study's contributions to the body of knowledge, and appropriate recommendations and conclusions. The chapter spells out the study's implications for the literature, implications for the management of hydropower, government policies, and for communities within the catchment area. Suggestions for further research are also stated in the chapter.

1.9 Chapter conclusion

This chapter sets the stage for the study and highlighted the main investigations and activities carried out during the course of the study to answer the research questions and achieve the aims and objectives. Climate change is a global challenge that impacts every sector of the economy. This study narrows the impact of the climate change to the impact on hydropower generation using the Akosombo Dam (the largest hydropower Dam in Ghana) as case study.

Among the other sources of energy production in Ghana, the Akosombo Dam is the largest contributor (Table 1). Efficiency of hydropower sources largely depends on the height of the water level in the dam. During certain years, the water level in the Akosombo Dam drops so low that management is compelled to reduce the number of turbines needed in the Dam to produce electrical energy. This cuts down the required amount of electrical energy needed per day leading

to a plunge in economic activities in Ghana. This and the identified research gaps related to climate change in hydropower demonstrate the need for this study. The questions, aims and objectives of the research paved the way forward in addressing these research gaps and the climate change impacts on hydropower production. The study further proposed a framework that enhances adaptation management of hydropower in the face of emerging climate change impacts. The study addresses some of the United Nations Sustainable Development Goals, namely goal 7 (work on affordable clean energy), goal 13 (work on climate action), goal 14 (life below water), and goal 17 (partnership for goals).

Even though the issues of climate change are global, this study is focused on Ghana using the Akosombo Dam as a case study. However, the findings and recommendations can be applied in the wider African context and beyond. The following chapter gives the overview of theoretical and contemporary literature on the phenomenon of climate change, narrowing it down to its impact on hydropower.

CHAPTER 2: LITERATURE REVIEW

"What do researchers know? What do they not know? What has been researched and what has not been researched? Is the research reliable and trustworthy? Where are the gaps in the knowledge? When you compile all that together, you have yourself a literature review." (Jim Ollhoff, 2019;32(2):49-50) (Reported by Bindu Sharma, 2019)

2.1 Introduction

This chapter presents the theoretical concepts that informed this study. They consist of the phenomenon of climate change, climate change-related risk, managing climate change and the interaction between climate change and hydropower plants. The chapter addresses the first research objective, which is to examine the theoretical concept of the phenomenon of climate change and its effects on hydropower generations. To do this, the chapter is broadly divided into five sections, which elaborate on the details of the theoretical concepts. The first section presents a broad discussion of the climate change phenomenon stating its drivers, impacts and risks. The second section deals with details of climate change-related risk, the third discusses the management of climate change, the fourth section locates hydropower plants in climate change discourse whilst the fifth section concludes the chapter.

2.2 Climate change: an overview of the phenomenon

Climate change is arguably one of the biggest challenges confronting the world's economic, social and environmental development efforts in the 21st century (Mendelsohn, 2013). As harsh as it may be, some communities are trying to adapt to the climate in which they live (Massetti & Mendelsohn, 2018). Drying lakes and rivers, flooding and rising sea levels are serious climate change-induced threats to natural resources, infrastructure, and human communities (Asante & Awuakwa-Mensah, 2015). According to Triscos, Mercow and Pigot (2020), there would be intolerable consequences if these climate change-induced threats remain. It has been established that most of the adverse impacts of climate change will be felt in developing countries with the African continent bearing the brunt of most of these effects (Stern *et al.,* 2006). Indeed, there is evidence of temperature increases and the decreasing of rainfall in a continent that faces deficits in food supplies largely because of the inadequacies of a dominant rain-dependent and predominantly subsistence agriculture sector (Keen, Barbara, Carpenter, Evans, & Foukona, 2017).

In addition, unplanned human settlements in an increasingly urbanising continent render some urban settlements vulnerable to climate change-linked flooding because some of these settlements are located in flood plains that in the majority of cases do not have adequate storm drainage infrastructure (Ibid).

Climate change can be defined in several ways. The Intergovernmental Panel on Climate Change (IPCC) defines it as “a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties that persist for an extended period, typically decades or longer” (IPCC, 2012:3). It also states that climate change is driven by both natural processes and persistent anthropogenic activities that change the gaseous composition of the atmosphere. Boadu (2016) cited the definition of the United Nations Framework Convention on Climate Change (UNFCCC) as “a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods” (UNFCCC, 2001: 18). A common feature of these and other definitions is that climate change is a long-term phenomenon with significant changes occurring over decades. In that regard it is different from climate variability, which is a short-term occurrence. Another distinguishing feature between climate change and climate variability is that the former is attributable to both natural and human activities while the latter is solely attributable to natural causes (IPCC, 2011).

It is well known that the earth’s climate is controlled and maintained by a continuous flow of energy from the sun (Beer, Mende & Stellmacher, 2000). Heat energy from the sun passes through the earth’s atmosphere and warms the earth’s surface. As the temperature of the surface increases, heat energy is sent back into the atmosphere (Ibid). Some of this heat is absorbed by gases in the atmosphere. The key gases, also classified as climate indicators in this regard include carbon dioxide (CO_2) a major contributor to global warming, water vapour, methane, nitrous oxide, ozone, and halo carbons (Bruhwiler *et al.,* 2021). These naturally occurring gases act as a blanket, trapping in the heat and preventing it from being reflected too far from the earth. They collectively keep the earth’s average temperature at about 15 °C which is warm enough to sustain human life as well as that of different flora and fauna (Allen *et al.,* 2018). Without these gases, the average temperature would be about -18 °C which is too cold for most life forms (Ibid). This natural warming effect results in what is called the greenhouse effect (Bruhwiler *et al.,* 2021). A rapid increase in the atmospheric concentration of these gases is mainly due to human activity,

particularly from the burning of fossil fuels and deforestation. This adds further insulation in the atmosphere driving the global warming effect which results in climate change (Ibid). The negative impacts and projected outcomes of climate change include an increase in average global temperature resulting in the melting of icebergs, which in turns result in sea-level rises, increase in the frequency and intensity of extreme weather events such as floods, droughts, snow falls and storms among other changes in weather patterns (David *et al*., 2000; Asante & Awuakwa Mensah, 2015). All these outcomes present climate risks that threaten the economic, social and environmental wellbeing of the earth's flora and fauna. For human beings, the risks are direct and include events such as drowning in floods and suffering heat-strokes from heat waves or indirect events such as damages and the destruction of infrastructure that supports human economic and social activities. Climate change does, however, also present opportunities. For example, opportunities come in the form of new business approaches arising from a demand for goods and services that suit the new climatic conditions such as a demand for certain clothing to help humans in extreme weather conditions. The observed and anticipated adverse impacts of climate change make it imperative to manage the associated risks.

2.3 Climate change related risks

Engel, Enkvist and Henderson (2015) identified six distinct climate change risks. The six comprise three risks that can be said to be external-stakeholder linked risks and the other three value-chain inherent risks.

2.3.1 External-stakeholder risk

External stakeholders' risks are those risks that are normally beyond the control of an entity (business, school or other organisations). Such risks are typically unpredictable, and usually occur at a low rate. Distinctly, such risks are normally influenced by external stakeholders. Examples of such risks are reputational risks, regulatory and ratings risks that relate to the climate change phenomenon.

(i) Reputational risks

This group of risks relates to the probability of adverse business impacts such as a decline in profitability as a result of customers avoiding purchasing a business's products and services because their production involves inputs and/or processes that the public considers being drivers of climate change and other forms of environmental degradation (Engel *et al*., 2015; Walsh, 2006).

Such perceptions, ultimately and adversely impact business viability and profitability. Several companies from a range of industries already project themselves as environmentally friendly broadly and climate change-friendly in particular. This projection helps to maintain established customer bases as well as attracting new clients. This is important for an increasingly climate change conscious clientele globally. Under such conditions, firms that successfully convince captured and potential clients that they are actively working to mitigate climate change stand to gain greater market shares at the expense of companies seen as lagging in the commitment of addressing climate change issues (Walsh, 2006). As consumers become increasingly aware of climate change, its drivers and adverse impacts on themselves and other communities, some companies may find themselves at a disadvantage if competitors manage to take the lead in promoting a positive image for their brand on the issue (McKibbin & Wilcoxen, 2002; Kortum & Weisbach, 2017).

(ii) Regulatory risks

These risks refer to the government action of enacting national, provincial (state or county) or local government policies and regulations that seek to manage the climate change phenomenon (Corfee-Morlot *et al.,* 2009; Coalition for Urban Transitions, 2019). For example, in Ghana the climate change management efforts are informed by the National Climate Change Policy of 2013. The policy articulates a vision of ensuring a climate-resilient and climate-compatible economy through equitable low-carbon economic growth (Government of Ghana, 2013). A number of regulations have been enacted to deliver this vision. Most notable in this space is the Renewable Energy Act, 2011 (Government of Ghana, 2011). The ultimate aim of the Act is to reduce energy-linked GHG emissions in Ghana by increasing the share of renewable energy in the country's energy mix. Elsewhere, Ethiopia has charted a course to become a middle-income country through low-emissions growth strategy as articulated in its Climate-Resilient Green Economy Strategy (Government of Ethiopia, 2011). Outside Africa, most states in the USA have introduced renewable energy portfolio standards, which require a certain proportion of their electricity to be produced from renewable sources (Rabe, 2007). In the state of Texas this has resulted in the rapid development and usage of wind energy compared to the usage of non-renewable energy.

As governments and world bodies enact and define GHG emission limiting regulations, enforcement actions can be expected against organisations that do not meet the set standards. Such actions include financial fines some of which may involve costly litigation (Walsh, 2006).

Organisations that make informed and voluntary efforts to reduce their emissions sooner rather than later will, all things being equal, find themselves in a better position to meet such dictates of regulations compared to those that wait for mandatory regulations (Ibid).

(iii) Rating risk

Ratings risk is the possibility of higher costs of capital because of climate-related exposure (Nordhaus, 2017). Such costs, inter alia, include high-interest rates on business loans, carbon pricing, supply-chain disruption, or product obsolescence (Engel, et al, 2015; Nordhaus, 2017). Ratings risk varies widely between and within industries. It is prudent for industries and companies to know the quantity of their GHG emissions as the first step to reducing them. The Carbon Disclosure Project is an initiative that seeks to encourage the private sector to determine and publicly disclose its GHG emissions. Its premise is that what is measured can be managed.

Although the three aforementioned risks are outside the control of various entities, there are those that are inherent in the various value chains in which entities operate. These types are discussed in detail in the following sub-section.

2.3.2 The value-chain inherent risks

This category of risks is characterised by uncertainties that affect the supply chains of businesses as a result of climate change impacts (Phyper & MacLean, 2009). The three distinguished risks under this category are physical risks, product risks, and price risks.

(i) Physical risks

In the climate change discourse, physical risks relate to damages to infrastructure such as roads, railway lines, bridges, factories and supply-chain operations, caused by an increased frequency and intensity of extreme weather events that include floods, wildfires, droughts, storms, rising sea level, or hurricanes (Phyper & MacLean, 2009; Trisos, Merow & Pigot 2020).

Virtually every value chain of any economy faces risks from the short and long-term physical effects of climate change (Walsh, 2006; Covington & Thamotheram 2015). Some impacts are direct, and others are indirect. An example of a direct impact is the case of property damage due to flooding. An example of an indirect impact is the case of reduced water availability due to droughts that result in competing demands between needs, such as the demand for water for

domestic use and the demand for the same water for commercial activities that include agriculture or the service industry and the manufacturing of industrial applications (Ibid).

Physical risks to climate change inevitably carry a pecuniary impact. The impact is repairing and replacing damaged infrastructure. Other impacts are indirect, for example, in 2012, Cargill, one of the world's largest food and agricultural companies, posted its worst quarterly earnings in two decades largely because of a drought that adversely impacted agriculture production in the USA (Engel et al, 2015).

(ii) Product risks

Product risks refer to core products becoming unpopular or unsellable as a result of a total change in applications and processes in which a business operates (Engel et al, 2015). For example, alternative cooling technologies could conceivably displace the current dominant air-conditioning systems that are important for indoor cooling to cope with climate change-linked increases in ambient temperatures. The new generation of air-conditioning systems could be designed to be of higher energy efficiency to meet climate change management regulations pertaining to energy efficiency among other related dictates.

Engel *et al* (2015) have suggested that companies can mitigate the adverse impacts of product risks by adopting an approach called the design to sustainability approach. Such an approach seeks to minimise waste through either the efficient use of virgin materials or through the reuse or recycling of materials. It also includes designing energy-efficient goods, services and processes. The design to a sustainability approach involves redefining corporate strategy seeking to align business interests with climate-change management.

(iii) Price risks

Price risks refer to the increased price volatility of raw materials and other commodities due to climate-related events (Roel *et al.*, 2014; Lamperti *et al.,* 2018). For instance, drought can increase the price of water or farm produce. Similarly, climate-related regulation can drive the cost of energy up. Organisations operating in climate-sensitive spaces are, by association, at a greater risk to the adverse impacts of climate changes compared to those that are not (Bowyer, Bender, Rechid & Schaller 2014).

While the focus of the discussion on climate change typically centres on the threats the phenomenon poses and the seriousness of the associated problems, climate change also provides business opportunities (Ibid). This may be because climate change management technologies and innovations can create lucrative business opportunities. For instance, opportunities for entrepreneurship are abound as evidenced by the staggering rise of "clean tech" companies and funding in recent years (Howard-Grenville, Buckle, Hoskins & George 2014). Equally available are opportunities for social entrepreneurship to address the challenges confronting the world's vulnerable societies, as well as natural and built infrastructure (Ibid). In this mix, what emerges strongly is that the climate change phenomenon needs to be managed to minimise its adverse impacts and to explore the potential opportunities.

2.4 Managing climate change

The management of climate change is categorised under two broad areas; namely climate change adaptation and climate change mitigation (UNFCCC, 2001; Boadu, 2016). Generally, climate change adaptation is an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects that moderate harm or exploit beneficial opportunities (IPCC, 2007). In contrast, climate change mitigation is an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases (Ibid). This aims to reduce or halt GHG emission and with that manage global warming and ultimately climate change. The details of the two approaches are discussed in the next two sub-sections.

2.4.1 Climate change adaptation

Global climate models indicate the earth will continue to get warmer over the 21st century, with temperature increases of 0.3 ^{o}C to 4.8 ^{o}C projected by the period 2081 to 2100 (IPCC, 2018). This calls for action to avoid the consequences of climate change that will affect humans as well as all the earth's flora and fauna. In other words, there is a need to learn to live with the consequences of climate change and minimally (as technologically and otherwise possible) suffer from its adverse effects (Massetti & Mendelsohn, 2018). This is the essence of climate change adaptation. For example, building flood defences will help minimize the destruction of infrastructural properties and the building of sea defence systems will help prevent the sea from submerging nearby lands.

Adaptations are manifestations of adaptive capacity, and they represent ways of reducing vulnerability. The forces that influence the ability of a system to adapt are the drivers or determinants of the adaptive capacity (Adger, 2003; Adger, Brown & Surminski, 2018). Examples of the determinants of adaptive capacity include economic resources, technology, infrastructure and institutions. In this space, economic resources are critical for gaining access to the necessary approaches and technologies needed to carry out the adaptation process (Smit & Pilifosova, 2001; Systemig, 2020). In this realm, increasing adaptive capacity, implies diversifying the economic activities of a jurisdiction (continental, national or sub-national) to allow access to a broader range of income sources to tackle adaptation (Smit & Pilifosova, 2003; Siders, 2019). Access to technology determines how innovation can be used in tackling the climate change stresses, making technology an important determinant of adaptation as well (Smit & Pilifosova 2001; Systemig, 2020). Linked to technology is infrastructure as critical element of adapting to climate change. Physical infrastructure, such as roads, railways, dams and buildings are critical in this regard as their ability to withstand the impacts of climate change are a measure of adaptation (Ibid).

A critical issue in this space is that the determinants of adaptive capacity are not independent of each other. For example, the presence of a strong kinship network may increase adaptive capacity by allowing greater access to economic resources, increasing managerial ability, supplying supplementary labour and buffering psychological stress (Smith & Wandel, 2006). The capacity of a system, household or community to cope with climate risks depends on the combination of the presence of an enabling environment in the community and resources and processes that drive adaptation measures and practices (Smit & Pilifosova, 2003; Siders, 2019). From the assertions of Smith and Wandel (2006), Smit and Pilifosova (2003), and Siders (2019), it can be said that the adaptive capacity of a system, household or community largely depends on its natural and human resources. This makes the quality of institutions a critical determinant of adaptation. Strong and high-quality institutions are critical for enhancing management capacities as well as building and maintaining long-term stable and consistent policies that support adaptation process making the institutions an important determinant.

Adaptation practices present economic opportunities to both private and public enterprises. The opportunities manifest in the development of both software and hardware that advance the adaptation agenda. An example of soft involvement in the adaptation space is information

technology software that enables the prediction of events linked to climate change and thus allowing for planning to appropriately and adequately adapt to extreme weather events. The hardware aspects involve creating adaptation infrastructure such as drainage systems to channel flood waters from the built environment or constructing dams and lakes to mitigate water shortages resulting from climate change induced droughts. To this end, a distinguishing feature of adaptation activities is that adaptation measures are typically location specific because the form and extent of the adverse impacts of climate change differ among geographic locations as determined by the vulnerability of these locations (Smith & Wandel, 2006). Differences in vulnerability to the adverse impacts of climate change arise from features such as topography, soil type, vegetation cover and the nature and forms of the built-environment among other determinants (Laukkonen *et al*., 2009). Consequently, local organisations are often best suited to deal with predictable, as well as unforeseen adaptation measures that may be necessary (Dovers & Hezri, 2010). Another feature is that adaptation measures are characterised by uncertainties as they both anticipate the severity and extent of adverse impacts of climate change events as well as dealing with such impacts after the fact (Laukkonen *et al*., 2009). Furthermore, adaptation measures have an inherent long-term horizon meaning that their benefits may not be immediately discernible (Ibid). This renders monetary expenditure in adaptation investments unpopular particularly when resources are scarce. This has led to a situation in which adaptation policies and measures lag behind those focused on mitigation. Within these characteristics of adaptation measure, the IPCC (2001) distinguishes three types of adaptation approaches as; (i) anticipatory or proactive adaptation, (ii) planned adaptation, and (iii) autonomous adaptation as being important.

Anticipatory or proactive adaptation is an adaptation that takes place before the dire impacts of climate change are experienced. The principle of anticipatory adaptation rests on the adage 'prevention is better than cure'. It seeks to avoid the high costs of action after the occurrence of an adverse climate change event. For example, having a seasonal climate forecasting strategy in place can help individuals or households prepare to avert the possible adverse impacts of climate change-induced flooding or drought. Anticipatory adaptation can be private adaptation in which case it is initiated and implemented by individuals or households out of their rational self-interest (Ibid). Alternatively, the adaptation could be public, meaning that the adaptation is initiated and implemented by governments at all levels and usually directed at collective needs (Osberghaus, Finkel & Pohl, 2010).

In *planned adaptation* a deliberate policy decision is in place, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve the desired state (IPCC, 2013). An example of planned adaptation is the carrying out of a normative exercise that involves the identification of possible policy strategies to inform adaptation practices based on the vulnerability across the broad range of climate change exposed situations (Tompkins *et. al.,* 2005; Massetti & Mendelsohn, 2018). This is then followed by an evaluation of options to minimise the adverse impacts of climate change under the given situations. For example, the identification and drafting of water development policies to tackle dwindling water resources resulting from climate change-linked increases in the severity and frequency of droughts. This can inform the kind of adaptation practice to be carried out, followed by evaluation and the determination of how best this can be done in order to reverse or minimise the adverse impacts of climate change-linked scarcity of water.

Autonomous adaptation refers to the changes that natural and most human systems go through in reaction to changes in their immediate environment. Such reactions occur irrespective of any broader plan or policy-based decisions (IPCC, 2013). Changes are triggered by observed changes in weather patterns that result in shifting market signals or welfare changes such as increases and changes in the prevalence of climate-linked diseases or changes in food crop yields that affect prices (Abdul-Razak & Kruse, 2017). Autonomous adaptation reactions include actions such as changes in farming practices in reaction to altered natural precipitation patterns, the purchase of air-conditioning devices due to increases in ambient temperatures and changes (both qualitatively and quantitatively) in the consumption of essential and leisure products (Amarnath & Ashok, 2017)

While there is a conceptual distinction between the different types of adaptation, they overlap in theoretical and practical terms. This is because as the adverse impacts of climate change increase, the need for adaptation policies, plans and measures also increases. For example, as climate change drives sea-level rises leading to the submerging of some coastal infrastructure such as homes and roads, there is the need to draft adaptation policies, take emergency plans and measures that reverse or minimise the related adverse issues affecting such communities. This means implementing adaptation policies to avoid these adverse impacts on the environment, infrastructure and people. Among the three types of adaptation, the anticipatory or proactive

adaptation is preferable. Its advantage is that it avoids or mitigates the adverse impact of climate change and minimises the financial and emotional costs of repairing damages that result from events linked to climate change.

However, it is not always possible to plan adaptation before the adverse events take place. Sometimes, communities react after the event either because they were not informed and consequently ill-prepared for an event or there was scepticism or inadequate resources to proactively adapt. This gives rise to the concept of reactive adaptation, in other words intervening after the climate change event. This has far-reaching consequences compared to the proactive adaptation. For example, in July 2005, Mumbai experienced an exceptionally high volume of rain which had a huge human and socio-economic impact and the loss of 630 lives (Stecko & Barber, 2007). Since flooding in Mumbai is an annual occurrence, it is reasonable to posit that the loss of human life was avoidable had the authorities proactively put appropriate and adequate measures in place before the rains came to protect human life and infrastructure. After all predictions of increases in the frequencies and severity of such events are established.

As the need for adaptation becomes visible and inevitable and can no longer be avoided or denied, it also becomes increasingly important to mainstream adaptation into routine economic and social activities. This necessitates the need to consider policies and practices that can either hinder or enhance adaptation efforts. This is the focus of the following sub-section.

2.4.2 The determinants of climate change adaptation practices

A guide to actions in both private and public sector practices is a policy regime that is supported by the relevant laws and regulations and where there is an adequate and relevant stock of appropriate best practice benchmarks and protocols. Vij *et al.* (2017) posit that four characteristics are important in the climate change policy space pertaining to adaptation, namely (i) flexibility, (ii) adaptiveness, (iii) scalability, and (iv) reflexivity.

(i) Flexibility

The flexibility characteristic relates to institutional flexibility. The term ‘institution’ in this case refers to laws and regulations governing it as described by North (1990). The essence of the institutional flexibility argument is that the unpredictable nature of the adverse impacts of events linked to climate change may demand a rapid change by institutions to cope with these impacts. This is

important to ensure that adaptation reactions do not remain locked in outdated policy decisions and remedies that may be both inadequate and irrelevant (Allen *et al.*, 2011 & Stiglitz, 2019). For example, in the 20th century when the rise in sea levels was low, people were allowed to live close to the coast. Now that climate change has accelerated the rate at which sea levels rise, people living close to the coast are being displaced rapidly compared to what happened in the 20th century. Therefore, policies, protocols and practices that relate to constructions in shorelines need to change to address this reality. Under such circumstances, a flexible institutional regime helps in taking effective decisions on short, medium and long-term strategies that strengthen response capacities and preparedness, reduce risks and promote effective adaptation. In contrast, an inflexible policy means that residential and business zoning policies may be difficult to change rapidly thereby exposing some communities to rising sea-water levels. Indeed, new perspectives on the magnitude of the scope of climate change adaptation measures are emerging as the previously entrenched challenge concerning the paucity of climate related data to inform climate change management policies and practice is being addressed (Venturini *et al.,* 2018). The related improvements can be contributed to a continuous increase and improvement in the sophistication, affordability, compactness and use of technology, which is enabling the rapid generation and analysis of copious data sets.

(ii) Adaptiveness

Related to the institutional flexibility characteristic is the need for policy approaches that adapt to the changes in the terrain of climate change management. The crux of this characteristic is governing under conditions of uncertainty; typical of the climate change adaptation policy and practice space. The adaptive nature of a policy response is lodged in the decision-making pathway and the flexibility of the decision by the institution (Wise *et al.,* 2014 & Du Toit *et al.,* 2018). This is important because climate change management policies have to take into account the level of uncertainty and the inter-temporal complexity of the climate system. This demands adjustable policies meaning that the decision-making process in the adaptation policy space should take into account the level of high uncertainty and the inter-temporal complexity (Wise *et al.,* 2014). Against this background it becomes necessary to prioritise adaptation efforts in communities where vulnerabilities are highest and where the need for safety and resilience is the greatest. It is at this level that lives and livelihoods can be protected, development promoted and safety and resilience ensured. These can also be carried to the national level.

(iii) Scalability

The effects of climate change go beyond any country's border and have an impact on other localities. This makes the scalability characteristics an essential factor because climate change is global in nature and adaptation responses could involve cross-scale interactions that go beyond a particular locality, border, nationality and regional boundaries (Wise *et al.*, 2014). Given this and the dynamics of the climate change phenomenon and its adverse impacts, it is important to draft policies and measures that learn from past experiences and also draw from predicted future outcomes. An example is the series of flooding events that occurred in the United Kingdom (UK) in late 2013 and early 2014 during which a series of major storms hit the UK in quick succession, leading to extensive and persistent flooding across England and Wales (Demski *et al.,* 2017). The impacts were consistent with projections for increased climate change-linked flooding risk in the UK. The events of 2013 and 2014 led to a major emergency response and drafting of policies to manage similar events in the future (Huntingford *et al.,* 2014).

(iv) Reflexivity

Drawing from past experiences leads to another essential factor, namely reflexivity in the climate change adaptation space. This relates to the fusion of policies from different sectors and new and old adaptation policies for an enhanced adaptation practice (Smit *et al.,* 2017). For instance, Bangladesh is undergoing rapid changes in adaptation policy formulation and revision which is expected to include both new and old policies and also the inclusion of both internal and external mechanisms such as the Paris agreement and the adaptation of finance initiatives (Ibid).

While the four aforementioned characteristics are important for a robust climate change adaptation policy, there are barriers that may impede on the effective implementation and the desired outcome of the adaptation policies. One such barrier, as mentioned by Venturini *et al.,* (2018), is the low quality and non-availability of data. This is critical for designing the appropriate adaptation policy measures. For example, the non-availability of rainfall and temperature data at the local government level could hinder an appropriate formulation of adaptation policies, for instance in the construction of bigger dams and the design of buildings that maintain desirable indoor temperatures. Another barrier is the lack of sufficient awareness about the nature and scope of climate change, its impacts and thus the required adaptation strategies. Often, this results in insufficient support from stakeholders, which is important in implementing comprehensive adaptation strategies. This necessitates increased awareness campaigns across

all social, economic and other groups of stakeholders. This must be accompanied by equally comprehensive training programmes that build the appropriate and adequate levels of adaptation capacity and capabilities in communities. Ideally, this training must enable communities to continue to adapt even post the training period. Awareness creation is critical because its paucity often results in the creation of knowledge gaps in communities rendering them unable and incapacitated to tackle the climate change menace. Sanou *et al.* (2004) confirm that a knowledge gap is a crucial barrier to climate change adaptation. This barrier results from a lack of training in the implementation of adaptation strategies in international, national and sub-national communities, compounding the adverse impacts of climate change.

Nevertheless, these barriers can be overcome. A critical issue in the successful implementation of climate change adaptation activities is that they require vast financial support. Unfortunately, such activities are currently underfunded (Bai, 2007). This calls for governments to deliberately seek to finance climate change adaptation activities. To mitigate the cost of implementing strategic adaptation activities, it is often necessary for governments to work with private sector stakeholders that include non-government organisations (NGOs), private companies and international organisations such as regional economic communities and the United Nations.

Summing up, the strategic implementation of climate change adaptation activities is bound to be successful when an appropriate and adequate set of financial, technical and policy capacity and capabilities supported by an equally appropriate and adequate set of regulations and incentives are acquired (Moser & Ekstrom 2010). When implementing the adaptation strategies, it remains critical for authorities to ensure that the phenomenon does not escalate. This calls for the other climate change management approach, namely mitigation. This is an anthropogenic intervention to reduce the origin of GHGs.

2.4.3 Climate change mitigation

Climate change mitigation is driven by governments, private and public enterprises primarily focuses on reducing the release of anthropogenic GHG emissions into the atmosphere. The focus of climate change mitigation is to slow down global warming and, in the process, reduce the magnitude and severity of climate change (IPCC, 2018). In this effort, it is important to note that climate change mitigation efforts carry a global mandate in that the positive or negative actions with regard to GHG emission in one part of the world either benefits or adversely affect other

regions on the planet (Ibid). This renders climate change mitigation measures applicable internationally, regionally, nationally and locally at both enterprise and individual levels (Laukkonen *et al*., 2009).

An examination of mitigation measures shows that they can be discussed under two categories. In one category the measures involve technological and infrastructure developments that either abate or eliminate anthropogenic GHG emissions (Swart, Robinson & Cohen*,* 2003; Systemig, 2020). The other category of mitigation focuses on changing the societal structure and human behaviour seeking to either abate or eliminate anthropogenic GHG emissions. Under the former category, there has been development regarding the efficient use of GHG emitting fuel sources, namely fossil fuels. The principle behind these developments is the efficient burning of fossil fuels to emit less GHG but generate greater energy amounts. In addition, the principle seeks the efficient consumption of the same energy in both industrial/commercial and domestic applications (Zhao, 2011 & Nyong *et al.,* 2007). In the case of industrial applications, the capital city of China, Beijing has conducted and continues to conduct a series of industrial energy conservation activities (Zhao, 2011). This initiative involves the closing of small but intensive energy enterprises, restricting the development of new high energy consumption enterprises and products, promoting the phasing-out of outdated energy intensive equipment while encouraging the adoption of energy efficient technologies. This is important for a fossil fuel dependent economy such as China. In domestic settings there have been similar developments on the energy efficiency front. Examples include the replacement of energy intensive incandescent light bulbs with new energy efficient light bulbs and the development of energy efficient domestic appliances, such as refrigerators and washing machines. A noteworthy consideration of such efforts is that improving energy efficiency in both industrial and domestic settings not only mitigate GHG emission but also deals with energy shortages from the supply side and manages the cost of energy consumption as well (Nyong *et al.,* 2007). The increased exploitation of renewable energy sources because of technological improvements in the harvesting, transmission and storage (where appropriate) of energy from these sources is important for the climate change mitigation drives (UNEP, 2007). Renewable energy sources such as solar, tidal waves, wind and hydropower need to be added to the current energy mix to reduce the dominance of fossil fuels. While technological advances can mitigate climate change, human behaviour and attitude can enhance the impact of these advances. For example, switching off lights in rooms that are not occupied in homes and offices as well as the prevention of indiscriminate cutting down of trees

are important elements of human behaviour and attitude that can be cultivated to help in the climate change mitigation efforts. Such behaviours can be encouraged and entrenched through education and awareness-raising campaigns (Bonifacio, Takeuchi & Shaw*.,* 2010). The United Nations Framework Convention on Climate Change (UNFCCC) recognises that education, training and public awareness must play a key role in the search for a holistic response to climate change at local, national and global levels.

While the drive for mitigation offers some tangible and immediate benefits compared to adaptation, it is not without disputes. There are sharp debates around the culpability of the industrialised countries that are presented as the biggest drivers of the current climate change effects through their historic GHG emissions from their previously inefficient, fossil fuel driven industrial bases. One of the suggested solutions in this debate is the Kyoto Protocol defined Clean Development Mechanism (CDM) (IPCC, 2007). The objective of the CDM is to stimulate the North-South transfer of climate-friendly technologies (Ibid). In that space, mechanisation is meant to stimulate sustainable development and emission reductions, while giving industrialised countries a degree of flexibility to meet their emission reduction targets. The latest notable compromise in this discourse is the Intended Nationally Determined Contribution (INDC), a major outcome in the 21st Conference of Parties (COP 21) held in Paris, France in 2015. In the Paris Agreement and through these non-binding INDCs, countries overtly outline their mitigation efforts and targets as part of global efforts to keep the increase in global average temperature to well below 2 °C, to pursue efforts to limit the increase to 1.5 °C and to achieve net zero emissions in the second half of this century. While the Paris Agreement was presented as a compromise that sought to accommodate the disparate views of the developing and developed economies, its lack of legal status weakens its implementation and indeed the USA under the Donal Trump presidency withdrew its consent and commitments. Stern and Stiglitz, (2021) indicate that the current administration of Joe Biden has re-joined the Paris Agreement. This change in approach adds to other contestations under the CDM mechanisms and together highlight the controversies in this space. Consequently, both industrialised and industrially lagging countries are yet to fully utilise all the mitigation measures at their disposal.

A number of factors determine the rate and extent of engaging with the climate change mitigation cause (Worrel *at al.,* 2009). Details of this are discussed in the next sub-section.

2.4.4 The determinants of climate change mitigation

A number of factors determine how and to what extent mitigation policies are implemented (IPCC, 2007 & 2018). Of interest to this study are four related factors, namely economic considerations, lack of interest by governments (in all or some government tiers), conflicting interests, and limits of powers for implementation.

Firstly, and most prominent under economic issues, is the issue of funding climate change mitigation. This determines whether an action will be taken or not. The bearers of the cost of climate change mitigation are either households, private firms, communities or the government (Ackerman & Stanton, 2008). An entity, such as a private firm, is often likely to take up the cost of implementing mitigation measures if the benefits of this implementation outweigh the cost, or if the various uncertainties of the economic results raise serious questions about whether or not the net costs and benefits of mitigating climate change over long periods are known to such a high level of accuracy to be reported to policymakers and the public (Agrawala & Fankhauser, 2008). Without accurate information and knowledge of other risks and cost benefits, private firms do not invest in climate change mitigation. In cases where the impact of climate change affects the entire community, economic considerations would make the community shift planned mitigation measures to the government (Ibid). For example, in the case of deforestation that affects the entire community, a community will shift the responsibility of afforestation to the government due to the capital intensiveness of the afforestation exercise. This was the case in the South African Forestry Company Limited and the Agricultural Research Council's afforestation exercise carried out in rural communities in 2010 (Government of South Africa, 2010).

Secondly, and linked to the issue of economic consideration, is the presence or absence of a government's interest to tackle climate change mitigation. The government of a country is an important player in mitigating climate change serving both as a signal and leader in climate change mitigation activities. Usually, when a government shows commitment in tackling the climate change menace it often gets the supports of technical and financial donors (Agrawala & Fankhauser, 2008). For instance, Ethiopia's quest to achieve a climate-resilient green economy is being supported by the International Monetary Fund (Government of Ethiopia, 2011). In contrast, when government is reluctant due to limited or competing needs, and political considerations, implementing measures that mitigate climate change mitigation often suffers a setback.

Strong commitment signals and the political interest by governments are a sign of political will to engage in climate change mitigation activities (Whitmarsh, 2009). However, and against a background of competing interests and lack of resources, it is not always an easy task to overcome the lack of political interest concerning climate change mitigation activities and policies (Jon, Detlef, Sprinze & Arild, 2009). One of the noted means of securing government interest in climate change mitigation activities is the provision of robust data sets that serve to assist in the development of appropriate climate change mitigation policies (Arbuckle *et al.,* 2015). This is the essence of evidence-based policymaking. In countries such as Chile and Mexico, successes in securing government interest in implementing mitigation policies are attributed to the provision of adequate and relevant data sets (Ibid). Another important factor in securing government interest is overcoming the barrier of coordination between government ministries. This is important not only for coherent intra-government action but also for government interaction with external parties both in the domestic and foreign platforms (Nachmany *et al.,* 2015). For example, Zimbabwe established the Climate Change Management Department under the Ministry of Environment, Water, and Climate as its Nationally Designated Authority (NDA) to coordinate climate change mitigation activities (Ibid). The Ministry is also mandated to guide the country's compliance in all multilateral environmental agreements, including the Intended Nationally Determined Contribution.

Thirdly, conflicting interests come to play when climate change mitigation policies are at variance with other economic, social and political interests of the government in power. For example, this may arise when climate change expenditure competes with other urgent issues such as funding road construction projects, education and other political activities that make it difficult to gain and maintain "political priority" for climate change mitigation (Bai, 2007). Sterman (2011) indicated this may arise because governments and senior decision makers seem to rate climate change risks as significantly less important than individuals working in academic and environmental organisations. This kind of stance by governments has resulted in the direct and indirect manifestation of the impacts of climate change on communities (Lauren, John & Yoshi*,* 2014). While the case for rapid reductions in global GHG emissions is compelling, the actions of businesses and political leaders continue to lag behind the required reduction levels (Brody, Grover, Lindquist & Vedlitz*,* 2010). Lauren *et al.* (2014) noted that in the USA, the rhetoric of political leaders to aggressive emission reduction goals rarely matches the necessary rapid

implementation of policies and the fact that local 'carbon management' efforts are constrained by the absence of effective federal government action. In addition, the analysis of Lauren *et al.* (2014) of 114 businesses, found that nearly half were 'hesitant' to take significant action to address climate risks. This could be due to the huge financial implications of implementing the necessary measures. More interesting is that even those with explicit climate change strategies were primarily engaging in symbolic actions. An analysis of the world's largest 30 corporations revealed that there was a limited indication of these corporations engaging in the radical rethinking of systemic problems that the gravity of the climate change challenge demands (Ibid). The inadequate action by federal government and businesses in the USA and also their equivalents in other countries calls for attention. Prospectively, the extent to which society mitigates climate change successfully depends on whether government and businesses use their considerable capacity and socio-political influence to support rapid emissions reduction measures across society (Heede, 2014).

The fourth determinant of interest concerns the limits on powers for implementation. Implementing the mitigation process requires bringing together different stakeholders operating at different levels. The stakeholders include scientists, public service bureaucrats, policy makers, politicians, civic organisations, non-governmental organisations and the youth. It is important that stakeholders follow all technical, financial and other requirements such as accurate and reliable scientific data, other information such as community views and the interest of business entities to ensure a successful mitigation process (Bulkeley, 2015). Unfortunately, the implementation process often suffers partly because of limited powers of local governments and government institutions, conflict within and between communities, the state, and global actors, as well as claims to authority over knowledge, resource use and environmental discourses (Rasch & Köhne, 2016). This study is centred on the limited powers of local governments and government institutions for implementation. Representatives of local governments and government institutions are run by individuals appointed by the National (federal) government in power. Often this means some senior local government officials hold allegiance to that government and advance the agenda of the government in power. Thus, if climate change mitigation is not on the agenda of the government in power, local government representatives and government institutions have limited power to implement any climate change mitigation processes (Lauren *et al.,* 2014).

In the drafting of climate actions and regulations, it is imperative that both mitigation and adaptation options are considered and integrated as there is growing evidence that one may not be sufficient to tackle the climate change menace, unless under particular circumstances where only one option needs to be carried out at a time.

2.4.5 Integrating climate change mitigation and adaptation

International organisations such as the United Nations Framework Convention on Climate Change (UNFCCC) identify two options in dealing with the climate change challenge. As stated earlier, the two options are mitigation and adaptation. The first is to reduce greenhouse gas emissions and enhance carbon sinks and the second involves activities carried out to adjust and minimise the impact of the consequences of climate change.

Climate change interventions at both national and international levels have centred on mitigation and as a result adaptation lags behind (Klein *et al.,* 2007). However, there has been a realisation that mitigation efforts alone, no matter how rigorous, cannot prevent climate change from happening and likewise carrying out adaptation action alone is inadequate for managing the climate change phenomenon (Hulme, 2010). The resultant call is for an integrated implementation of both approaches simultaneously. The realisation was slow in coming because of a number of reasons of which three are relevant to this study. One of the reasons is economic in nature. At the highest level of government, mitigation and adaptation compete for limited financial resources. Governments are of the view that integrating both interventions could raise the costs of climate initiatives and this could be counter-productive. In addition, governments also view mitigation and adaptation as policy substitutes, complementing each other (IPCC, 2013). Another reason is that adaptation and mitigation may have to be carried out at different sectors. Governments in power may also have targeted sectors for development and thus choose and carry out interventions that fall within the targeted sector (Bruno et al. 2016). Furthermore, the benefits of adaptation are seen to be only at the national level while that of mitigation is seen to be at the global level. This has resulted in international governing bodies of climate change, such as the UNFCCC, pushing more funds into mitigation activities at the expense of adaptation (Tol, 2005).

Despite the aforementioned factors, Mjimba and Sibanda (2019) argue that considering how nature rapidly, gradually, and systemically adjusts to stimuli and eventually achieves a dynamic equilibrium, it is prudent to integrate mitigation and adaptation strategies for maximum benefits

rather than separating the two. For instance, there are benefits of integrating adaptation and mitigation within the area of land use. Within the land use space, adaptive farming practices such as the conservation of soil can be carried out on farmlands to produce climate resilient plants. Such adaptation practices will reduce the vulnerability of local communities (Abdul-Razak & Kruse, 2017). Alongside, the plants serve as carbon stocks thereby contributing to mitigation efforts. Similarly, mangroves simultaneously contribute to protecting coastal areas and storing carbon (Caplow, Jagger, Lawlor & Sills, 2010). Integration also connects mitigation and adaptation with natural resource management, biodiversity conservation and measures to combat desertification (Klein, Schipper & Dessai, 2003; Mjimba & Sibanda, 2019). For instance, forest mitigation projects such as forest conservation have the potential to facilitate the adaptation of forests to climate change by reducing anthropogenic pressures on forests, enhancing connectivity between forest areas and conserving biodiversity hotspots (Caplow *et al.,* 2010; Vicedo-Cabrera *et al.,* 2018). Other forest mitigation projects, such as afforestation and reforestation, biomass energy plantations, agro-forestry, urban forestry are good examples of adaptation and mitigation integration (Dang, Michaelowa & Tuan, 2003; Mjimba & Sibanda, 2019). For instance, reforestation prevents flooding and erosion and sequesters carbon. This is another scenario of integrating adaptation and mitigation. Soil conservation (storing carbon), low water requirements and biofuel production (reducing emissions) are also forms of integrating adaptation and mitigation (IPCC, 2007 & 2018).

In the water sector, the development of hydropower plants can reduce fossil-fuel-linked energy use and reduce dependency on foreign energy imports. If properly designed and managed, the associated water storage can also limit vulnerability to climate change-linked precipitation variability (Swart & Raes, 2007). Managing hydropower plants is therefore a means of integrating climate change adaptation and mitigation work. Details of climate change and hydropower plants are discussed in the next section.

2.5 Climate change and hydropower plants

Hydropower is the most widely used form of renewable energy. The electrical energy generated from these facilities is not GHG intensive compared to that generated by burning fossil fuels. In the advent of global efforts that seek to mitigate climate change, there is a growing interest in developing such facilities to complement and, where possible, substitute the largely fossil-dominated energy generating activities. For instance, through the GERD project, Ethiopia has

constructed a hydrodam that is expected to generate 6,000 MW of electricity (Batisha, 2015) and the Democratic Republic of Congo is expected to construct its next phase of hydrodam that will generate 4,500 MW (Kruger, 2017). These and other similar projects add to the hydropower base where currently 90% of national electricity generation in Ethiopia, Malawi, Mozambique, Namibia and Zambia comes from hydropower (Ibid).

Water sources that generate hydropower interact with climate change and other environmental concerns both positively and negatively. As mentioned earlier, their relative less carbon-intensity makes them an ideal complement or even replacement of energy intensive fossil fuel dependent electricity generating plants. In addition, water reservoirs such as dams and lakes can be used to mitigate water shortages caused by climate change within and away from the concerned facilities (Castano, 2011). While this is a definite advantage in mitigating water shortages linked to climate change, there are disadvantages associated with such facilities. First, the fact that these facilities rely on water against a background of droughts linked to climate change and the related shortage of water makes hydropower plants vulnerable to climate change (Singal, Saini & Raghuvanshi, 2010). Solaun and Cerdá (2017) predict a decrease in the generation of hydropower facilities in Spain attributing the decrease to a climate change-induced decrease in water levels in the dams and lakes of that country. Elsewhere, the most recent example is the Kariba Dam facility (on the border of Zambia and Zimbabwe) where the IPCC has categorised it as exhibiting the worst potential effects of climate change compared to eleven major dams in African. This is because of the resonating effect of the increase in temperature and decrease in rainfall (Government of South Africa, 2015). Over the next century, climate change is expected to increase this variability, and the vulnerability of the dam to these changes (Ibid). These and other examples show how energy supplies from hydropower facilities are vulnerable to climate change. In fact, Vicuna *et al*. (2007) have shown that hydropower generation and subsequent revenue in-flows decrease during the dry conditions and increase during the wet conditions. Climate change-induced droughts, especially during the dry conditions, also reduce water levels in hydropower plants. It threatens other direct and indirect water-dependent economic and social activities such as, agriculture, fishing, water sports and the supply of water to urban settlements (Singal, Saini & Raghuvanshi, 2010). During the wet conditions, water routinely extends from the hydropower facilities to submerge large tracts of land and vegetation when the water accumulates. In the process, human settlements and related facilities may also be submerged and subsequently affect livelihoods. When the submerged vegetation starts to decompose it releases methane, which is greenhouse

gas (Florentina *et al.,* 2012). This does not necessarily make the hydropower facilities carbon neutral although they are often assumed to have an apparent zero carbon content. Nevertheless, their carbon content is far less than those of thermal power plants that burn either coal, petroleum fuels and even biomass. This makes the hydropower plant an important component in the mitigation of climate change. Another challenge posed by dams and lakes is that they block the natural flow of water downstream and with that the movement of nutrients in the same direction (Richter *et al.,* 2010). Furthermore, dam walls may seasonally block the movement of some marine animals up and downstream (Ibid).

Despite these and other challenges involving hydropower facilities, Castano (2011), predicts a global increase in the quantity and size of hydropower facilities. This makes it imperative to understand the dynamics of the hydropower plants and climate change nexus.

2.5.1 The management of hydropower plants

Taking hydropower plants as a system, the effectiveness of this system to adapt to climate change is a function of its level of vulnerability and adaptive capacity. The vulnerability of a system is reflective of its exposure and sensitivity to hazardous conditions and the ability or capacity or resilience of that system to cope, adapt or recover from the effects of those conditions (Smith & Wandel, 2006). The interaction between exposure, sensitivity and adaptive capacity determines the degree of vulnerability of the system. Exposure and sensitivity determine the level of the climate change impact whilst the adaptive capacity and the level of impact determines the degree of vulnerability (IPCC 3rd report). In effect, systems such as hydropower that are highly exposed, sensitive and less able to adapt are vulnerable (Vulnerability = Hazard Exposure x Sensitivity – Adaptive Capacity) (Ibid).

Many of the global hydropower facilities have to adapt to the impacts of climate change already present. Referring to this adaptation, Wilby, Dawson and Barrow (2002) have highlighted issues that can be used to assist dam and lake management authorities adapt to climate change. Broadly, the process comprises three steps, namely:

(i) *Policy, planning and assessment*, which involve an examination of all issues that need to be considered when planning a new reservoir. Going through the process of policy planning and assessment presents opportunities to amend existing relevant legislation and public policy.

(ii) *Design and construction*, which pertain to implications of climate change on the design standards and the construction standard of hydropower facilities under the new and projected climatic conditions.

(iii) *Operation and maintenance*, which relate to data gathering and analysis. This enables facility management to develop flow charts and related notes that help in assessing vulnerability and help in adopting monitoring and adaptation measures for existing reservoirs.

A combination of these three steps is the basis of the adaption framework shown in Figure 5.

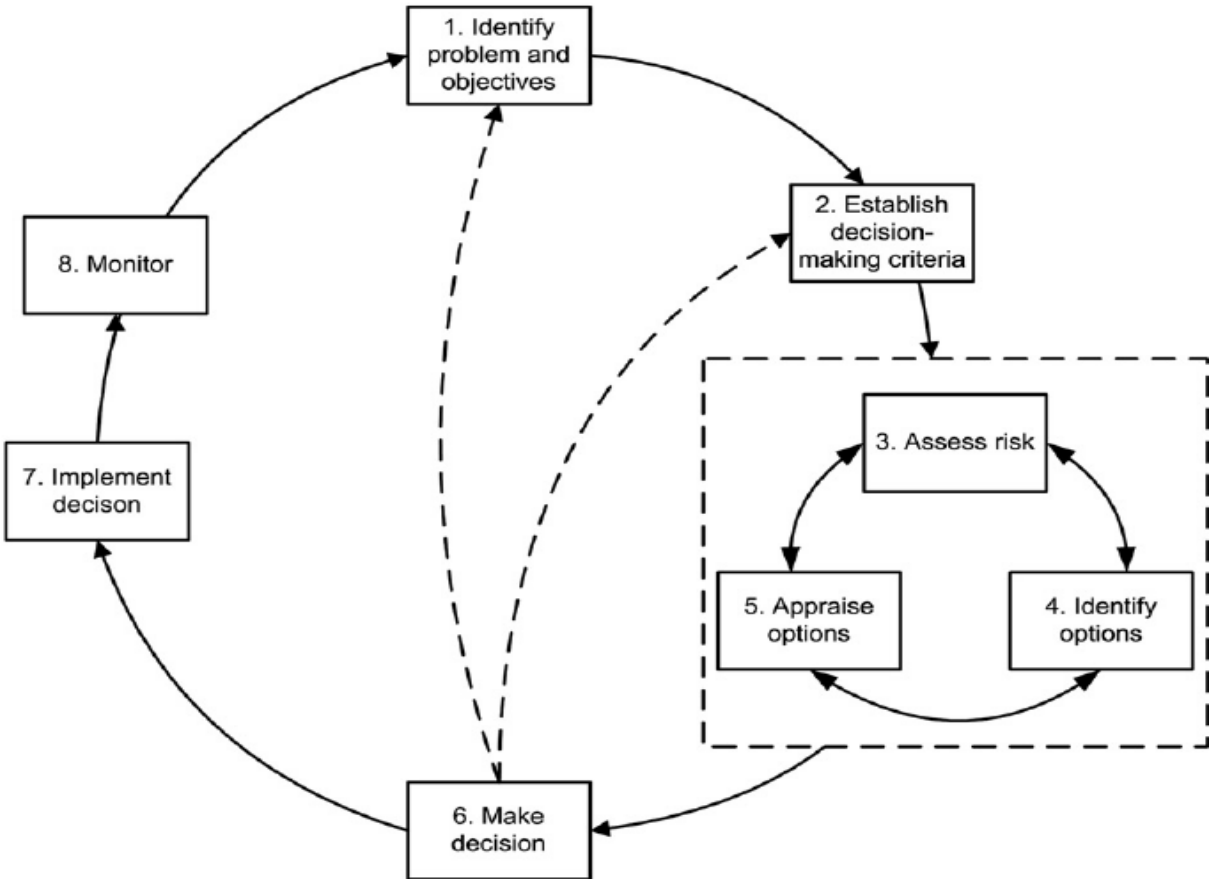

Figure 5: Climate change adaptation framework.
Source: Willows and Connell (2003:7)

The climate change adaptation framework shown in Figure 5 is useful in determining practical tasks and suitable support tools in climate change adaptation. It helps to answer four main questions, namely: (i) The specific target of adaptation, that is “adaptation to what?” (ii) The entities and components that need to adapt, that is “who or what adapts?” (iii) The process of

adaptation, that is “how does adaptation occur?” and (iv) The efficacy and efficiency (how good) of the adaptation (Smith *et al.,* 2000: 229).

According to Smith *et al.,* (2000), the question of “adaptation to what” refers to adaptation to climate change. It can be in response to adverse effects or vulnerability or in response to opportunities provided by climate change. The response is to the past, actual or anticipated conditions, adverse changes or opportunities. In this research it refers to hydropower plants’ adaptation to climate change. The question of “who or what adapts” refers to people, social and economic sectors and activities, managed or unmanaged natural or ecological systems, practices, processes or structures of systems. In this particular research it is the system (directly and indirectly) regarding the Akosombo hydropower plant in Ghana. In answering the question of “how does adaptation occur”, Smith *et al.,* (2000) noted that the process of adaptation can occur passively, reactively or anticipatory. It can also occur spontaneously or planned depending on the management in place. This is the focus of this research. The question of “how good is the adaptation” refers to the evaluations of adaptation in terms of cost, benefits, equity, efficiency, urgency and implementability. This will also be answered in the course of this study.

As noted earlier, the success of implementation of an adaptation measure is dependent on its flexibility to cope with new and future changes and its robustness to deal with a variety of climate change effects (Droogers, Butterfield & Dyszynski, 2009). Also, the implementation carries monetary costs (Ibid) and therefore calls for diligent financial planning. Fankhauser (2009) estimated the cross-sectorial costs of essential adaptation interventions in Africa over a 10 to 20-year period range between US$20 and US$30 billion per year. These costs will be additional to existing developmental needs of Africa (Ibid). To meet these and other costs it is necessary for African countries to individually and collectively mobilise domestic resources as well as engage developmental partners. Fankhauser (2009) also noted that the benefit-cost ratio of implementation measures suggest that the long-term benefits may outweigh the short-term costs by a factor of at least two. This makes adaptation, particularly regarding major infrastructure like the Akosombo Dam, imperative. To ensure the full benefits of adaptation, there is a need to develop and implement appropriate and relevant policies and strategies. The next sub-section discusses some of these policies.

2.5.2 Cases of climate change and hydropower policies

Recently observed extreme weather events that include exceptionally high temperatures, frequently and increasingly severe droughts as well as floods in Africa have triggered discussions and planning on how to mitigate and adapt to these situations. The planned adaptation target is to reduce the projected adverse impacts of climate change. Consequently, in Africa and beyond national governments are initiating governance systems for adaptation. The hydropower sector is not excluded in this regard. Examples of countries that have implemented some adaptation measures related to hydropower facilities or water resources include Egypt, Botswana and the United Kingdom. A common feature of these and other adaptation initiatives is that they carry a disaster risk management slant. They involve adjustments in technologies and infrastructure, ecosystem-based approaches, basic public health measures, and livelihood diversification. Collectively these measures seek to reduce vulnerability.

Egypt has vast desert areas characterised by water scarcity and densely populated coastal zones making it a country highly vulnerable to climate change (El Raey, 2004). This raises the need to adapt to climate change particularly focusing on the efficient use of water resources. Policies related to climate change in Egypt include the National Strategy for Adaptation to Climate Change and Disaster Risk Management, the National Renewable Energy Strategy and the National Energy Efficiency Action Plan (Government of Egypt, 2004). The goal of the National Strategy for Adaptation to Climate Change and Disaster Risk Management policy is to increase Egypt's flexibility in dealing with climate change risks and disasters as well as the Egyptian community's "ability to absorb, contain, and reduce such risks and disasters" across different sectors (Government of Egypt, 2004). It evaluates the current situation and risks across key sectors, in particular the intersection of coastal zones with water resources and irrigation, agriculture, health, urban areas, housing, roads, and tourism (Ibid). The National Renewable Energy Strategy establishes a target of generating 20% of electricity from renewable sources by 2020, 12% of which will be generated by wind farms (Government of Egypt, 2004). The National Energy Efficiency Action Plan outlines energy efficiency targets and measures to be implemented. It establishes a target of achieving a cumulative energy savings of 5% (Ibid).

In Botswana, the central government has taken the lead in the implementation of climate change response policy by establishing a National Climate Change Unit responsible for implementation, monitoring and compliance with climate change response measures as defined by the policy

(Government of Botswana, 2005). Some of its targets include: (i) integrating climate change response measures in the water planning processes across all economic sectors and (ii) utilisation of shared water courses for the benefit of Botswana. The policy on integrating climate change response measures in the water planning processes across all economic sectors enables the government to engage in a robust approach to building capacity that enhances the country's competency to implement international treaties and decisions that are foundational to domestic climate change actions, including adaptation and mitigation actions (Ibid). The adaptation actions are dedicated to specific measures as well as their integration into existing development processes and activities. Policy was formulated to cover the utilisation of shared water courses for the benefit of Botswana out of the realisation that Botswana has varied and low rainfalls that have largely affected most sectors of the economy, especially major economic drivers such as hydropower generation, agriculture, mining and wildlife (Government of Botswana, 2005). Also, since Botswana's development and growth potentially depend on the availability of water for domestic and economic purposes, the policy has some measures that adopt relevant strategies in key national priority areas such as water resources, including hydrodams (Ibid).

In the United Kingdom (UK), managing climate change is underpinned by a range of policies that are designed, administered and overseen by government departments, regulators, independent advisors and executive agencies (UK Government, 2008). Some of the climate change related policies include (i) the Carbon Price Floor (CPF) Policy, which supports the European Union's emissions trading system. Its intention is to underpin the price of carbon at a level that drives low carbon investment in that a higher carbon price increases the cost of emitting CO_2 whilst rewarding low carbon innovations. (ii) UK climate change Act, passed in November 2008 (UK Government, 2008), prescribes that an economy-wide annual emissions of greenhouse gases in 2050 must be at least 80% lower than the 1990 levels and should also ensure a continuous approach to adaptation (Sam, Alina & Jared, 2018).

2.6 Chapter conclusion

The review of the literature highlights the indisputable fact that climate change is real and its impacts have, most commonly, adversely affect the economic, social as well as environmental wellbeing. Consequently, almost all the nations of the world have and are making attempts to mitigate or adapt to the climate change phenomenon. The mitigation arm of managing climate change has advanced much faster than the adaptation arm, which lags far behind. The literature

review shows that this approach is inefficient and as a result there are efforts seeking to raise the level of importance of climate change adaptation to the same level as mitigation. Despite these efforts, there are research gaps that were identified and which this study addresses. These research gaps include the lack of research to ascertain the sustainability of the various adaptive capacity created (such as building of flood defences and sea defence system) against the adverse effects of climate change and the absence of a management adaptive framework that involves monitoring and evaluation within and around hydropower dams with all stakeholders participating in the monitoring and the evaluation other than the hydropower dam managers alone. This study contributes to this endeavour by proposing a cost-effective management adaptive framework with monitoring and evaluation component involving all external stakeholders which is expected to enhance adaptive management of hydropower dams. This cost-effective management adaptive framework will be an improvement over that of the climate change adaptive framework by Willows and Cornell (2003:7) identified in the literature review. Willows and Cornell (2003:7) adaptive framework does not indicate an evaluation component with sustainable indicators and does not show the involvement of all other stakeholders whilst this study proposed cost-effective management adaptive framework will include the evaluation component with sustainable indicators involving all stakeholders in addition of the hydropower dam managers.

The monitoring and evaluation component within the framework will encourage periodic monitoring and this will help management to foresee any possible impending climate change related disaster against the hydropower dam and surrounding communities for action to be taken. The evaluation component will enable management to periodically evaluate any adaptive capacity created to ensure it has not outlived its usefulness and can withstand emerging climate change impacts. The monitoring and evaluation component will be a source of feedback to management for continuous improvement and responding to emerging trends in the literature.

To this end, elevating the status of adaptation is important for the operation and sustenance of facilities such as hydropower plants. The next chapter addresses the research methodology, the rationale behind the choice of the research design, data analysis and the choice of study area for further investigations.

CHAPTER 3: RESEARCH METHOLOGY

"The literature [Nobel] laureate of this year has said that an author can do anything as long as his readers believe him." William Kennedy (1916 – 2004)

3.1 Introduction

This chapter outlines the methodology of the research, presenting and explaining the rationale behind the choice of the research design, the study area, the data collection instruments and the data analysis approach used in this study. The chapter also discusses the ethical considerations, the research limitations encountered during the study and how these issues were dealt with in order to deliver and ensure a credible and high-quality research outcome.

3.2 Research design

Typically, research either seeks to explore, describe, explain, predict or evaluate phenomena (Dawson, 2009). To achieve this requires a strategy that logically and coherently integrates different components of a study ensuring that relevant data are collected to unambiguously address the research questions and fulfil the research objectives. This is the kernel of a research design (Mouton, 2002). This research sought to explore the impact of climate change on hydropower facilities and therefore sought a research design that could best explore this phenomenon.

There are three types of research design, namely the quantitative, qualitative and mixed-method approaches. These can be used to explore the impact of hydropower facilities on climate change. Qualitative research is multifaceted involving an interpretative and naturalistic way of investigating a subject matter (Denzin & Lincoln, 2005). This means that qualitative researchers study things in their natural settings, attempting to make sense of or interpret phenomena, in terms of the meanings people bring to them (Ibid). In making sense and/or interpreting phenomena based on the meanings people bring to them, the qualitative approach uses a number of instruments that include observations, ethnography and interviews to collect the relevant data (Bryman, 2001). Denzin and Lincoln (2005) again argued that quantification procedures can be used to extend and reinforce certain kind of data and its interpretations. The quantitative approach is concerned with accessing quantifiable data that can show scalable correlations between research variables (Bryman, 2001). The approach uses data-gathering instruments that include surveys, structured

interviews and questionnaires. It employs statistical manipulations to draw research conclusions. In reality, different parts of a phenomenon are better explored and explained by both qualitative and quantitative means. For example, the severity and impact of a storm can be described by the type and scope of its damage, and this can be quantified as well. The essence of the mixed methods research design is combining both the qualitative and quantitative research approaches. This study uses the mixed-method research design because the mixed-method approach is considered to be the best approach to help answer the research questions that seek to determine the impact of the changes in the natural settings of the Akosombo Dam from 1970 to its current state, determine the impact of policies adopted and the impact that changes in rainfall quantities have had on the Akosombo Dam and its power generation.

Bryman (2001) views the mixed-methods design not as a simple mix of qualitative and quantitative research approaches. Instead, the scholar states that it refers to employing beyond one type of research method. The methods could be a mix of qualitative and quantitative procedures, a mix of quantitative procedures or a mix of qualitative procedures (Bryman, 2001). In contrast to Bryman, Creswell and Plano Clark (2011) distinguish six different types of the mixed-methods design namely: (i) sequential explanatory design, (ii) sequential exploratory design, (iii) sequential transformative design, (iv) concurrent triangulation design (v) concurrent nested design and (vi) concurrent transformative design.

The sequential explanatory design involves the collection and analysis of quantitative data followed by a collection and analysis of qualitative data. The purpose is to use qualitative data to assist in explaining and interpreting the findings of a quantitative study. Contrasting the sequential explanatory design is the sequential exploratory design approach. The latter involves an initial phase of collecting and analysing qualitative data followed by a phase of collecting and analysing quantitative data. In both the sequential explanatory and exploratory designs, the two types of data reinforce each other (Ivankova *et al.,* 2006). The sequential transformative design makes use of either the sequential explanatory model or the sequential exploratory model. It involves the collection of either quantitative or qualitative data first, integrating the data and then analysing the combined data to arrive at the results. It is normally engaged in a study that is solely based on theory as it best serves the theoretical perspective. The concurrent triangulation design makes use of two or more methods to confirm, cross-validate, or corroborate findings within a study. Data collection in this method is concurrent. It serves to overcome a weakness in using one method

and also to seek information at different levels. The concurrent nested design approach gives priority to one of the methods and guides the project while the other method is embedded or "nested". The purpose is to address a different question than the dominant one and to seek information from different levels. The concurrent transformative approach makes use of a theoretical perspective reflected in the purpose or research questions of the study to guide all methodological choices. It serves to evaluate a theoretical perspective at different levels of analysis. The sequential exploratory mixed methods approach was applied in this case study setting because of limited financial resources and the time limits to explore many cases in many settings within and outside Ghana. This approach was used in this study by dividing the data collection period into two phases. Within the first phase, qualitative data were collected and analysed. At a later date, the second phase was carried out with the collection and analysis of the quantitative data. The purpose of this strategy was to use the qualitative data to explore the quantitative findings, that is helping in the triangulation of the data for deeper analysis. It also ensured that the limitations of the qualitative data were balanced by the strength of the quantitative data and vice versa. Yin (2018) states that the case study research design facilitates the exploration of a phenomenon in a bounded system within its contexts using a variety of data sources. Broadly, four types of case study types are distinguished (Ibid). These are (i) exploratory case study, (ii) explanatory case study, (iii) multiple-case study and (iv) single case study. The exploratory case study investigates distinct phenomena that lack detailed preliminary research and a specific research environment that limits the choice of methodology. Explanatory case study is employed when a researcher seeks to answer a question that presumes casual links in real-life interventions that are too complex to come to terms with, whilst the multiple-case study enables a researcher to explore differences within and between cases. The single case study design is used when there is only one subject matter under investigation. Using Yin (2018) principle, this study also employed the single case study design because of the Akosombo Dam, which is the only subject matter under investigation.

Blaxter *et al.,* (2001) argue that because of case study flexibility and adaptability to investigation methods, it is ideally suited to the needs and resources of a small-scale researcher. The Akosombo Dam was chosen as the case because it is the largest such facility in Ghana. The research proceeded following the case study approach cognisant of criticisms to generalisations derived from case studies. For instance, Bassey (1999) states that case studies lead to unclear generalisations that report an occurrence in one setting as possible or likely in another particularly

if the settings share similar features. Yin (2009) states that a case study is only generalisable to theoretical proposition and not to populations. Despite these and other shortcomings, the study proceeded on the premises of counter arguments to these affirmations. Evers and Wu (2006) summarise the counter arguments making a case for case study derived generalisations that are of relevance to this work. For example, the researchers, Evers and Wu (2006) postulate that some empirical evidence from case studies is predisposed to what they refer to as regulative generalisation. The foundation of their argument is that since certain behaviours are driven by principal regulations, it is thus acceptable to make extrapolations from these behaviours even when they have been observed in a relatively small number of instances. They further argue that in such instances studying many cases will not alter conclusions because the observed practices are not merely regulated by rules but are also defined by rules (Evers & Wu, 2006:512-513).
Flyvbjerg (2006) adds to the argument stating;

> *One can often generalise on the basis of a single case, and the case study may be central to scientific development via generalization as supplement or alternative to other methods. But formal generalization is overvalued as a source of scientific development, whereas "the force of example" is underestimated (*Flyvbjerg*, 2006:228).*

An important criticism of case study derived generalisation is that the study tends to overaccentuate the statistical limits of generalising from single case studies whilst disregarding the depth of knowledge case studies generate (Flyvbjerg, 2006). The argument posits that the validity of generalising case study findings and deductions is dependent on the type of case(s) study(ies). Where possible, this research sought to draw generalisations and is thus designed to gather and analyse data in a manner that permits this objective.

3.3 Study area

The study focussed solely on the country Ghana. Ghana is located in West Africa's Gulf of Guinea. On the western side it shares borders with Côte d'Ivoire, with Togo on the eastern side, Burkina Faso to the northern side and is also bordered to the south by the Gulf of Guinea and the Atlantic Ocean. Within Ghana, the study was specifically located at the Akosombo Dam named after the nearby small town of Akosombo, located in the eastern region of Ghana. Figure 6 shows the map of Ghana indicating the study site.

Figure 6: Map of Ghana showing the Akosombo Dam and neighbouring countries
Source: Barry *et al.,* 2005

The construction of the Dam started in 1962 and was completed in 1966. The Akosombo town near the Dam is now home to about 15,000 predominantly migrant people that come from all parts of Ghana and beyond. The working population of the area comprises employees engaged in power generation activities at the Dam, farmers and numerous small businesses that provide a variety of essential services to the town (VRA Newsletter, 2018). The construction of the Akosombo Dam on the Volta River Basin in Ghana created the Volta lake which at one time was the largest man-made lake by surface area in the world (Barry *et al.,* 2005). The maximum capacity of Akosombo Dam is approximately 150,000 million cubic metres (m^3) of water at its peak of 85 m. The actual reservoir has a surface area of about 8500 km^2, an average depth of about 18.8 m and a shoreline of about 5,500 km (Barry *et al.,* 2005).

The climate in Ghana is tropical, with temperatures varying according to season and elevation. Except in the north, there are generally two rainy seasons between April to July and from September to November. Annual rainfall ranges from about 1,100 millimetres (mm) in the north

to about 2,100 mm in the southeast. The coolest time of year is between May and June, the main rainfall months. The Harmattan, a dry desert wind, blows from the northeast from December to March, lowering the humidity and creating hot days and cool nights in the north. In the south, the effects of the Harmattan are felt in January. In most areas the highest temperatures occur in March and the lowest in August. Variations in temperature both annually and daily are small. The minimum temperature is around 23 °C which is warm (Ghana Meteorological Agency, 2020). Average temperatures at the Akosombo area vary very little. High humidity makes the area feel hot throughout the year. The least humid month is December (53.5% relative humidity), and the most humid month is July (73.6%) (Ibid). The hottest months are January, February, and then March. The warmest time of year is generally late April where highs are regularly around 36.6 °C (Ghana Meteorological Agency, 2020) and temperatures rarely dropping below 28.6 °C at night (Ibid). The months with the lowest chance of significant precipitation in Akosombo are February, December, and August. On average the Akosombo Dam is usually calm. The windiest month is April, followed by September and February. On average, the calm periods are characterized by wind speeds around 5.6 kilometres per hour (km/h) which is considered “light air”. Higher wind speeds are experienced in mid-April with February and September also with average top wind speeds reaching 6.6 km/h. The vegetation around Akosombo Dam area is largely semi-deciduous forest type (Ampofo, Ampadu & Abanyie, 2015). However, continuous human activities such as burning and cultivation with short fallow periods over the years have resulted in the degradation of the original forest (Forestry Research Institute of Ghana, 2003). This has resulted in the encroachment of Savannah type vegetation into the area. Some of the vegetation in the area is scrub and stunted trees particularly on rocky slopes (Volta River Authority Report, 2005). The topography of the area is characterised by a range of hills located mostly along the reservoir with undulating plains behind it (Ampofo, Ampadu & Abanyie, 2015). The hills range between 50 to 150 meters high and have very steep gradients and sometimes have massive rocky outcrops. Two ranges of hills have created a steep gorge which has been dammed for the hydroelectric power generation (Forestry Research Institute of Ghana, 2003).

3.4 Data sources

The research gathered both primary and secondary data. Primary data refer to first-hand data collected by the researcher directly from participants (Sundararajan, 2007) whilst secondary data refer to data collected earlier by others other than the researcher but which is useful to other researchers in different research projects (Kell, 2005). After securing permission letters to collect

data (Appendix 3), the study collected primary data and some secondary data from four main government agencies namely; the VRA, the Energy Commission, the Water Research Institute and the Ghana Meteorological Agency with most secondary data (mainly from internet sources) from the Ministry of Environment, Science, Technology and Innovation. In addition to these state agencies, selected inhabitants living within the Akosombo Dam catchment area were also engaged. The research used the informed consent form (Appendix 2) to seek permission from individuals to engage them for data collection.

Established in 1961, the Volta River Authority was mandated to generate, transmit and distribute electricity under the Volta River Development Act, 46 of the Republic of Ghana (Government of Ghana, 2015). A 2015 amendment of the Act 46 curtailed the authority's role solely to the generation of electricity. In this role the VRA has a direct jurisdiction to manage the Akosombo Dam and hydropower generation machinery. Data obtained from the Volta River Authority pertains to the content of policies that seek to tackle the impacts of climate change and the Authority's extent and nature of collaborations between government and other institutions. The data also contains how the Volta River Authority in dealing with the impacts on the Akosombo Dam. At the time of collecting data for this study, data on water inflows into the Dam, evaporation from the Dam, the Dam storage levels and water levels were not available from the Authority. This compelled the study to do with the available data, that is rainfall and temperature data. Another source of data was the Energy Commission, a body established by an Act of Parliament (Act 541) in 1997. The Commission's mandate is the regulation, management, development and utilisation of all available energy resources in Ghana. To this end its mandate includes contributing to the development and elaboration of national policies and strategies for all renewable sources of energy including micro hydropower facilities in the country. The Commission serves as the technical regulator of Ghana's electricity, natural gas and renewable energy industries advising the Government on all energy related matters. It provided the study with data relating to energy planning and policies put in place to deal with the impact of climate change on hydropower and renewable energy in general. The Water Research Institute is among one of the thirteen institutes of the Council for Scientific and Industrial Research (CSIR). It was established in 1996 with the mandate of conducting research that generates scientific information to guide the formulation of strategies and services that develop and manage water resources for energy, transport and agriculture purposes in Ghana. The Institute informed the study on the nature and extent of the impacts of climate change on water bodies in the country with a particular focus on the Akosombo

Dam. The Ghana Meteorological Agency provides weather and climate data sets that include patterns and changes in rainfall and temperatures. The levels of rainfall determine the amount of rainwater that eventually flows into dams in Ghana, including the Akosombo Dam. Temperature levels determine how much water is lost from dams through evaporation. The Ministry of Environment, Science, Technology and Innovation is critical in the environment management space. It was established in 1993, initially as the Ministry of Environment and Science and has undergone a series of name changes before 2013.It is now known as the Ministry of Environment, Science, Technology and Innovation. Its mandate includes continually developing and reviewing policies, laws, rules, regulations and spearhead government agenda on environmental issues, technology and innovation sector in the economy. In this study, the ministry was the source of secondary data relating to the development of national policies on climate change and other broader environmental management policies and regulations. Another source of data, apart from the Government agencies, is the inhabitants living near the Akosombo Dam. The areas included Abome, Konkonte Kpeje with its people mainly made up of fishermen and farmers. They served as a source of data about the indigenous knowledge of climate change.

To complement the primary data, the study also gathered secondary data. Such data are in the form of records kept by organisations, private and public policy documents, textbooks, working papers and peer reviewed journals among other sources (Ibid). The sources of secondary data in this study included government reports, public policy documents and legislation documents mainly from the Ministry of Environment, Science, Technology and Innovation. Another important source of secondary data for this study was the Ghana Meteorological Agency. The agency was the source of data relating mainly to rainfall and temperature.

Other sources of secondary data may include published journal articles, private sector publications, working papers opinion pieces, policy briefs and peer reviewed journals. Table 3 shows some government policy, legislative and report documents that relate to this study.

Table 3: List of some policy, legislative and report documents

No.	Document	Document Type
1	Ghana National Climate Change Policy	Policy document
2	Ghana National Climate Change Master Plan Action Programmes for Implementation: 2015 – 2020	Policy document
3	National Environmental Policy	Policy document
4	Ghana Climate Change Legislation	Legislative document
5	ODI Report on Climate Change Finance in Ghana,	Report

Source: Author's compilation 2021

The gathering of both primary and secondary data was important for triangulation. Triangulation is important for enhancing the validity of research findings and conclusions through obtaining different perspectives on the same issue (Noble & Smith, 2015). This can be attained by using different sources of data, an approach known as data triangulation or methodological triangulation, which involves using more than one data gathering instrument. Approaching different organisations and the gathering of both primary and secondary data served the data triangulation purpose. Gathering both primary and secondary data attained the methodological triangulation goal in this study. This was further enhanced using different primary data gathering instruments.

3.5 Gathering primary data

A significant part of the study relied on primary data. The primary data were gathered through three main methods: 1) the administration of semi-structured questionnaires and 2) electronic recorded face-to face interviews posing open-ended questions to senior and middle level officials of the VRA, the Energy Commission, the Water Research Institute and the Ghana Meteorological Agency. Appendices 4 and 5 respectively show the semi-structured questionnaire and the open-ended interview guide used in the inquiry. The third method of gathering data was direct observation, observing any possible changes in the features of the Akosombo Dam facility due to the impact of climate change.

The development and use of the questionnaire and interview instruments unfolded in three phases. The first phase involved formulating the questions and piloting the exercise to determine the clarity, feasibility and appropriateness in addressing the research questions (Porta, 2008). Piloting also serves to identify potential problem areas and deficiencies in the research instruments before they are used in a large-scale study (Hassan *et al.,* 2006).

This study piloted its data collection instruments in two stages. The first stage served the purpose of testing the clarity of the questions in the questionnaire and the interview guides. This stage revealed the need to refine the quality of the data collection instruments particularly identifying the need to eliminate the use of technical terms, such as climate models, simulation and odour which may not be easily understood by some inhabitants due to their low level of education. In addition, piloting serves to ensure that the sequence of questions does not confuse the targeted respondents. Furthermore, it also revealed repetition of some questions. These shortcomings were addressed, and the instruments were then subjected to a second piloting stage for further refinement. This piloting stage occurred at the study site, the Akosombo Dam and its catchment area. Here, the piloting engaged 10 of the respondents. This piloting served to assess the logistics for conducting the research in this area. Issues of focus included locating, alerting and securing the consent of the targeted respondents about the forthcoming study. Another focus was to determine the clarity of the questions. The piloting also revealed that the student researcher who assisted with the interviews needed to be conversant with the inhabitant's local language (the Twi language) for easy interaction and communication about the research questions to the inhabitants particularly the respondents since some could not speak and understand English. The researcher was competent in the inhabitant's local language and therefore language was not a barrier.

After refining the data collection instruments and obtaining both verbal and written participation consent and secured appointments, the main data gathering phase, the third phase of gathering primary data for the study began.

3.5.1 Primary data collection

As mentioned earlier the questionnaire and interview approaches were the key primary data gathering methods in this study. A questionnaire is a research instrument that gathers research data from respondents through a series of questions (O'Sullivan & Rassel, 1999). There are three types of questionnaires: (i) structured or closed questionnaire, (ii) semi-structured questionnaire, and (iii) unstructured questionnaire (Bishop, 2007). The structured or closed questionnaire poses closed-ended questions, that is, the researcher poses a question and provides the respondents or the research participants with options of answers to choose from. It has the advantage of being able to access and obtain responses from a large number of people quickly, easily and efficiently. It is relatively quick and easy to create, code and interpret. It is also easy to standardise in that

every respondent is asked the same question in the same way (Bishop, 2007). This ensures that everyone in the sample answers exactly the same questions making it a very reliable method of research. The format of the questionnaire design makes it difficult for the researcher to examine complex issues. When the researcher is not present it is always difficult to know whether or not a respondent has understood a question and the researcher has to hope the questions asked mean the same to all the respondents as they do to the researcher (Ibid). The semi-structured questionnaires use a mixture of closed-ended and open-ended questions, that is a mixture of questions with options of answers for respondents to choose from and some questions without answers where respondents need to provide their own answers (Bishop, 2007). In using the semi-structured questionnaires, it allows informants the freedom to express their views in their own terms, provide reliable, comparable qualitative data and encourages two-way communication in that respondents can ask questions. The use of the semi-structured questionnaires needs to be carefully planned in order not to make the questions prescriptive or leading. Certain skills are required to analyse the data, and this could be a problem as there is a risk of construing too much.

The unstructured questionnaire exclusively or mainly contains open-ended questions. Options of answers are not provided and thus the respondents provide their own answers to the questions (Ibid). It has the advantage of the researcher getting to understand the respondent better. It also provides flexibility in that the concept can be explained in a very informal way exhibiting pure knowledge. It is not reliable as it is not standardized, and the process is time-consuming as sometimes some answers from respondents may call for unplanned questions for further discussion (Bishop, 2007).

This study used the semi-structured questionnaires because it gave the opportunity to ask both closed-ended and open-ended questions which provided answers to the research questions. The closed-ended questions sought to understand the policies, legislation and practices available to the management of the Akosombo Dam to manage concerns about climate change. The open-ended questions were focused on the nature and the extent of climate change impact on the Akosombo Dam and the extent and nature of collaborations between the VRA, the government and other institutions in dealing with the climate change impact on the Akosombo Dam. The questionnaires also gathered data that included a description of the rainfall patterns made up of the intensity, frequency, magnitude of rainfall as well as changes in the nature and degree of rain

water harvesting techniques and other water-related adaptation measures of the Akosombo Dam catchment area.

Questionnaires can be administered through a number of approaches that include mailing hard or soft copies to the respondent or alternatively through personal administration of the instruments with or without the use of research assistants. This research used the personal administration approach without employing research assistants. This administration was followed by interviews which enabled the exploration of narratives about the challenges, events and practices regarding climate change at the Akosombo Dam. An interview is a systematic way of collecting data by posing questions through talking and listening to people as individuals or in groups (Bishop, 2007). Broadly, there are three types of interviews, namely (i) structured or closed interview, (ii) semi-structured interview and (iii) unstructured styles of interview (Ibid). Rubin and Rubin (2005) distinguish these types of interviews as follows: the structured or closed interview consisting of a complete script that is prepared beforehand and has no room for improvisation; the semi-structured interview is a verbal interchange where one person (the researcher) attempts to elicit information from another (the respondent) by asking questions (Longhurt, 2003). Although the researcher prepares a list of predetermined questions, the semi-structured interview unfolds in a conversational manner offering participants the chance to explore issues they feel are important. The unstructured style of interview is similar to that of the semi-structured interview but in addition the researcher may ask unplanned questions based on the answers of the respondents. This study employed the use of the semi-structured type of interview to gather more of the qualitative data using the interview guide. This approach was deemed appropriate because the semi-structured type of interview provides more reliable and comparable qualitative data. In addition, it enhances the validity and the credibility of research.

Due to time constraints, the study intended to engage only five respondents comprising of three senior and two middle level officials in each of the targeted government agencies. These categories of officials were chosen because the senior management level staff are assumed to be familiar with both policy and practice issues concerning the management of climate change. In addition, the middle management staff were targeted to enrich the inquiry by expounding on the practices targeting the management of climate change. Interviewing these two tiers of staff also enabled data triangulation to be done. However, the busy schedules of some of the targeted respondents resulted in some of them being unavailable for the interviews at the scheduled times.

In such cases, the targeted respondents were accessed through electronically administered semi-structured questionnaires. While this approach enabled access to all targeted respondents it does not deliver the narratives and nuances of the open-ended interview approach to gathering data. Table 4 gives the number of targeted respondents, the actual number of respondents that informed the research, the means of engagement and the response rate as a percentage of the target.

Table 4: The semi-structured questionnaire response rate

Agency	No. of intended senior level staff to be engaged	No. of senior level staff actually engaged	Means of engagement	No. of intended middle level staff to be engaged	No. of middle level staff actually engaged	Means of engagement	Total response rate (%)
Volta River Authority	3	3	Email	2	1	Email	80
Energy Commission	3	1	Face-to-face interaction	2	none	None applicable	20
Water Research Institute	3	3	Face-to-face interaction	2	1	Face-to-face interaction	80
Ghana Meteorological Agency	3	2	Face-to-face interaction	2	2	Face-to-face interaction	80
Total	12	9		8	4		260

Source: Author's compilation 2021

The table shows a maximum of 80% response rate by all the targeted organisations except the Energy Commission. The relevant findings (responses) to the engagement were extracted and quoted in the discussions in chapters 4, 5, 6 and 7. At the time of this research, the Energy Commission did not have any middle level management respondents. Probing revealed that the commission's climate change unit was staffed by one senior level staff member who attends to all climate change related issues. This employee reports to the chief executive officer of the Commission.

The research also engaged some inhabitants within the Akosombo Dam catchment area through the open-ended interviews and semi-structured questionnaire approaches. Given that climate change is a long-term phenomenon, this engagement purposively selected respondents that had lived in the catchment area for at least fifteen years. This part of the inquiry engaged with a total

of 26 community members comprising the elected parliament representative of the area, five senior citizens who have been residents in the area for more than twenty years and twenty others randomly selected qualifying inhabitants. The engagement gathered qualitative data on the views of communities on how, if at all, climate change had changed their activities and some aspects of the Akosombo Dam. Summary of survey results on the dealings of climate change by the government agencies and assessment of community knowledge on climate change

In addition to these two methods, the research also used observation to gather some qualitative data. Observation relates to a method of collecting evaluative information in which a researcher observes the subject of the study in its natural or usual environment without altering that environment (Kumar, 2011). Observations in this research pertained to the features of the Akosombo Dam that indicate change. For example, waterline marks on the Dam's shoreline and Dam-wall show changes in the relative volume of water in the Dam.

All the data collected was analysed as discussed in the next sub-section.

3.6 Data analysis

Data analysis involves examining, manipulating and interpreting data to distil the research findings that in turn facilitates the drawing of research conclusions (De Vos, 1998 & Morrison *et. al.,* 2012).

This study adopted the thematic analysis approach. Thematic analysis involves identifying, examining, analysing and reporting patterns or themes within data (Braun & Clarke, 2006). According to Boyatzis (1998) thematic analysis is data interpretation through the organisation of data into codes, categories and themes. This analysis can be carried out at two levels, namely the semantic and latent levels. At the semantic level the themes are identified at the surface meanings of the data merely based on what a participant has said or what has been written. It usually involves a progression from description, where the data have simply been organised to show patterns that are summarised for interpretation. The latent level goes beyond the semantic level in that it involves interpretative work and analysis by identifying and examining the underlying ideas, assumptions, conceptualisations and ideologies that are theorised from the semantic content of the data (Boyatzis, 1998). In data sets, a theme represents the level of patterned response or meaning from the data that is related to the research questions (Braun & Clarke, 2006). The principle of latent analysis was applied in this study to identify and examine the depth

of knowledge inhabitants around the Akosombo Dam catchment area have of climate change and how they are using the knowledge to manage climate change. The same principle was used to analyse climate change data and policies developed by the management of the Akosombo Dam towards the management of climate change.

Thematic data analysis can be carried out inductively or deductively (Ibid). In the inductive approach, the themes identified are strongly linked to the data generated (Boyatzis, 1998 & Thomas, 2006). That is, themes emerge from the data without researchers imposing preconceived analytical themes. This approach provides a relative less rich description of the data and more of a detailed analysis of some aspects of the data. It is useful for coding aimed at addressing specific research questions (Ibid). Its advantage is that it gives room for a greater exploration of the data to test the accuracy and validity of particular judgements or inferences. A disadvantage is that it is limited in the sense that it always begins with something specific and then tries to generalise making the approach prone to errors. Also, it cannot be used to understand all topics in science (Ibid).

In contrast, in the deductive approach, themes are theory-driven and analysis is limited to the preconceived frames (Crabtree, 1999; Azungah, 2018). The deductive approach is advantageous in that it gives the possibility to measure concepts quantitatively and also allows the researcher to have a cluster of observations from which deductions can be made to arrive at valid conclusions (Ibid). However, it also has disadvantages. For instance, the deductive approach may be based on invalid assumptions. This means that conclusions based on such assumptions are also inaccurate and invalid. With this approach it is also difficult to test the validity of conclusions because the conclusions drawn may neither be feasible nor practicable.

This research used the inductive approach analysis to analyse the qualitative data. The verbatim transcription of interview records, interview notes as well as observation records and secondary data were analysed and interpreted in three broad themes deemed critical to climate change and hydropower generation. The themes were (i) nature, level and pattern of rainfall changes (ii) changes in the Akosombo Dam features and current level of electricity generation and (iii) policies and practices adopted to control the impact of climate change on the Akosombo Dam and water inflows into the Dam.

The quantitative data analysed statistically generated descriptive statistics. Descriptive statistics are tools used to describe or summarize a dataset, which can be either a representation of the entire or a sample of a population in ways that make the dataset meaningful and useful (Spriestersbach *et al*., 2009). It helps to provide basic information about variables in a dataset and to highlight potential relationships between variables (Ibid). This analysis in this study allowed for the description of the data through the examination of the relationships between the variables (De Vos, 1998; Spriestersbach *et al*., 2009; Morrison, 2012). This supported the emerging themes and explanations, which lead to a justifiable conclusion.

3.7 Validity and credibility

Conclusions should withstand two important tests, namely validity and credibility (Noble & Smith, 2015). Validity refers to the precision and accuracy with which the research findings reflect the data (Long & Johnson, 2000). Credibility pertains to the confidence which can be ascertained in the truth in the research findings (Macnee & McCabe, 2008). These two aspects serve as important tools for testing the integrity of research findings and conclusions. They also establish whether or not the research findings represent the appropriate information obtained from the original data (Graneheim & Lundman, 2004).

There are a number of ways to gain both validity and credibility in research. These include triangulation, prolonged engagement in the field and peer examination (Creswell & Miller 2000). To ensure validity in this study two types of triangulations were used, namely the data triangulation and methodological triangulation. The use of data triangulation involved employing both the questionnaire and interview instruments to gather data. In addition, these instruments were administered to different respondents, that is, more than one respondent in one organisation and location. Further, it is undoubted that the mixed method approach that gathered both qualitative and quantitative data advanced the notion of methodological triangulation.

3.8 Ethical considerations

Ethical considerations are important in research. They define and distinguish between what is acceptable and unacceptable in conducting research. This research adhered to strict ethical considerations. To comply with the university's research ethics standards, an application was submitted to the research ethics committee of the College of Agriculture and Environmental Science at the University of South Africa. This was done in order to seek ethical clearance to

conduct the research. To ensure quality assurance prior to the research, all the data collection permission letters and data gathering instruments (Appendixes 3, 4 and 5) to enable data collection from government institutions (made up of the VRA, Energy Commission, Water Research Institute and Ghana Meteorological Agency) were vetted by this committee. The committee evaluated the research proposal, the data gathering instruments, and the permission letters and thereafter issued a written ethical clearance document with ethics clearance number 2017/CAES/037 (Appendix 1).

In addition to the data gathering instruments and the research proposal the informed consent form (Appendix 2) was created. Within it, all respondents were told of their right to consent or reject to participate in the study. Further, they were informed that their participation was out of their willingness to do so and they had the right to excuse themselves from participation at any point during the course of the research. This consent was sought and confirmed in writing prior to every engagement. The consent forms explained the study assuring the participants that any information they gave was solely intended for academic purposes. In cases where engagements needed to be recorded electronically, the consent of the participants was sought prior to recording. In such cases, respondents were assured that all voice recordings would only be accessible to the principal researcher and these, together with the transcripts, would be kept in a locked drawer on the desk of the office of the principal researcher. They were also assured that the reporting of the research findings would be done in such a way that does not link any particular respondent to his or her identity. The respondents were also informed that all voice records will be destroyed after three years from the date of the recording.

3.9 Limitations of the study

All research carries inherent weaknesses (Thorlakson, 2011) and this one was no exception. Three weaknesses are worth mentioning in this case. First, doctoral research is time bound, meaning all activities are carry out within defined temporal limits. This limit meant that at times it was not possible to follow up all of the interesting data defined as outside the scope of the study but also viewed as having the potential to inform some insights generated by the study. The second limit pertains to access to some senior personnel in the targeted organisations. Some of the targeted respondents cancelled appointments to fulfil urgent duty related engagements elsewhere. In such cases rescheduling appointments was both a lengthy and cumbersome process. Attempts to mitigate this included electronic administration of questionnaires or attempts

to conduct interviews via the telephone. The former approach denied opportunities for probing questions about both close-ended and open-ended questions. The latter approach was expensive and was also characterised by interruptions as a result of technical shortcomings in the telephone system in Ghana. A third weakness is that the research was confined to one site, namely the Akosombo Dam. This research was self-funded from the researcher's earnings as a government employee. This limited funding meant that it was not possible to conduct a multiple case study research either within Ghana or to compare Ghana with other countries. Although climate change adaptation measures carry location-specific peculiarities, comparative cases could have offered a platform for data, information and experience comparison and sharing in the process providing important learning points for governments and the related agencies.

3.10 Chapter conclusion

The study combined the single case and mixed-method research design seeking to explore how hydropower facilities are coping with the climate change phenomenon. This research design and the research instruments were deemed suitable to manage the stated constraints, which appropriately delivered valid and credible research findings and conclusions. The description of the research methodology indicates that the research environment was challenging and meant that at times the research had to 'make do' with the available and accessible data and respondents despite the need for more. The next chapter presents, analyses and discusses the data corpus.

CHAPTER 4: CLIMATE CHANGE LINKED VARIATIONS IN AKOSOMBO AND ITS CATCHMENT AREAS.

"Education is the most powerful weapon you can use to change the world." (Nelson Mandela 1918 – 2013)

4.1 Introduction

The focus of this chapter is to identify the weather variations linked to climate change, focusing on rainfall and temperature within Akosombo and its catchment areas and how these variations impact hydropower generation at the Akosombo dam. This chapter achieves research objective 2 as stated in section 1.3 of Chapter 1, namely to determine the nature and extent of climate change linked variations on rainfall quantities and temperature patterns within Akosombo and the surrounding areas and its effects on the dam's electricity generation capacity. As stated in Chapter 2, climate change affects hydropower facilities and there are ways to react to these impacts. More important and relevant here is that these impacts and reactions vary in time, scope and sequence.

The Ghana Meteorological Agency is the custodian of all weather-related data in Ghana, rainfall and temperature in this case. Unfortunately, the agency did not have complete data for most parts of the upper section of the Akosombo dam and this is a shortcoming of this study. The researcher had to work with the best available data from weather stations that relates to the dam as indicated by the agency.

Following this introduction, the chapter unfolds in three sections. Firstly, the research findings are presented, then analysed and discussed with the aim to address the aforementioned questions. The first section begins with the issue of changing rainfall quantities and patterns within the water catchment areas of the Akosombo dam in Ghana exclusively. Owusu, Waylen and Qiu (2008) indicated that rainfall within the catchment of the Volta river basin (which covers Benin to the east, Burkina Faso to the north, Côte d'Ivoire to the west, Mali, Togo and Ghana to the south) which is above the Akosombo dam has been declining hence this study is narrowed down to the part of the basin exclusively in Ghana looking at the rainfall and temperature within the catchment areas of the Akosombo dam. The section further discusses the possible impacts that the changes in rainfall quantities and patterns might have on the water level and flow, and consequently,

hydroelectricity production from the dam. The second section examines climate change-linked variations on temperature patterns and how these variations might have impacted the Akosombo dam facility physically and in terms of its hydropower generation. The third section concludes from the preceding analysis and discussion of findings.

4.2 Annual rainfall quantities and patterns within the selected weather stations

One of the most visible pieces of evidence of climate change is the increase in the severity and frequency of extreme weather events as well as gradual, but noticeable, shifts in annual and seasonal climatic variations and patterns (IPCC, 2013). Most notable in this space is a shift in rainfall patterns and quantity. Generally, rainfall patterns in Ghana is characterised by three distinct seasons, namely the main rain season that occurs in the months of March, April, May and June, the second rain season that occurs within the months of July, August, September, October and November and the dry season that occurs in December, January and February (Ghana Meteorological Agency 2020). Changes in rainfall patterns carry visible impacts on water dependent facilities and activities such as hydropower plants and irrigation operations in agriculture. Typically, the efficient operation of hydropower facilities such as the Akosombo dam hydropower plant is dependent on the amount of water held by such reservoirs and where there are no reservoirs by the amount of water flowing in that river and through the electricity generation machinery (Kaunda, Kimambo & Nielsen, 2012). In this study, the source of the water for the dam under study is the Volta river that receives water inflows from numerous upstream rivers, streams and surface runoff within and outside Ghana. This study focuses on sources and runoffs within Ghana. As indicated earlier, the Ghana Meteorological Agency did not have complete data for most parts of the upper section of the Akosombo dam and so the researcher had to work with the best available data from weather stations that relate to the dam. These weather stations include Akosombo, Kete-Krachi and Adidome as shown in Figure 7.

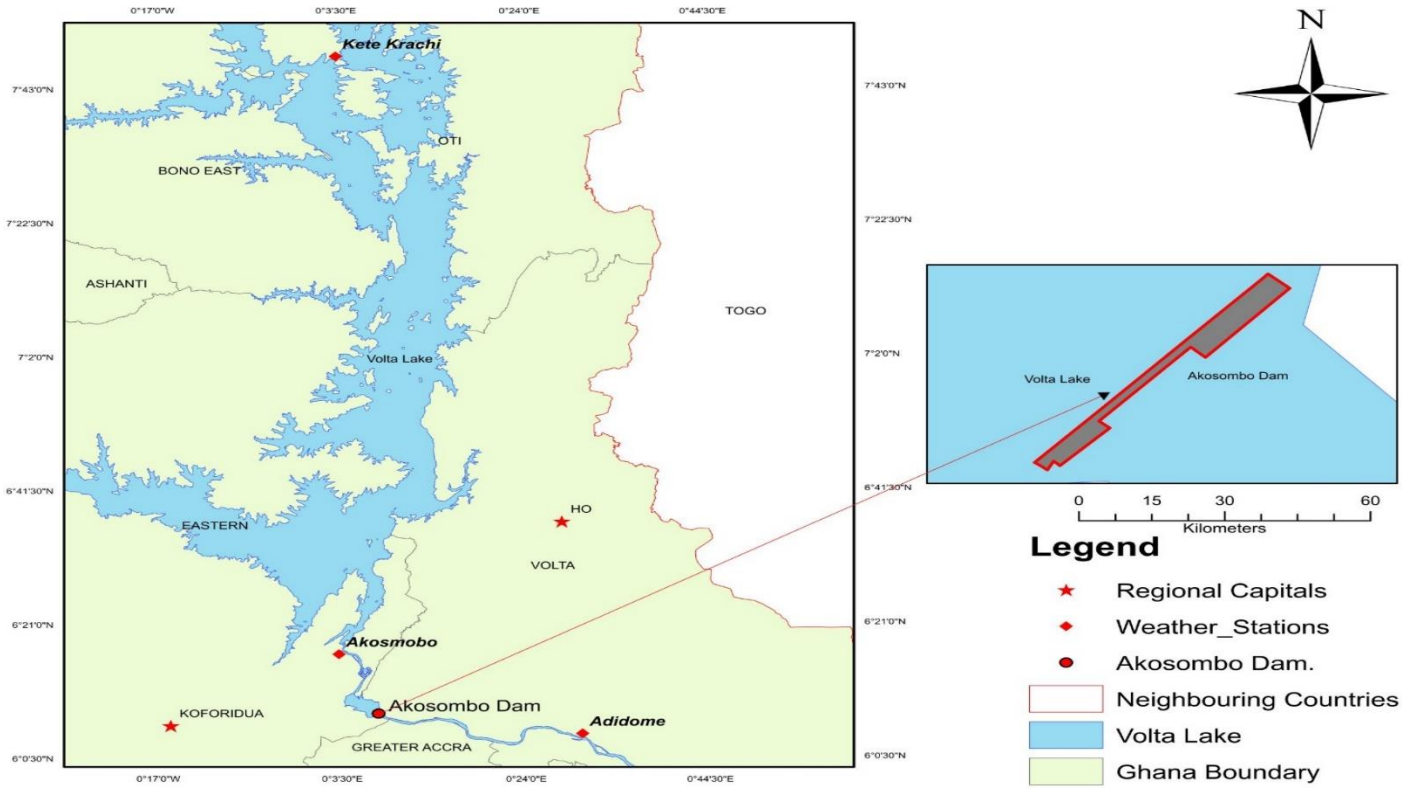

Figure 7: Selected weather stations connecting to the Akosombo Dam.
Source: Author, 2021

The figure shows the selected weather stations used in this study and their proximity to the dam. The unavailability of complete data confirms the argument that data availability and storage pose a challenge in Africa and that measures need to be put in place to avert the situation if developing countries want to improve their management of climate change (Zhang, 2017). The importance of the Akosombo hydropower plant to the economy of Ghana makes it imperative to collect adequate and reliable ranges and quantities of data to enable informed climate change adaptation. Seeking to address the limited internal data collection challenges, attempts were made to access data from the World Meteorological Organisation (WMO). The WMO in its response, referred the researcher to the Ghana Meteorological Agency (Appendix 6), but unfortunately complete data were not available. This compelled the researcher to do with the best available data provided by the Ghana Meteorological Agency. The following sub-sections discusses the annual rainfall quantities and patterns with the best available data from Akosombo, Kete-Krachi and Adidome.

4.2.1 Annual rainfall quantities and patterns in Akosombo

Climatic conditions at Akosombo usually have unexpected impacts on the frequency and intensity of rainfall patterns (Ghana Meteorological Agency, 2020). Analysing the rainfall data ranging from the year 2000 to 2020 shows that, at Akosombo, there has been a gradual decline in annual rainfall over the period as shown in the trend in figure 8. This pattern confirms the prediction that many parts of Africa will experience a decrease in rainfall due to climate change (Lube & McGeehin, 2008).

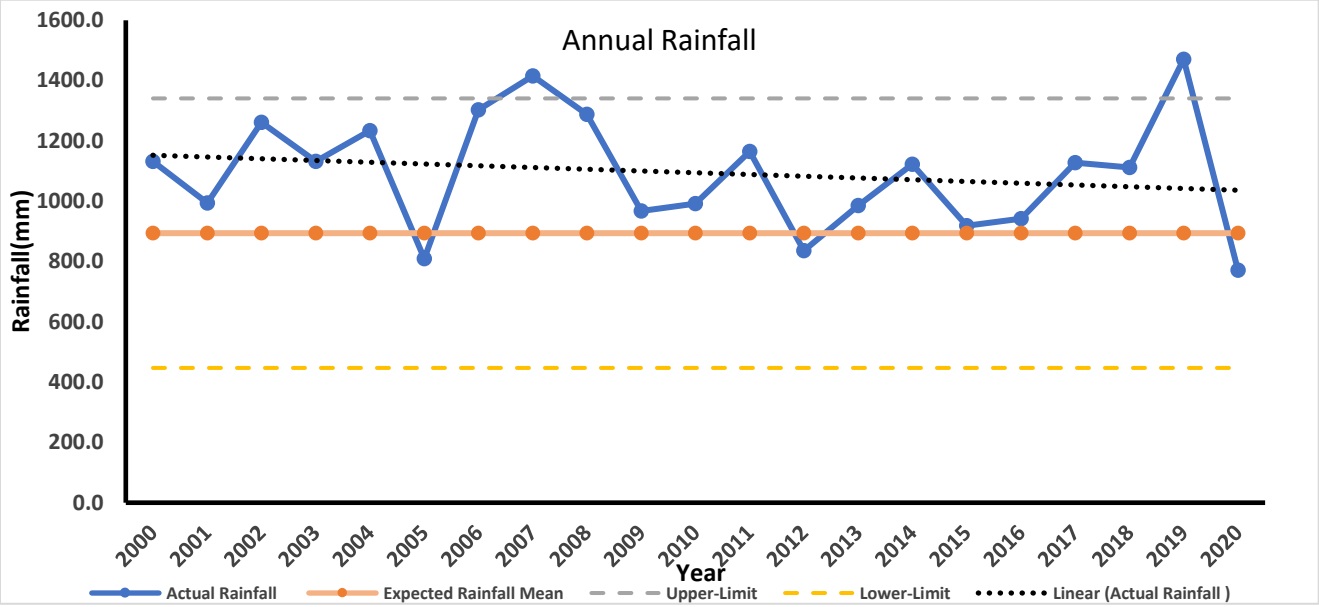

Figure 8: Annual rainfall patterns in Akosombo, 2000 – 2020
Source: Author (Data from Ghana Meteorological Agency, 2020)

Figure 8 shows the actual or real rainfall patterns, the expected rainfall based on historical data stretching far back into the past and used to assess whether there has been an increase or decrease in rainfall in modern times (Ghana Meteorological Agency, 2020), the upper and lower limit which are rainfall records more than 50% above or below the expected rainfall used to classify rainfall as either extremely low or extremely high and the linear which shows the trend in the actual rainfall over the years under study.

The trendline in the figure indicates that, cumulatively there have been a gradual but noticeable decline in rainfall within Akosombo. Considering the extreme ends of the trendline with the upper end recording a rainfall of approximately 1140 mm and the lower end recording approximate

rainfall of 1010 and by simple subtraction, annual rainfall in Akosombo has decreased by 130 mm over the period under study. In percentage terms, the decrease over the years (2000 to 2020) is about 11%, derived from the percentage formula as:

$$\frac{\alpha_x - \alpha_y}{\alpha_x} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where α_x is the rainfall value at the upper end of the trendline which is approximately 1140 mm and α_y is the rainfall value at the lower end of the trendline which is approximately 1010 mm. The trend of declining rainfall over the period under review is partly driven by the frequency and severity of extreme rainfall events. The frequency of the extreme rainfall events would depend on whether the changes in climate conditions are due to climate variability or effects of climate change. A less than ten-year period of a particular climatic condition could classify the extreme rainfall event as due to climate variability whilst more than ten years of a particular climatic condition could classify the extreme rainfall event as due to climate change effects. Climate data collected for this study span a 21-year period (2000 to 2020) indicating that the declining rainfall at Akosombo has been occurring for more than ten years hence the possibility of attributing the cause of the declining rainfall to climate change phenomenon. Another interesting observation made is that the decline in rainfall occurred even though almost all the years (apart from the years 2005, 2012 and 2021) had a rainfall above the expected annual rainfall of 894 mm (expected annual rainfall provided by the Ghana Meteorological Agency). It is also observed that the volume of rainfall generally increased (above the expected annual rainfall of 894 mm) over the study period but the volume kept decreasing from the year 2000 to 2020 as indicated by the trendline. Notable among the years of rainfall above the expected annual rainfall of 894 mm include 2007 and 2019 which experienced extremely high rainfall events recording rainfall of 1415 mm and 1491 mm respectively. While increases in rainfall are welcome, particularly where they support the relative climate change, extremely high rainfall can lead to flooding in mitigation projects such as those in hydropower and agriculture. In the case of Akosombo, increasing rainfall and extremely high rainfall events have resulted in instances of flooding as confirmed by a resident who recounted how they sometimes encounter flooding cases and its subsequent impact on their farm produce stating that:

> *There are cases of intense flooding that sometimes destroys our farm crops. This makes us lose money because there is no crop to sell. (Extract from the interview session.)*

However, such cases are not the norm and thus in this case, the years of extremely high rainfall can be viewed as a blessing in that it partly compensates for years of reduced rainfall leading to a reduced amount of water flowing into the Akosombo dam. Whereas there were two years (2007 and 2019) of extremely high rainfall, there was no case of extremely low rainfall. The absence of extremely low rainfall could also account for the minimal decline in rainfall resulting in the 11% or the 130 mm decline over the period under study.

An arising question is, which months are contributing to these annual rainfall patterns in Akosombo leading to the gradual annual decline in rainfall. A closer examination of the seasonal and monthly rainfall patterns over the years under study reveals the source of these annual rainfall quantities and patterns leading to the decline in the rainfall. To this end, the next section discusses the seasonal and monthly rainfall quantities and patterns within Akosombo.

4.2.1.1 Seasonal and monthly rainfall quantities and patterns at Akosombo

Leading from the previous section showing a decline in the annual rainfall at Akosombo, this section attempts to identify the reasons for the decline in seasonal and monthly rainfall. The seasonal and monthly rainfall are represented in Figures 9.1 to 9.12 from the years 2000 to 2020 for each month. The figures indicate the main rain season (March to June), represented by the dash lines, the second rain season (July to November) represented by the dotted lines and the dry season (December to February) represented by the solid line. It also shows the extremely low and high rainfall events during the period where the extremely high and low events are those more than 50% above and below the expected rainfall respectively.

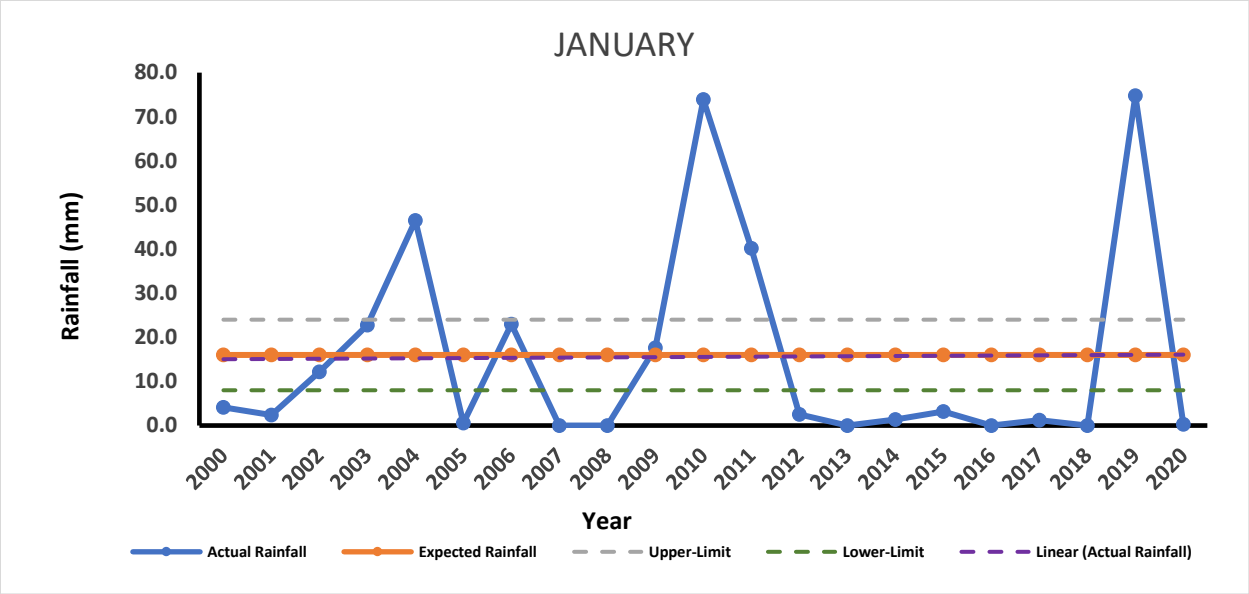

Figure 9.1: January rainfall at Akosombo
Source: Author (Data from Ghana Meteorological Agency, 2020)

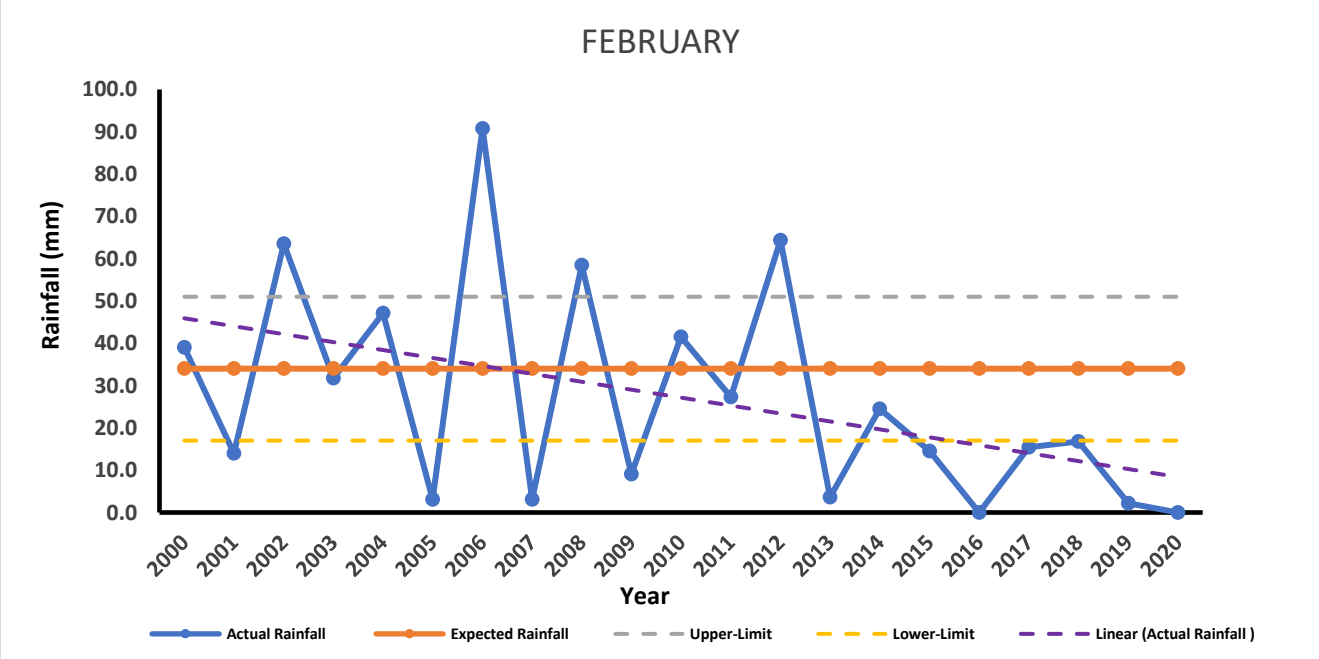

Figure 9.2: February rainfall at Akosombo
Source: Author (Data from Ghana Meteorological Agency, 2020)

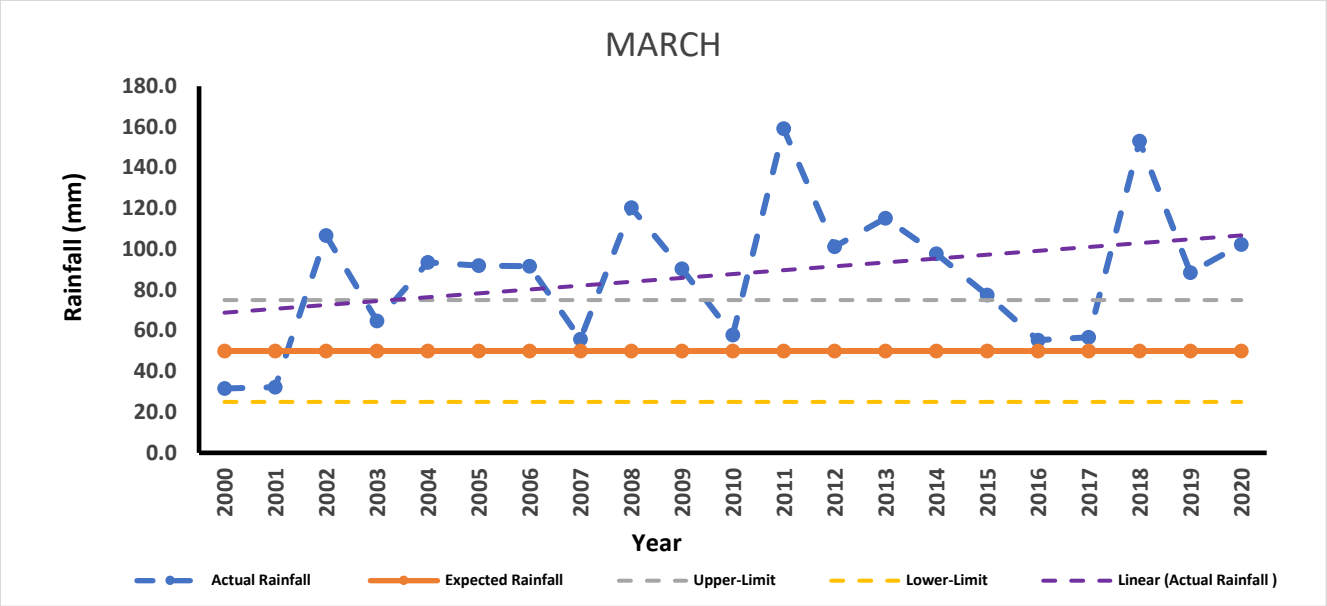

Figure 9.3: March rainfall at Akosombo
Source: Author (Data from Ghana Meteorological Agency, 2020)

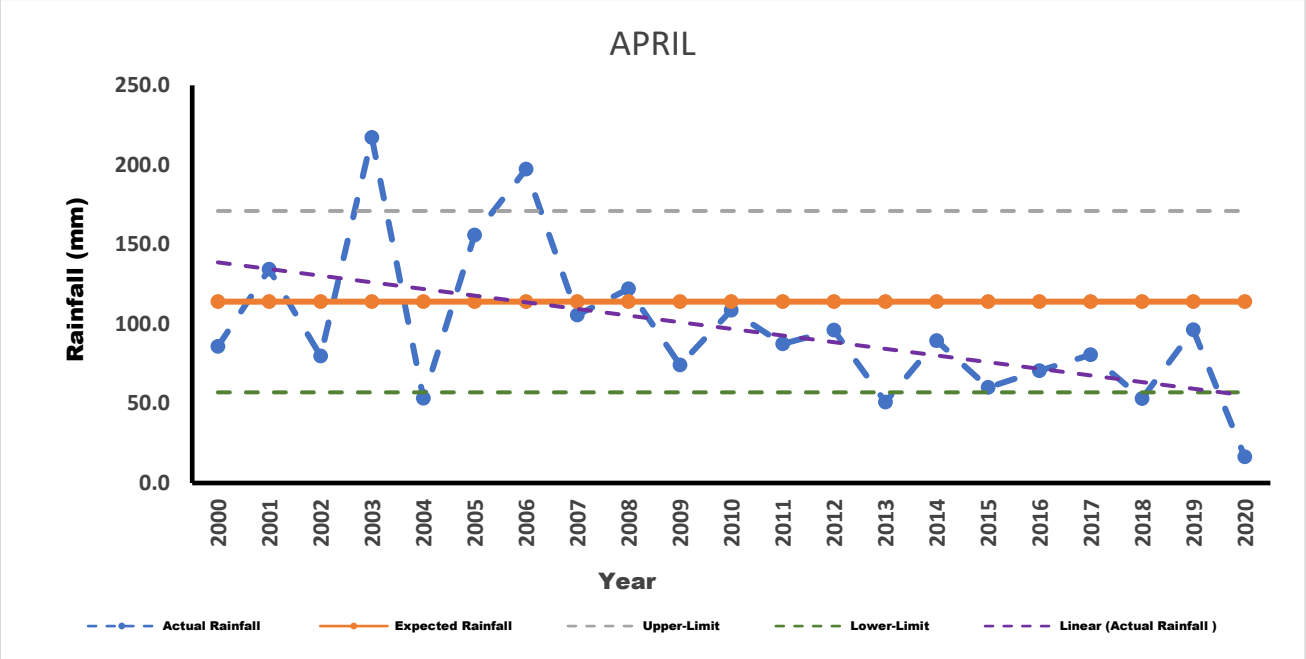

Figure 9.4: April rainfall at Akosombo
Source: Author (Data from Ghana Meteorological Agency, 2020)

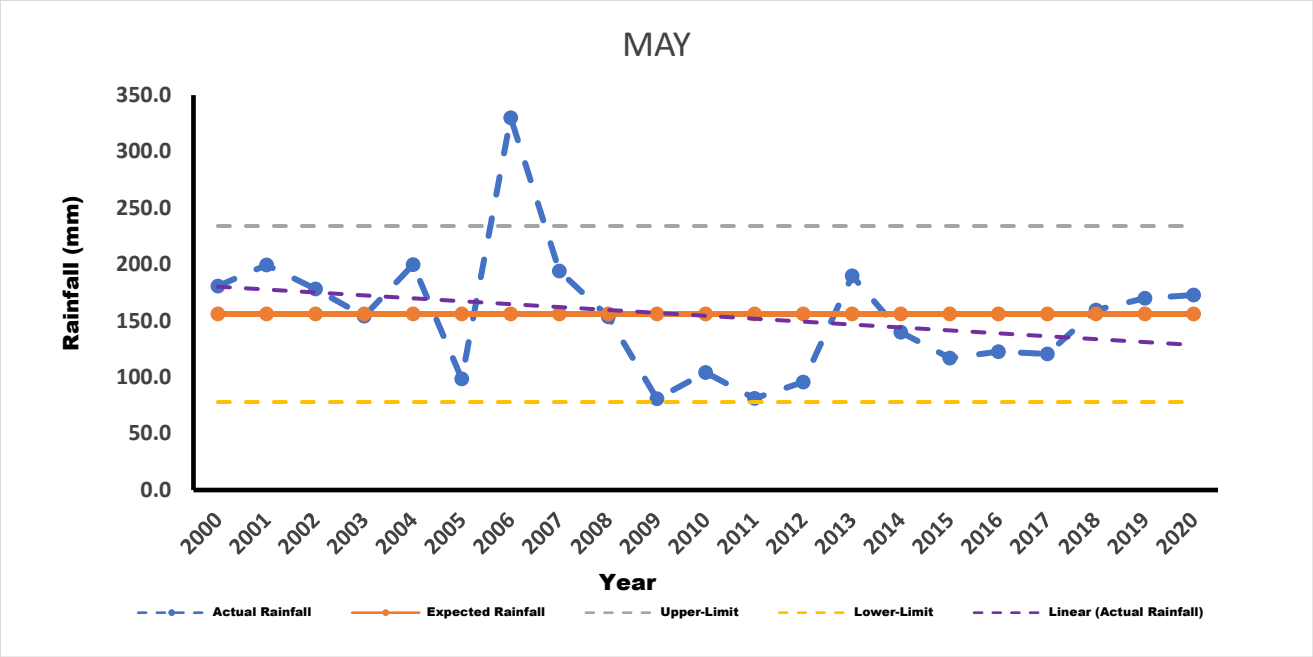

Figure 9.5: May rainfall at Akosombo
Source: Author (Data from Ghana Meteorological Agency, 2020)

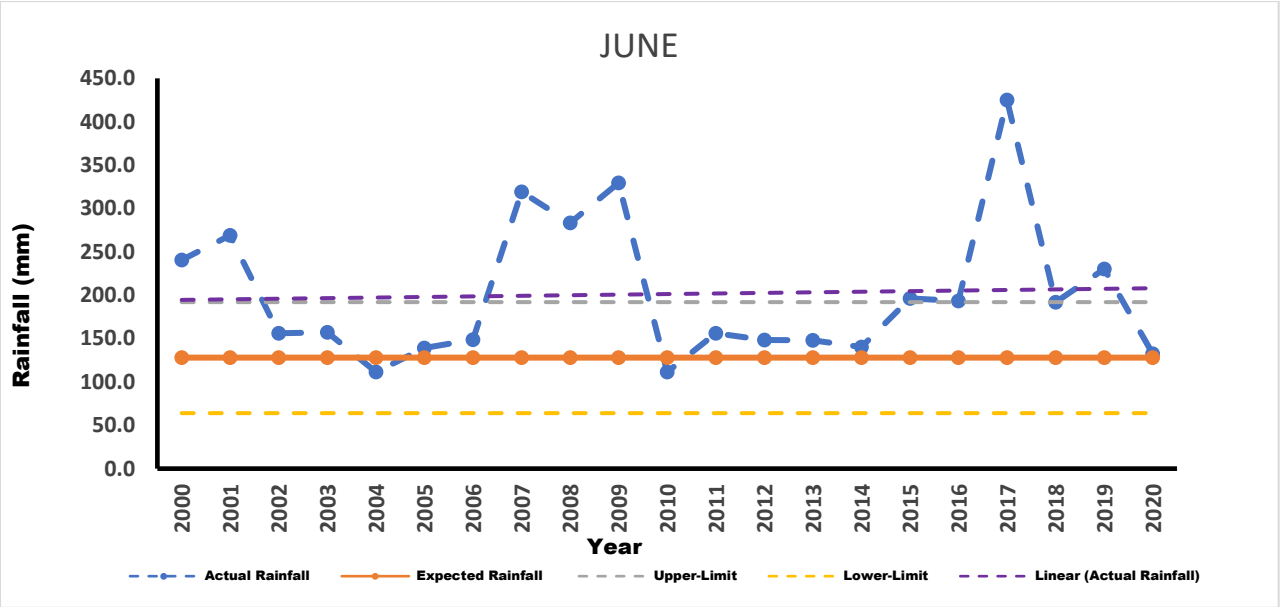

Figure 9.6: June rainfall at Akosombo
Source: Author (Data from Ghana Meteorological Agency, 2020)

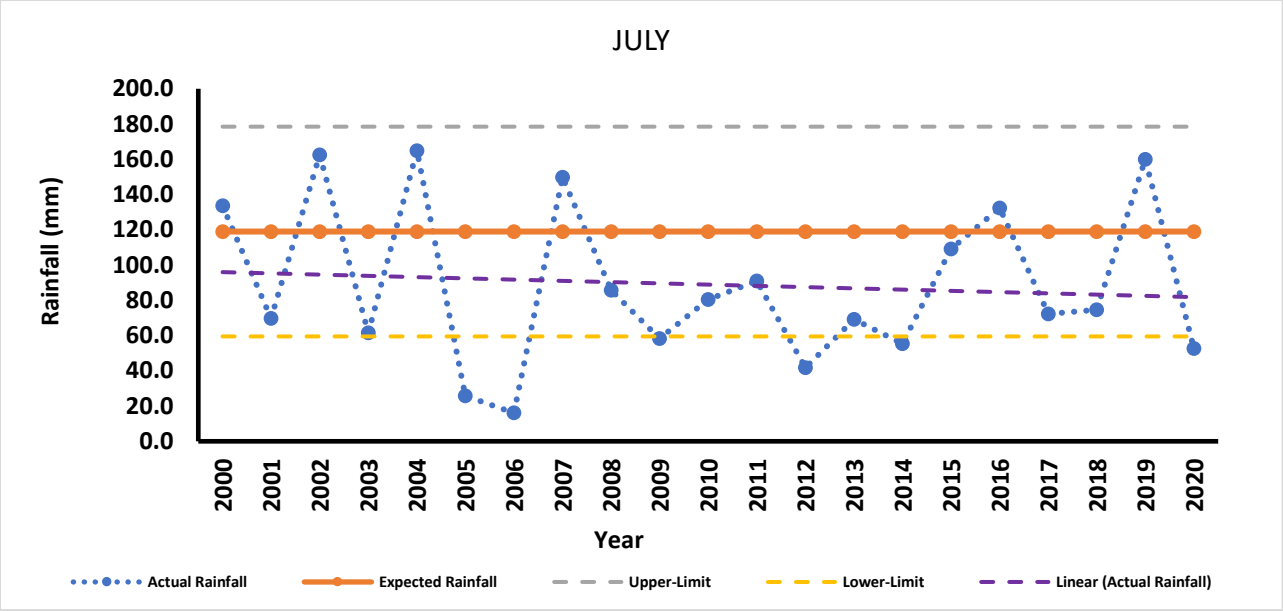

Figure 9.7: July rainfall at Akosombo
Source: Author (Data from Ghana Meteorological Agency, 2020)

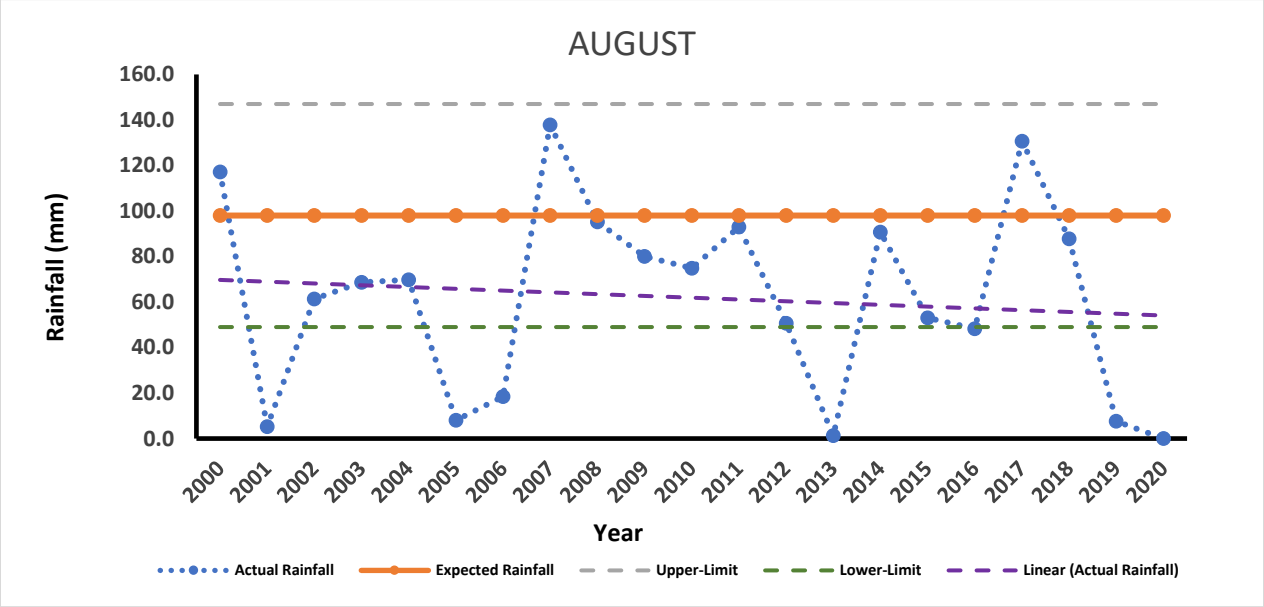

Figure 9.8: August rainfall at Akosombo
Source: Author (Data from Ghana Meteorological Agency, 2020)

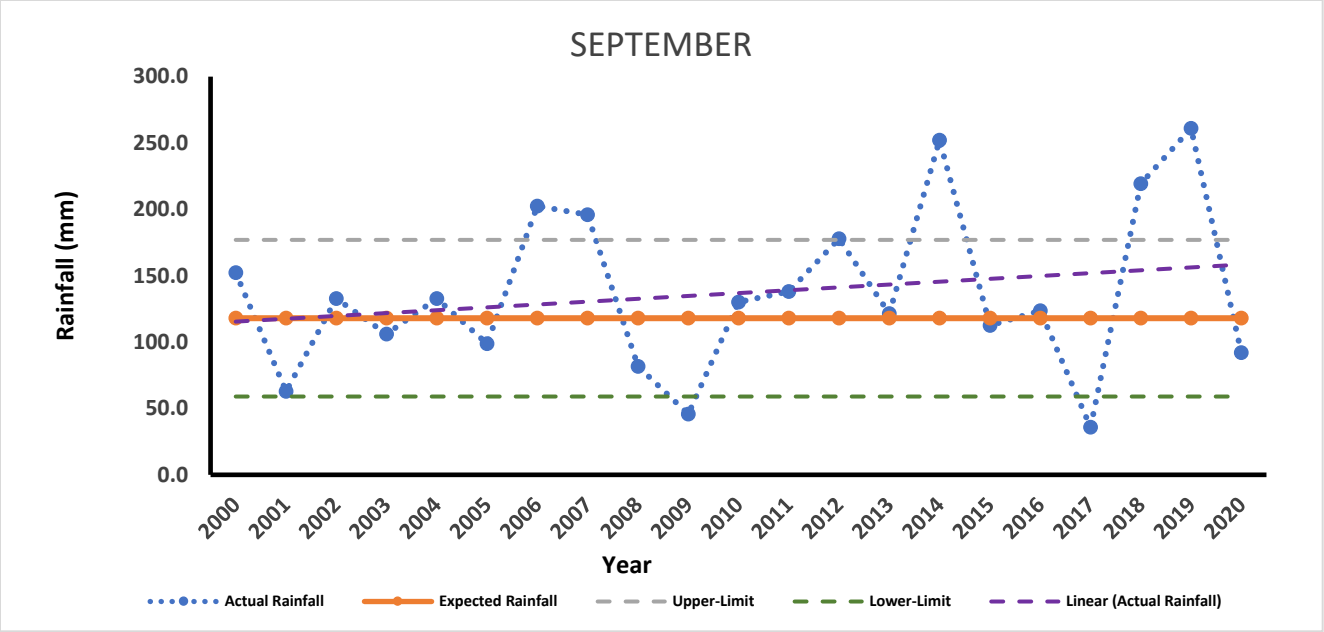

Figure 9.9: September rainfall at Akosombo
Source: Author (Data from Ghana Meteorological Agency, 2020)

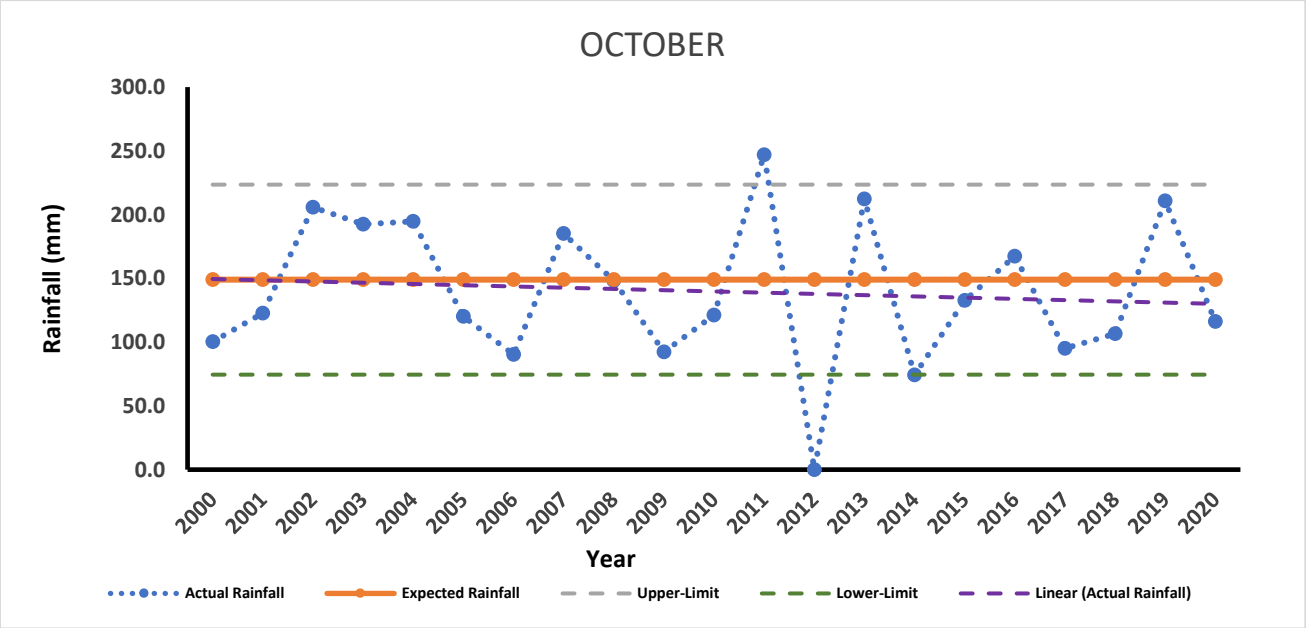

Figure 9.10: October rainfall at Akosombo
Source: Author (Data from Ghana Meteorological Agency, 2020)

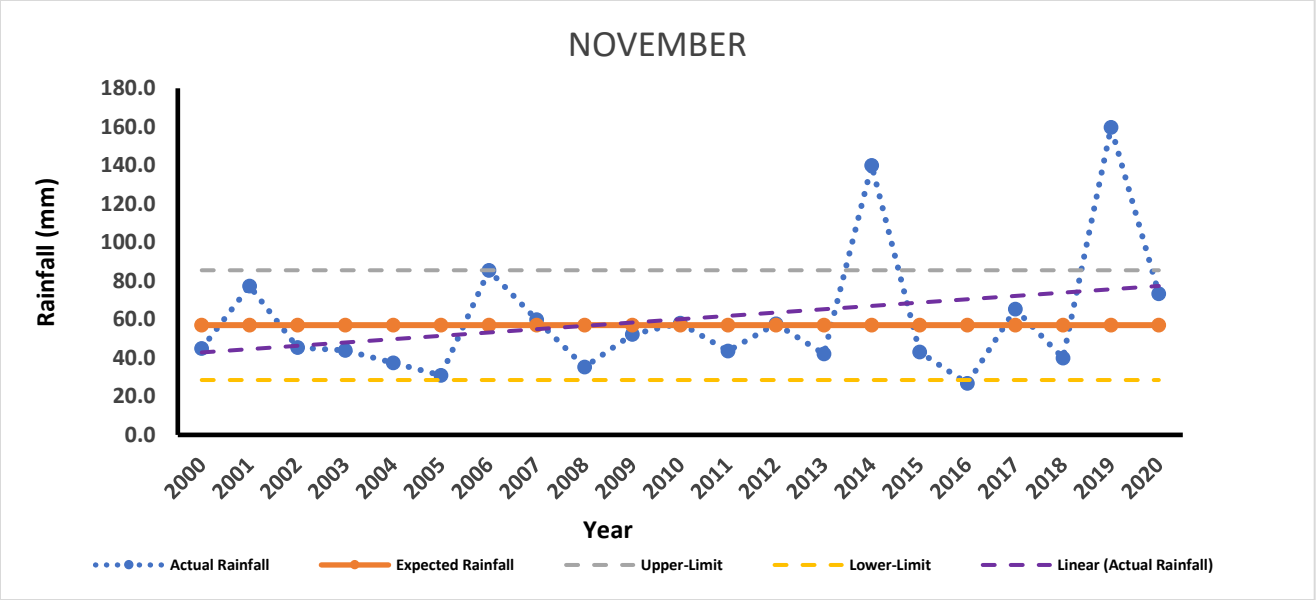

Figure 9.11: November rainfall at Akosombo
Source: Author (Data from Ghana Meteorological Agency, 2020)

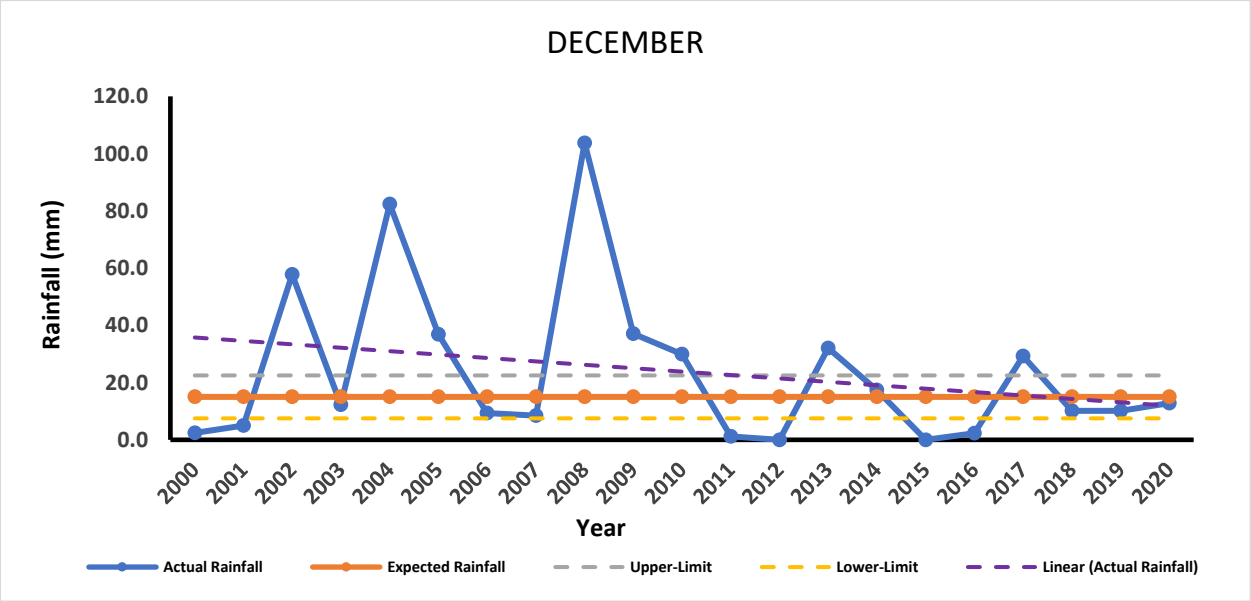

Figure 9.12: December rainfall at Akosombo
Source: Author (Data from Ghana Meteorological Agency, 2020)

Examining the monthly rainfall shows that the highest rainfall within the period under study (2000 to 2020) occurred in the main rain season during the month of June with rainfall of 424.9 mm, this occurred in the year 2017. An interesting observation is that, two of the months within the main

rain season, that is the months of April (Figure 9.4) and May (Figure 9.5) had decreasing rainfall over the period whilst June (Figure 9.6) and March (Figure 9.3) witnessed increasing rainfall. Observing the trendline, the month April had an intense decrease in rainfall followed by the month of May. With the upper end of the trendline recording approximately 140 mm and the lower end recording approximately 55 mm, rainfall during the accumulated months of April over the study period decreased by 85 mm. With the upper end of the trendline recording approximately 181 mm and the lower end recording 130 mm, rainfall in the month of May decreased by 51 mm. The months of March and June show an increase in rainfall and can therefore be classified as not contributing to the annual decline. This could be the cause of the slight annual rainfall decline of 11% or 130 mm in Akosombo over the period under study. It is observed that during March and June many cases of extremely high rainfall events were experienced, with March having recorded 14 of the years witnessing extremely high rainfall events whilst June experienced 8 extremely high rainfall events. April and May experienced 2 and 1 extremely high rainfall events respectively. This means the months of March and June witnessed much flooding cases in Akosombo. This was confirmed by some residents during the interview stating that:

> *Most of the times we experience more flooding in June to the extent of having to relocate to stay at a place on a high-level ground to avoid being swallowed in the floods. (Extract from the interview session.)*

There were mixed situations of increasing and decreasing rainfall during the second rain season (July to November). The months of July (Figure 9.7), August (Figure 9.8) and October (Figure 9.10) witnessed decreasing rainfall whilst September (Figure 9.9) and November (Figure 9.11) experienced increasing rainfall. Among the decliners, the month of October recorded the highest decline with rainfall declining from 150 mm to 125 mm resulting in 25 mm decline in rainfall over the study period. This was followed by the month of August with a slight decline in rainfall, reducing by 14 mm after having the upper end of the trendline to be approximately 70 mm and the lower end being approximately 56 mm. This is followed by the month of July with its rainfall decreasing by 13 mm. It is therefore not surprising to see August and July having 6 and 5 extremely low cases of rainfall over the period. Months of September and November experienced increasing rainfall and so cannot be described as a contributor to the annual rainfall decline as shown in Figure 8.

Figure 9 shows that the dry season (December to February) in most cases experienced declining rainfall, except for the month of January (Figure 9.1) which did not show any change over the

years. The month of February (Figure 9.2) experienced the most intense decline in rainfall as shown in the Figure. With the upper end of the trendline recording approximately 46 mm and the lower end being approximately 8 mm, rainfall in the month of February decreased by 38 mm. With upper end of the trendline recording 35 mm and the lower end having 12 mm, the month of December (Figure 9.12) contributed 23 mm of reduced rainfall to the annual declining rainfall at Akosombo.

With the month of April recording a total rainfall decline of 85 mm over the period under study and that May recording 51 mm over the same period, the main rain season can be classified as the major contributor to the annual declining rainfall in Akosombo. Having recorded rainfall declines of 38 mm and 23 mm for the months of February and December respectively, the dry season can be categorized as the second contributor to the annual declining rainfall in Akosombo. There was a minimal contribution to the annual declining rainfall by the second rain season. This is evidenced by the rainfall decline of 14 mm, 13 mm and 25 mm recorded in the months of August, July and October respectively. This implies that, water in the Akosombo dam would likely experience major shortfalls during the major rain season. Ironically, the major rain season is the season of high expectancy of rainfall. Management of the dam need to be cautious around this period and ensure farmers around the dam do not harvest the water for their farming activities. Although the amount of rainfall in the second rain season is not much compared to the major rain season, it (the second rain season) can complement the major rain season since there is not much reduction in rainfall during that season (the second rain season). The dry season being the second contributor to the annual declining rainfall with the month of February and December recording 38 mm and 23 mm in rainfall decline respectively, already worsens a precarious situation. This is because already, the dry season is a season with far less rainfall and the little rains falling are again reducing in higher amounts. Critical measures need to be put in place by the management of the dam during this period. Another weather station within the catchment of the Akosombo dam worthy of analysing its rainfall patterns due to its impact on the water level of the dam is Kete-Krachi. The next sub-section discusses the annual rainfall quantities and patterns within Kete-Krachi.

4.2.2 Annual rainfall quantities and patterns in Kete-Krachi

According to the Ghana Meteorological Agency (2020), weather conditions in Kete-Krachi are such that the wet season is oppressive and overcast, the dry season is muggy and partly cloudy, and it is hot year-round. These are derived from historical climate data collated over the past far

years. Analysed rainfall data collated over the period under study, ranging from the year 2000 to 2020 shows that rainfall in Kete-Krachi has been declining over the years as shown in Figure 10.

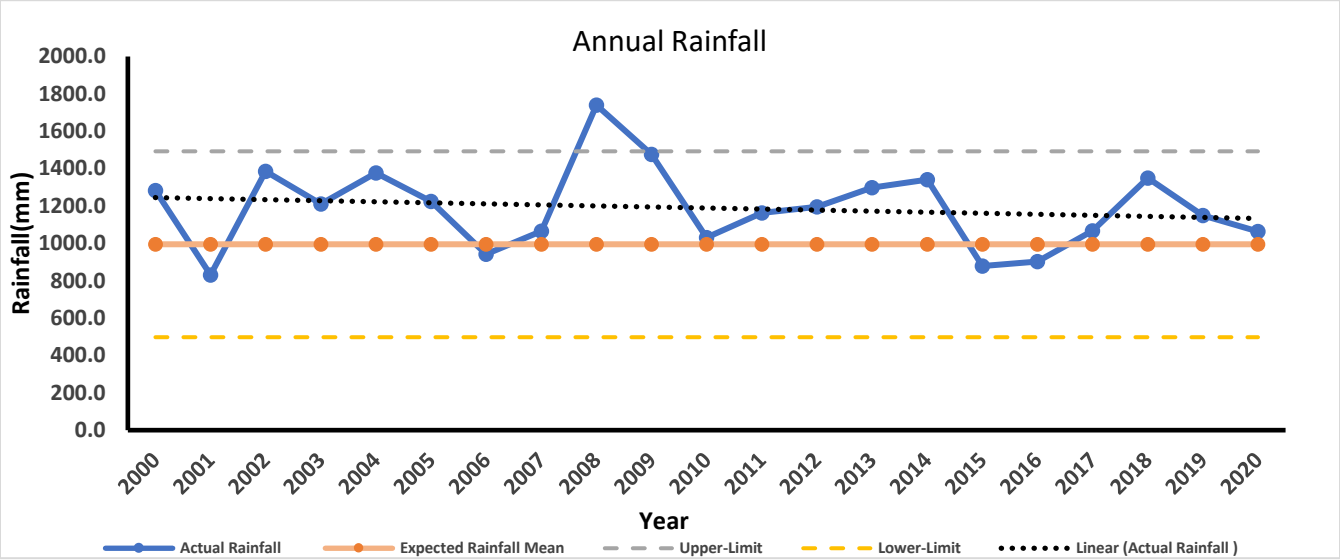

Figure 10: Annual rainfall patterns in Kete-Krachi, 2000 – 2020
Source: Author (Data from Ghana Meteorological Agency, 2020)

Examining the rainfall patterns in Figure 10, it is observed that for 17 years (out of the 21 years – 2000 to 2020), rainfall was above the expected rainfall of 995 mm. The years 2001, 2006, 2015 and 2016 experienced rainfall below the expected with rainfall values of 831 mm, 941 mm, 879 mm and 903 mm respectively. This implies that rainfall has generally increased in volume over the years above the expected rainfall of 995 mm. However, cumulatively, the increased amount of rainfall has been gradually declining from the year 2000 to 2020 as indicated by the trendline. The upper end of the trendline indicates a rainfall value of approximately 1,260 mm and the lower end with rainfall of approximately 1140 mm indicating that the amount of rainfall has generally declined by 120 mm. Using the percentage formula in equation 1, the percentage decrease in rainfall over the study period is 9.5%. Further examination of the rainfall patterns indicates that there was one case of an extremely high rainfall event over the period under study. This occurred in the year 2008 with rainfall of 1740 mm. This indicates possibility of flooding cases in the year 2008. Other years could have also experienced flooding cases, but this cannot be ascertained by the annual rainfall graph since there is no record of an extremely high rainfall more than 50% above the expected rainfall. There is no record of an extremely low rainfall event as compared to the one case of an extremely high. Also, there are 16 cases of rainfall above the expected rainfall compared to the 4 cases of rainfall below the expected rainfall. The volume of rainfall above the

expected rainfall is generally high compared to the volume of rainfall below the expected rainfall. Generally, annual decline in rainfall has not been so significant from the year 2000 to 2020 and so may not have had much negative effect on the water level of the Akosombo dam but one thing remains for sure, and that is that the amount of rainfall is gradually declining and is likely to keep declining over the next decade to the point of being significant and having a negative impact on the water level of the Akosombo dam. Management of the Akosombo dam needs to plan ahead for any future eventualities. Chapter 6 of the study proposes climate change management adaptation framework that the management of the Akosombo dam can adopt to plan to secure the dam from any future eventualities.

The annual rainfall is constituted and computed by the monthly rainfall. It is therefore imperative to figure out which months contribute to the nature of annual rainfall quantities and patterns leading to the decline in the annual rainfall. This is covered in the next section, which discusses the seasonal and monthly rainfall quantities and patterns within Kete-Krachi.

4.2.2.1 Seasonal and Monthly rainfall quantities and patterns at Kete-Krachi

Arising from the previous section that shows the annual decline in rainfall at Kete-Krachi, this section reveals the sources of the annual rainfall decline from the monthly rainfall. The rainfall period over the study period (2000 to 2020) constitutes three distinct seasons. Figures 11.1 to 11.12 show these three distinct seasons as main rain season made up of March to June, represented by the dash lines, the second rain season made up of July to November, represented by the dotted lines and the dry season made up of December to February, represented by the solid line. Again, the figures show the extremely low and high rainfall events over the period where the extremely highs and lows events are those which are more than 50% above and below the expected rainfall respectively.

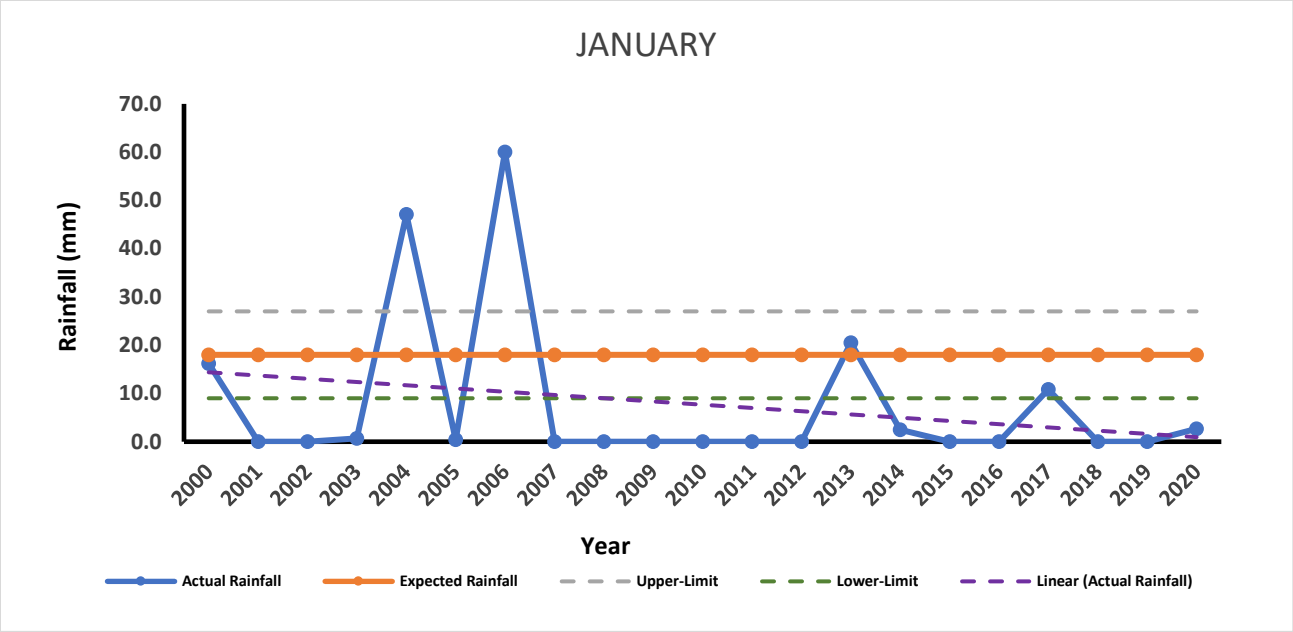

Figure 11.1: January rainfall at Kete-Krachi
Source: Author (Data from Ghana Meteorological Agency, 2020)

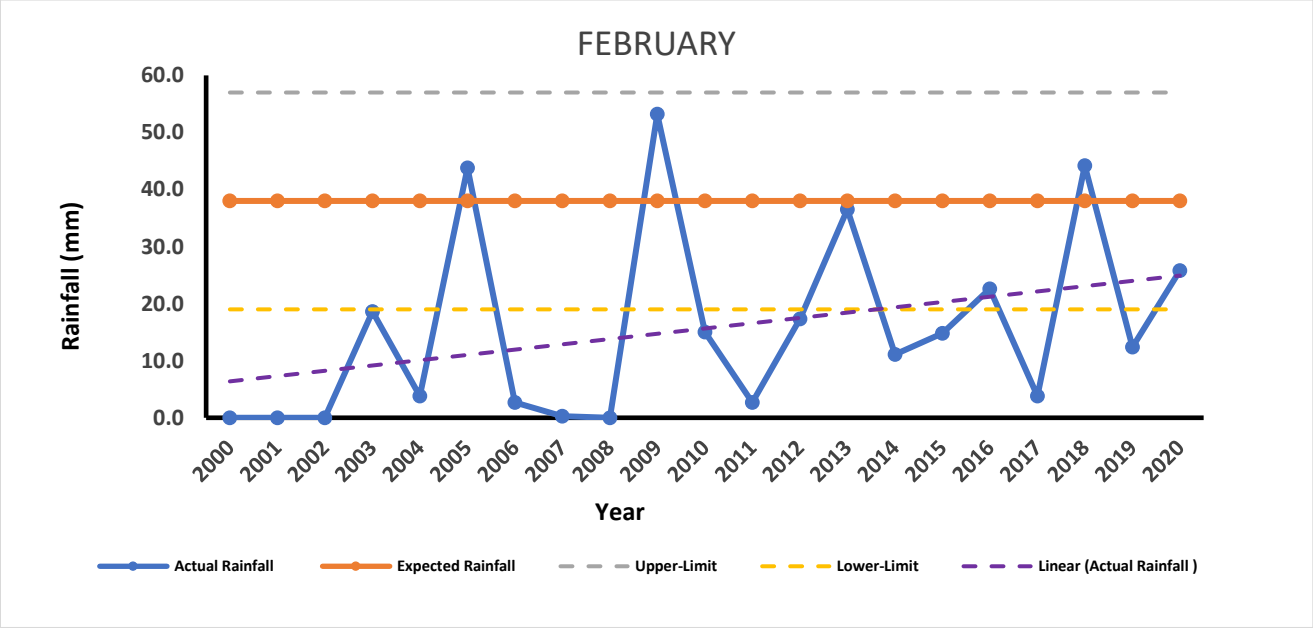

Figure 11.2: February rainfall at Kete-Krachi
Source: Author (Data from Ghana Meteorological Agency, 2020)

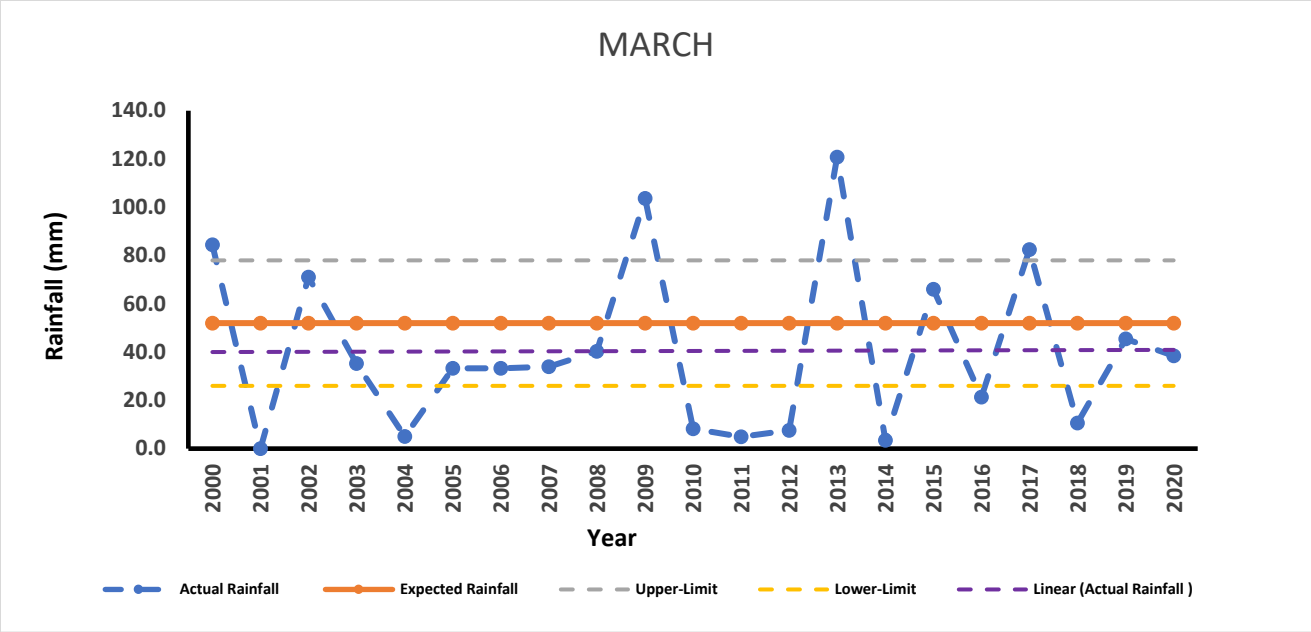

Figure 11.3: March rainfall at Kete-Krachi
Source: Author (Data from Ghana Meteorological Agency, 2020)

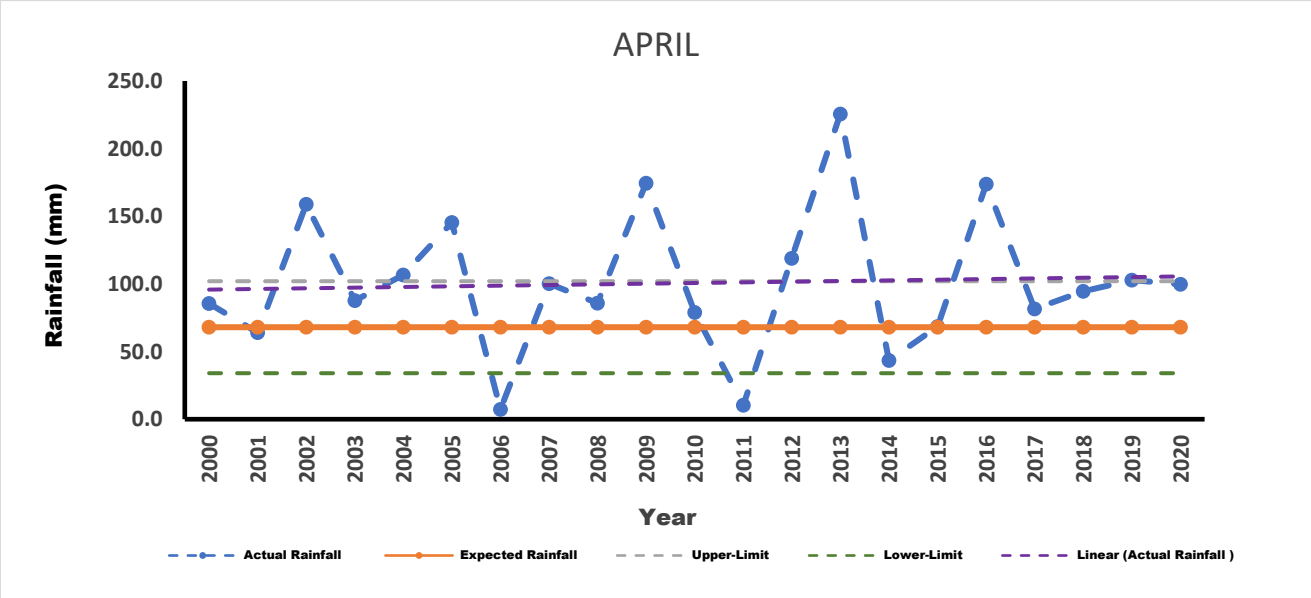

Figure 11.4: April rainfall at Kete-Krachi
Source: Author (Data from Ghana Meteorological Agency, 2020)

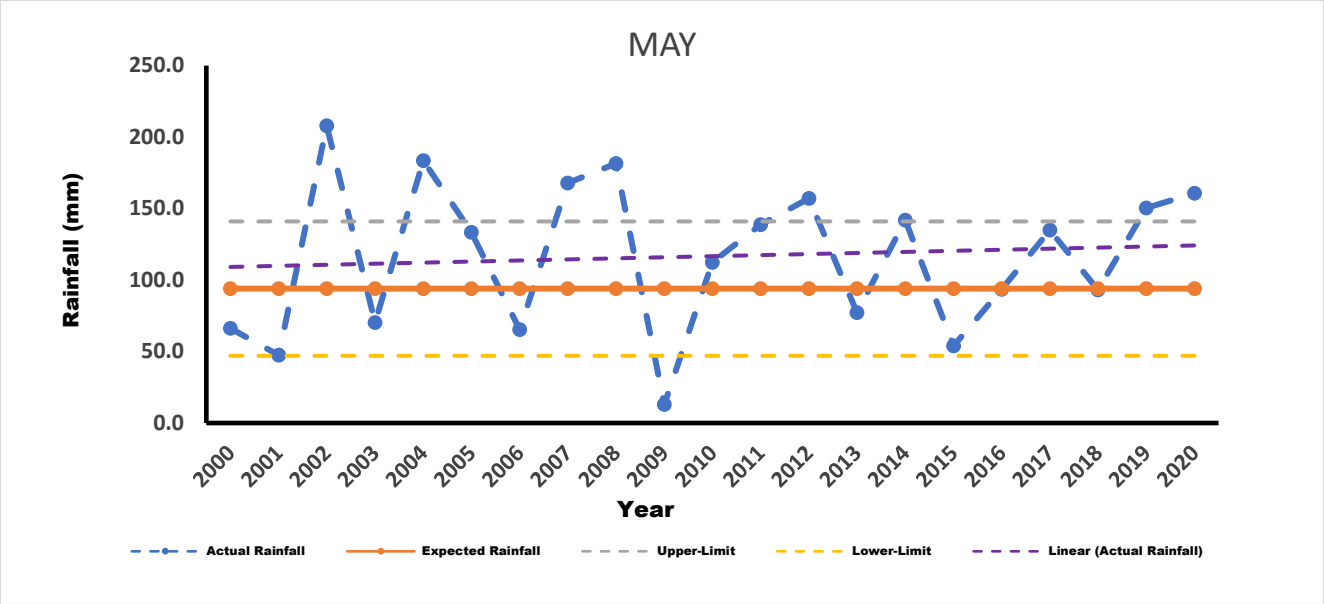

Figure 11.5: May rainfall at Kete-Krachi
Source: Author (Data from Ghana Meteorological Agency, 2020)

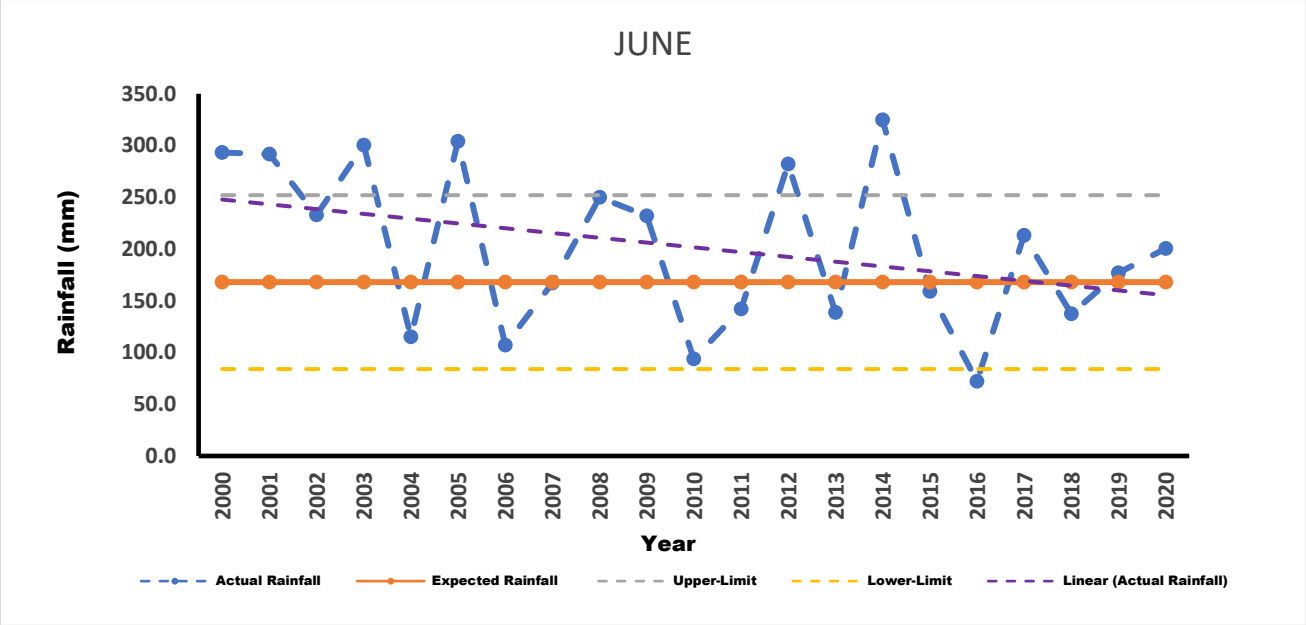

Figure 11.6: June rainfall at Kete-Krachi
Source: Author (Data from Ghana Meteorological Agency, 2020)

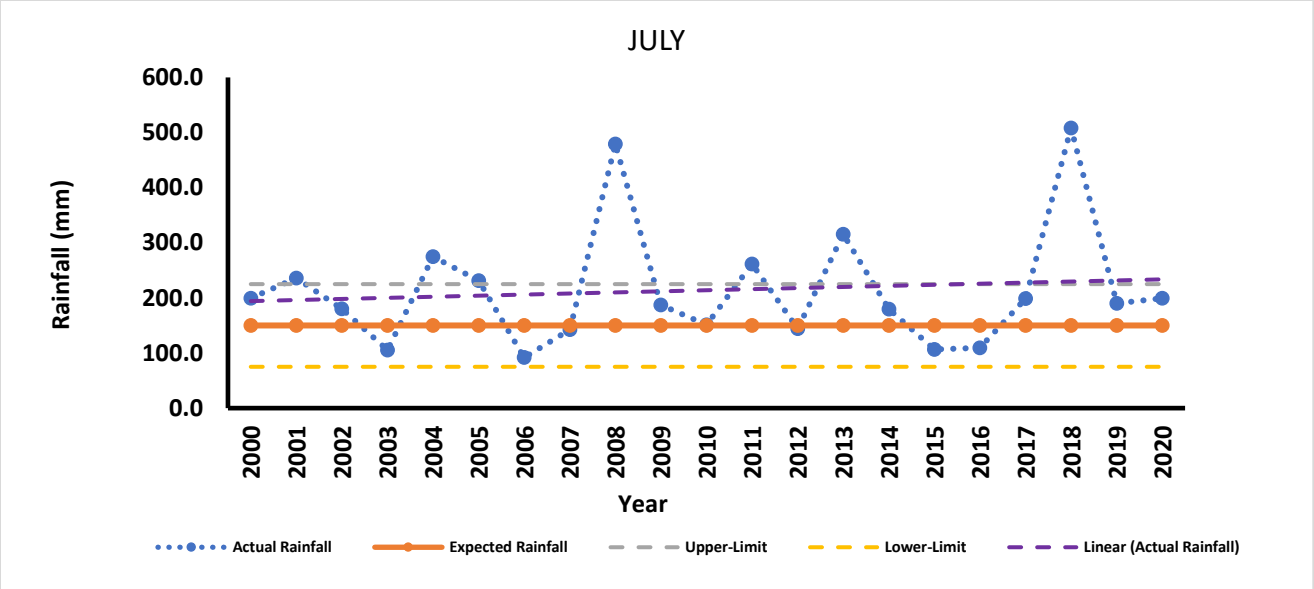

Figure 11.7: July rainfall at Kete-Krachi
Source: Author (Data from Ghana Meteorological Agency, 2020)

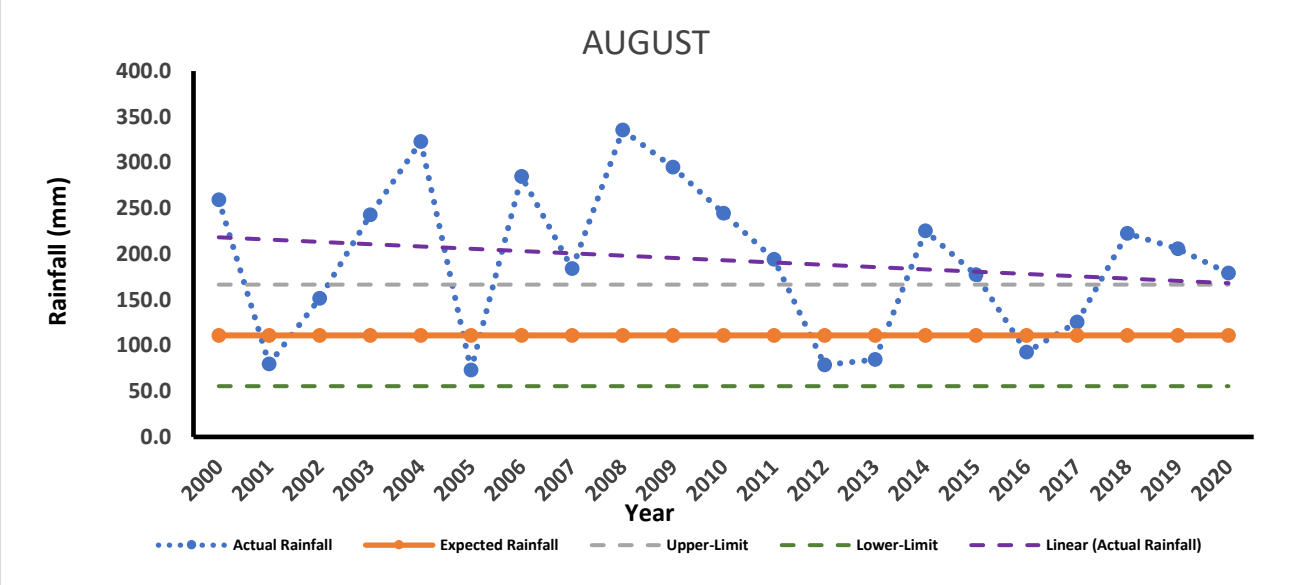

Figure 11.8: August rainfall at Kete-Krachi
Source: Author (Data from Ghana Meteorological Agency, 2020)

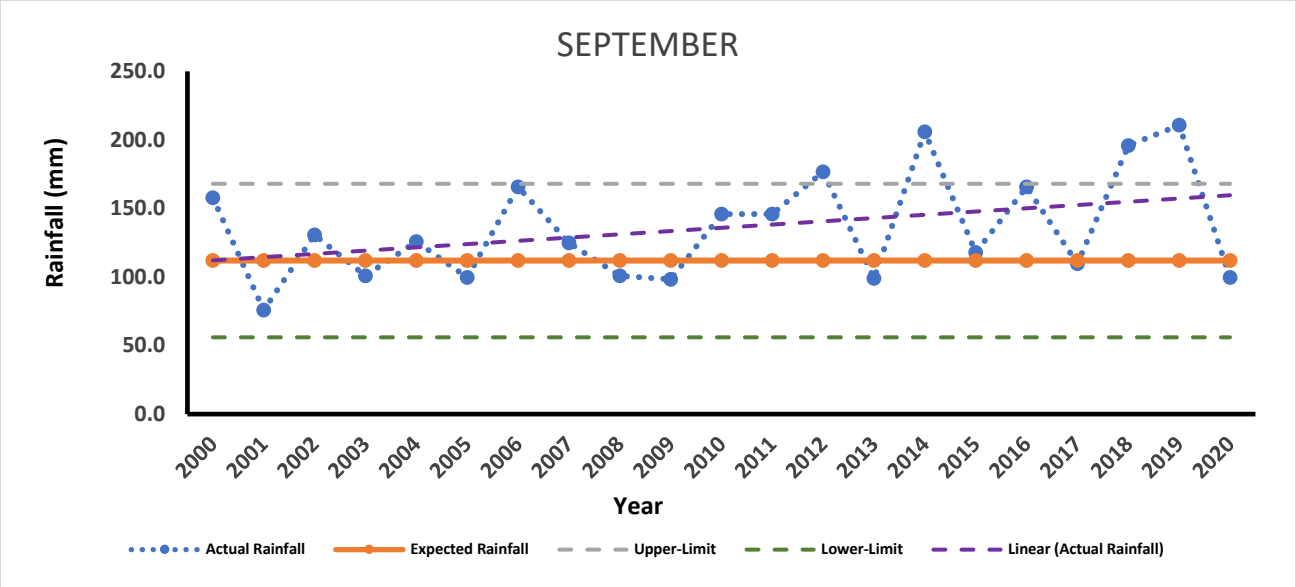

Figure 11.9: September rainfall at Kete-Krachi
Source: Author (Data from Ghana Meteorological Agency, 2020)

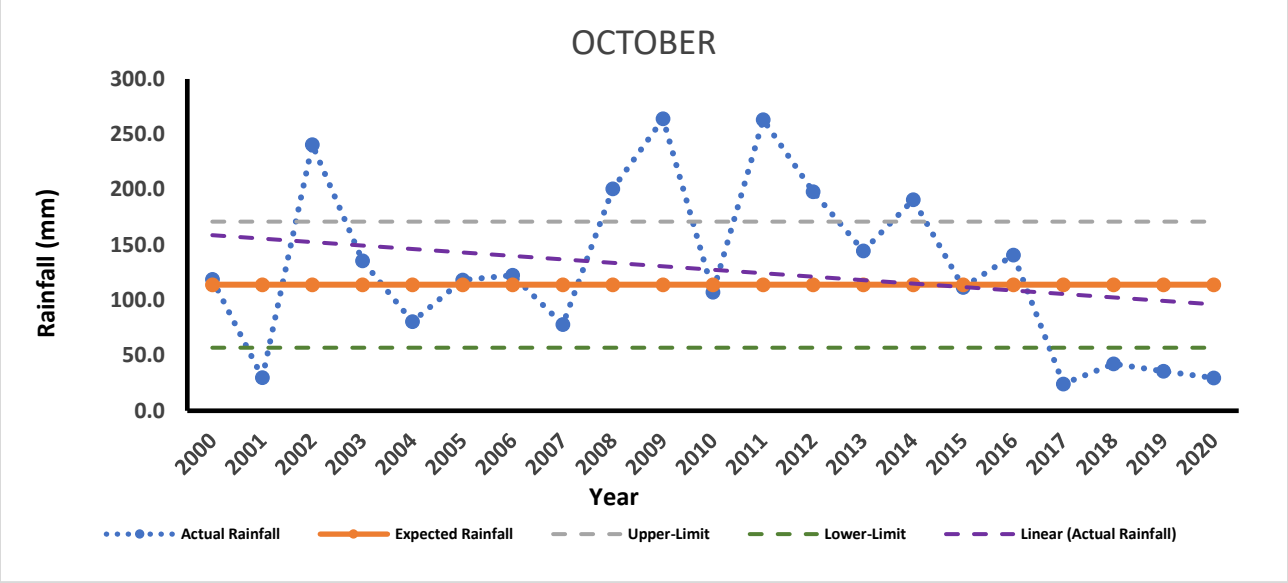

Figure 11.10: October rainfall at Kete-Krachi
Source: Author (Data from Ghana Meteorological Agency, 2020)

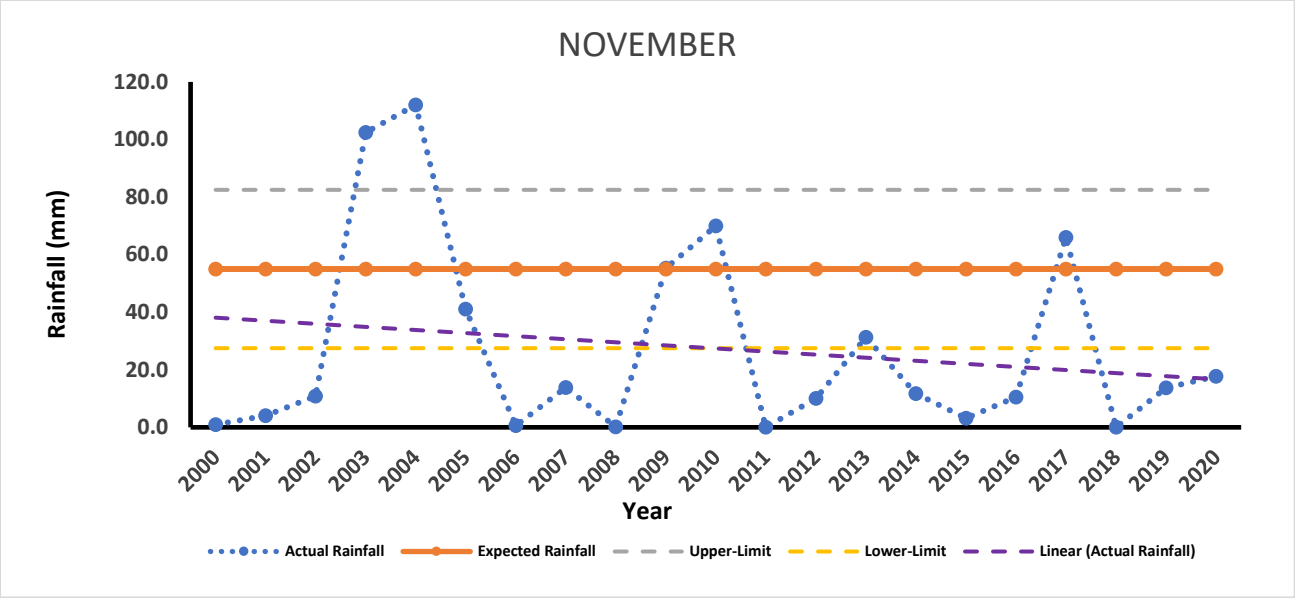

Figure 11.11: November rainfall at Kete-Krachi
Source: Author (Data from Ghana Meteorological Agency, 2020)

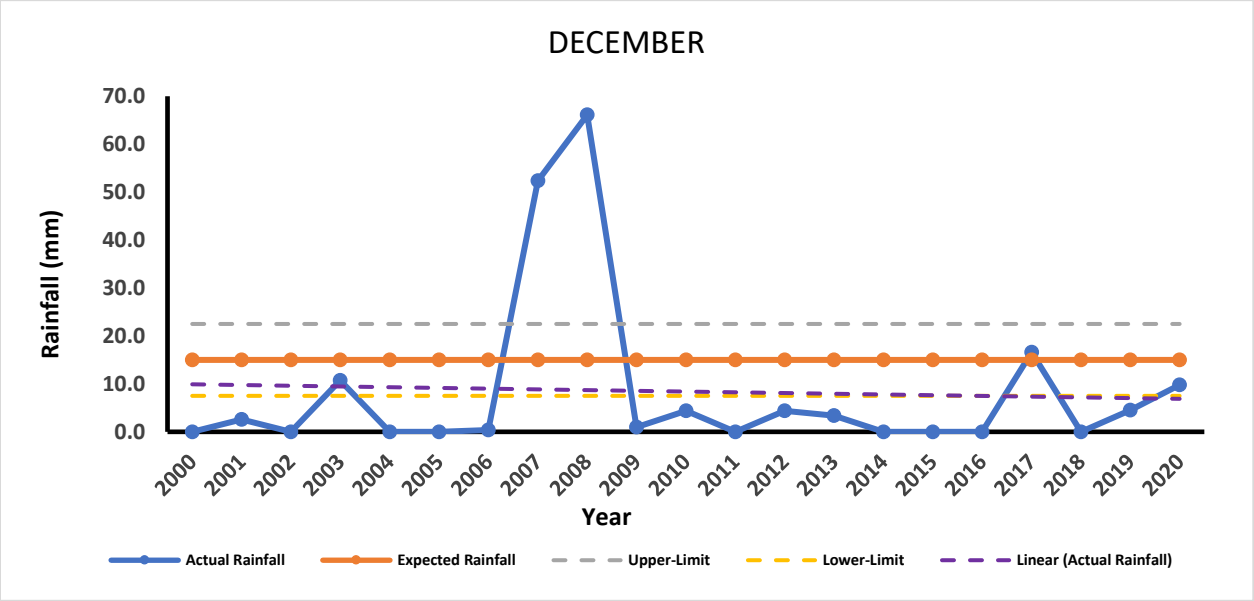

Figure 11.12: December rainfall at Kete-Krachi
Source: Author (Data from Ghana Meteorological Agency, 2020)

A close examination of the seasonal and monthly rainfall patterns at Kete-Krachi shows that the month of June (Figure 11.6) witnessed the most intense rainfall decline as indicated by the sharp decline in the trendline. The upper end of the trendline recorded rainfall of approximately 250 mm

and the lower end recording 150 mm resulting in a rainfall decline of 100 mm over the period under study. Within the main rain season, only the month of June witnessed a declining rainfall. Months of April (Figure 11.4) and May (Figure 11.5) witnessed increases in rainfall whilst there is no change in the direction of the rainfall, in other words whether it increased or decreased) in the month of March (Figure 11.3). The month of June is the only month within the main rain season that can be classified as a contributor to the annual declining rainfall in Kete-Krachi. The highest rainfall in June occurred in the year 2014 with a total rainfall of 325 mm. Whiles it recorded 1 case of extremely low rainfall of 72 mm in 2016, it recorded six cases of extremely high rainfall in the years 2000, 2001, 2003, 2005, 2012 and 2014 with rainfalls of 293 mm, 291 mm, 300 mm, 304 mm, 282 mm and 325 mm respectively. This implies that there is high likelihood of intense flooding cases during these years. In most cases June is expected to be the month with highest rainfall, ironically the highest rainfall during the period under study occurred in the month of July which falls within the second rain season. It recorded its highest rainfall of 508 mm in 2018 whilst June recorded its highest rainfall of 325 mm in the year of 2014. This could be a signal of possible shift in seasons in that the period of the main rain season could exchange position with the period of the second rain season. It is not surprising that the month of July (Figure 11.6) experienced increasing rainfall over the period under study and recorded 14 of the years with rainfall above the expected rainfall of 150 mm. The month of September (Figure 11.9) also witnessed an increasing rainfall over the period and therefore July and September cannot be considered as months that contributed to the annual declining rainfall in Kete-Krachi. Months of August (Figure 11.8), October (Figure 11.10) and November (Figure 11.11) however, recorded decreasing rainfall. The upper point of the trendline in the month of August recorded rainfall of 224 mm whilst the lower end recorded 166 mm of rainfall resulting in 58 mm reduction in rainfall. October shows the most intense decline, declining from 155 mm to 90 mm leading to 65 mm reduction of rainfall. The month of November witnessed minimal reduction in rainfall decreasing from 38 mm to 20 mm resulting in 18 mm decrease in rainfall. The months of August, October and November can be classified as contributors to the annual declining rainfall in Kete-Krachi recording decreased rainfall of 58 mm, 65 mm and 18 mm respectively. The dry season (December to February) as indicated in Figure 11 shows that December (Figure 11.12) and January (Figure 11.1) witnessed a slight decrease in rainfall whilst February (Figure 11.2) experienced moderate increase in rainfall. The increase in rainfall during the month of February is a bit surprising because that period is noted as a dry season therefore increasing rainfall is not expected, at worse it is expected that there would be no change in the rainfall. Due to the recorded increased in rainfall during the month

of February, it is therefore ruled out as a contributor to the annual decline in rainfall as shown in Figure 10. The trendline shows that the month of December had rainfall decreasing from approximately 10 mm to 6 mm resulting in the contribution of 4 mm to the annual declining rainfall. January's rainfall shows significant decrease over the period under study (2000 to 2020). The rainfall decreased from 15 mm to 0.5 mm resulting in a decrease 14 mm in rainfall.

In Kete-Krachi, the second rain season is the major contributor to annual declining rainfall contributing a total of 141 mm in rainfall decline. This is attributable to the months of August, October and November recording decreasing rainfalls of 58 mm, 65 mm and 18 mm respectively. Declining by 100 mm, the month of June and the main rain season is the second highest contributor to the annual declining rainfall. The interesting observation is that there could be a shift in seasons in Kete-Krachi as indicated earlier where the main rain season could become the second rain season and vice versa. This is the evidence that in some seasons that were previously dry, the climate change phenomenon may increase rainfall which could even results in flooding in an unexpected season (IPCC, 2013). Ghana has seen such cases. An example is the south-western part of Ghana which has seen cases of unexpected flooding with one event that led to an explosion at a fuel filling station that resulted in a death of over 152 lives (Asumadu-Sarkodie, Owusu & Rufangura, 2015). The management of the dam should take note of this possible shift in season so as to put in the necessary structures to avoid surprises in this regard. Another well-functioning weather station with adequate and complete data and in close proximity to the Akosombo dam worth analysing, is Adidome. The next sub-section discusses the annual rainfall quantities and patterns in Adidome.

4.2.3 Annual rainfall quantities and patterns in Adidome

In Adidome, the general weather condition is such that the wet season is mostly cloudy, the dry season is partly cloudy, and it is hot and oppressive year-round. These weather conditions vary in recent times due to climate variability and phenomenon of climate change. Available climate data depict the degree of climate variability and climate change leading to the formation of certain patterns within an area. In this study, the climate data of the annual rainfall patterns collated from the year 2000 to 2020 is shown in Figure 12. The figure show that cumulatively, rainfall had declined marginally over the period from 2000 to 2020.

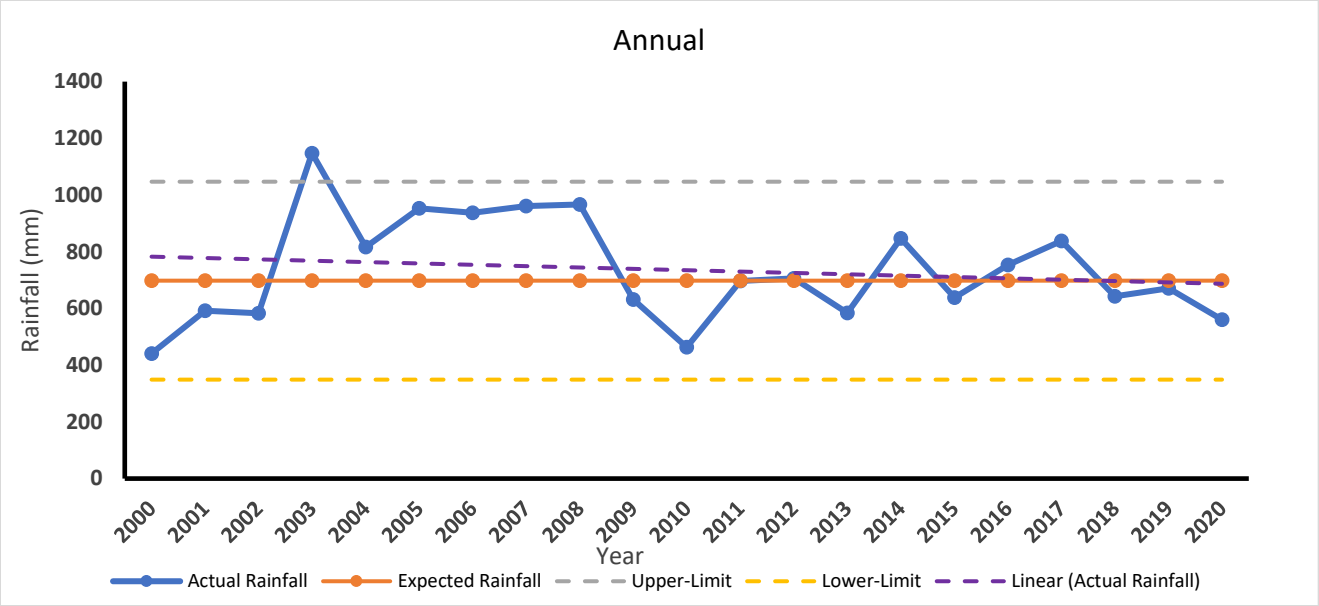

Figure 12: Annual rainfall patterns in Adidome, 2000 – 2020
Source: Author (Data from Ghana Meteorological Agency, 2020)

Here again, the figure shows the actual or real rainfall patterns, the expected rainfall obtained from historical data set stretching far back into the past and is used to assess whether there has been an increase or decrease in rainfall in modern times (Ghana Meteorological Agency, 2020), the upper and lower limit which are rainfall records more than 50% above or below the expected rainfall used to classify rainfall as either extremely low or extremely high and the linear which shows the trend in the actual rainfall over the years under study. Close examination of the rainfall patterns in Adidome shows that, the amount of rainfall has not increased much above the expected average rainfall of 698 mm, neither has it decreased much below the expected average rainfall. There is almost equal distribution of the rainfall above and below the expected rainfall as there are nine years of rain above the expected rainfall and 10 years of rain below the expected rainfall of 698 mm. The rest of the two years in 2011 and 2012 had rainfalls equal to the expected rainfall. This means that generally, rainfall in Adidome has not increased nor decreased much compared to the expected rainfall of 698 mm. There was only one year with extremely high rainfall which occurred in 2003, recording rainfall of 1148 mm whilst there was no case of extremely low rainfall. Cumulatively, the amount and pattern of rainfall resulted in a marginal annual rainfall decline in Adidome. This is likely to be caused by the extremely high rainfall case in 2013. The upper end of the trendline indicates a rainfall value of approximately 790 mm and the lower end with rainfall of approximately 700 mm indicating that the amount of rainfall has generally declined

marginally by 90 mm, the lowest among the three weather stations under consideration. Using the percentage formula in equation (1), the percentage decrease in rainfall over the study period is 11%. This indicates that the annual rainfall decline is not so significant and may not have impacted much on the water level of the Akosombo dam. Management of the dam, however, would have to put in climate change adaptation structures to forestall any impact from the emerging climate change. This is because the study has established from the three weather stations that rainfall decreased over the years, and is likely to keep decreasing over the next years. Generally, annual rainfall emerges and results from monthly rainfall. In the same way, the marginal decline in the annual rainfall and its patterns at Adidome emerges from its monthly rainfall. For this reason, the next section discusses the seasonal and monthly rainfall quantities and patterns and discovers which of the months and seasons are contributing factors to the declining annual rainfall in Adidome.

4.2.3.1 Seasonal and monthly rainfall quantities and patterns at Adidome

Leading from the previous section that indicates the decline in the annual rainfall at Adidome, this section reveals the sources of the annual decline in rainfall from the months and seasons. As indicated earlier, the rainfall period over the study period (2000 to 2020) constitutes three distinct seasons. Figures 13.1 to 13.12 show these three distinct seasons as main rain season made up of March to June, represented by the dash lines, the second rain season made up of July to November, represented by the dotted lines and the dry season made up of December to February, represented by the solid line. Again, the figure shows the extremely low and high rainfall events over the period where the extremely highs and lows events are those which are more than 50% above and below the expected rainfall respectively. It also shows the upper and lower limit which are rainfall records more than 50% above or below the expected rainfall used to classify rainfall as either extremely low or extremely high and the linear which shows the trend in the actual rainfall over the years under study.

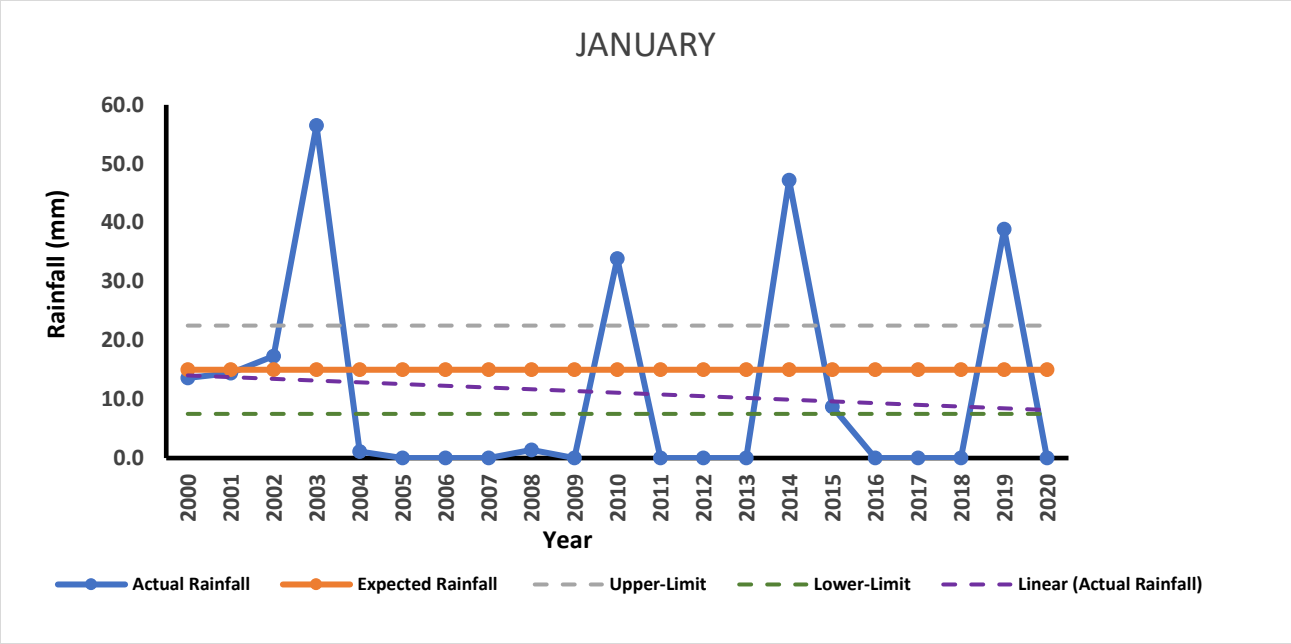

Figure 13.1: January rainfall at Adidome
Source: Author (Data from Ghana Meteorological Agency, 2020)

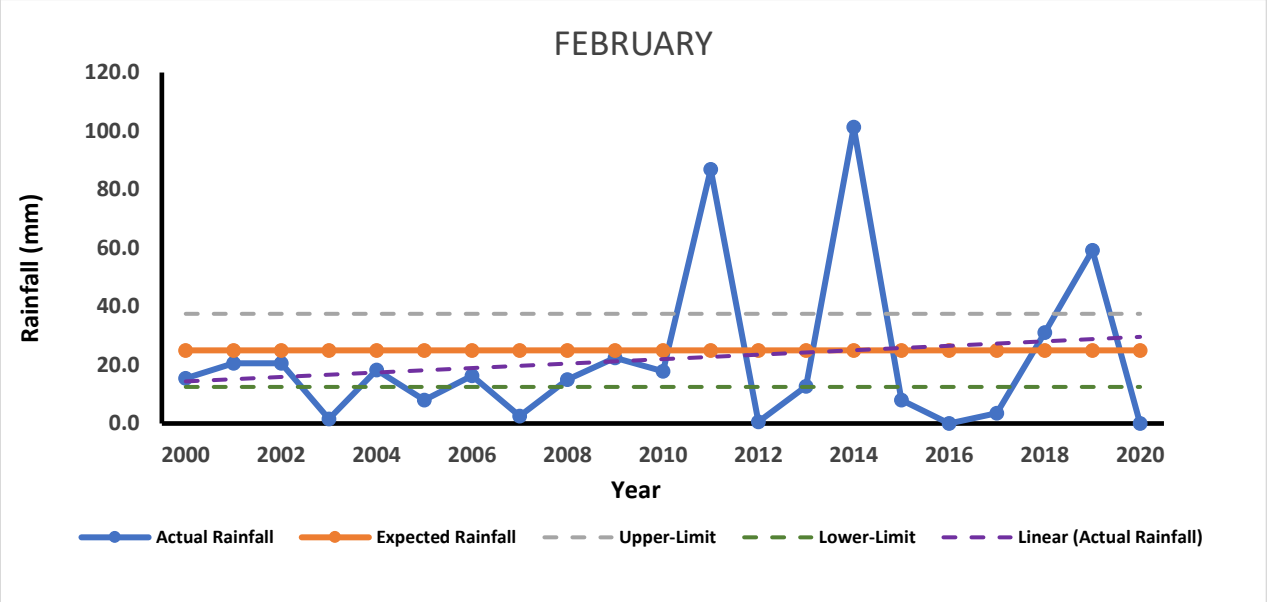

Figure 13.2: February rainfall at Adidome
Source: Author (Data from Ghana Meteorological Agency, 2020)

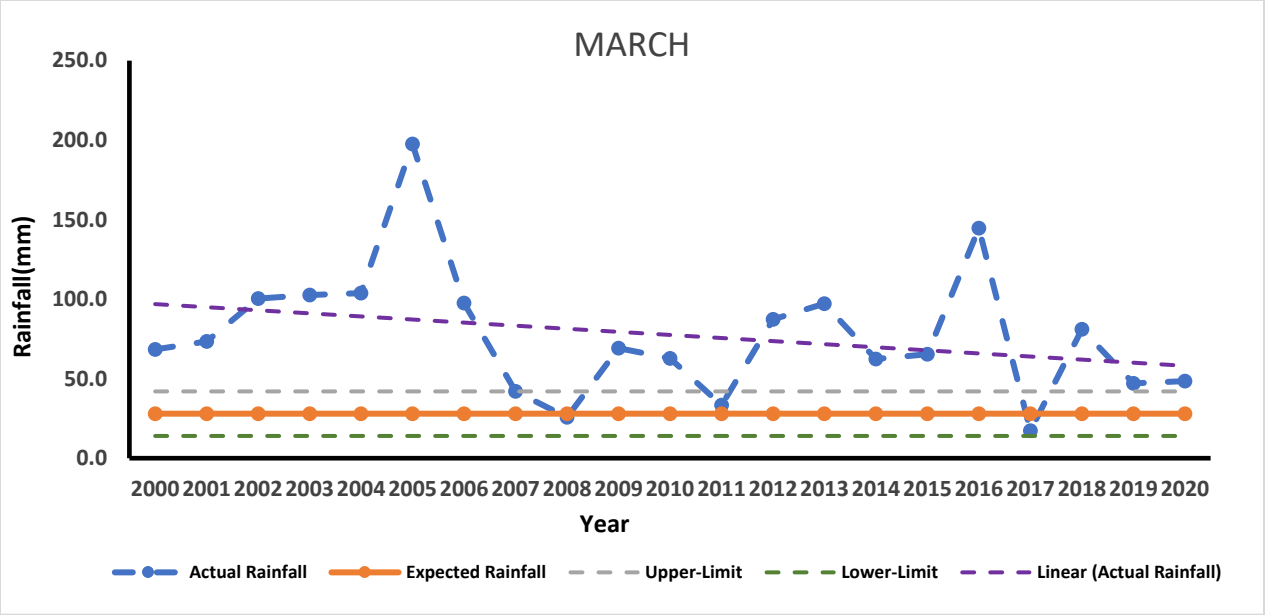

Figure 13.3: March rainfall at Adidome
Source: Author (Data from Ghana Meteorological Agency, 2020)

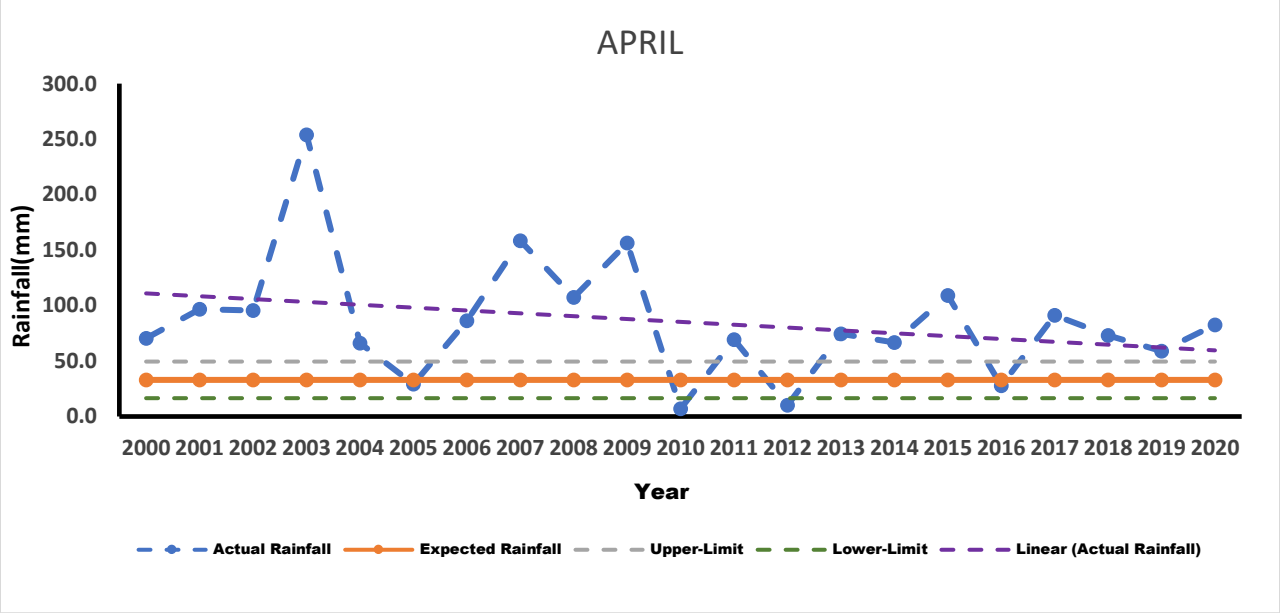

Figure 13.4: April rainfall at Adidome
Source: Author (Data from Ghana Meteorological Agency, 2020)

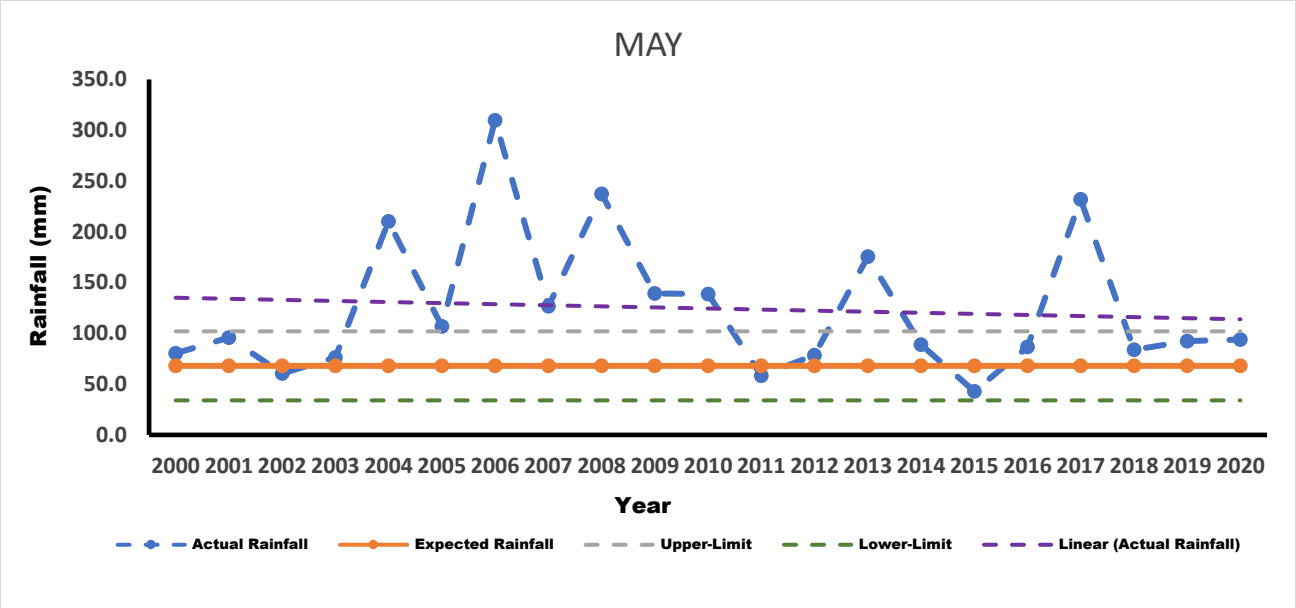

Figure 13.5: May rainfall at Adidome
Source: Author (Data from Ghana Meteorological Agency, 2020)

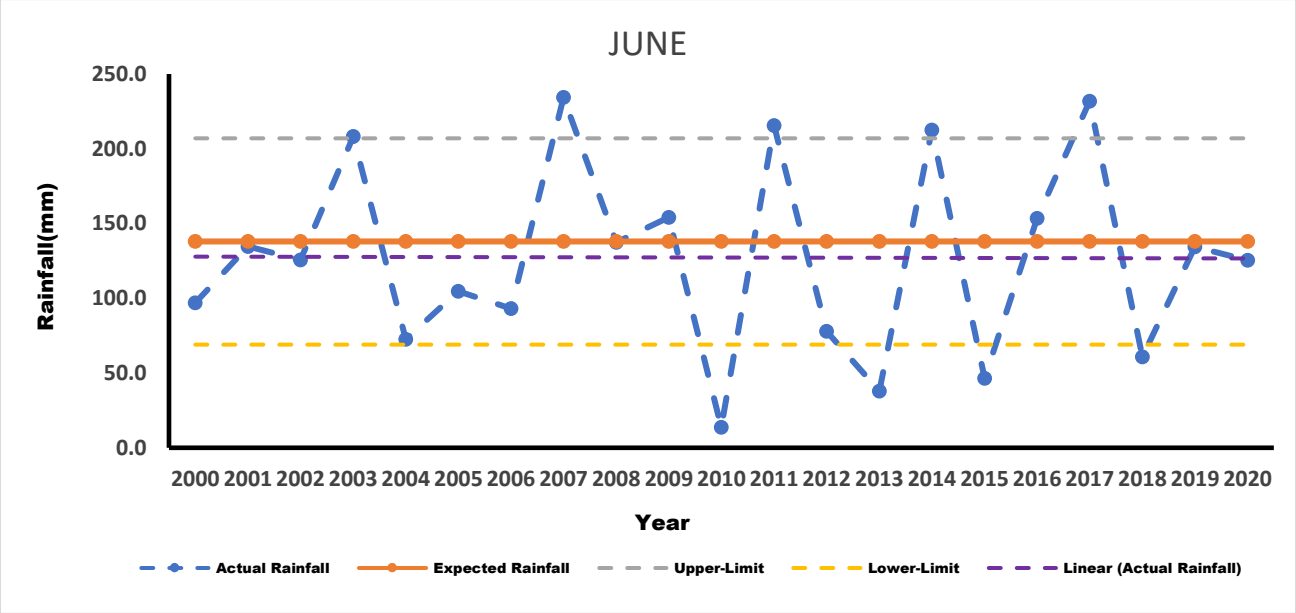

Figure 13.6: June rainfall at Adidome
Source: Author (Data from Ghana Meteorological Agency, 2020)

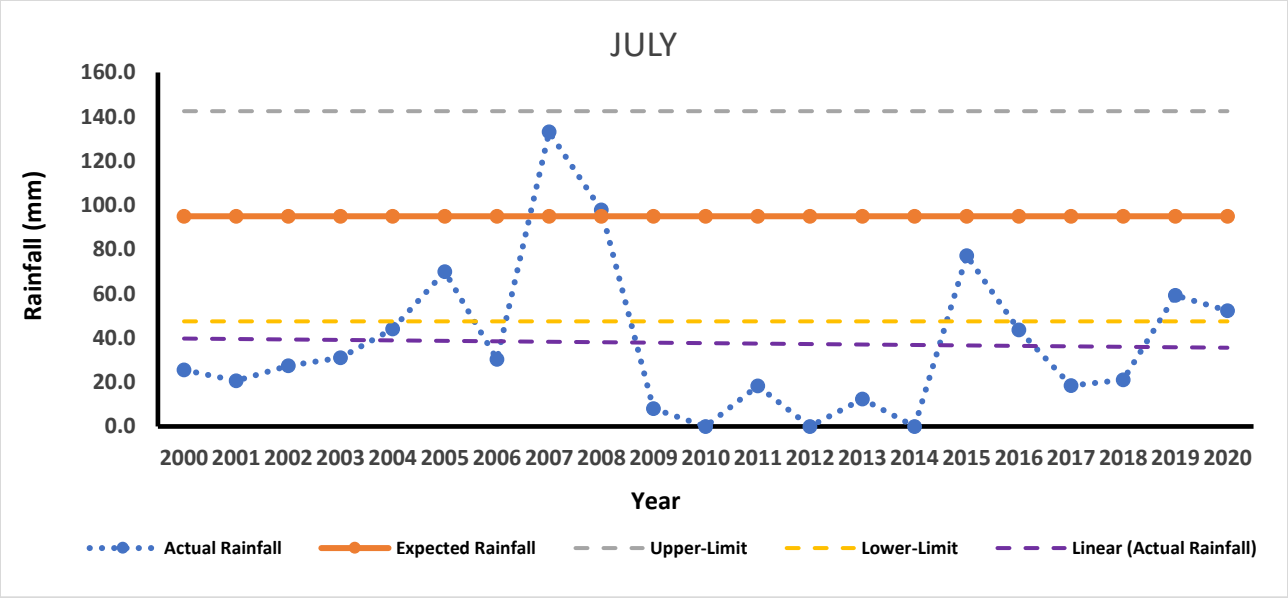

Figure 13.7: July rainfall at Adidome
Source: Author (Data from Ghana Meteorological Agency, 2020)

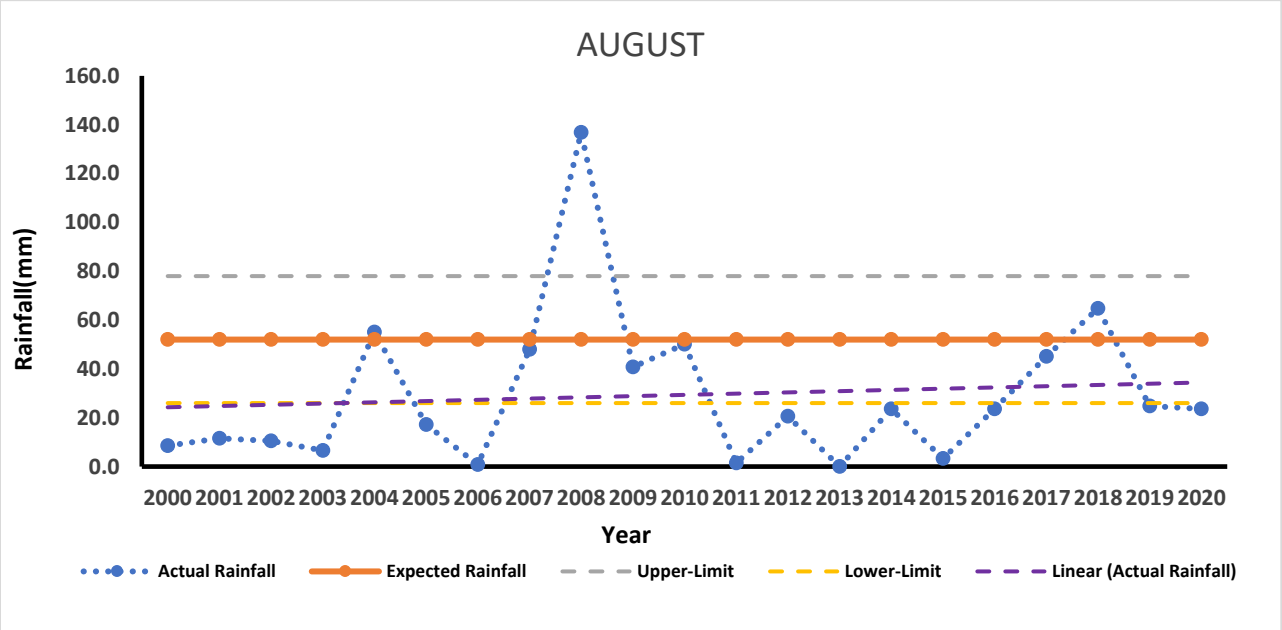

Figure 13.8: August rainfall at Adidome
Source: Author (Data from Ghana Meteorological Agency, 2020)

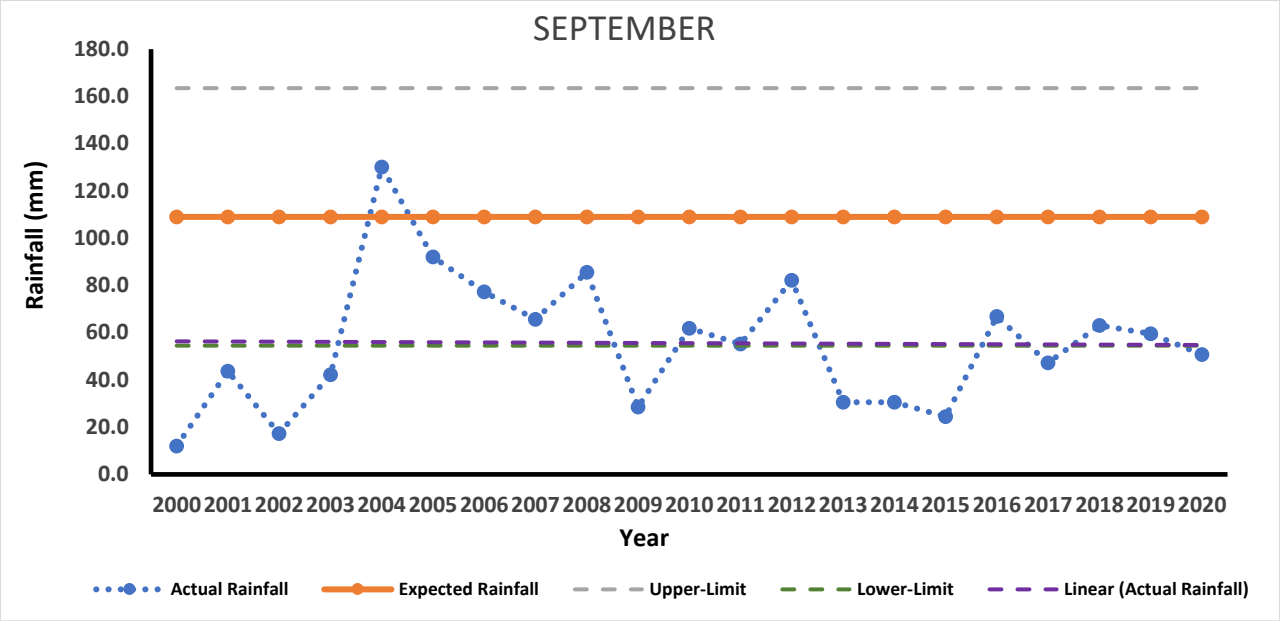

Figure 13.9: September rainfall at Adidome
Source: Author (Data from Ghana Meteorological Agency, 2020)

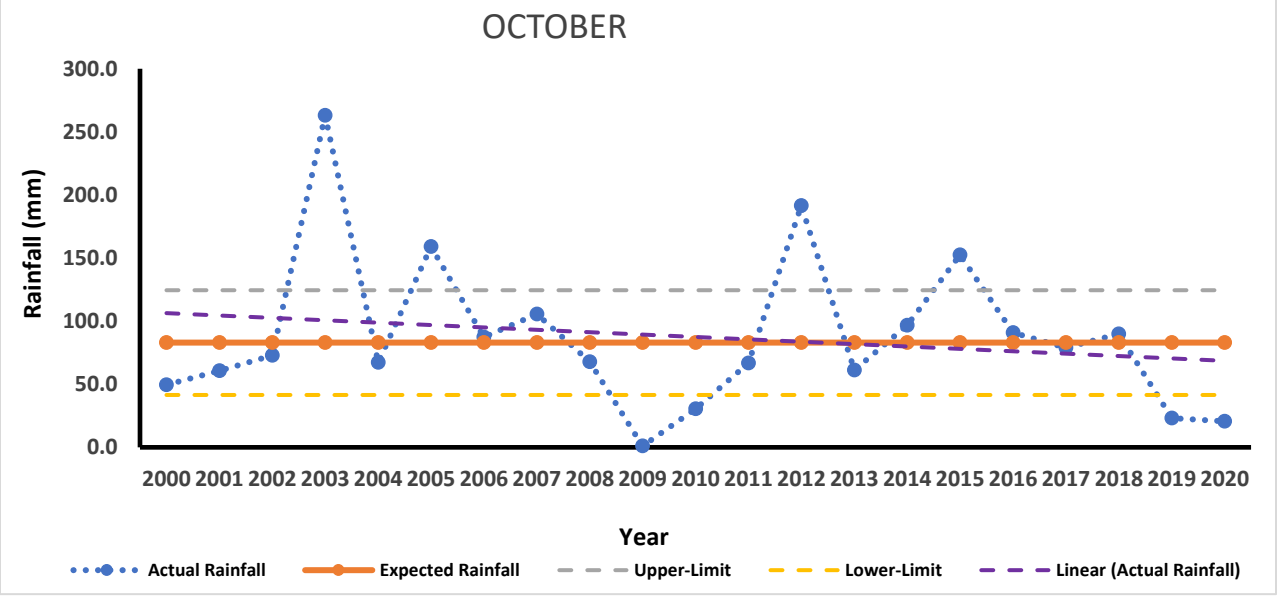

Figure 13.10: October rainfall at Adidome
Source: Author (Data from Ghana Meteorological Agency, 2020)

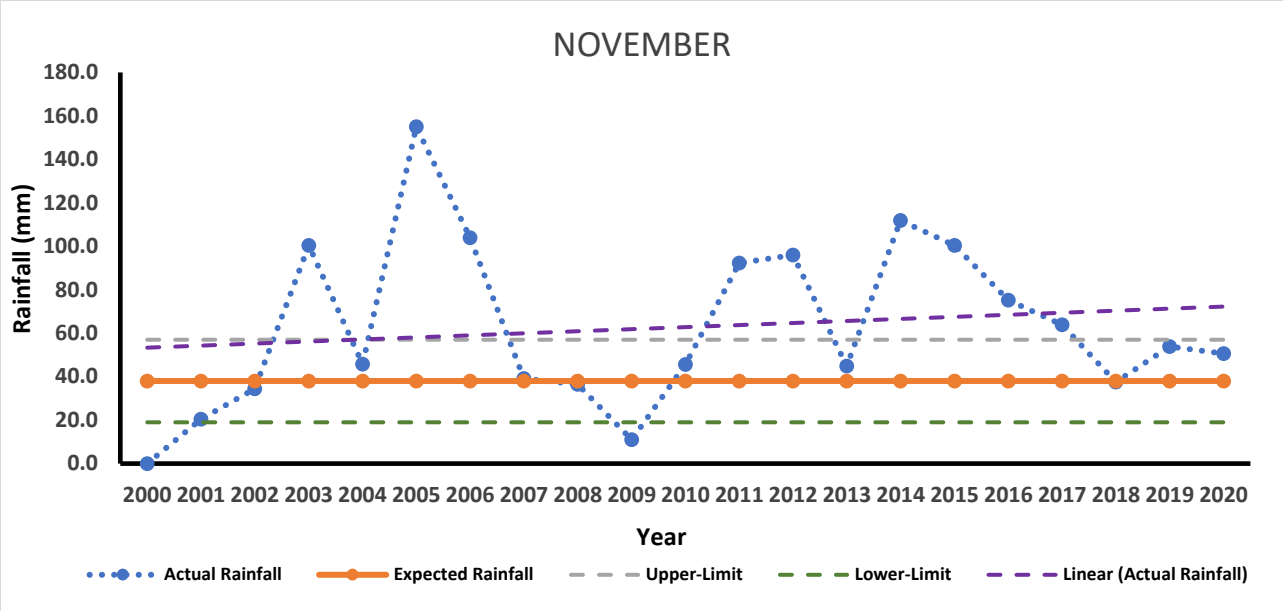

Figure 13.11: November rainfall at Adidome
Source: Author (Data from Ghana Meteorological Agency, 2020)

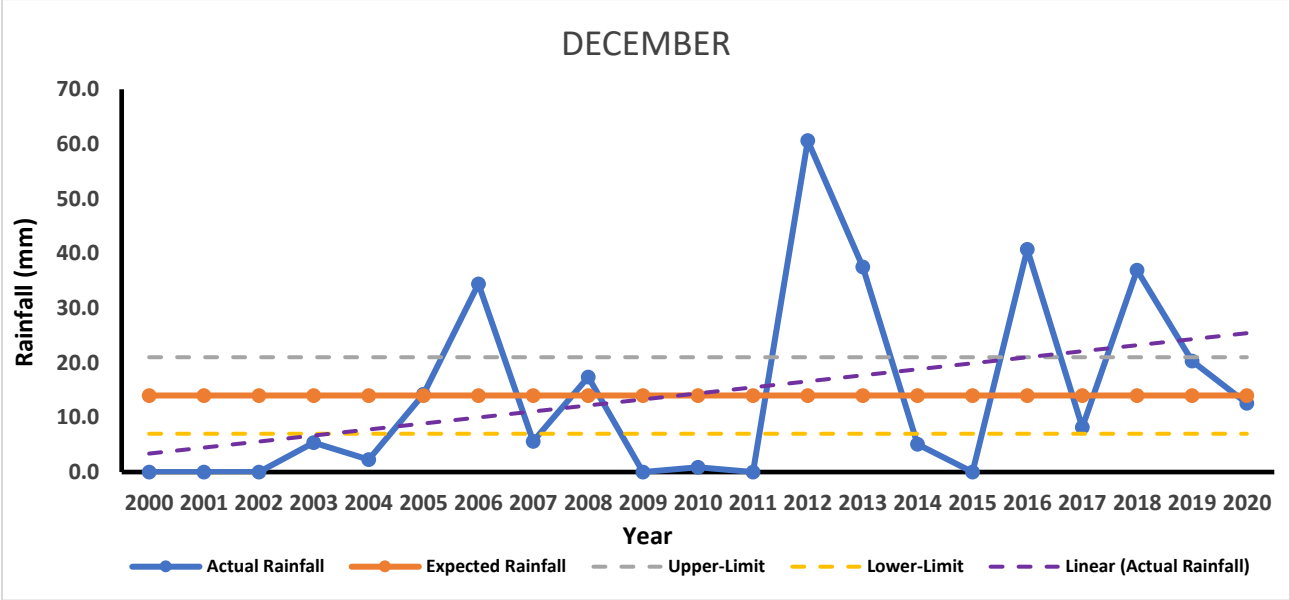

Figure 13.12: December rainfall at Adidome
Source: Author (Data from Ghana Meteorological Agency, 2020)

Examination of the figure reveals that out of the 12 months the month of May (Figure 13.5) was the period with the highest rainfall. Its highest rainfall occurred in the year 2006 with rainfall of 310 mm. This is not so surprising as the month of May falls within the main rain season which comes

with the expectation of higher amount of rain. Apart from the years 2002, 2011 and 2015, all the other years had rainfall above the expected rainfall of 68 mm. This means for 18 years rainfall was above the expected rainfall. Out of the 18 years, there were incidences of extremely high rainfall occurring more than 50% above the expected rainfall for nine years whilst there was no extremely low incidence of rainfall. The month of May is observed to be the month with the highest amount and levels of rainfall and possibility of many flooding incidence. Cumulatively, there is a slight decrease in rainfall over the period under study (2000 to 2020). With the upper end of the trendline indicating approximately 135 mm of rainfall and the lower end showing 115 mm of rainfall, the month of May witnessed a slight decline of 20 mm in rainfall. Rainfall in the months of March (Figure 13.3) and April (Figure 13.4) exhibited similar characteristics like that of May. March was characterised by high amount and levels of rainfall with 19 of the years experiencing rainfall above the expected rainfall of 28 mm. Out of the 19 years, 17 of the years experienced extremely high rainfall recording rainfall more than 50% above the expected rainfall, the highest being 198 mm rainfall occurring in the year 2005. Again, there was no case of extremely low rainfall. Cumulatively, there was a decline rainfall in the month of March, declining from 100 mm to 55 mm which led to a 45 mm decrease in rainfall. Similarly, the month of April had 17 of the years having rainfall more than 50% above the expected rainfall. This is an indication of flooding cases within the month of April. It (April) also recorded two cases of extremely low rainfall recording rainfall of more than 50% below the expected rainfall. This occurred in the years 2010 and 2012 with rainfall records of 17 mm and 10 mm respectively. The trendline indicates that, cumulatively, rainfall in the month of April decreased from 115 mm to 55 mm resulting in a decrease of 60 mm. Surprisingly, rainfall in the month of June (Figure 13.6) indicates no change in the amount of rainfall, that is there was neither a decrease or increase in the amount of rainfall over the study period. June is therefore ruled out as a contributor to declining annual rainfall in Adidome. The month experienced an equal number of extremely high and extremely low rainfall more than 50% above and below the expected rainfall of 138 mm respectively. The extremely high rainfall occurred in the years 2007, 2011, 2014 and 2017 recording rainfall of 234 mm, 216 mm, 213 mm and 232 mm respectively. In the case of the extremely low rainfall, it occurred in the years 2010, 2013, 2015 and 2018 recording rainfall of 14 mm, 38 mm, 47 mm and 61 mm respectively. Within the main rain season, the month of April was the highest contributor to the annual decline in rainfall at Adidome with a total decline of 60 mm in rainfall. With 45 mm and 20 mm decline in rainfall, the months of March and May were the second and third contributors respectively to the annual rainfall decline.

Apart from the month of October (Figure 13.10) during which rainfall of 263 mm was recorded, rainfall within the second rain season was generally low, with the rest of months (July, August, September and November) recording below 160 mm. It is observed that most of the rainfall recorded was below the expected rainfall. For instance, the month of July (figure 13.6) recorded 19 of the years having rainfall falling below the expected rainfall 95 mm and out of this, 15 of years recorded rainfall below the extremely low rainfall. Similarly, the month of August (Figure 13.8) recorded 18 of the years having rainfall below the expected rainfall of 52 mm. 14 out of the 18 years recorded rainfall below the extremely low rainfall. However, there was only one incidence of extremely low rainfall which occurred in the year 2008 with rainfall of 137 mm. In the case of September (Figure 13.9), 20 of the years recorded rainfall below the expected rainfall of 109 mm, out of which 10 of the years recorded rainfall below the extremely low rainfall. November (Figure 13.11), however, witnessed a different pattern of rainfall. It recorded 14 of the years with rainfall above the expected rainfall of 38 mm. Apart from having almost equal distribution of rainfall around the expected rainfall, the month of October recorded higher amounts and levels of rainfall with the highest level of rainfall of 263 mm recorded in 2003. It (October) recorded 4 of the years with extremely high rainfall more than 50% above the expected rainfall of 83 mm. These occurred in the years 2003, 2005, 2012 and 2015 recording rainfall of 263 mm, 159 mm, 192mm and 153mm respectively. Observing the trendline, the months of July and September show almost no increase or decrease in rainfall over the period under study whilst August and November indicated increasing rainfall over the period. These months can therefore not be classified as contributors to the annual rainfall decline. The month of October indicated decreasing rainfall, decreasing from approximately 110 mm to 65 mm, resulting in a decrease of 45 mm, contributing to the annual rainfall decline as indicated in Figure 12. Rainfall in the second rain season at Adidome is generally lower than expected. This type of situation leads to prolonged periods of dryness. This negatively affects water related activities like hydropower dams and fish farming as the situation tends to dry up water bodies. A management member of the VRA affirmed the effects of prolonged dry periods on the Akosombo dam stating that;

> *Most of the times we shut down some of the turbines due to low water levels resulting from prolonged dry periods. This subsequently leads to suboptimal operation of the dam. (Extract from the field interview.)*

Shutting down some of the turbines means that the dam does not operate at its maximum energy production capacity of 1,020 megawatts (MW) of power (Nortey, Doku-Amponsah & Ocran 2017). This leads to power outages and prolonged load shedding in some situations.

Some residents who are predominantly farmers and fishers also confirmed the effects of prolonged dryness on their trade during the interview. A resident lamented how the declining rainfall quantities are affecting farming activities. Referring to fish farming, the resident stated that;

> *The water in our fishponds is drying up gradually because the rains are not falling as expected these days. (Extract from a resident during the field interview.)*

During the dry season, there is no expectation of much rain. Nonetheless, the months of December (Figure 13.12) and February (Figure 13.2) indicated an increase in rainfall over the period under study. December recorded 7 of the years with rainfall above the expected rainfall of 14 mm. Most of this rainfall occurred towards the latter years of the period under study hence the increasing rainfall in December. There was a similar case in the month of February with increasing rainfall in the year 2011, 2014 and 2019 recording rainfall above the expected rainfall of 25 mm. These years recorded rainfall figures of 87 mm, 101 mm and 59 mm respectively. January (Figure 13.1) however, recorded slight decrease in rainfall over the period under study with rainfall decreasing from 13 mm to 8 mm. This resulted in a total decrease of 5 mm of rainfall in January. Rainfall in the dry season is generally expected to be low.

Obviously, the main rain season is the major contributor to the annual rainfall decline in Adidome. The study has revealed that the main rain season in most cases is the major contributor to all annual rainfall declines. This is because the high amount and levels of rainfall that usually occur in the main rain season comes with its equivalent noticeable loss of rains in cases where there is not much rain. In addition to rainfall, another climate change linked variation likely to have an impact on the features and operations of the Akosombo dam is temperature. In this regard, the study considered only temperatures at Akosombo (the location of the dam) because unlike water runoff that flows from other areas like Kete-Krachi into the Akosombo dam which necessitates the investigation of rainfall patterns in Kete-Krachi and others, temperature in Akosombo is not expected to affect water bodies in other areas and vice versa. Since the area under study is the Akosombo dam, investigation into the state of temperature patterns will be centred only in the

area of Akosombo (the location of the dam). The next sub-section details the nature of temperature patterns at Akosombo area and how it impacts the dam's hydropower generating activities.

4.3 Temperature patterns and its impact on the features and operations of the Akosombo Dam

Global temperatures have risen by 1 °C and are expected to rise further in the future (Kennedy et *al.,* 2019). This increasing global average temperatures is associated with widespread changes in rainfall patterns as discussed under section 4.2. Generally, increasing temperature leads to an intensification of water circle resulting in dry areas becoming dryer and wet areas wetter (Ibid). The dryer periods resulting from the increase of temperature can cause the depletion of water levels in hydropower dams because the evaporation rate increases. Wetter periods are also capable of increasing precipitation and this might lead to flooding thereby causing destruction and break down of equipment required for electricity generation (Cole et *al.,* 2014). The issue of increased temperatures is no different from the temperature situations in Akosombo. Figure 14 shows the temperature distribution patterns at Akosombo from the year 2000 to 2020.

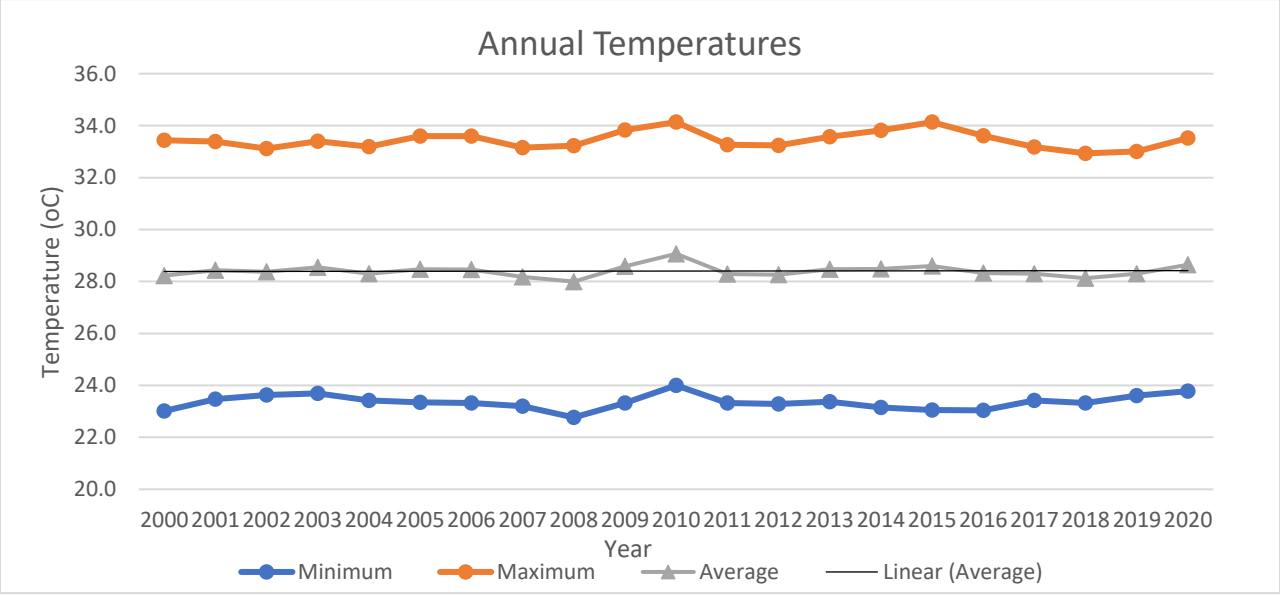

Figure 14: Annual temperature patterns at Akosombo
Source: Author (Data from Ghana Meteorological Agency, 2020)

Examining the minimum and maximum temperature levels, the figure shows that there have been infinitesimal increases in temperature over the study period. This was pronounced in the year 2010 with a temperature record of 24 ^{o}C (the highest among the minimum temperatures over the study period) and 34 ^{o}C (the highest among the maximum temperatures over the study period). The temperature decreased after 2010, but started increasing from 2020 onwards. Increases in temperature such as what occurred in 2010 coupled with a decrease in rainfall impact negatively on water resources, particularly hydropower dams - the focus of this study - because the rate of evapotranspiration of water into the atmosphere increases and this leads to the depletion of the dammed water faster than usual. This has led to the gradual decline in the electricity generation capacity of the Akosombo Dam (VRA Newsletter, 2018). A management employee also confirmed the effect of the depleting water levels in the Dam and the corresponding gradual decline in the electricity generation capacity noting that suboptimal operations of the dam were pronounced around the year 2010, stating that:

> *One of the worst performances of the Akosombo dam occurred around 2010. The energy production of dam was reduced to 175MW per day instead of the expected 1020MW per day. (Extract from the interview session.)*

The increases in temperature also confirms the prediction by the Intergovernmental Panel on Climate Change that the earth will continue to get warmer over the course of the 21st century (IPCC, 2013). Additionally, it is expected to contribute to the intensity of other extreme weather events including wildfires, droughts, rising sea level due to melting iceberg and farming activities (Phyper & MacLean, 2009). Some of these extreme weather events are being witnessed by some of the residents interviewed. One of them stated that:

> *The surrounding rivers and other sources of water used for irrigation are drying up. This is negatively affecting the growth of our plants." (Extract from the field interview.)*

One other respondent from the Water Research Institute also reiterated the effects of the increasing temperature stating that:

> *There seems to be a lot of drying up of our water bodies which must be tackled swiftly otherwise there would be dire consequences on hydropower production and other sectors of the economy. (Extract from field interview.)*

The IPCC has also indicated that, over the next century, climate change is expected to increase the variability and the vulnerability of many hydrowater dams. The Akosombo dam is no exception, and this was confirmed by a management officer of the dam during the interview stating that:

> *The dam has been experiencing some sort of climate change-linked water shortages leading to fluctuating water levels particularly in-between the rain and dry season. (Extract from field interview.)*

The fluctuating water levels had left marks on the dam walls as indicated in Figure 15. The Figure shows the marks of the different water levels experienced by the Akosombo dam during the various seasons (the main rain season, second rain season and the dry season).

Figure 15: The various levels of water marks on the Akosombo dam during the different seasons. Source: Author, 2021.

At the maximum operating level of 278ft (85 m), the Akosombo dam uses all the six turbines to produce the required maximum power of 1,020 megawatts per day. When the water level drops due to climate change induced increasing temperatures, the dam is forced to run on four turbines to produce 680 megawatts of power. This severely affects the efficiency of the hydropower generation leading to grid electric energy load shedding across the country. In addition, increases in temperature has led to some residual effect on the features of the Akosombo dam that could impact negatively on the dam's power generation performance and also have financial implications caused by the need for regular maintenance. For instance, field observation revealed fading of the penstocks of the dam as indicated by the arrow in Figure 16.

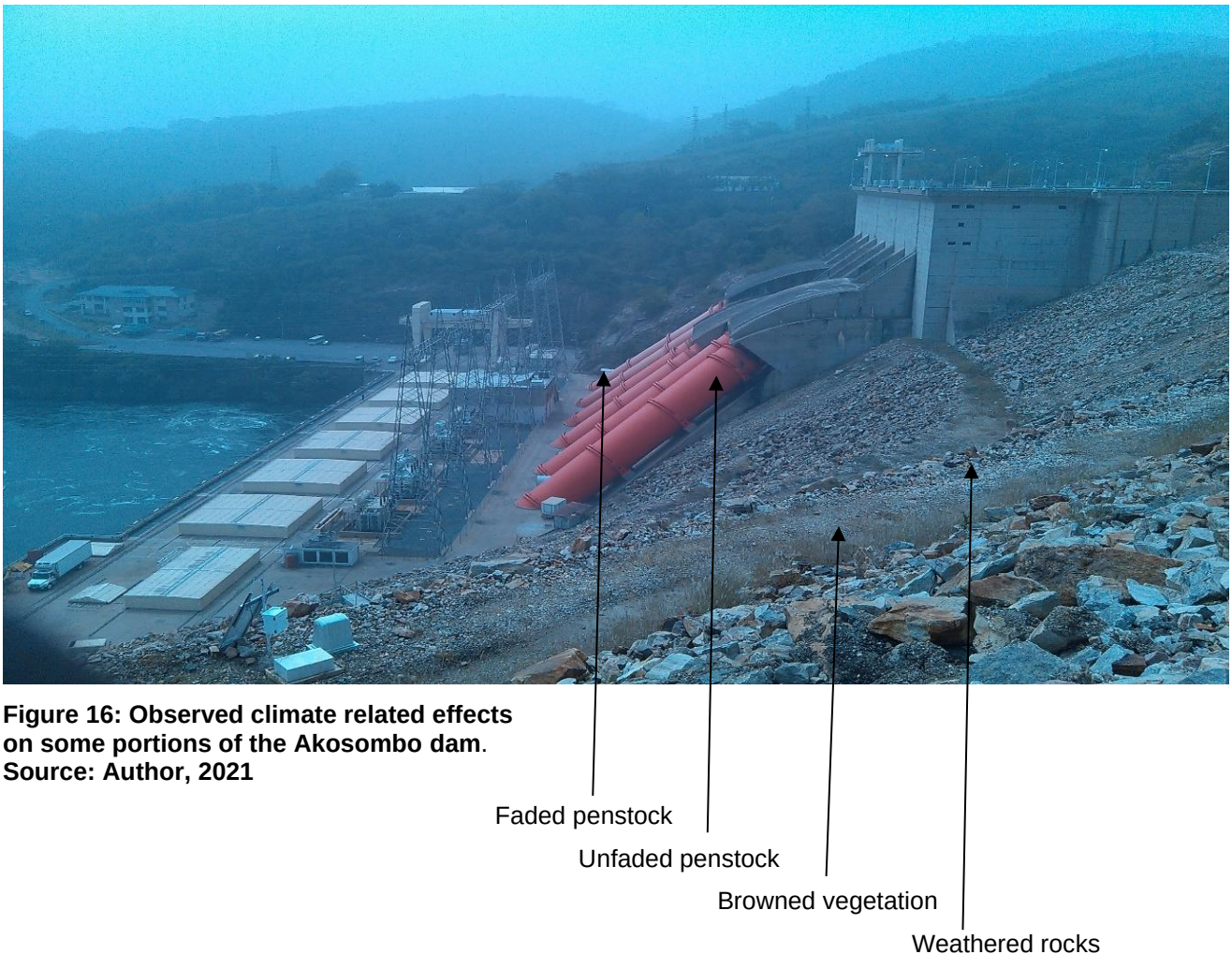

Figure 16: Observed climate related effects on some portions of the Akosombo dam.
Source: Author, 2021

From the figure, it is observed that two of the penstocks (from the far right and indicated by the arrow) are fast fading. Another observation is the outer surroundings of the dam that shows weathering of rocks and browning of vegetation cover around the dam. This could also be partly attributed to the climate change-linked increasing temperatures. Substantial action will be required by the management of the Akosombo dam to avert these occurrences. The management of the dam could consider the following options, namely a series of physical interventions made up of planting indigenous and exotic drought tolerant tree varieties around the dam, providing more water storage facilities to reduce exposure to dry spells and creating contour bunds to prevent runoff, soil erosion and weathering of the rocks. Wind barriers could also be erected to minimise weathering of the rocks.

4.4 Chapter conclusion

Decreasing rainfall and rising temperatures are the typical climate change effects projected for most parts of Africa. Ghana has not been spared in this respect as its natural resources including water resources and the Akosombo dam in particular are experiencing decreases in water volumes, particularly due to the increasing temperatures. The resultant effect is the shutting down of some of the dam's turbines thereby reducing the total amount of hydropower generated. This results in power deficits that lead to grid electric energy load shedding across the country. For instance, and as stated earlier, the Akosombo dam is forced to operate on four turbines instead of the maximum six turbines to produce 680 megawatts of hydropower per day, instead of the maximum 1,020 megawatts of hydropower.

Despite these and other challenges regarding hydropower facilities, Castano (2011), predicts a global increase in the quantity and size of hydropower facilities and Ghana is no exception to this global increase. As part of its (Ghana) plans to increase electricity generation across the country, it plans to construct (though is the least among the plans) an additional hydro dam- the Pwalugu Hydrodam Project (as indicated in Table 2 of Chapter 1). In 2019, the Parliament of Ghana gave the approval for the construction of the Pwalugu Hydro dam Project. For this reason and due to recently observed extreme weather events that include decreasing rainfall, exceptionally high temperatures, frequently and increasingly severe droughts as well as floods in Africa, there are calls for planning on how to mitigate and adapt to these situations particularly through policy formulations. To this end the next chapter achieves the fourth research objective as it discusses

how Ghana has been responding to this call and chronicles its national policy and legislation for managing climate change in Ghana to enhance the operations of hydro dams and the Akosombo dam in particular.

CHAPTER 5: POLICY, LEGISLATION AND INSTITUTIONAL IMPLEMENTATION TERRAIN FOR MANAGING CLIMATE CHANGE IN GHANA

"Speak only if it improves upon the silence." Mohandas Karamchand Gandhi (1869 – 1948)

5.1 Introduction

Leading from the previous chapter that presented and discussed the physical issues that relate to the impacts of climate change in and around the Akosombo dam, this chapter focuses on the climate change policy and legislation regime in Ghana. The focus of the chapter addresses the third research objective, namely: "to determine how the climate change adaptation institutions and policy regime are responding to the management of climate change in Ghana".

To this end the chapter presents, analyses and discusses how Ghana's climate change policy and legislation regime is affecting practices that seek both mitigation of and adaptation to climate change. In so doing, the chapter examines and discusses the range of Ghana's policies, programmes and legislation relating to the management of climate change. The examination of policy and legislation regime is against a background of anthropogenic practices that contribute to the climate change menace and the resultant changes in weather patterns. It is also arguable that policy can deliberately alter anthropogenic practices to manage the climate change menace covering its drivers and its impacts.

The chapter unfolds in three sections. The first section presents the broad policy and legislation terrain pertaining to general environmental management concerns linking this to climate change in Ghana. The second section focuses on the climate change challenge and its management as a key mandate of the national government through the ministry in charge of the relevant policies, programmes and initiatives that apply to the entire policy and practice space in Ghana. The third section presents discussions on how the broad policy and legislation are translated to specific programmes and initiatives that relevant government agencies such as the Ministry of Environment, Science, Technology and Innovation, Environmental Protection Agency and the VRA apply to the management of climate change.

5.2 Policy and legislation landscape for managing climate change in Ghana

It is arguable that beginning with the administration of Jerry John Rawlings (First President of the Fourth Republic of Ghana from January 1993 to January 2001), successive administrations in Ghana have made explicit and implicit policy and legislation moves to deal with the challenge of climate change. This focus is partly attributable to the country's grand economic development plan of Vision 2020. The Vision 2020 plan as compiled by the National Development Planning Commission (NDPC) was formulated and publicly articulated as Ghana's blueprint for sustainable socio-economic development (Government of Ghana, 1996: 19). Although Vision 2020 is now obsolete, the plan remains an important landmark by which successive administrations in Ghana have tried to attain rapid economic growth simultaneously with an efficient utilisation of natural resources and maintaining the integrity of the environment (Ibid). Again, although the document does not explicitly refer to the climate change challenge, it nevertheless has sections that address concerns pertaining to this phenomenon. The lack of explicit reference to climate change is typical of policy documents of that era during which the climate change discourse was in its infancy. Consequently, addressing the climate change phenomenon and its related adverse impact manifested through addressing broader environmental management concerns. Section 2.6 of Vision 2020 articulates the critical areas earmarked for environmental management concerns stating that:

> *The principal environmental problems in Ghana at the present time are deforestation, desertification and soil erosion; inefficient waste management; coastal erosion; and pollution of air, sea, soil and water. (Government of Ghana, 1996: 19).*

Regarding this study, three major issues are of concern. The first one being the concern of managing deforestation, desertification and soil erosion that is the key focus of improved practices of managing forests ecosystems. The proper management of forest ecosystems is critical for managing carbon sinks and contributing to the mitigation of climate change. It is established that forest ecosystems are important in the global carbon cycle in two ways (Canadell & Raupach, 2008). Firstly, the concern of the role of forests terrestrial ecosystems in removing all carbon and most importantly anthropogenic carbon from the atmosphere. Globally, this ecosystem removes an estimated 3 billion tons of anthropogenic carbon every year absorbing about 30% of all carbon emissions from fossil fuel burning (Ibid). The importance of tree planting to maintain the forest ecosystem in the mitigation of climate change was reiterated by a management member of the Ghana Meteorological Agency stating that:

> *Regular tree planting has become very essential in this era of climate change management because trees serve as carbon sinks that contribute to the absorption of carbon in the atmosphere. (Extract from the field interview.)*

Further to the concern above are the concerns of carbon sequestration. Global forests store large amounts of carbon estimated at double the amount of carbon in the atmosphere (Ibid). The discussion of managing climate change as presented in Chapter 2 revealed that deforestation leads to rapid increases of carbon concentrations in the atmosphere (Carter, Parry, Harasawa & Nishioka*,* 1994; Scot *et al.,* 2018). This leads to global warming, subsequently increasing the climate change and its effects. This makes Vision 2020's consideration of managing deforestation critical to Ghana's contribution to the global efforts of mitigating climate change.

The second concern relates to coastal erosion. Global warming is linked to an increased rate and extent of melting icebergs, a process that leads to the rise in sea levels leading to an increased covering of some coastal lands (Mendelsohn, 2013). Rising sea levels and related tides contribute to coastal erosion and the interruption of economic and social activities around coasts. Mendelsohn (2013) confirms that flooding and sea level rise are serious climate change induced threats to coastal natural resources, infrastructure, and human communities. Arguably, tackling the challenge of coastal erosion as stipulated in Vision 2020 begins with tackling the challenge of climate change (Government of Ghana, 1996). Given that some of the effects of climate change are now inevitable, activities and infrastructure in the coast of Ghana and elsewhere need to adapt to this reality. Some appropriate adaptation practices to this end include the building of sea defence structures to prevent the sea from overflowing its current shores and the erection of fence walls to prevent sand extractors from getting access to extract sea sand.

The third major issue relates to proper waste management. The traditional waste management approach has been collecting and disposing of waste in dumpsites. A management member of the VRA indicated the importance of proper waste management in relation to climate change stating that:

> *The issue of proper waste disposal is of necessity in tackling environmental and climate change challenges and that is why the VRA developed office waste segregation policy and guidelines to ensure the proper waste disposal right from the office level (Extract from field interview.)*

Decomposing organic waste emits GHGs, water vapour, methane, nitrous oxide, ozone and halocarbons (Beer *et al.,* 2000; Renaud *et al.,* 2017). As discussed in section 2.1 of Chapter 2, these gases contribute to global warming and ultimately to climate change. Globally, GHGs from municipal waste dumps, accounts for approximately 5% of GHG emissions making it imperative to change this approach of managing waste (Eggleston *et al.,* 2006). Section 2.6.4 (page 20) of Vision 2020 suggests the use of some of this waste as an energy source indicating that "instead of dumping collected refuse in landfill sites, near river basins and areas with high water tables with a high risk of leachate contaminating the water bodies, this refuse can be channelled into energy production". Such waste is part of the larger renewable energy drive that includes sources such as wind, solar and hydropower. The use of renewable energy as envisaged in the Vision 2020 policy document has culminated in the current Renewable Energy Act 2011, Act 832 (Government of Ghana, 2011). The Act aims to reduce energy linked GHG emissions in Ghana by increasing the share of renewable energy in the country's energy mix.

Another notable feature of Vision 2020 is the elevation of science and technology in the various development programmes. This is important against an established link between science, technology and innovation as an input to the processes of economic development. Nyong *et al.,* (2007) confirm this link stating that technological advances in clean energy sources such as solar have led to economic development in countries that include Germany and China. In the same vein, science, technology and innovation are important for managing the drivers of climate change as well as adapting to its adverse impact in Ghana and elsewhere. For example, science, technology and innovation advances have led to the gradual shifting to the use of natural gas and other renewable energy sources as primary energy sources and thus diversification of energy mix from the sole dependence on fossil energy sources (UNEP, 2007). Such diversification not only mitigates GHG emissions but also addresses energy security concerns (Ibid).

Building on the positives of Vision 2020 and learning from its shortcomings, Ghana has made several efforts to formulate and implement short, medium and long-term development plans. Plans such as the Ghana Poverty Reduction Strategy (GPRS) I and II are important in this regard. The first GPRS was formulated in 2003 to enhance the developmental agenda articulated in Vision 2020 (Government of Ghana, 2003). The second strategy, GPRS II sought to accelerate the growth of the economy so Ghana could achieve middle-income status by 2010 (Ibid).

An important prerequisite and outcome of the articulated economic growth and development vision is the availability of adequate, secure and reliable supply of energy - electricity in particular. Considerations under the climate change discourse as discussed in Chapter 2 favour the use of renewable energy from sources that include, solar energy, organic waste material and the focus of this study, hydropower. However, hydropower is susceptible to climate change and its effects- climate change induced droughts in particular.

Science, technology and innovation can mitigate the impact of such events linked to climate change. For this reason, the GPRS II has a focus on the energy-science-technology nexus as a means of ensuring a smooth trajectory towards the intended economic growth and development. In fact, section 3.3.2 of the GPRS II policy document makes explicit reference to the fact that the intended acceleration of economic growth will depend on the promotion of the use of renewable energy such as hydro energy while at the same time recognising and minimising the potential sources of environmental impacts that hamper national development (Government of Ghana, 2005: 36). The policy seeks to make use of science and technology to establish an efficient research system that contributes to the production of innovative and efficient energy technologies (Ibid). The aim here is to tackle climate change by minimising environmental pollutants from the various forms of energy production (Government of Ghana, 2005). This strategy was once used by Smit and Pilifosova (2003) by adopting science and technology to develop modern technologies that minimize environmental pollutants (section 2.4.3. of Chapter 2). Another situation where science and technology were adopted was in Beijing, where the development of low emission and low energy intensive products led to the restriction of the use of energy intensive products and the phasing-out of outdated energy intensive equipment while encouraging the adoption of energy efficient technologies (Zhao, 2011). This makes science and technology an important determinant in tackling the climate change menace. To this end, Ghana can completely avoid or narrow the energy intensive development path and develop an energy efficient economy instead.

Broadly, Ghana's plans have to date, not yielded the envisaged development success. For example, despite the presence of environmental policies to safeguard the environment and tacitly manage climate change, bad mining practices and the indiscriminate tree felling continue to undermine the implementation of related policies (Marfo, Adam & Darko-Obiri, 2009). For

instance, Ghana used to have 8 million hectares of vegetative cover, which now stands at only 1.2 million hectares because of uncontrolled human activities such as logging, mining, farming, hunting among others (Ibid). Noteworthy, the forest reserves serving as carbon sinks have been degraded to the point where the country has to import timber (Owusu *et al*., 2006). A management member of the Water Research Institute expressed sentiments on this development stating that:

> *Ghana needs to take a critical look at the implementation of its policies and ensure proper enforcement otherwise its natural resources shall continue to be depleted to the detriment of future generations (Extract from the interview.)*

Learning from past experiences, the National Development Planning Commission (NDPC) has formulated another grand development policy; the 40-Year National Development Plan (Government of Ghana, 2015). Notable in the plan is the issue of involving the consulting of relevant stakeholders, most importantly the government ministries with the statutory obligations to formulate policies and legislation that supports this long-term plan covering the period 2018 to 2057. Interestingly, this time span almost matches Africa's Agenda 2063, which also articulates broad environmental management objectives and highlights the management of climate change as critical to the development aspiration of the continent (Africa Union Development Agency, 2019). It also falls within the ambit of the 15-year Sustainable Development Goals of the United Nations.

As part of these endeavours, Ghana's plan is set to be implemented through four medium term development plans (MTDPs) each with a time span of 10 years. In turn the MTDPs are subdivided into Annual Plans (APs) that are set to receive their appropriate annual budgetary support. While grand development plans are important, the design of operations is informed by the translation of the grand plans into sectoral policies. Government ministries play an important role in this. Notably under this discussion, the Ministry of Environment, Science, Technology and Innovation is a critical ministry in this regard.

5.3 The Ministry of Environment, Science, Technology and Innovation

Established in 1993 as the Ministry of Environment and Science, Ghana's Ministry of Environment, Science, Technology and Innovation (MESTI) has undergone a series of name changes until 2013 when it settled for its current name. The current Ministry envisages attaining sustainable development through the utilisation of science, technology and innovation (STI) for

wealth creation and sound environmental governance in a modern and competitive economy (Government of Ghana, 2013). Some of the core functions of the ministry include: (i) Providing leadership and guidance for environment, science, technology and innovation within the broad sector of the economy through sound policy formulation and implementation, (ii) Ensuring the establishment of a regulatory framework and the setting of standards to govern the activities of science and technology and the management of the environment for sustainable development and (iii) Initiating, simulating and coordinating research including the continuous development and review of policies, laws, rules and regulations in the environment, science, technology and innovation sector of the economy and ensuring effective environmental management and governance.

Broadly speaking, the ministry's mandate is to ensure accelerated socio-economic development of the nation through the formulation of sound policies and a regulatory framework to promote the use of appropriate environmentally friendly, scientific and technological practices. In this space, its major responsibilities include continual development and reviewing of climate change and environmentally related policies, laws, rules and regulations as well as spearheading the government agenda on technology and innovation. In fulfilling this mandate, MESTI has formulated a number of policies and pieces of legislation. Table 5 lists some broad government policies and legislation developed by MESTI that are relevant to this study (environmental and climate change related policies and legislation).

Table 5: List of policy and legislation documents

No.	Document
1	National Environmental Policy, 2012
2	Ghana National Climate Change Policy, 2013
3	Ghana Climate Change Legislation, 2015
4	Ghana National Climate Change Master Plan Action Programmes for Implementation: 2015 – 2020

Source: Author's compilation, 2021

The next sub-section details how some of the listed policies and legislation were developed, have been and are being used in environmental and climate change management in Ghana.

5.4 National environmental management in Ghana

Globally, environmental challenges have been on the rise and the problems in the critical areas of pollution, urban congestion, loss of biodiversity and climate change have worsened. A senior researcher from the Ghana Meteorological Agency reiterated the potential global impact of climate change stating that:

> *Climate change is an escalating threat with the potential to cause significant disruption across the globe. (Extract from field interview.)*

Nationally, Ghana's desire and willingness to make concerted and conscious efforts to tackle environmental challenges date to its participation in the Stockholm Conference in 1972. After the conference, the government commitment in this regard rose as evidenced by increased callings for the formulation of an environmental policy that will guide environmental management in the country. After a series of meetings, the initial environmental policy was formulated in 1992 and was incorporated in Chapter 6, Article 36 (9) of the 1992 Fourth Republican Constitution of Ghana (Government of Ghana, 1992). Since then, this 1992 environmental policy has undergone a series of revisions seeking to ensure that it conforms to current realities. The latest version of the policy was revised and adopted in 2012. It seeks to fulfil four broad purposes, namely (i) guide environmental governance in Ghana, (ii) serve as a reference material for research and development, (iii) guide the country's development along a sustainable path and (iv) ensure the country's commitment to international conventions, protocols and agreements (Government of Ghana, 2012: 7). Again, its broad goal is to accelerate economic development, which simultaneously considers ecological wellbeing as articulated in the Constitution of the Republic of Ghana (Government of Ghana, 1992). Article 36 (9) of the Constitution advances that notion stating that;

> *The State shall take appropriate measures needed to protect and safeguard the national environment for posterity; and shall seek co-operation with other states and bodies for the purposes of protecting the wider international environment for mankind. (Government of Ghana, 1992: 28).*

This enjoins the Government of Ghana to ensure sound management of the environment and the use of its resources in a sustainable way to avoid irreparable damage for the benefit of future generations. Notably, the environment is a multi-dimensional entity. Consequently, managing the environment calls for practices and protocols that cut across all variables that contribute to the

environment wellbeing of Ghana. Considerations under this focus spans issues that range from climate change, pollution, deforestation to other environmentally related problems. This is in consonant with Act 490 and Legislative Instrument 1652 of 1999, which indicates that any adverse effect on the environment tends to affect other areas including health, socio-economic and cultural sectors, making the effects of climate change multi-sectorial (Government of Ghana, 1999). An example of such a multi-sectorial effect includes health and socio-economic sectors where fossil fuel emissions from vehicles pollute the environment. This affects the health of other road users causing respiratory disorders when these emissions are inhaled. The affected victims would have to seek medical attention and this leads to parting away with some money through the payment of medical bills affecting their socio-economic status. To avert this, there is the need for an interdisciplinary strategy involving environmental health experts and economists to strategically develop a holistic plan to deal with the environmental challenges that could have an impact on the health and subsequently the socio-economic wellbeing of citizens.

Again, according to the 1992 environmental policy, environment-linked challenges confronting Ghana manifests under four issues namely: (i) natural resources issues, (ii) socio-cultural issues, (iii) economic issues and (iv) institutional issues. Among these four issues, natural resources such as forest reserves and water bodies are most vulnerable to the adverse impacts of climate change as presented and discussed in Chapters 2 and 4. Subsequently, the environmental policy acknowledges climate change as a critical phenomenon that affects the lives of citizens directly or indirectly because modern human economic and social activities are heavily dependent on natural resources. For this reason, Ghana signed up to the United Nation Framework Convention on Climate Change (UNFCCC) in 1992 and ratified the same in September 6, 1995.

As part of the requirement for Ghana signing up to the UNFCCC, the country must employ environmentally sound technologies to manage the threats of climate change as well explore any opportunities the phenomenon may bring forth. To fulfil the related requirements, Ghana initially conducted a needs assessment study. The study produced scientific evidence to prove that the potential negative impacts of climate change were immense, and Ghana particularly was vulnerable due to lack of capacity to undertake adaptive measures that address the environmental problems and the related socio-economic costs of climate change (Government of Ghana, 2012: 17). The study also listed a number of desired technologies which were prioritised in a technology transfer and acquisition plan (TTAP). Within the TTAP, the technologies were categorised into

three namely: (i) energy efficient lighting using compact florescent lamps (CFL), (ii) industrial energy efficiency, and (iii) landfill methane gas recovery.

Under the energy efficient lighting using compact florescent lamps programme, the government distributed free energy efficient florescent lamps to all households across the country (Government of Ghana, 2012). This action was able to reduce the energy consumption at the household level. A senior management official of the Energy Commission indicated that the reduction in the energy consumption by household reflected in the reduction of the energy units consumed and reduction in the amount of electricity bills paid. In the case of the industrial energy efficiency, a fiscal mechanism was established in 2012 to support industries transform to use low power consuming equipment (Ibid). The result is that less pressure is placed on the Akosombo dam to enable it to provide equal power to other sectors without necessarily using the load shedding mechanism. Through the landfill methane gas recovery initiative, waste is collected and treated in order to generate methane gas that is channelled to power electricity generating plants. This is important in mitigating the release of methane from landfill because methane is 23 times more destructive as a GHG compared to carbon dioxide (Rojas-Solórzano, Rahmaputro, Ruiz & Anaglate, 2012). The needs assessment study also referred to other climate change related problems that need tackling. These include climate change associated health problems, climate induced disruption of agricultural systems, flooding of coastal areas that are already undergoing erosion and the most relevant to this research dealing with the low operating water levels of the major hydro power generating dams in the country.

Looking at all the focus on the broad environmental management challenge, the acute and often unique challenges of climate change have seen the need for specific and narrowly focused policies and legislation. Indeed, many countries have such policies and legislation, and Ghana is no exception.

5.4.1 Climate change policies and legislation in Ghana

Legislation is one of the instruments governments use to organise and protect citizens, infrastructure as well as national natural resources for the benefit of current and future generations. The adverse impacts of the climate change phenomenon are threatening the wellbeing of all global citizens and natural resources. Various national and sub-national

governments are reacting accordingly through the development of policies and legislations guided by both local and international requirements.

Legislative functions in Ghana are driven through a 275-seat parliament elected for a four-year term (Government of Ghana, 2012). During these terms, members of the legislature carry out all primary legislative functions, including the passing of bills that require the assent of the president, before becoming law. Concerning climate change related policy and legislation in Ghana, the policy and legislation regime is largely informed by the United Nation Framework Convention on Climate Change (UNFCCC) requirements, which Ghana ratified in 1995. A key policy in this space is the National Climate Change Policy Framework of 2011 (Government of Ghana, 2011). This framework guides the development, coordination and implementation of climate change management processes in Ghana. Broadly, the aim of the framework is to ensure a climate resilient and climate compatible economy while achieving sustainable development and equitable low carbon economic growth for Ghana. It outlines three major objectives to attain: (i) low carbon growth, (ii) social development and (iii) effective adaptation to climate change (Ibid). Activities resulting in low carbon growth could lead to less emission of GHGs and subsequently mitigate global warming and climate change.

The National Climate Change Framework was the precursor to the National Climate Change Policy approved by cabinet in 2013 (Government of Ghana, 2013). Proceeding from the goals of the framework, the National Climate Change Policy aims to promote a low carbon development and increase policy coherence focusing on managing the impacts of the climate change phenomenon in Ghana. Energy is one of the focus areas of the National Climate Change Policy. The policy recognises that hydropower facilities are the major source of electrical power for Ghana and thus the need to protect them from the adverse impacts of climate change through the development of policies.

Despite this recognition, the National Climate Change Policy document is silent on the development of hydropower facilities but explicit on the promotion of other renewable sources of energy. For instance, Ghana aimed to derive 10% of its energy from renewable resources other than large-scale hydropower by 2020. In addition, the policy also targeted the use of renewables by replacing biomass with LPG at a rate of 10% from 1995 to 2020. The policy also intends to carry out the following: (i) reduction of average wood fuel energy intensity per household by 50%

by 2020, (ii) reduction of firewood intensity per rural household by 10% by 2020, (iii) achieving 5% solar energy penetration in hotels and restaurants by 2020 and (iv) 10% increase in the use of biogas in cooking by hotels and restaurants by 2020 (Government of Ghana, 2012). Again, the emphasis of hydropower sources of energy was lacking. Nevertheless, the reduction of wood fuel is expected to tackle the indiscriminate cutting down of trees and thus promoting the preservation of carbon sinks that absorb anthropogenic carbon from the atmosphere (Canadell & Raupach, 2008). The reduction of wood fuel, however, does not guarantee a reduction in the cutting down of trees as they can be cut down for other purposes such as the production of paper and for the construction industry. The industries do indeed need timber for their sustainability making the total stoppage of tree cutting impossible thus necessitating a need for the sustainable exploitation of forests. A management member of the Ministry of Environment, Science, Technology and Innovation concurred to this by stating that:

> *Human activities such as clearing of forest for farming, construction and illegal mining among others are difficult to totally clamp down. (Extract from field interview.)*

In pursuant of promoting more of the other renewable energy, the government developed a proposal to establish its own Renewable Energy Fund under the Renewable Energy Act, 2011 (Act 832). The Renewable Energy Act, 2011 (Act 832), mandates an increase in renewable energy capacity particularly solar energy. It plans to integrate solar energy into the national power system (Government of Ghana, 2011). This is in pursuant of section 46, sub-section 1 of the Renewable Energy Act, 2011 (Act 832) which states that:

> *The Public Utilities Regulatory Commission and the Energy Commission shall in developing regulations and guidelines for the provision of electricity, take into account the particular nature of the electricity generated from renewable energy sources to ensure that relevant renewable energy projects are integrated into the power system. (Government of Ghana, 2011: 20.)*

This Act places much emphasis on solar energy more than on any other source, including hydropower. This is evident in the electrification of approximately 10,000 homes using photovoltaic panels (Gyamfi *et al.,* 2017). While this progress is welcome, it is concerning that there is a paucity of policy focus targeting Ghana's considerable hydropower potential. This indicates a need for the government to practically act to develop the various hydropower sources. Developing the hydropower sources such as dams will not only avoid the use of fossil generated

energy but will also serve to store water to mitigate the impact of climate change linked droughts. This concurs with Castano's (2011) assertion, as presented in section 2.5 of Chapter 2, that water reservoirs such as dams and lakes can be used to mitigate climate changed induced water shortages within and away from the concerned facilities. This study is, however, cognisant of the fact that dams and lakes are sometimes GHG emitters when the vegetation they cover begins to decompose. That notwithstanding, this study is of the position that these emissions are less, making them negligible compared to those emitted by the fossil-based fuels because the earth's natural systems may adequately sequester GHG from lakes and dams.

Noting that implementing policies and legislation that seek to manage the climate change challenge is both wide and deep, the Ministry of Environment, Science, Technology and Innovation has agencies that implement the various facets of these policies under contextualised conditions. For instance, the implementation of its climate change and environmental related policies, which is the focus of this study, are spearheaded by the Environmental Protection Agency and those related to hydro energy spearheaded by the VRA. The next sub-section details these agencies and their general implementation strategies.

5.4.2 Climate change and environmental related policy implementing agency in Ghana

The Environmental Protection Agency is the leading public policy implementation body regarding protecting and improving environmental wellbeing in Ghana. It was initially established by the Environmental Protection Council Decree of 1974 (NRCD 239) and was subsequently amended by the EPC (Amendment) Decree 1976 (SMCD 58). The Environmental Protection Agency Act, 1994 (Act 490) transformed the Environmental Protection Council into the current Environmental Protection Agency. Through this Act, the agency is given the responsibility of ensuring the implementation of environmental and climate change policies that are developed by the Ministry of Environment, Science, Technology and Innovation.

The broad mission of the EPA is to co-manage, protect and enhance the country's environment as well as seek common solutions to global environmental problems such as climate change (Government of Ghana, 1994). The accomplishment of the EPA's mission is expected to be achieved through research that advances scientific, technological and innovative approaches to environmental management. The EPA has taken the lead in the implementation of many

environmental and climate change policies and is currently spearheading the implementation of the Ghana National Climate Change Master Plan Action Programmes for Implementation: 2015 – 2020. The master plan provides a clearly defined pathway for the implementation of the National Climate Change Policy. It mainstreams the implementation process, the associated estimated cost, the accompanying monitoring and evaluation and also outlines strategies for effective implementation.

In other attempts to tackle some of the causative agents and activities of climate change, the EPA, through the government, has established a legislative instrument, L.I 1812 known as "Management of Ozone Depleting Substances and Products Regulations, 2005" (Government of Ghana, 2005). This legislative instrument prohibits the importation or exportation of substances or products that deplete the ozone layer. The successful execution of the L.I 1812, ensures the maintenance of the natural level of the ozone layer. Maintaining the natural level of the ozone layer traps and prevents excessively high temperatures from reaching the earth and causing evaporation and drying up of water resources. Specifically related to this study is the prevention of excessive evaporation of hydrodams from reaching a level that is detrimental to their operations. In particular relation to the Akosombo dam, the VRA as government agency responsible for managing Ghana's hydropower facilities, has developed climate change and environmental related policies with the aim of enhancing the efficiency of hydropower generation in Ghana.

Established in 1961 through the Volta River Development Act, Act 46 of the Republic of Ghana, the Volta River Authority was initially mandated to generate, transmit and distribute electricity (Government of Ghana, 2015). A 2005 amendment led to the limiting of the mandate of the VRA solely to the generation of electricity. Through this mandate, the VRA has jurisdiction to manage Ghana's hydropower facilities and the associated generation machinery. In fulfilling its mandate and to tackle the challenge of climate change associated with hydropower generation, the VRA has formulated environmental and climate change policies. Table 6 lists the policies developed by the VRA.

Table 6: Policies developed by the VRA

No.	Document
1	VRA corporate environmental policy statement, 2005
2	Community development programme policy, 2012
3	VRA policy on renewable energy generation, 2016
4	Office waste segregation policy and guidelines, 2017

Source: Author's compilation, 2021

Largely, the policies developed by the VRA (Table 6) seek to maintain the viability of the Akosombo dam and tacitly other hydropower infrastructure in Ghana against a background of possible threats presented by climate change and other environmentally related threats. For instance, the corporate environmental policy ensures continuous improvement of environmental performance to minimise the impacts of all its operations on the environment and to ensure sustainable development while complying with national and international environmental protection regulations. By the actions mentioned in the policy, its ultimate aim is to protect the environment and also invariably help tackle the climate change menace. In pursuant of dealing with renewable energy in particular, the VRA board passed resolution 707 in 2010 to approve a policy on renewable energy and authorised its operationalisation with the Renewable Energy Development Programme (VRA, 2010). The policy seeks to develop and operate renewable energy plants in an efficient, cost effective, timely manner whilst fighting environmentally related problems including climate change (Ibid). This is reiterated in one of its strategic policy objectives that states that:

> *VRA will diversify its generation portfolio in a sustainable manner with a low carbon footprint (VRA, 2016: 3).*

While the government and its agencies can drive action that seek to manage climate change, it remains important to involve communities that face some of these impacts and whose action are critical to the related management policies and practices. For this purpose, the VRA developed a community-centred policy, namely the "Community Development Programme Policy". The policy is meant to environmentally protect and promote community development initiatives and maintain

mutually beneficial relationships with communities in which it operates. Some of the climate change and environmental protection initiatives within the policy include tree planting, aquatic weed management and dredging. The tree planting is particularly important for maintaining and increasing the magnitude of carbon sinks and the related benefits of mitigating global warming. Good aquatic weed management helps preserve water bodies, including those meant for hydropower generation. The aquatic weed management should, however, be carried out in a way to avoid excessive weed growth as this has the potential of affecting the efficiency of hydropower systems (Fearnside, 2016). Dredging on the other hand tackles the problem of flooding. It paves the way for open gutters providing a good drainage system for easy passage of rainwater in case of high volumes of rain which has become rampant in the era of climate change (Jones, Marten & Harris, 2015). From the community level to a smaller setting, the VRA aims to reduce and properly manage the total volume of waste generated in its offices. This subsequently led to the development of the "Office waste segregation policy and guidelines". According to a management officer of the VRA, the policy and guidelines are cognisant of the impact of waste on the environment and on global warming and climate change. Additionally, it has both local and global environmental benefits and is part of a raft of attempts seeking to reduce the carbon footprint of the VRA, thus supporting the nationally determined contributions policy action of the NCCP.

Being cognisant of the importance of tackling the environmental and climate change effects, the VRA draws from its policies and guidelines to conduct special programmes and take strategic initiatives to ensure the successful management of climate change. Table 7 details some of these special programmes and initiatives and their expected and realised outcomes.

Table 7: VRA's policy programmes and initiatives and related outcomes

Policy Programme	**Expected outcome/realised outcome after implementation**
Carbon Footprint Management Programme	Identified CO_2 emission levels of VRA generation plants to allow for the mitigating measures to be developed.
Conversion of simple cycle power plants to Combine Cycle	This has resulted in the conversion of 220MW T1 and T2 projects at Aboadze to a 330MW Combine Cycle Power Plants resulting in the generation of additional 110MW each with the same volume of fuel.
West Africa Gas Pipeline Project	This has resulted in the establishment of the West Africa Gas Pipeline Company, which provides natural gas to supply cleaner energy for VRA's thermal power pants.

RE Development Programme Phase 1 (REDP1) aims at developing about 164 MW of installed renewable energy capacity	The programme consists of three components, specifically (a) 150 MW Wind Power Phase 1 (b) 14.6 MW Solar Power Phase 1, and (c) Renewable Energy Planning & Development Integration. VRA subsequently in May 2013 commissioned the first of the PV plants, a 2.6 MW photovoltaic plant near Navrongo in the Upper East Region of Ghana. Other projects which are at various stages of developments are: Planned 75MW Wind Power Project 1 (Anloga Extension) Planned 75MW Wind Power Project 2 (Wokumagbe and Goi) Planned 8 MW Solar Power plant in Kaleo in the Upper/w Region Planned 4 MW Solar Power plant in Lawra in the Upper West Region of Ghana Also under this programme, VRA has registered all its combined cycle projects under the Clean Development Mechanism (CDM) and has developed Pipeline Development Plan (PDP) for the expansion of the existing 110 MW SC TT1PP into a 330 MW CC Plant which will resulting in 255,271.91 tons of CO_2e. annual savings as well as the conversion of 220MW SC KTPP to 330 MW CC resulting in 400,000 tons CO_2e annual savings.
VRA Reforestation Programme	Planted 3,193 hectares of forest cover as at close of 2015 and contributing between 300,000 – 730,000 tons of carbon sink.
Community Development Programme (CDP)	The CDP enables VRA to continue to maintain mutually beneficial relationships with the communities in which the Authority has carried out its primary operations since its establishment. It is expected that by promoting their empowerment and supporting the people to develop their skills, VRA will boost economic activities in all the communities and foster veritable development
Climate Smart Stoves Initiative	Construction of 200 Fuel efficient cookstoves for riparian communities. Results of an assessment of these biomass cookstoves by the Industrial Research Institute of CSIR in March 2017 showed a percentage difference in fuel savings of 51.45% and processing rate of 76.6% respectively with an estimated annual carbon savings of 664 kg CO_2 as against the traditional “3-Legged Cook Stoves”. The stoves meet international requirements of minimum of 40% fuel efficiency. The trial has been successful, as over 90% of the beneficiaries have embraced its adoption for use due to evidence that it significantly reduces fuelwood consumption and excessive exposure to heat and smoke.

Source: VRA, 2018

The table shows that the special programmes and strategic initiatives undertaken by the Volta River Authority are focused on the generation of carbon sinks and the development of renewable energy projects targeted to reducing carbon emission. These initiatives are in the path of yielding the desired outcomes. For instance, as at 2015, the afforestation programme has contributed between 300,000 – 730,000 tons of Carbon sink that helps in the mitigation of the climate change phenomenon.

5.5 Chapter conclusion

The chapter revealed the essence of having climate change and environmentally related policies to manage climate change. It elucidated the fact that extreme weather occurrences resulting from the effects of climate change made it necessary to formulate the national climate change and environmental related policies and legislation to control activities that influence the environment leading to climate change.

Since climate change is transboundary and does not respect borders it is laudable and good practice for Ghana to sign unto the global efforts of curbing the menace of climate change. This has led to the Government of Ghana developing a number of climate change and environmental-related policies. The climate change and environmental policies and legislation formulated by Ghana have become important and key instruments for the management and control of climate change. It is, however, important that these policies and legislation are enforced to the letter to realise its impact. As the legal system is used to ensure enforcement of the policies and legislation, a rewards system could also be developed and established to encourage the implementation of the policies and legislation.

Having discussed the available climate change and the environmental related policies developed by the Government of Ghana and its agencies, the study contributes to the management of climate change by proposing a comprehensive conceptual management adaptation framework that is expected to enhance climate change adaptation management of hydropower within the Ghanaian context. This is detailed in the next chapter.

CHAPTER 6: ADAPTATION FRAMEWORK FOR THE MANAGEMENT OF HYDROPOWER

"I am always doing that which I cannot do In order that I may learn how to do it." Pablo Ruiz Picasso (1881 – 1973)

6.1 Introduction

Within the space of environmental management, different functional frameworks have developed over the years. These functional frameworks have been developed towards the management of the environment in general but not hydropower specifically. This chapter addresses this lack of a hydropower specific framework by seeking to answer research objective 4, which is: "to develop comprehensive conceptual management adaptation frameworks that enhances climate change adaptation management of hydropower within the Ghanaian context". The development of the management adaptation framework was carried out in three phases. The first phase was to develop an integration and coordination network framework. This was necessary because the research survey conducted during the study indicated a lack of cross management integration amongst the necessary government agencies (VRA, Energy Commission, Water Research Institute, Ghana Meteorological Agency) and the community (within the hydropower catchment area) in response to climate change adaptation management of the Akosombo hydropower plant in Ghana. The integration and coordination network framework is therefore expected to bridge the cross-management integration gap and to result in a cohesive integrated network of stakeholders that consist of the cross-management and community leaders. This is expected to contribute to the enhancement of the management of hydropower in the face of emerging climate change related disasters. The second phase was to develop a conceptual adaptation framework of interaction (framework of adaptation options) that shows the adaptation options that the integrated stakeholders can choose from before carrying out any adaptation activities. The third phase developed the final framework, called the adaptation framework of outcomes. The adaptation framework of outcomes is an infusion of the integration and coordination network framework, the conceptual adaptation framework and the filling in of the gaps identified in the literature.

This chapter is divided into three main sections. The first section discusses the need and choice of framework, the second section discusses the three frameworks which the study proposes as its contribution to the body of knowledge and the third section concludes the chapter.

6.2 The need for a framework

Kivunja (2018), differentiated theoretical frameworks and a conceptual framework. A theoretical framework comprises ideas expressed by experts in a field of study from which a researcher, can draw upon to provide a theoretical coat hanger for a set of data analysis and interpretation of results. It can also be described as a structure that summarizes concepts and theories from experts, from which a researcher can synthesize to have a theoretical background or basis for data analysis and interpretation of the meaning contained in a research data, (Swanson, 2013). On the other hand, a conceptual framework is the total, logical orientation and associations of anything and everything that forms the underlying thinking, structures, plans and practices and implementation of an entire research project (Kivunja, 2018). It can also be described as a logical conceptualisation of the entire research that helps to give a logical conclusion to the research project. According to Ravitch and Riggan (2017), a conceptual framework comprises the researcher's thoughts on identification of the research topic, the problem to be investigated, the questions to be asked, the literature to be reviewed, the theories to be applied, the methodology to be used, the methods, procedures and instruments, the data analysis and interpretation of findings, recommendations and conclusions the researcher will make. This study made use of a conceptual framework to enhance the management of the Akosombo hydropower in the face of emerging climate change impacts. The conceptual framework was chosen because it fits well in the theory of Ravitch and Riggan (2017) as is appropriate to answer the research question four and is going to be built upon from the literature review and from the views expressed by management and community members during the research survey. In this study, the research objective 4 as spelt out in section 1.3 of Chapter 1 will be addressed through the development of conceptual frameworks to reach a logical conclusion.

6.2 Development of conceptual frameworks

As indicated earlier, this chapter aims to develop a management framework that enhances climate change adaptation management of hydropower within the Ghanaian context. The outcome of the survey conducted with the Government agencies in this research reveals a lack of integration among these agencies. There is the need for these agencies to integrate and harness the management of hydropower in Ghana. Even though the Water Research Institute has an office stationed at the Akosombo catchment area, a response from one of the respondents clearly shows the disintegration between the institute and the other agencies. He indicated that

Our work schedule is to analyse and test water bodies to ensure safe aquatic life for the benefit of the community. We are involved in climate change related activities but not involved in hydropower generation. (Extract from the field interview.)

The study did not only highlight the lack of coordination and integration between these Government agencies, but also the lack of interaction between these institutions and the community. This lack of integration is not a unique problem to hydropower management. The literature review (in Chapter 2) shows that strategic management frameworks have been developed over a period of time, but lack cross-management integration and coordination. This study builds on that to propose an integration and coordination network framework between the Government agencies, the community and the environment to enhance cross management of the hydropower sector of the country. As shown in Figure 17, this integration and coordination network framework will provide a strong and cohesive cross-management that will navigate a volatile hydropower sector to deliver a competitive advantage in the face of emerging climate change impacts.

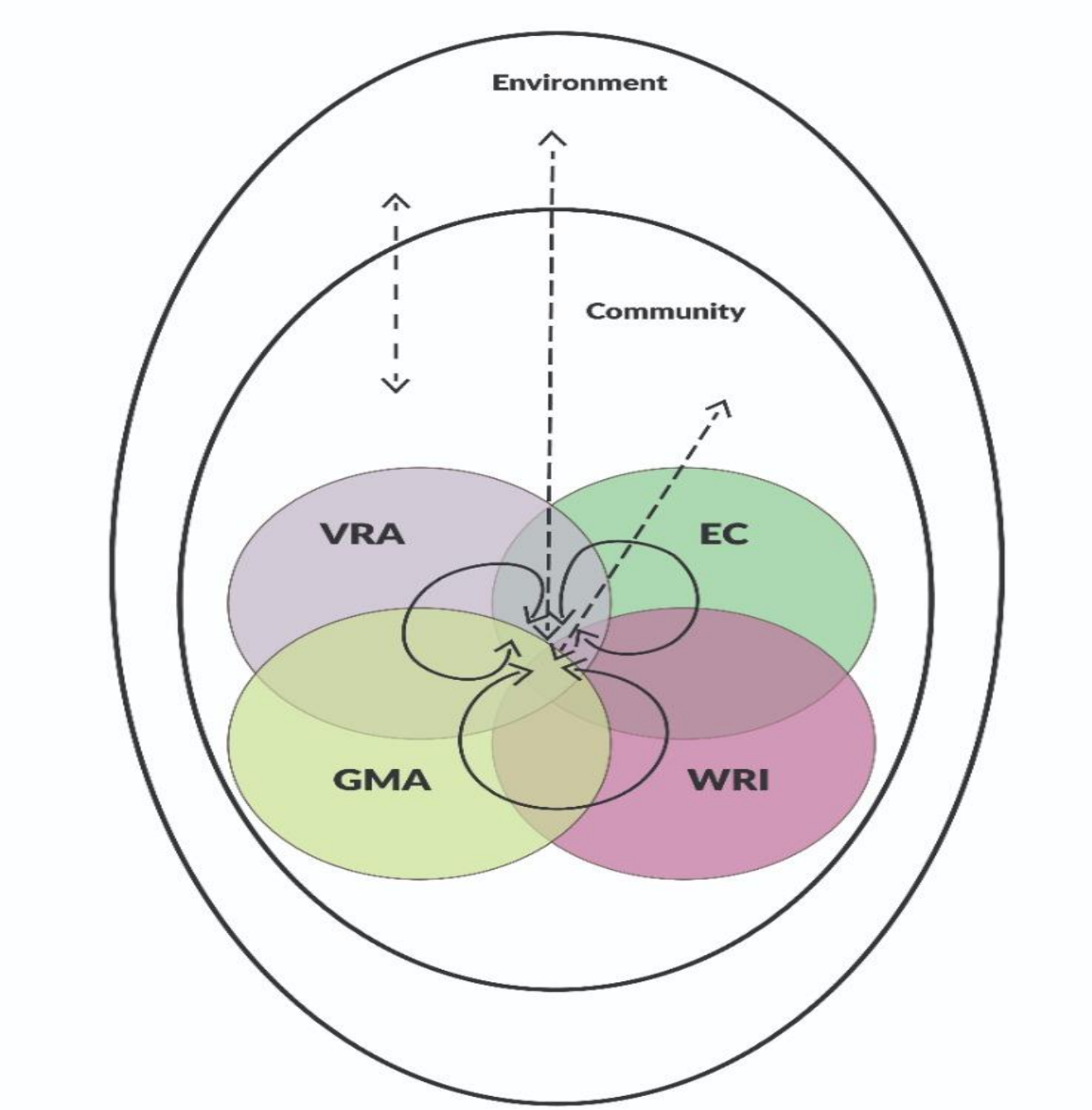

Figure 17: Integration and coordination network framework
Source: Author, 2021

In the figure, the government agencies include the Volta River Authority represented by the abbreviation VRA, the Energy Commission represented by EC, the Ghana Meteorological Agency represented by GMA and the Water Research Institute represented by WRI. These agencies are the high-level overview variables involved in the planning process. To promote the integration and

coordination network, it is essential to understand the variables that influence the strategic planning of adaptation activities leading to a more sustainable management of hydropower. To have successful adaptation activities, it is essential that these variables (the government agencies) interact with each other and the community within the environment they exist. This assertion alludes to John Donne (1572 – 1631) saying that *"No man is an island entire of itself; every man is a piece of the continent or a part of the main.* This quote demonstrates the need for organisations and individuals to work together to achieve a better result compared to working in isolation. The integration and coordination network framework shows dotted lines and arrows to indicate the non-linearity and the interdependence of all the variables hence the need to plan and execute climate change adaptation in association and not in isolation. In the literature review, under section 2.5.1, Wilby *et al*. (2002) highlighted three issues that can be used to assist dam and lake management authorities adapt to climate change. The first issue borders on policy, planning and assessment, the second on design and construction whilst the third borders on operation and maintenance. Relevant to this section is the first issue which borders on policy, planning and assessment, involves an examination of all issues that need to be considered when planning for a new reservoir or dam. The planning that authorities and management can undertake to adapt to climate change is not holistic enough in the sense that it does not involve other key stakeholders that this study intends to involve. The involvement of the other key stakeholders including the community leaders is likely to ensure successful implementation of the climate change adaptation activities. Chapter 3 revealed the mandate of these four main Government agencies. The Volta River Authority's mandate includes the management of the Akosombo dam and hydropower generation machinery including undertaking activities that tackle the impact of climate change. The mandate of the Energy Commission (EC) is to contribute to the development and elaboration of national policies and strategies for all renewable sources of energy including micro hydropower facilities in the country and also to serve as data source relating to energy planning and policies put in place to deal with the impact of climate change on micro hydropower and renewable energy in general. The Water Research Institute's (WRI) mandate is to conduct research that generates scientific information to guide the formulation of strategies and services that develop and manage water resources for energy, transport and agriculture purposes in Ghana. This study focused on its water resources management for energy since that is the direction of the study. The Ghana Meteorological Agency (GMA) is to provide weather and climate data sets that include patterns and changes in rainfall and temperatures. Considering the similarities in activities of these four main government agencies (such as working

towards energy improvement and climate change management) as discovered by this study, there is the need for integrating their activities especially the climate change adaption activities. To ensure the buy-in of the communities within the catchment area and the success of implementing adaptation activities calls for total integration between the government agencies and the communities. After having a successful integration between the government agencies themselves and the communities, the study further developed a conceptual adaptation framework of interaction (Figure 18). The conceptual adaptation framework of interaction shows the adaptation options from which the integrated stakeholders can choose and then goes further to identify adaptation opportunities that they (the integrated stakeholders) can take advantage of whilst at the same time recognising the possibility of adaption constraints that need to be overcome before carrying out any adaptation activities.

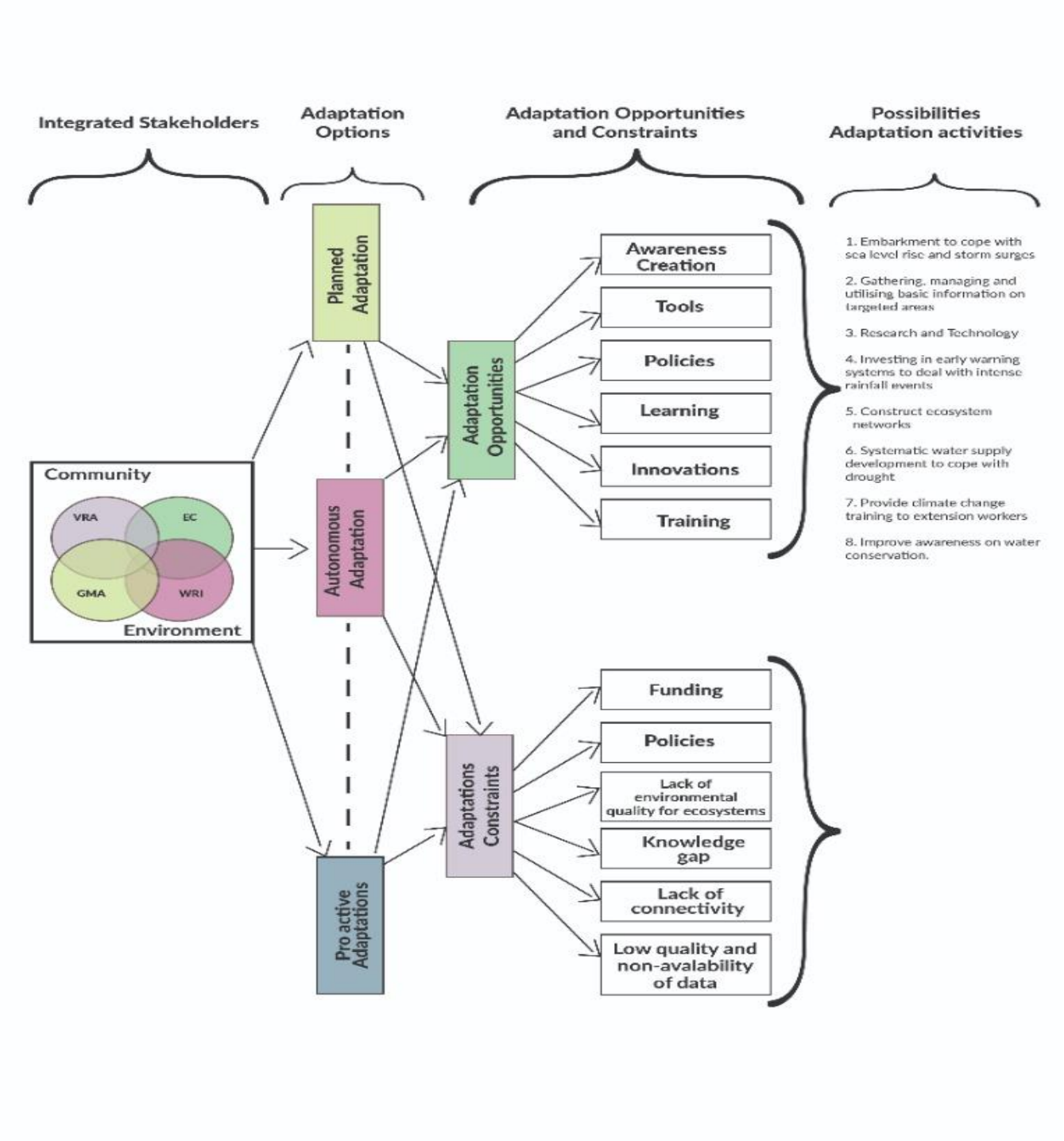

Figure 18: Adaptation framework of interaction
Source: Author, 2021

The framework as depicted in Figure 18 draws on a number of statements from the literature review of this study and the integration and coordination network framework in Figure 17. From the literature review under section 2.4.1, the IPCC (2001) mentioned three types of adaptation options that are very important when considering adaptation measures. These include the proactive adaptation, planned adaptation and autonomous adaptation. The framework (Figure 18) shows these adaptation options that the integrated stakeholders can consider in their deliberations. The proactive adaptation takes place before the dire impacts of climate change occur. It seeks to avoid the high costs of action after the occurrence of an adverse climate change event. With the planned adaptation there is a deliberate policy decision based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state (IPCC, 2013). The autonomous adaptation refers to the changes that natural and most human systems go through in reaction to changes in their immediate environment, where such reactions may occur irrespective of any broader plan or policy-based decisions (Ibid). Going further from the knowledge of the adaptation options to application needs specification as to who or what is adapting, what they are adapting to, and the process of adaptation (Smit *et al.,* 2000). Hence, the need to inculcate and explore adaptation opportunities and adaptation constraints within the framework as shown in Figure 18 arises. It is worthy to note that an element listed as an adaptation opportunity could also serve as an adaptation constraint, depending on its position. Examples are policies and technology. For instance, technology could serve as an adaptation opportunity if it is available, and people have been trained on how to use it. It could also serve as an adaptation constraint if it is not available or is available, but people have not been trained on how to use. This will make it redundant. The following Sub-sections 6.2.1 and 6.2.2 give the details of the two types of adaptations (adaptation opportunities and adaptation constraints), under each also is the discussion of some selected adaptation opportunities and adaptation constraints elements.

6.2.1 Adaptation opportunities

According to Klein *et al.,* (2014) adaptation opportunities represent enabling factors that aid implementers to plan and implement actions to achieve their adaptation objectives against climate change risk. The IPCC (2018) further argued that these enabling factors enhance the ability of implementers to secure their existing objectives or for a natural system to retain its productivity. It is worthy to note that different implementers have differential capacities to adapt to climate variability and change, although those capacities can be difficult to measure, (Ibid). In this study,

the implementers refer to the integrated stakeholders who after settling on all or any of the three adaption options shown in Figure 18, would need to identify the adaptation opportunities (enabling factors) that facilitates the implementation of the adaptation activities. The adaptation opportunities range from increasing awareness of climate change, its consequences, and the potential costs and benefits of adaptation options to the implementation of specific policies that create conditions that are conducive to adaptation implementation. Section 2.4.2 of the literature review indicated that it is critical to create awareness because its paucity often results in the creation of knowledge gaps resulting in the inability and incapacitation to tackle the climate change menace. For instance, the literature has identified water resources and in this case hydropower to be particularly vulnerable to the effects of climate change (Solaun & Cerdá, 2017). Therefore, planning and implementation of adaptive responses will be an important component of managing the risk of climate change in hydropower production (Ibid). Fortunately, a range of other factors are available to support adaptation opportunities including the use of analysis tools to better understand vulnerabilities and thresholds hydropower production and develop scenarios of future consequences. That information could then be communicated to managers of hydropower facilities, national governments, and international agencies to increase awareness of potential risks. Policies can also be used to incentivize adaptation to boost hydropower production. According to Lavell *et al.,* (2012) there are other adaptation opportunities that the integrated stakeholders can consider to minimise the risk of climate change for other sectors. These include risk assessment, partnerships, developing finance mechanisms, and formal adaptation policy development. Another identifiable factor is sustainable economic development, which is a critical foundation for the creation of adaptation opportunities, because it has the potential to build the capacity of individuals and organisations to adapt (Ibid). Sustainable economic development is associated with increasing opportunities for research, training, and education as well as for enhancing access to expertise and tools for assessment activities and decision support. It also increases access to technologies that can enhance efficiencies. For example, water use in the USA has remained relatively constant since the mid-1980s despite population growth and the expansion of electricity generation (Kenny *et al.,* 2009). Improvements in technology and management practice stimulated by innovation, education and learning have increased water use efficiency and this has increased the resilience of water resources to climate change. The next sub-section gives some details of how some of these adaptation elements (opportunities) can boost a successful implementation agenda.

6.2.1.1 Awareness creation

Awareness creation involves measures put in place to promote awareness among community members on the impact of climate change and the strategies involved in its mitigation and adaptation. The importance of awareness creation cannot be underestimated because not all community members and stakeholders are aware and informed about their vulnerability to climate change and the measures they can take to proactively mitigate or adapt to climate change. Awareness raising is therefore an important component of the mitigation and adaptation process to manage the impacts of climate change, enhance adaptive capacity, and reduce overall vulnerability. Awareness creation is also important to increase the interest, enthusiasm and stimulate self-mobilisation and action in mobilising local knowledge and resources.

Awareness creation can address groups of people in a region affected by a particular climate threat, groups of stakeholders or the general public with the ultimate aim to achieve long-term lasting behavioural changes towards the environment. It aims to ensure that all stakeholders involved understand the impacts of climate change and take action to respond to it.

6.2.1.2 Policies

Climate change Policies are meant to be mechanism put in place by governments and other regulatory bodies to provide incentives but few requirements to reduce GHG emissions and minimise the impact of climate change. For example, a number of tax incentives are in place to encourage purchase of more efficient vehicles and to make efficiency improvements to buildings. Other incentives induce agricultural producers to enhance soil carbon. The policies may also come in handy in the form of providing information, technical assistance and awards to institutions and other consumers to quantify and reduce their GHG emissions. Such policies are generally intended to encourage emission reductions that are already economical but that do not occur because of market inefficiencies. For example, some GHG reductions are also achieved by regulations and policies governing the energy efficiency of vehicles and appliances, methane emissions from landfills, and other controls. There are some policies also devoted to developing new technologies that would be necessary to reduce GHG emissions below current levels thereby minimizing the impacts of climate change.

6.2.1.3 Innovation

Innovation is one of the effective responses to climate change on the local and global scale leading to the development and diffusion of a broad variety of new clean technologies in both developed and developing countries. Clean technology innovation is one of the keys to addressing the global impact of climate change. Clean technologies help to improve environmental performance as they are more protective of the environment, display lower pollution levels, deploy resources in a more sustainable manner, recycle a higher share of wastes and products, and treat residual wastes in an environmentally more friendly and acceptable way. In dealing with climate change mitigation and adaptation, mitigation technologies aim to reduce emissions of greenhouse gases or to capture them, while adaptive technologies allow users to adjust to the negative effects of climate change or to explore positive ones.

Innovation comes in two dimensions, made up of technology development and technology diffusion. Technology development refers to the use of scientific knowledge to obtain solutions whilst technology diffusion is the process by which new technologies are transmitted from one party to another. Climate-friendly technologies, no matter how advanced, clearly do not serve their purpose until they are actually deployed and used. A meaningful solution requires the world to collectively embrace a broad array of clean technology solutions, many of which are already widely available on the market today.

6.2.1.4 Training

Training is about enhancing the ability of individuals and organisations to identify, plan and implement ways to mitigate and adapt to climate change. Within the climate change arena, training is necessary to enable the acquisition of knowledge and skills towards climate change mitigation and adaptation. It is also viewed as the enhancement of skills and ability that translates into better climate change mitigation and adaptation practices.

Training in the climate change mitigation and adaptation practices could be carried out in the area of strategies and actions, and monitoring and evaluation. Strategies and actions refer to the specification of a climate change training at organisational or individual levels to address any possible knowledge gaps concerning the impacts of climate change. These can encompass various approaches to building skills and cognitive capacity at different levels, which is aimed at enhancing awareness and increasing knowledge and skills development for actions against the

impacts of climate of change. Monitoring and evaluation are necessary to assess the progress of any action implemented against climate change to see if the desired outcome is being achieved. Evaluation is required to assess the overall impact of any implemented action against climate change.

The discussion shows that some of the elements in the adaptation opportunities are inter-related hence the selection of some for detailed discussion. Examples are elements of innovation and technology, and training, awareness creation and knowledge gaps. The same applies to the elements of adaptation constraints, details of which is discussed in the next sub-section.

6.2.2 Adaptation constraints

A number of factors are capable of constraining the planning and implementation of adaptation options. These factors categorised as adaptation constraints represents factors or processes that makes adaptation planning and implementation more difficult. This may include reductions in the range of adaptation factors that can be implemented, increases in the costs of implementation, or reduced efficacy of selected options with respect to achieving adaptation objectives (Klein *et al.,* 2014). The adaptation constraints can restrict the variety and effectiveness of options for implementers to secure their existing objectives or for a natural system to change in ways to achieve the desired results. Section 2.4.4 of the literature review mentioned some of the commonly constraints to include economic considerations leading to low or no funding, unfavourable policies, lack of interest by governments, conflicting interests, limits of powers for implementation, low quality and non-availability of data. Others that can be considered include absence of the right technology, knowledge gaps, institutional characteristics that impede action, lack of connectivity and environmental quality for ecosystems. The study has discussed the first six constraints under the literature review of section 2.4.4. The next sub-section elaborates how the rest of the constraints can impede the integrated stakeholders from having a successful implementation.

6.2.2.1 Institutional policies that impede action

There are also adaptation constraints associated with governance, institutional arrangements, and legal and regulatory issues as indicated in the literature review. Adaptation to climate change will necessitate the mobilisation of resources, decision making, and the implementation of specific policies by institutions (Huang *et al.,* 2011). Two key factors realised during the interview with the

Government institutions that impede adaptation action is funds and the political will to do so. One official interviewed at the Water Research Institute claims donation from donor agencies to the Government for climate actions has reduced and this has affected implementation of adaptation actions. The Government also lacks the political will to undertake any adaptation action due to competing demands with limited resources available. Issues of funds affecting adaptation implementation action cut across Governments in the world. For example, Lesnikowski *et al.,* (2013), found that planned adaptation by the public health sector among different nations is significantly associated with national GDP. Adaptation efforts may recognize these constraints, but do not necessarily articulate institutional arrangements that facilitate their coordination and reconciliation to achieve common adaptation objectives. Institutions associated with different scales may have different perceptions of the need for adaptation as well as the factors that constrain or enable adaptation (Biesbroek et al., 2011). In this context, scale refers to analytical dimensions used to study adaptation (including spatial, temporal, institutional, or jurisdictional), and each scale can be comprised of multiple levels (e.g., local to global in the context of spatial scales or household to central government in the context of jurisdictions of governance). Within the context of scale, section 2.4.2 of the literature review indicates that the effects of climate change go beyond any country's border to other localities. This makes scalability characteristics an essential factor due to the global nature of climate change and the fact that adaptation responses could involve cross-scale interactions that go beyond a particular locality, border, nationality and regional boundaries (Wise *et al.*, 2014). Adaptation planning and implementation creates new governance challenges and new institutions and bridging organisations may be needed to facilitate integration of complex planning processes across scales.

6.2.2.2 Lack of environmental quality for ecosystems.

The degradation of environmental quality is another source of adaptation constraints (Darling, 2010). Non-climatic stresses to ecological systems can reduce their resilience to climate change as evidenced by studies on coral reefs and marine ecosystems, tropical forests, and coastal wetlands (Afreen *et al*., 2011). Ecological degradation also reduces the availability of ecosystem goods and services for human populations. For instance, degradation of coastal wetlands and coral reef systems may reduce their capacity to buffer coastal systems from the effects of tropical cyclones. This was amplified in section 5.2 of Chapter 5, stating that the effects of climate change are now inevitable and so activities and infrastructure in the coast of Ghana and elsewhere need to adapt to this reality and start implementing some adaptation practices including building of sea

defence structures to increase the capacity to buffer the coastal system and prevent the sea from overflowing. Similarly, soil degradation and desertification can reduce crop yields and the resilience of agricultural and pastoral livelihoods to climate stress.

6.2.2.3 Knowledge gaps

There are significant knowledge gaps and impediments to the flow of information that can constrain adaptation. Literature shows the extent to which education and knowledge about climate change influences perceptions of risk. For example, studies suggest overconfidence in the ability of implementers to manage risk or differences in the perception of climate risk between implementers and governing institutions can constrain adaptation. Therefore, capacity building through education, training, and information access represents a valuable opportunity for implementation of adaptation practices. Issues also arise with respect to the role of traditional knowledge in adaptation. Survey conducted with communities during this study shows that members of the community did not know climate change could be the leading cause of the change in climate variability. About 80% of those interviewed had no knowledge of climate change. The lack of knowledge could serve as a constraint to implementation of any adaptation practices. There is the need to carry out education on climate change at the community before any meaningful adaptation activities can be carried out. Jones and Boyd (2011) also indicated that cultural preferences regarding the value of traditional versus more formal scientific forms of knowledge influence what types of knowledge and adaptation options to be considered legitimate. The tussle between traditional knowledge in adaptation and formal scientific knowledge hinders smooth implementation of adaption activities. The literature review suggests that the extent to which knowledge acts to constrain or enable adaptation is dependent on how that knowledge is generated, shared, and used to achieve desired adaptation objectives.

6.2.2.4 Lack of connectivity

Potential differences among stakeholders regarding adaptation options may result in some actions being simultaneously perceived as adaptive and maladaptive (Bardsley & Hugo, 2010). Maladaptation arises from the implementation of adaptation options that increase the vulnerability of individuals, institutions, sectors, or regions (Ibid). Individuals or institutions may have specific management objectives or values that they seek to achieve or maintain through adaptation. For every objective, however, there may be multiple adaptation options, each of which is associated

with a particular set of costs, benefits, and externalities. For example, biotechnology may contribute to the development of drought and pest-resistant cultivars that can maintain or enhance yields despite more challenging climate conditions. Yet, ecological and public health concerns over the use of biotechnology and genetically modified crops can constrain the use of such technologies. Agricultural producers may view biotechnology as an adaptive response, while some consumers may view it as a maladaptation that increases risks to ecosystems and food security. This disjointed view lacking connectivity may lead to trade-offs that can challenge an adaptation planning and implementation.

6.2.2.5 Technology

Considerations with respect to technology as an adaptation constraint that the integrated stakeholders must consider include the availability of technology, access to the technology including the capacity to finance, operate, and maintain, to be acceptable to users and affected stakeholders; and the effectiveness in managing climate risk. Although technology has implications for regional adaptive capacity, Zhu, Linham and Nicholls (2010), noted that in-depth exploration of technology in the adaptation literature is often associated with specific sectors. For example, Fleischer, Mendelsohn and Dinar (2011), noted the importance of technology options for facilitating adaptation including applications of existing management strategies as well as introduction of innovative solutions such as bio- and nanotechnology. Several studies from Africa have explored how different factors drive awareness, uptake, and use of adaptation technologies for agriculture (Deressa, Hassan & Ringler 2011). While such literature identifies specific adaptation technology options, and in some cases the costs associated with their implementation, quantitative understanding of the extent to which improving technology will enhance adaptive capacity or reduce climate change impacts remains limited.

There are some cardinal adaptation constraints that the integrated stakeholders should include in their planning to overcome that will ensure successful implementation of adaptation activities. That notwithstanding there would be a need to conduct monitoring of the implemented activities and subsequently measure the adaptation outcome to assess its success. The monitoring of the implemented activities and the measurement the adaptation outcome is key in the development of next framework called the adaptation framework of outcomes. The next sub-section elaborates on the adaptation framework of outcomes.

6.3 Adaptation framework of outcomes

Another contribution to the body of knowledge is the development of the adaptation framework of outcomes. The literature shows that measuring of adaptation outcomes is absent in most frameworks and this is where this study fills that gap. For instance, in the literature review (section 2.5.1 of Chapter 2), the climate change adaptation framework of Willows and Connell, (2003) indicates the process of identifying the problem and objectives, establishing the decision-making criteria, assessing risk, identifying the options available to choose from and then appraising the options after which a final decision is made on the choice of options. After making the final decision comes the implementation of the decision made followed by the final stage, called the monitoring stage. The framework is also absent with interaction with community members and other stakeholder leading to the missing element of co-management. The study incorporated this in its proposed conceptual framework to enhance adaptation management of hydropower. The framework of Willows and Connell (2003) only helps to answer the definition and the process of adaptation. The framework and the whole process are devoid of measurement of adaptation outcomes. Measurement of the adaptation outcomes is crucial to the whole adaptation process to ensure success and enhance the learning process where there are pitfalls.

A further literature search revealed that Cross *et al.* (2012), designed an adaptation framework that supports collaborative, scientifically defensible planning and decision-making for specific landscapes or seascapes as shown in Figure 19.

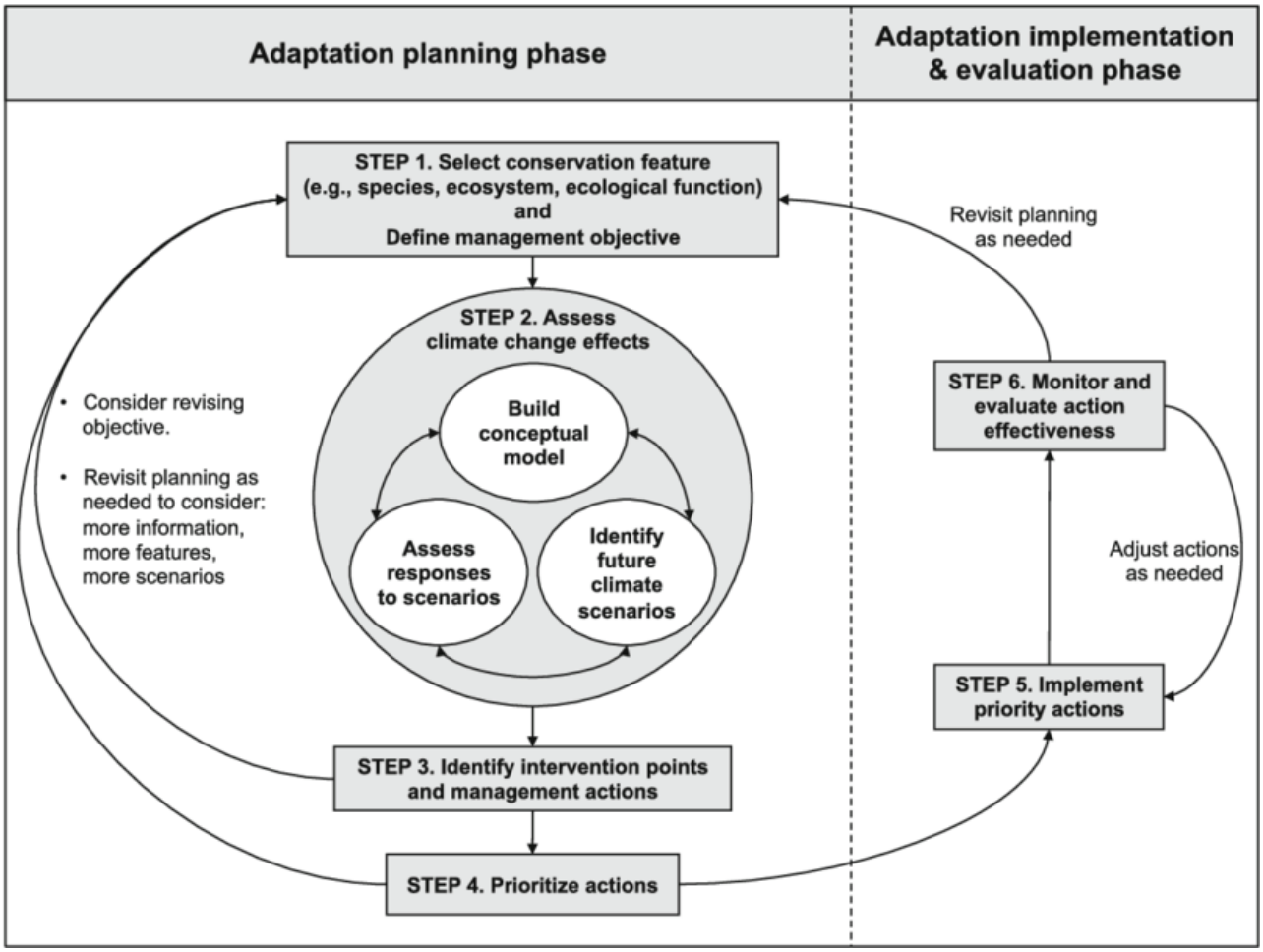

Figure 19: Climate change adaptation framework
Source: Adapted from Cross *et al.,* (2012)

The framework builds on elements of natural resources using local knowledge, conceptual modelling and adaptive management into a process of addressing climate change. It identified six steps in the adaptation process, steps 1 to 4 represent the adaptation planning phase whilst Steps 5 to 6 represent the adaptation implementation and evaluation phase. As shown, the framework did not include any steps indicating any measurement of adaptation outcomes. It did, however, indicate an action plan to monitor and evaluate specific action effectiveness and not the entire adaptation process and as indicated earlier, this study fills that gap resulting in the development of the novel adaptation framework of outcomes as shown in Figure 20.

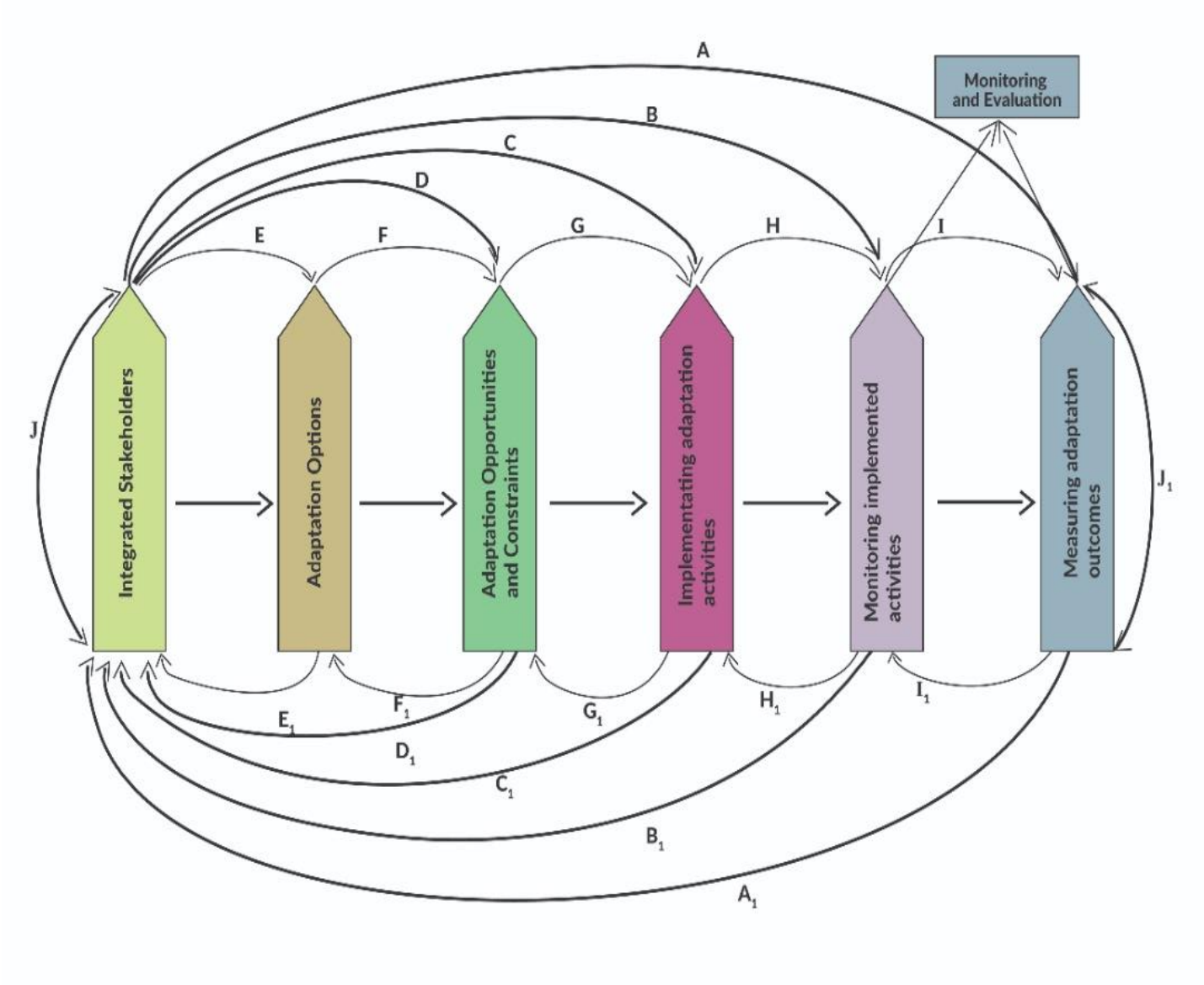

Figure 20: Adaptation framework of outcomes
Source: Author, 2021

The adaptation framework of outcomes (Figure 20) is an infusion of Figure 17 (integration and coordination network framework) and Figure 18 (adaptation framework of interaction) together with the filling of gaps identified in the literature. The arrows labelled “A” to “J” distinguish the various directional signs and indicates the activities to be taken under each arrow. For instance, activities “B, C, D” under arrow “A”. Arrow “B” indicates the summery of activities to be carried out, that is “E, F, G, H”. Arrow “C” indicates the summery of activities to be carried out, that is “E,

F, G" whiles arrow "D" indicates the summery of activities to be carried out, that is "E, F" The adaptation framework of outcomes includes two important steps, namely the monitoring of implemented activities and the measurement of the adaptation outcomes that fills the literature gap. The framework depicts a cyclical nature and shows the stage-by-stage activities (indicated by EFGHIJ and $E_1F_1G_1H_1I_1J_1$) to be undertaken by the integrated stakeholders who considers the various adaptation options available and the possible adaptation opportunities and constraints to be considered before implementing the adaptation activities as depicted in Figure 18. (These parts in Figure 18 - adaptation options available and the possible adaptation opportunities and constraints have been elaborated on in the earlier sections of this chapter.) Again, alphabets (A to J) and the corresponding alphabets with subscripts (A_1J_l) shows the cyclical and evolving process of the adaptation framework of outcomes. As shown in Figure 20, the process begins with the integrated stakeholders (made up of the management of the VRA, the Energy Commission, Ghana Meteorological Agency and the Water Research Institute together with community leaders) to consider and choose one or some or all of the adaptation options available. The next step is to consider the adaptation opportunities and the constraints that comes with the chosen adaptation option. Depending on which option provides more opportunities and less constraints, which will lead to the desired results, one or more of the adaption options is chosen. This then leads to the implementation stage where the adaptation activities are implemented considering those with fewer barriers (constraints) and with more opportunities (facilitators). The next stage is to monitor the progress of the implemented activities and evaluate them in order to see whether the implemented activities are achieving the intended outcomes hence labelling the framework as adaptation framework of outcomes. The last stage is to measure the level of significance of the outcomes achieved (if they were achieved). The cyclical nature of the adaptation framework of outcomes also makes it possible for the integrated stakeholders to reassess every stage of the process (indicated by EE_1 and $I I_1$) so that objectives that are not met at any stage will be determined and worked on even before reaching the final stage of measuring the adaptation outcomes. This approach makes the system more flexible and promotes the incorporation of new ideas while the process is on-going. As indicated earlier, after implementing the adaptation activities, it becomes necessary to undertake monitoring of the implemented activities and above all measure the adaption outcomes. The monitoring of the implemented activities and the measuring of the adaptation outcomes are categorised under monitoring and evaluation as shown in Figure 20. Monitoring and evaluation (M & E) is an emerging theory that

has gained prominence recently. Incorporating strong monitoring and evaluation analysis in the adaptation framework of outcomes would strengthen the entire adaptation process and ensure a high success rate. Within the adaptation framework of outcomes, the monitoring fits in the segment of the monitoring of the implemented activities whilst the evaluation sits well under the measuring of the adaptation outcomes hence classifying them under monitoring and evaluation. Details of this is discussed in the next sub-section.

6.3.1 Monitoring and evaluation within the adaptation framework of outcomes

Monitoring and evaluation is a tool for tracking progress towards project implementation activities through the documentation of intermediate and long-term measurable outcomes. The discourse of monitoring and evaluation (M & E) and the impact it produces in almost every area of practice (health, economics, etc.) and theory has gained prominence over the years. It continuously monitors and improves stakeholder and community engagement and the implementation of the adaptation activities. The incorporation of the monitoring and evaluation in the adaptation framework of outcomes promotes strong management of the hydropower as it identifies who is responsible for what. It enables the integrated stakeholders identified in the study to track progress during the implementation of the adaptation activities. The literature shows that monitoring and evaluation are different but complement each other. For example, monitoring provides information on where the intended implementation of adaptation activities is in relation to the intended goal. If goals are not met, evaluation provides evidence why the goals are not met. To this end, it is necessary to segregate and differentiate the monitoring and the evaluation. Table 8 gives the differentiation between the two.

Table 8: Differentiation between monitoring and evaluation

Monitoring	Evaluation
Clarifies programme objectives.	Analyses why intended results were achieved or were not achieved.
Links activities and their resources to objectives.	Assesses the specific causal contribution of activities to results.
Translates objectives into performance indicators and set targets.	Examines the implementation process.
Routinely collects data on those indicators.	Explores unintended results

Reports progress to the manager and alerts them of problems.	Provides lessons, highlights significant accomplishment or programme potential, and recommends improvement.

Source: From the work of Kabonga (2019)

Kabonga (2019), quoted Valadez and Bamberger (2004), as defining monitoring as a programme activity, whose role is to determine whether project activities are implemented as planned. If to the contrary, it determines the cause of the anomaly and what can be done to address the anomaly. Kariuki (2014) further defined monitoring as a continuous assessment of the function of project activities in the context of implementation schedules and the use of project inputs. Within the adaptation framework of outcomes (Figure 20), arrow B points to the stage of monitoring implemented adaptation activities. That that point, the integrated stakeholders will continuously assess the functions and efficiency of the implemented adaptation activities. This is essential to assess every stage to ascertain if objectives are being met over time. According to the World Bank (2007) report, evaluation is the systematic and objective assessment of an on-going or completed project, programme, or policy and its design, implementation and results. It is usually conducted after some months or a year or more of implementing the adaptation activities and seeks to answer the effectiveness, efficiency, impact, efficacy, relevance and sustainability of a development intervention. In this study, the intervention here is the implemented adaptation activities, where the integrated stakeholders will have to evaluate its efficiency, impact, efficacy, relevance and sustainability.

In the case of the hydropower, the adaptation activities including the development of the systematic water supply to cope with frequent droughts, construction of a well-balanced ecosystem around the dam and the erection of early warning systems to deal with intense rainfall events will be assessed for its efficiency, impact, efficacy, relevance and sustainability. All that the integrated stakeholders need are clearly defined expected results, a delivery strategy, to make sure they measure and evaluate performance, to make adjustments where necessary and to be able to improve conditions over time. All stakeholders involved in monitoring and evaluation processes should be aware that the M & E results can illuminate, as they inform and make sense of a complex contextual environment but also have the potential to complicate and to oversimplify complex situations and practices (Abraham, 2019).

6.4 Chapter conclusion

The chapter utilised framework development to develop a three comprehensive conceptual adaptation framework that enhances climate change adaptation management within the space of hydropower operations. The development of the three comprehensive conceptual adaptation framework is to ensure the sustainability of hydropower production in the face of emerging climate change impact. The three conceptual adaptation frameworks developed in this chapter include the integration and coordination network framework, adaptation framework of interaction and the adaptation framework of outcomes. The integration and coordination network framework was developed to bridge the cross management integration gap and community leaders (within the hydropower catchment area) so as to build a strong and cohesive integrated stakeholders that will serve as frontiers and implementers of adaption activities within the catchment area. The community leaders are needed to be part of the cross management to serve as intermediary between the community members and the management and to ensure the buy-in of the community. Without the buy-in of the community members, implementation and sustenance of the adaptation activities will be near impossible. The development of the adaptation framework of interaction was meant to show the various adaptation options available as revealed by the literature. The integrated stakeholders can take advantage of the adaptation framework of interaction to choose any of adaptation activities to be carried out bearing in mind all the constraints available. The adaptation framework of outcomes was developed out of infusion of the integration and coordination network framework, the adaptation framework of interaction and the filling of gaps identified in the literature. The study also made use of theories from Willows and Connell, (2003) and Cross *et al.,* (2009) to develop the adaptation framework of outcomes. The three proposed frameworks are the author's contribution to the body of knowledge and answers the research objective 4 – "to develop a comprehensive management adaptation framework that enhances climate change adaptation management of hydropower within the Ghanaian context". The three frameworks are interdependent, depending on one another for a common goal. The success of its applicability will largely depend on how organisations are set up and what their relationship is with the community in which they operate. Hence countries with a similar organisational setup as Ghana are likely to succeed in the use of the frameworks.

The next chapter, Chapter 7 presents the summary of the findings of the study and gives the possible implications and provides recommendations. The limitations of the study and suggestions for future research are also stipulated in the chapter.

CHAPTER 7: CONCLUSION

"A winner is a dreamer who never gives up." (Nelson Mandela 1918 – 2013)

7.1 Introduction

This study investigated the climate change variables that impact on hydropower generation. Whilst the phenomenal impact of climate change is global, the study focused on climate change impact on hydropower generation within the Ghanaian context using the Akosombo Dam in Ghana as a case study. Climate change and hydropower operate in a complex multi-stakeholder environment. The researcher consulted the key stakeholders within the climate change, hydropower and water resources space. They included the VRA with the mandate to manage the Akosombo Dam and hydropower generation machinery including undertaking activities that tackle the impact of climate change, the Energy Commission with the mandate to contribute to the development and elaboration of national policies and strategies for all renewable sources of energy including micro hydropower facilities in the country and also serve as data source relating to energy planning and policies put in place to deal with the impact of climate change on micro hydropower and renewable energy in general, the Water Research Institute with the mandate to conduct research that generates scientific information to guide the formulation of strategies and services that develop and manage water resources for energy, transport and agriculture purposes in Ghana, the Ghana Meteorological Agency with the mandate to provide weather and climate data sets that include patterns and changes in rainfall and temperatures and the Community within which the hydropower operates.

The aim of the study was to determine the extent to which climate change has contributed to changes in the Akosombo Dam's electricity generation capacity, how different relevant authorities are responding to the management of climate change impacts and to develop some climate change adaptation frameworks that can be used in managing hydropower. In working to achieve the aim, the study advanced the following research questions:

(i) what are the literature gaps and theories surrounding the phenomenon of climate change and its effects on hydropower generations?

(ii) what is the nature and extent of climate change linked variations on rainfall quantities and temperature patterns within Akosombo (the location area of the dam) and the surrounding areas and its effects on the dam's electricity generation capacity?

(iii) how is climate change related institutions and policy regime responding to the climate change impacts in Ghana?

The research questions and the aim of the study was totally achieved by fulfilling the following four objectives;

(i) to review the literature regarding the overview and the theoretical concept of the phenomenon of climate change and its effects on hydropower generations

(ii) to determine the nature and extent of climate change linked variations on rainfall quantities and temperature patterns within Akosombo and the surrounding areas and its effects on the dam's electricity generation capacity

(iii) determine how the climate change adaptation institutions and policy regime are responding to the management of climate change in Ghana.

(iv) develop comprehensive conceptual management adaptation frameworks that enhance climate change adaptation management of hydropower within the Ghanaian context.

The study adopted the mixed methods approach to achieve the aim, address the research questions and fulfil the research objectives. The first point of action was a thorough review of the literature focusing on theoretical concepts that informed the study. Primary data were collected from the four key government sources namely the VRA, the Energy Commission, the Water Research Institute, and the Ghana Meteorological Agency. Secondary data were obtained from the Ministry of Environment, Science, Technology and Innovation. Data on indigenous knowledge of climate change were also gathered from the community members living within close proximity of the Akosombo dam catchment area.

The significance of the study bordered on the following areas by helping enhance their existence and making them more profitable. These included the area of water conservation, energy conservation and tourism because the Akosombo dam site serves as excursion and tour site to the general public, especially students. The significance also bordered on the fact that the study fulfilled four of the United Nations Sustainable Development Goals. The four are SDG goal 7 (access to affordable, reliable, sustainable and modern energy for all), SDG goal 13 (climate action) was fulfilled as the study bordered on climate change impact on hydropower, SDG goal 14 (life below water) was fulfilled because the study worked to enhance and maintain the appropriate water level thereby aquatic life below the water is enhanced and by engaging the key

stakeholders (management of the Volta River Authority, the Energy Commission, Ghana Meteorological Agency and the Water Research Institute), SDG goal 17 (partnership for goals) is fulfilled.

The study developed and proposed climate change adaptation frameworks that can be considered in the strategic and cross management of hydropower. The subsequent sub-sections of this chapter summarise the achievement of the research objectives, the contribution to the body of knowledge, the shortcomings and limitations of the study, recommendations for further studies and the conclusion.

7.2 Achieving the research objectives

This section considers the achievement of the four research objectives which in turn led to the achievement of the research aim, answering the research question and bridging the research gaps.

7.2.1 Achieving research objective 1

Research objective 1 was to review the literature regarding the overview and the theoretical concept of the phenomenon of climate change and its effects on hydropower generation was achieved in Chapter 2. A wide range of topics and various sources from different fields were consulted during the literature review. These sources included Government acts, books, news articles, journal articles and the internet. The review of the literature highlighted the fact that climate change is real and its impacts have, most commonly been adverse to economic, social as well as environmental wellbeing. It also led to the discovery that among the two means of tackling climate change (that is through mitigation and adaptation), the mitigation option is advanced much faster than the adaptation. It is for this reason that this study focused much on the adaptation option to elevate the importance of climate change adaptation to the same level as mitigation. The literature review also identified some research gaps that were addressed in the study. These research gaps include the lack of research to ascertain the sustainability of the various adaptive capacity created (such as building of flood defences and sea defence system) against the adverse effects of climate change and the absence of a management adaptive framework that involves monitoring and evaluating within and around hydropower dams with all stakeholders participating in the monitoring and the evaluation other than only the hydropower

dam managers. The research gaps were filled in Chapter 6. For instance, the cost-effective management adaptive frameworks developed in Chapter 6 is an improvement over that of the climate change adaptive framework by Wilson and Cornell (2003:7) identified in the literature review. The adaptive framework of Wilson and Cornell (2003:7) does not indicate an evaluation component with sustainable indicators and does not show the involvement of all other stakeholders whilst this study's proposed cost-effective management adaptive framework includes the evaluation component with sustainable indicators involving all stakeholders in addition to the hydrodam managers.

7.2.2 Achieving research objective 2

The research objective 2 was to determine the nature and extent of climate change linked variations on rainfall quantities and temperature patterns within Akosombo and the surrounding areas and its effects on the dam's electricity generation capacity. This research objective was answered in Chapter 4. It was discovered that volume and frequency of rainfall has been decreasing over the years whilst temperature has been increasing. This affected the Akosombo dam resulting in decreases in the water level in the dam leading to periodic shutting down of some of the dam's turbines depending on the water level. This resulted in reducing the total amount of hydropower generated by the dam leading to power deficits that results in load shedding across the country. For instance, during such periods, the Akosombo dam is forced to operate on four turbines instead of the maximum six turbines to produce 680 megawatts of hydropower per day instead of the maximum 1,020 megawatts of hydropower. Due to these climate change related challenges around hydropower facilities and observed extreme weather events that include decreasing rainfall, high temperatures, frequently and increasingly severe droughts as well as floods in Africa, there are calls for planning on how to mitigate and adapt to these situations particularly through policy formulations.

7.2.3 Achieving research objective 3

Research objective 3 was to determine how the climate change adaptation institutions and policy regime are responding to the management of climate change in Ghana. This was achieved under Chapter 5. Apart from the dwindling water level in the Akosombo dam due to the decreasing rainfall over the years, Ghana has experienced extreme climate change related occurrences. An example is the south-western part of Ghana which witnessed cases of unprecedented flooding, one of such flooding cases happened within the premises of a fuel station where the flood water

happens to mix up with some of the fuel leading to an explosion at the fuel station that resulted in the death of over 152 lives (Asumadu-Sarkodie *et al.,* 2015). The study found out that successive governments have made attempts at formulating policy and legislation to deal with the challenge of climate change. These policy and legislation attempts have gone through a series of amendments and enhancements from environmental policies to climate change specific policies in alignment with international treaties that relate to climate change. For instance, the climate change policy and legislation regime in Ghana is largely informed by the United Nation Framework Convention on Climate Change (UNFCCC) requirements, which Ghana ratified in 1995. A key policy in this space is the National Climate Change Policy Framework of 2011. Other climate change related policies formulated and developed by the Government of Ghana include the Ghana's National Environmental Policy (2012), Ghana National Climate Change Policy (2013) and the Ghana National Climate Change Master Plan Action Programmes for Implementation (2015 – 2020). The study revealed that these policies and legislative documents were purposely developed to serve as reference material for research and development, guide the country's development along a sustainable path and ensure the country's commitment to conventions, protocols and international agreements and treaties. But the broad goal is to bring economic development in balance with ecological processes consistent with the 1992 constitution of the Republic of Ghana as they relate to the environment. They (the climate change and environmental policies and legislation) are also important instruments for the management and control of climate change in the country. What is lacking, as discovered by the researcher, is the implementation and enforcement of the policies. It is important that these policies and legislation are enforced to the letter to realise its potency. As the legal system is used to ensure enforcement of legislation, the researcher proposed that a rewards system could be developed and established to encourage the implementation of the policies.

7.2.4 Achieving research objective 4

Research objective 4 was to develop comprehensive conceptual management adaptation frameworks that enhance climate change adaptation management of hydropower within the Ghanaian context. This was achieved in Chapter 6. Within the chapter, the researcher developed and proposed three comprehensive conceptual adaptation frameworks that enhance climate change adaptation management within the space of hydropower operations. These three comprehensive conceptual management adaptation frameworks include the integration and coordination network framework (Figure 17), adaptation framework of interaction (Figure 18) and

the adaptation framework of outcomes (Figure 20). The integration and coordination network framework was develop to bridge the cross management integration gap and community leaders (within the hydropower catchment area) so as to build strong and cohesive integrated stakeholders that will serve as frontiers and implementers of adaption activities within the catchment area. The development of the adaptation framework of interaction was meant to show the various adaptation options available as revealed by the literature. The adaptation framework of outcomes was developed by infusing the integration and coordination network framework, the adaptation framework of interaction and the filling of gaps identified in the literature. The study also made use of theories by Willows and Connell, (2003) and Cross *et al.,* (2009) to develop the adaptation framework of outcomes.

7.3 Key implications

The study has provided a range of implications and recommendations. Firstly, the implications emanating from the literature are discussed, providing a shortlist of implications for current frameworks and literature. This was followed by discussions on the implications for the management of hydropower facilities, the implications for government policies and the implications for communities within the catchment area.

7.3.1 Implication to literature

The study traverses across fields including the area of climate change management, which is in the field of environmental management, managing hydropower which is the field of energy and water resources management, the involvement of the community members cut across the field of human resources management and the inclusion and emphasis on monitoring and evaluation which is in the field of social sciences. By way of working across these different fields, the study bridges gap between the different disciplines. For instance, the study bridged the gap between the field of social sciences and water resources management by the inclusion and emphasis of the aspect of monitoring and evaluation in the management of hydropower. This is expected to create new areas in the literature. The study developed three comprehensive conceptual adaptation frameworks to enhance the cross management of hydropower. The frameworks outlined the variables of importance to the cross management of hydropower and show how these variables relate to current scientific literature. The study indicated that although the climate change frameworks developed by Willows and Connell, (2003) and Cross *et al.,* (2009) are useful,

they lacked the cross-management integration and the detailed evaluation of adaptation outcomes. This aspect adds a new dimension to the literature.

7.3.2 Implications for the management of hydropower

The study proposed and developed three comprehensive conceptual adaptation frameworks that can alter in the planning and management of hydropower processes. The frameworks deliver some essential variables that hydropower managers need to consider and inculcate in their planning as well as providing a planning approach to follow. The managers of hydropower may need to pay attention to the highlights made under the new management approach. These include the need for a more integrated approach that closes the gaps between the Government agencies involved (Volta River Authority, Energy Commission, Ghana Meteorological Agency and the Water Research Institute) and community members lead by their nominated leaders. The study indicated the importance of an integrated approach and the necessary outcome it is likely to yield. Communities and other stakeholders can make or break any adaptation initiative hence the need for managers to continue working with communities within the vicinity of the dam and to plough value back into these communities through local sourcing, employment and other corporate social responsibility activities. The study also shows the need for management to go beyond ordinary monitoring to evaluating the outcomes of the implementation of the adaptation activities. The evaluation provides management the opportunity to track progress towards project implementation activities and reassess what may be preventing the intended results. There may be the need for management to increase resources to carry out any reassessment which may have implications for the institution's budgetary allocation. The importance of management training is increasingly becoming evident because there may be the need for management to undergo training in monitoring and evaluation since this may be a new introduction in the management systems, especially the evaluation aspect.

7.3.3 Implications for government policies

Right from the onset, the study provides a clear picture of how climate change is impacting every sector of the economy, particularly hydropower generation. For instance, in the case of the Akosombo dam there have been cases of low water levels resulting from decreasing rainfall which has left the management of the dam with no option than to operate the dam on four turbines instead of the usual six turbines. This reduces the power generation from the maximum of production of 1,020 megawatts power to 680 megawatts. Consequently, this reduces the power

distribution across the nation leading to load shedding and subsequently negatively affecting the economic activities. Also, unprecedented flooding cases has led to the death of over 152 lives (Asumadu-Sarkodie *et al.,* 2015). This indicates how critical government policy decisions are in managing climate change and averting such negative situations. This implies that Government of Ghana may need to update its current climate change policies making it capable of mitigating current threats posed by the emerging climate change. The Ghana's National Environmental Policy (2012), Ghana National Climate Change Policy (2013) and the Ghana National Climate Change Master Plan Action Programmes for Implementation (2015 – 2020) may need to be revised and updated to reflect current realities of climate change. Much attention would need to be given to the implementation aspect during the revision of the policies. Government would have to engage in a robust capacity building of stakeholders to enhance the country's competence to implement international treaties and decisions that are foundational to domestic climate change actions, including adaptation and mitigation actions.

7.3.4 Implications for communities within the catchment

The study engaged local community members who live within the Akosombo dam catchment to assess the level of their awareness and knowledge on climate change related issues. They were engaged through open-ended interviews. The respondents were selected purposively and were made up of those who have lived in the area for at least fifteen years including the elected parliamentary representative of the area, five senior citizens who have lived in the area for more than twenty years. The elected parliamentary representative of the area and the five senior citizens served as the key informants. The study engaged a total of 26 community members due to the small population of the community and because many had to go out of the community to engage in their routine economic activities. The study revealed that knowledge of climate change among community members interviewed was below 50%, signifying a significant knowledge gap among members of the community in relation to climate change matters. The interview also revealed a lack of climate change awareness among the community members. These were evident in statements made by community members including statements such as:

"Sometimes we experience low rainfalls and some other times we experience high volumes of rainfall. We see these as normal and depends on when God wants to release more rains or not."

"I don't think falling of trees has anything to do with the rainfall."

“Since I came to live here in 1962, the rainfall has been the same, I don’t see any difference”.

“To me climate change is a change in the weather conditions.”

“I a farmer and have never engaged in tree planting exercise before.”

These statements signify lack of awareness and knowledge gaps regarding climate change matters among community members. This implies that community leaders have a task of conducting periodic awareness creation within the community. Creating awareness is critical because a lack thereof often results in the creation of knowledge gaps in communities rendering them unable and incapacitated to tackle the climate change menace. Frequent education and training efforts need to also be carried out to bridge the knowledge gap identified among some of the community members. This makes the integration of the community leaders with the management of the government institutions (Volta River Authority, the Energy Commission, Ghana Meteorological Agency and the Water Research Institute) in tackling the climate change challenge a dire need.

7.4 Contribution to the body of knowledge

Climate change is an interrelated global issue that needs to be tackled holistically and involving all countries. This study narrows the tackling of the climate change to the impact on hydropower production using the Akosombo dam (the largest hydrodam in Ghana) as case study. The Akosombo dam is the largest contributor to the production of electrical energy in Ghana, contributing 30% of the total electrical energy (Table 1.1) making it very necessary for management to tackle any climate change related impact on the dam and hence the significance of this study.

The study identified gaps in the literature including the absence of climate change management adaptive framework that emphasises monitoring and evaluation in hydropower dams. This also involves all stakeholders participating in the monitoring and the evaluation other than the hydropower dam managers alone. The other literature gap identified is the lack of research evaluation to ascertain the sustainability of the various adaptive capacity created (such as building of flood defences and sea defence system) against the adverse effects of climate change. This

study contributed to the body of knowledge by proposing the development of a cost-effective climate change adaptive framework with the monitoring and evaluating component involving all external stakeholders. The study's adaptation framework comes in three forms which includes the integration and coordination network framework (Figure 17), adaptation framework of interaction (Figure 18) and the adaptation framework of outcomes (Figure 20). The integration and coordination network framework bridged the cross-management integration gap and community leaders (within the hydropower catchment area) so as to build a strong and cohesive integrated stakeholders that will serve as frontiers and implementers of adaption activities within the catchment area. The adaptation framework of interaction was meant to show the various adaptation options available as revealed by literature. The adaptation framework of outcomes was developed out of infusion of the integration and coordination network framework which helps management to evaluate critically and assess ant adaptation activities.

The study also contributed to four of the SDG goals. They include SDG goal 7 (access to affordable, reliable, sustainable and modern energy for all), SDG goal 13 (climate action) because the study borders on the impact of climate change on hydropower, SDG goal 14 (life below water) because the study helped maintained the appropriate water level, enhancing any biological life below the water and by engaging the stakeholders in the energy sector (management of Volta River Authority, Energy Commission, Ghana Meteorological Agency and the Water Research Institute), SDG goal 17 (partnership for goals) is addressed.

7.5 Shortcomings and limitations of the study

The Akosombo hydropower plays a vital role in the economic development of Ghana, this makes managing the impact of climate change on the hydropower provision very critical. Because of this, it makes it imperative to collect adequate and reliable ranges and quantities of data to enable informed climate change adaptation. One of the challenges encountered during the study was data related challenges, for instance, the Ghana Meteorological Agency could not provide all the climate data requested. Seeking to address this, the researcher made attempts to access the data from the World Meteorological Organisation (WMO). The WMO referred the researcher back to the Ghana Meteorological Agency (Appendix 6) indicating that the Ghana Meteorological Agency are the primary source of such data. The researcher had no option than to proceed and make use of the best data provided by the Ghana Meteorological Agency. The study engaged a limited number of community members during the period of the interview because some had gone

out of the community to engage in their routine economic activities. Access to some of the senior personnel in the targeted organisations was a challenge. Some of the targeted respondents cancelled appointments to fulfil urgent duty related engagements elsewhere. Attempts were made to mitigate such situations by conducting electronic administration of the questionnaires. This approach denied opportunities for probing questions around both close-ended and open-ended questions. Though this study has implications for other African countries, it was limited to Ghana specifically using the Akosombo hydropower as a case study. Despite these shortcomings and limitations, data and other information collated during the study were enough to get a reliable result and make valid conclusions.

7.6 Recommendations for future research

The available climate change policies in Ghana are an indication that the Government is making efforts at fighting the climate change menace. These efforts are, however, less concentrated towards the management of hydropower in the country despite the fact that hydropower has climate change related advantages. For instance, hydropower can serve to store water to mitigate the impact of climate change linked droughts. Hydropower does not use fossil fuel that contribute to climate change. Though this assertion is cognisant of power being GHG emitter when the vegetation they cover begins to decompose, these emissions are less than those emitted by the fossil-based fuels. Also, these assertions are site-specific and the results not applicable to the great majority of reservoirs elsewhere (Fearnside, 2016). In view of this, the following are recommendations made to enhance the management of hydrodams in the face of the climate change menace to optimise its use:

1. The government should consider drafting policies specifically towards the management of hydropower in the face of the climate change effects. Hydropower to be built in future should specifically be climate resilient hydrodams.
2. Extensive research should be conducted to discover a tried and tested climate resilient hydropower. This will enable future hydropower to be built specifically “climate resilient hydropower”.
3. Extensive awareness of the existence of the National Climate Change Policy and its implementation strategy across the country should be created. This could get all citizens to put their hands on desk and lead to a positive behavioural change towards the fight against the impact of climate change.

4. The Right-to-Information bill passed by parliament of Ghana in 2019 should be enforced to the letter as this will make researchers gain easy access to climate data and all other necessary data for carrying out climate research and all other research towards the development of the country.
5. Climate data at the Ghana Meteorological Agency should be given to student researchers free of charge. Charging for the climate data can serve as a hindrance to financially challenged students from gaining access to the data. This serves as a hindrance from carrying out their research and subsequently completing their course of study which could have contributed to nation building.
6. Ghana's climate change policies should be revised to be attuned to the United Nations Sustainable Development Goals in the tackle against climate change which is aimed to be achieved by the year 2030.

In the policy analysis, this study made use of environmental and climate change related policies in Ghana. In particular relation to the Ghana National Climate Change Policy:2013 and the Ghana National Climate Change Master Plan Action Programmes for Implementation: 2015 – 2020, there is the need to conduct further studies on the outcomes of the implementation programmes ideally after 2020 since the implementation plan spans from 2015 to 2020. Further study is also recommended to research into how best to develop "climate resilient hydropower".

7.7 Conclusion

Energy is no doubt one of the focus areas of the Ghana National Climate Change Policy, 2013. It would be realised that the policy document acknowledges the fact that hydropower is some of the major sources of electricity and at the same time highly vulnerable to the adverse impacts of climate change. This notwithstanding, the policy documents are much less concerned about the enhancement and protection of hydropower from the impact climate change has. This is evident as policy documents have not specifically incorporated the management of the Akosombo Dam and the other dams from the impacts of climate change. The policies are more focused on solar energy. This is evident as the Renewable Energy Act 2011, (Act 832) mandates an increase in renewable energy capacity particularly in solar energy.

From the field observations it can also be concluded that there is limited adaptation practices and a lack of proactive measures put in place particularly towards the Akosombo Dam. Apart from the

National Climate Change Policy, the Volta River Authority has no climate change policy and adaptation framework to specifically deal with the management of Akosombo dam. The three novel climate change adaptation frameworks developed and proposed by the study would therefore be useful in managing climate change that affects the Akosombo dam. The three include the integration and coordination network framework (Figure 17), adaptation framework of interaction (Figure 18) and the adaptation framework of outcomes (Figure 20).

Though the benefits of the implementation of its environmental and other stated policies can offset some of the impacts of climate change, it would be prudent for the Volta River Authority to specifically have its own climate change policy and adopt the three novel climate change adaptation frameworks developed and proposed by the study for managing the Akosombo Dam in the current wave of the climate change effects.

Climate change is a global common enemy that needs to be tackled head-on. With concerted global effort, making use of all arsenals available including technology and funds, the world can successfully fight this enemy and be on top of its issues making the environment and the world at large increasingly serene for humanity promoting sustainability and the wellbeing of all.

REFERENCES

Abrahams, M. A. (2019). Editorial – 2019: Omniscience of monitoring and evaluation. *African Evaluation Journal* 7(1): 433. Available at: https://doi.org/10.4102/aej.v7i1.433

Abdul-Razak, M. & Kruse, S. (2017). The adaptive capacity of smallholder farmers to climate change in the Northern Region of Ghana. *Climate Risk Management* 17:104-122. Available at: https://doi.org/10.1016/j.crm.2017.06.001

Ackerman, F. & Stanton, E. A. (2008). The cost of climate change. Natural Resource Defense Council. Available at: www.nrdc.org/globalwarming/cost/cost.pdf

Adesina, F. O., Siyambola, W. O., Oketola, F.O., Pelemo, D. A., Ojo, L. O., & Adegbugbe, A. O. (1999). Potentials of agroforestry for climate change mitigation in Nigeria: some preliminary estimates. *Global Ecological Biogeogr* 8:163–173

Adger, W. N. (2003). Social aspects of adaptive capacity, in *Climate change, adaptive capacity and development* edited by JB Smith, RJT Klein & S Huq. London: Imperial College Press.

Adger, W. N., Brown, I. & Surminski, S. (2018). Advances in risk assessment for climate change adaptation policy. Phil. Trans. R. Soc. A 376: 20180106. http://dx.doi.org/10.1098/rsta.2018.0106

Africa Union Development Agency. (2019). First continental report of the implementation of Africa Agenda 2063.

Afreen, S. N., Sharma, R. K., Chaturvedi, R., Gopalakrishnan R. & Ravidranath, N. H. (2011). Forest policies and programs affecting vulnerability and adaptation to climate change. *Mitigation and Adaptation Strategies for Global Change*, 16(2): 177-197.

Agrawala, S. & Fankhauser, S. (2008). Economic aspects of adaptation to climate change: costs, benefits and policy instruments. Paris: Organisation for Economic Co-operation and Development.

Allen, M. R., Dube, O. P., Solecki, W., Aragon−Durand, F., Cramer, W., Humphreys, S., Kainuma, M., Kala, J., Mahowald, N., Mulugetta, Y., Perez, R., Wairiu, ,M., & Zickfeld, K. (2018). Framing and context. in "Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty."

Amarnath, T. & Ashok, K. M. (2017). Knowledge and passive adaptation to climate change: an example from Indian farmers. *Climate Risk Management* 16: 195-207.

Amisigo, B. A., McCluskey, A. & Swanson, R. (2015). Modeling impact of climate change on water resources and agriculture demand in the Volta basin and other basin systems in Ghana. *Sustain* 7, 6957–6975. Avaialble at: http://dx.doi.org/10.3390/su7066957.

Ampofo, S., Ampadu, B., & Abanyie, S. K. (2015). Landcover change patterns in the Volta Gorge area, Ghana: interpretations from satellite Imagery. *Journal of Natural Sciences Research*. 5:4.

Andah, W. E.I., Van de Giesen, N., & Biney, C. A. (2004). Water, Climate, Food, and Environment in the Volta Basin. Contribution to the project ADAPT (Adaptation strategies to changing environments),

Anderson, E., Pringle, C., & Rojas, M. (2006). Transforming tropical rivers: An environmental perspective on hydropower development in Costa Rica. Aquatic Conservation: Marine and Freshwater Ecosystems. 16. 679 - 693. 10.1002/aqc.806.

Arbuckle, J. G., Morton, L.W., & Hobbs, J. (2015). Understanding farmer perspectives on climate change adaptation and mitigation: the roles of trust in sources of climate information, climate change beliefs, and perceived risk. *Environment and Behavior* 47(2): 205–234. Available at: http://doi.org/10.1177/0013916513503832

Arnell, N. W., Vuuren, D, P., & Isaac M. V. (2011). The implications of climate policy for the impacts of climate change on global water resources. *Global Environmental Change* 21: 592 – 603.

Aronica G. T., & Bonaccorso, B. (2013). Climate Change Effects on Hydropower Potential in the Alcantara River Basin in Sicily (Italy). Earth Interactions, Vol. {17},1-22.

Aryan, G., & Bayan H. (2013). Hydroelectric dams. Swcphysics30. Availbale at: https://Swcphysics30.Wordpress.Com/2013/01/16/Hydroelectric-dams-2/.

Aryeetey, E. B., Atuguba, R., & Kunbuor, B. B. (2004). The right to development report: Ghana Country Study. Accra, Ghana: Legal Resources Centre.

Asanga, G., & Kua, H. W. (2014). A comparison of climate change mitigation and adaptation strategies for the construction industries of three coastal territories. *Sustainable Development* 22: 52–62 (2014)) DOI: 10.1002/sd.527

Asante, F. A., Amuakwa-Mensah, F. (2015). Climate Change and Variability in Ghana: Stocktaking. *Climate*. 2015; 3(1):78-99. https://doi.org/10.3390/cli3010078

Asumadu-Sarkodie, S., Owusu, P., & Rufangura, P. (2015). Impact analysis of flood in Accra, Ghana. *Advances in Applied Science Research* 6: 53-78. 10.6084/M9.FIGSHARE.3381460.

Azungah, T. (2018). Qualitative research: deductive and inductive approaches to data analysis. *Qualitative Research Journal* 18 (No. 4): 383-400. Available at: https://doi.org/10.1108/QRJ-D-18-00035

Baker, JS, McCarl, B, Murray, BC, Rose, SK, Alig, RJ, Adams, D, Latta, GS, Beach, RH & Daigneault, A. 2010. Net farm income and land use under a US greenhouse gas cap and trade. Policy Issues. [Internet]. [cited 2010 Apr];PI7:1–5. Available at: http://www.aaea.org/publications/policy-issues/PI7.

Bardsley, D. K., & Hugo, G. J. (2010). Migration and climate change: examining thresholds of change to guide effective adaptation decision-making. *Population and Environment*, 32: 238-262.

Bai, X. (2007). Integrating global environmental concerns into urban management: the scale and readiness arguments. *Journal of Industrial Ecology* 11(2): 15–29.

Barry, B., Obuobie, E., Andreini, M., Andah, W. & Pluquet, M. (2005). The Volta river basin, comprehensive assessment of water management in agriculture: comparative study of river basin development and management. *IWMI Comprehensive assessment of water management in Agriculture*

Batisha, A. (2015). Sustainability assessment in transboundary context: Grand Ethiopian Renaissance dam. *Modeling Earth Systems and Environment.* 1. 10.1007/s40808-015-0033-2.

Beer, J., Mende, W., & Stellmacher, R. (2000). The role of the sun in climate forcing. *Quaternary Science Reviews* 19: 403 – 415.

Berkhout, F. (2011). Adaptation to climate change by organisations. *WIREs Clim Change*. doi: 10.1002/wcc.154.

Berga, L. (2016). The role of hydropower in climate change mitigation and adaptation: a review. *Engineering*, 2: 313-318, 10.1016/J.ENG.2016.03.004

Biesbroek, G. R., Klostermann, J., Termeer, C., & Kabat, P. (2011). Barriers to climate change adaptation in the Netherlands. *Climate Law*, 2(2):181-199.

Bishop, L. (2007). A reflexive account of reusing qualitative data: beyond primary/secondary dualism. *Sociological Research Online* [Online], Special Section on Reusing Qualitative Data, 12(3) Available at: http://www.socresonline.org.uk/12/3/2.html

Blaxter, L., Hughes, C., & Tight, M. (2001). How to Research Second Edition. Philadelphia: Open University Press.

Boadu, F. O. (2016) Agricultural Law and Economics in Sub-Saharan Africa, DOI:http://dx.doi.org/10.1016/B978-0-12-801771-5.00017

Bonan, G. (2008). Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests. Science (New York, N.Y.). 320. 1444-9. 10.1126/science.1155121.

Bonifacio, A., Takeuchi, Y., & Shaw, R. (2010). Mainstreaming climate change adaptation and disaster risk reduction through school education: perspectives and challenges, in *Climate change adaptation and disaster risk reduction: issues and challenges*, edited by R Shaw, J Pulhin & J Pereira. London: Emerald Group Publishing.

Bowyer, P., Bender, S., Rechid, D., & Schaller, M. (2014). Adapting to climate change: methods and tools for climate risk management, Climate Service Center, Germany.

Boyatzis, R. (1998). *Transforming qualitative information: thematic analysis and code development*. Thousand Oaks, CA: Sage Publications.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology* 3 (2): 89.

Brody, S., Grover, H., Lindquist, E., & Vedlitz, A. (2010). Examining climate change mitigation and adaptation behaviours among public sector organisations in the USA. *Local Environment*. 15. 591-603. 10.1080/13549839.2010.490828.

Bruhwiler, L., Basu, S., Butler, J., Chatterjee, A., Dlugokencky, E., Kenney, M., McComiskey, A., Montzka, S., & Stanitski, D. (2021). Observations of greenhouse gases as climate indicators. Climatic Change. 165. 10.1007/s10584-021-03001-7.

Bruno, L., Giacomo, F., Virginie, F., Alastair, B., (2016). Synergies between adaptation and mitigation in climate change finance. *International Journal of Climate Change Strategies and Management* 8(1):112-128, Available at: https://doi.org/10.1108/IJCCSM-07-2014-0088

Bryman, A. (2001) Social Research Methods. Oxford University Press, Oxford.

Bulkeley, H., & Betsill, M. (2003). *Cities and climate change: urban sustainability and global environmental governance*. London: Routledge.

Bulkeley, H. (2015). *Accomplishing climate governance*. Cambridge: University of Cambridge Press.

Bunea, F., Houde, S., Ciocan, G. D., Oprina, G., Baran, G., & Pincovschi, I. (2010). Aspects concerning the quality of aeration for environmental friendly turbines, 25th IAHR Symposium on Hydraulic Machinery and Systems, IOP Conference Series: *Earth and Environmental Science* 12, 012035)

Canadell, J. G., & Raupach, M. R. (2008). Managing forests for climate change mitigation. *Science* 320 (5882):1456-7. doi: 10.1126/science.1155458.

Caplow, S., Jagger, P., Lawlor, K., & Sills, E. (2010). Evaluating land use and livelihood impacts of early forest carbon projects: lessons for learning about REDD+. *Environmental Science and Policy* 14: 152-167.

Carbon Trust Report (2005). Brand Value at Risk From Climate Change. Available at: www.thecarbontrust.co.uk. (Retrieved on June 28, 2017.)

Carter, T. R., Parry, M. L., Harasawa, H., & Nishioka, S. (1994). IPCC, Technical Report for Assessing Climate Change Impacts and Adaptations, Department of Geography, University College, London, UK and Centre for Global Environment Research, National Institute for Environmental Studies, Japan.

Cash, D. W., Moser, S. C. (2000). Linking global and local scales: designing dynamic assessment and management processes. Global Environmental Change 10 (2): 109–120.

Castano, I. (2011). Hydroelectricity, biofuels to lead Latin American renewables growth. *Renewable Energy World.* Available at:

https://www.renewableenergyworld.com/baseload/hydroelectricity-biofuels-to-lead-latam-renewables-growth/#gref

Chavalala, B., & Nhamo, G. (2016). An assessment of South Africa's coal mining sector response to climate change adaptation demands. PhD Thesis.

Coalition for Urban Transitions (2019). Climate emergency, urban opportunity: how national governments can secure economic prosperity and avert climate catastrophe by transforming cities. World Resources Institute (WRI), Ross Centre for Sustainable Cities and C40 Cities Climate Leadership Group, London, UK.

Cole, M. A., Elliott, J. R., & Strobl, E. C. (2014). Climate change hydro-dependency and the African dam boom, proceedings on climate change workshop. Department of Economics, University of Birmingham, United Kingdom

Corbetta, P. (2003). *Social research: theory, methods and techniques*. London: Sage Publications.

Corfee-Morlot, J. L., Kamal-Chaoui, M. G., Donovan, I., Cochran, A. R., Teasdale, P. J., (2009). Cities, climate change and multilevel governance. OECD Environmental Working Papers N° 14, 2009, OECD publishing.

Covington, H., & Thamotheram, R. (2015). The case for forceful stewardship (Part 1): the financial risk from global warming. Available at SSRN: http://ssrn.com/abstract=2551478 or http://dx.doi.org/10.2139/ssrn.2551478

CC DARE Workshop, (2009). National Climate Change Adaptation Strategy. A joint UNEP/UNDP Programme for sub-Saharan Africa.

Crabtree, B. (1999). *Doing qualitative research*. Newbury Park, CA: Sage Publications.

Creswell, J. W., & Plano Clark, V. L. (2011). *Designing and conducting mixed methods research*. 2nd edition. Thousand Oaks, CA: Sage Publications.

Creswell, J. W., & Miller, D. L. (2000). Determining validity in qualitative inquiry. *Theory Into Practice*, 39:3:124-130, DOI: 10.1207/s15430421tip3903_2.

Cross, M., Zavaleta, E., Bachelet, D., Brooks, M., Enquist, C., Fleishman, E., Groves, C., Hannah, L., Hansen, L., Hayward, G., Koopman, M., Lawler, J., Malcolm, J., Nordgren, J., Petersen, B., Rowland, E., Scott, D., Shafer, S., Tabor, . (2012). The Adaptation for Conservation Targets (ACT) Framework: A Tool for Incorporating Climate Change into Natural Resource Management. Environmental management. 50. 341-51. 10.1007/s00267-012-9893-7.

Dang, H. H., Michaelowa, A., & Tuan, D. D. (2003). Synergy of adaptation and mitigation strategies in the context of sustainable development: the case of Vietnam. *Climate Policy* 3(S1): S81–S96.

David, M., & Sutton, C. D. (2004). *Social research: the basics.* London: Sage Publications.

David, R. E., Gerald, A. M., Camille, P., Stanley, A. C., Thomas, R. K., & Linda, O. M. (2000). Climate extremes: observations, modeling, and impacts**.** *Science* 289 (5487): 2068-2074. DOI: 10.1126/science.289.5487.2068

Davidse, B., Othengrafen, M,. & Deppisch, S. (2015). Spatial planning practices of adapting to climate change. European Journal of Spatial Development. 1.

Davis, S. J., Caldeira, K., Matthew, D. (2010). Future CO_2 emissions and climate change from existing energy infstructure. *Science,* September, 9. 329. 1330 – 1333

Dawson, C. (2009). *Introduction to research methods: a practical guide for anyone undertaking a research project*. 4th edition. Oxford: How to Books.

De Vos, D. (1998). *Research at grass roots: a primer for caring professions*. Pretoria: Van Schaik.

Demski, C. C., Capstick, S. B., Pidgeon, N. F., & Spence, A. (2017). Experience of extreme weather affects climate change mitigation and adaptation responses. *Climatic Change* 140 (2):149-164. 10.1007/s10584-016-1837-4 file

Denzin, N. K., & Lincoln, Y. S. (Eds.). (2005). *The sage handbook of qualitative research*. Thousands Oaks, CA: Sage

Deressa, T. T., Hassan, R. M., & Ringler, C. (2011). Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. *Journal of Agricultural Science*, 149: 23-31.

Dessai, S., & Hulme, M. (2001). Climatic implications of revised IPCC emission scenarios, the Kyoto Protocol and quantification of uncertainties. *Integrated Assessment* 2 (3): 159–170.

DFID. (2011). Defining disaster resilience: a DFID Approach Paper. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/186874/defining-disasterresilience-approach-paper.pdf. (Accessed June 2017.)

Dimitrakopoulos, D., & Richardson, J. (2001). Implementing EU Public Policy. In European Union: Power and Policy-Making. London: Routledge. Available at: http://www.nuff.ox.ac.uk/Politics/Jeremy3.html

Domitrovich, C. E., Bradshaw, C. P., Poduska, J. M., Hoagwood, K., Buckley, J. A., Olin, S., H., Romanelli, L., Leaf, P.J., Greenberg, M. T., & Nicholas, S. I. (2008). Maximizing the implementation quality of evidence-based preventive interventions in schools: a conceptual framework. *Advances in School Mental Health Promotion* 1 (3): 6–28.

Dovers, S. R., & Hezri, A. A. (2010). Institutions and policy processes: the means to the ends of adaptation. *Wiley Interdisciplinary Reviews: Climate Change* 1(2): 212–231.

Droogers, P, Butterfield, R, & Dyszynski, J. (2009). Climate change and hydropower, impact and adaptation costs: Case Study Kenya. Available at: https://www.futurewater.nl/downloads/2009_Droogers_FW85.pdf

Du Toit, M., Dallimer, M., Goddard, M., Guenat, S., Cornelius, S. (2018). Urban green infrastructure and ecosystem services in sub-Saharan Africa. Landscape and Urban Planning. 180. 10.1016/j.landurbplan.2018.06.001.

Dubois, K. M., Chen, Z., Kanamaru, H., & Seeburg-Elverfeldt, C. (2012). Incorporating climate change considerations into agricultural investment design: a guidance document. Rome: FAO.

Durlak, J. A., & Du Pre, E. P. (2008). Implementation matters: a review of research on the influence of implementation on program outcomes and the factors affecting implementation. *American Journal of Community Psychology* 41 (3-4): 327–50.

Eggleston, S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (2006). IPCC guidelines for national greenhouse gas inventories. *Institute for Global Environmental Strategies,* 48–56.

El Raey, M. (2004). *Adaptation to Climate Change for Sustainable Development in the Coastal Zone of* Egypt. ENV/EPOC/GF/SD/RD(2004)1/FINAL, OECD, Paris.

Engel, H., Enkvist, P., & Henderson, K. (2015). How companies can adapt to climate change. Available at: http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/how-companies-can-adapt-to-climate-change.

Evers, C. W., Wu E. H., (2006). 'On generalising from single case studies: Epistemological reflections', *Journal of Philosophy of Education*, vol. 40, pp. 511 - 526, http://dx.doi.org/10.1111/j.1467-9752.2006.00519.x

FAO (Food and Agricultural Organization). (2008). Atlas in regional integration in West Africa. Rome: FAO.

FAO. (2015). The state of food and agriculture: Social protection and agriculture Breaking the cycle of rural poverty. Rome: FAO. Available at: http://www.fao.org/3/a-i4910e.pdf

FAO. (2016). Climate change and food security: Risks and responses. Rome: FAO. Available at: http://www.fao.org/3/a-i5188e.pdf

FAO. (2004). Drought impact mitigation and prevention in the Limpopo River Basin, A situation analysis. Land and Water Discussion Paper 4, FAO, Rome, 160 pp.

Fankhauser, S. (2009). 'The costs of adaptation'. *CCCEP Working Paper No. 8 / GRI-CCE Working Paper No. 7*. London, UK: Centre for Climate Change Economics and Policy (CCCEP) and the Grantham Research Institute on Climate Change and the Environment (GRI-CCE).

Fearnside, P. M. (2016). Greenhouse gas emissions from hydroelectric dams in tropical forests, in *Alternative Energy and Shale Gas Encyclopedia* edited by J Lehr & J Keeley. New York: John Wiley & Sons, pp. 428-438.

Fixsen, D. L., Sandra, F. N., Karen, A. B., & Robert, M. F. (2005). Implementation research: a synthesis of the literature. Available at: http://www.popline.org/node/266329.

Fixsen, D. L., Karen, A. B., Sandra, F. N., & Frances, W. (2009). Core implementation components. *Research on Social Work Practice* 19 (5): 531–40. doi:10.1177/1049731509335549.

Fleischer, A., Mendelsohn, R., & Dinar, A. (2011) Bundling agricultural technologies to adapt to climate change. *Technological Forecasting and Social Change*, 78(6), 982-990.

Florentina, B., Bucur, D. M., Dumitran, G. E., & Gabriel Dan Ciocan, G. D. (2012). Water Quality in Hydroelectric Sites, Ecological Water Quality - Water Treatment and Reuse, Dr. Voudouris (Ed.), ISBN: 978953-51-0508-4, InTech, Available at: http://www.intechopen.com/books/ecological-water-quality-watertreatment-and-reuse/water-quality-in-hydroelectric-sites)

Flyvbjerg, B. (2006). Five Misunderstandings About Case-Study Research. Qualitative Inquiry. 12. 219-245. 10.1177/1077800405284363..

Fujii, H., Iwata, K., & Managi, S. (2017). How do urban characteristics affect climate change mitigation policies? *Journal of Cleaner Production*, 168. DO - 10.1016/j.jclepro.2017.08.221

Fussel, H-M. & Klein, R. J. T. (2006). Climate change vulnerability assessments: an evolution of conceptual thinking. *Climatic Change* 75: 301–329.

Fussel, H-M. (2007). Adaptation planning for climate change: concepts, assessment approaches, and key lessons. *Sustainability Science and Springer* 2:265–275. DOI 10.1007/s11625-007-0032-y

Georgakakos, A. P., Fleming, P., Dettinger, M., Peters-Lidard, C., Richmond, T. C., Reckhow, K., White, K., & Yates, D. (2014). Ch. 3: Water Resources. Climate Change Impacts in the United States: The Third National Climate Assessment, 69-104. 10.7930/J0Z31WJ2.

Ghana Meteorological Agency (2020) Report. Available at https://www.meteo.gov.gh/gmet/

Goklany, I. M. (2005). A climate policy for the short and medium term: stabilization or adaptation? *Energy. Environment.*, 16: 667-680.

Goklany, I. M. (2007). Integrated strategies to reduce vulnerability and advance adaptation, mitigation, and sustainable development. Mitigation Adaption Strategies for Global Change. 12 (5), 755–786.

Government of Egypt (2004). Industrial Policy in Egypt 2004–2011 Report

Government of Ghana Constitution of 1992 with Amendments through 1996. Available at: http://extwprlegs1.fao.org/docs/pdf/gha129754.pdf

Government of Ghana (2015). Ghana Statistical Service Labour Force Report 2015

Governmet of Ghana: Medium Term Expenditure Framework (MTEF) For 2019-2022. Ministry of Environment, Science, Technology and Innovation, Programme Based Budget Estimates for 2019

Government of Ghana National Environmental Policy, 2012.

Government of Ghana: National Energy Efficiency Action Plan (NEEAP) Ghana Period [2015-2020]

Government of Ghana, Environmental Protection Agency, Legislative Instrument 1812(2005)

Government of South Africa. (2010). South African Forestry Company & Agricultural Research Council on status of afforestation and reforestation projects, deforestation and climate change effects on the forestry sector: briefing. Available at: https://pmg.org.za/committee-meeting/12014/

Government of South Africa, (2015). The Institute of Risk Management South Africa's risk research report, 2015

Government of Ethiopia (2011). Ethiopia's Climate-Resilient Green Economy. Available at: http://gggi.org/site/assets/uploads/2017/11/2015-08-Sectoral-Climate-Resilience-Strategies-for-Ethiopia-1-Agriculture-and-Forestry-Climate-Resilience-Strategy.pdf

Graneheim, U. H., & Lundman, B. (2004). Qualitative content analysis in nursing research: concepts, procedures and measures to achieve trustworthiness. *Nurse Education Today*, 24(2): 105112. doi:10.1016/j.nedt.2003.10.001)

Gyau-Boakye, P. (2001). Environmental impacts of the Akosombo dam and effects of climate change on the lake levels. *Environment, Development and Sustainability* 3:17-29.

Gyamfi, S., Diawuo, F., Kumi, E., Sika, F. & Modjinou, M. (2017). The energy efficiency situation in Ghana. *Renewable and Sustainable Energy Reviews* 10.1016/j.rser.2017.05.007.

Gore, C., & Robinson, P. (2009). Local government response to climate change: our last, best hope? in *Changing climates in North American politics: institutions, policymaking, and multilevel governance,* edited by H Selin & S VanDeVeer. Cambridge: MIT Press, 137 – 158.

Hardoy, J., & Romero-Lankao, P. (2011). Latin American cities and climate change: challenges and options to mitigation and adaptation responses. *Current Opinion in Environmental Sustainability*, doi: 10.1016/j.cosust.2011.01.004

Hassan, A. Z., & Schattner, P., & Mazza, D. (2006). Doing A Pilot Study: Why Is It Essential? Malaysian Family Physician. 1.

Heede, R. (2014). Tracing anthropogenic carbon dioxide and methane emissions to fossil fuel and cement producers, 1854–2010. *Climatic Change* 122:229–241.

Hepburn, C., O'Callaghan, B., Stern, N., Stiglitz, J., and Zenghelis, D. (2020) Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change? Oxford Smith School of Enterprise and the Environment, Working Paper No. 20-02. Available at: https://www. smithschool.ox.ac.uk/publications/wpapers/workingpaper20-02.pdf

Howard-Grenville, J., Buckle, S. J., Hoskins, B. J., & George, G. (2014). Climate change and management. *Academy of Management Journal*, 57(3): 615–623. Available at: http://dx.doi.org/10.5465/amj.2014.4003

Huang, C., Vaneckova, P., Wang, X., FitzGerald, G., Guo, Y., & Tong, S. (2011). Constraints and barriers to public health adaptation to climate change: a review of the literature. *American Journal of Preventive Medicine*, 40(2): 183-190.

Hulme, M. (2010). Problems with making and governing global kinds of knowledge. *Global Environmental Change*, 20 (4):558-564.

Huntingford, C., Marsh, T., Scaife, A., Kendon, E., Hannaford, J., Kay, A., Lockwood, M., Prudhomme, C., Reynard, N., Parry, S., Lowe, J., Screen, J., Ward, H., Roberts, M., Stott, P., Bell, V., Bailey, M., Jenkins, A., Legg, T., Allen, M. (2014). Potential influences on the United Kingdom's floods of winter 2013/14. Nature Climate Change. 4. 769-777. 10.1038/nclimate2314.

Hupe, P. L. (2011). The thesis of incongruent implementation: revisiting Pressman and Wildavsky. *Public Policy and Administration* 26 (1): 63–80. doi:10.1177/0952076710367717.)

IPCC. (2001). Climate Change 2001: Synthesis Report. Contribution of Working Groups I, II, III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, R.T. Watson and the Core Team, Eds. Cambridge and New York: Cambridge University Press, 398.

IPCC. (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Annex I., M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds. Cambridge: Cambridge University Press: 976.

IPCC. (2018). Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty edited by V Masson-Delmotte, P Zhai, H-O Pörtner, D Roberts, J Skea, PR Shukla, A Pirani, W Moufouma-Okia, C Péan, R Pidcock, S Connors, JBR Matthews, Y Chen, X Zhou, MI Gomis, E Lonnoy, T Maycock, M Tignor & T Waterfield.

IPCC. (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F . Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, KJ, G-K Mach, S. K. Plattner, M Allen, Tignor M. & Midgley, P. M. (eds.). Cambridge and New York: Cambridge University Press: 582.

IPCC. (2013). Summary for policymakers. In: Climate Change 2013: the Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge and New York: Cambridge University Press.

IRENA. (2019). Climate change and renewable energy: national policies and the role of communities, cities and regions (Report to the G20 Climate Sustainability Working Group (CSWG)), International Renewable Energy Agency, Abu Dhabi.

Ivankova, N., Creswell, J., Stick, & S. (2006). Using Mixed-Methods Sequential Explanatory Design: From Theory to Practice. Field Methods. 18. 3-20. 10.1177/1525822X05282260.

Jon, H., Detlef, S., & Arild, U. (2009). Implementing long-term climate policy: time inconsistency, domestic politics, international anarchy. *Global Environmental Politics* 9(3): 20-39.

Jones, D., Marten, K., & Harris, K. (2015). Underwater sound from dredging activities: Establishing source levels and modelling the propagation of underwater sound. Conference: CEDA Dredging Days 2015: Innovative dredging solutions for ports. At: Rotterdam, the Netherlands

Jones, L & Boyd, E. (2011). Exploring social barriers to adaptation: insights from Western Nepal. *Global Environmental Change* 21(4): 1262-1274.

Kabo-bah, A. T., Diji, C., Nokoe, K. S., Mulugetta, Y., Obeng-Ofori, D., & Akpoti, K. (2016). Multiyear rainfall and temperature trends in the Volta river basin and their potential impact on hydropower generation in Ghana. *Climate* 4. 10.3390/cli4040049.

Kabonga, Itai. (2019). Principles and practice of monitoring and evaluation: a paraphernalia for effective development. *Africanus: Journal of Development Studies* 48(21). 10.25159/0304-615X/3086.

Kariuki, J. (2014). An exploration of the guiding principles and challenges of monitoring and evaluation of community development projects and programmes. *International Journal of Business and Social Science* 5(1):140–147.

Kaunda, C. S., Kimambo, C. Z., & Nielsen, T. K. (2012). Hydropower in the context of sustainable energy supply: a review of technologies and challenges. *International Scholarly Research Network*. Available at: https://doi.org/10.5402/2012/730631.

Keen, M., Barbara, J., Carpenter, J., Evans, D., & Foukona, J. (2017). Urban development in Honiara: harnessing opportunities, embracing change. Canberra: Australian National University.

Kelly, M. (2005). *Primary and secondary data,* McKinnon Secondary College. Available at: http://www.mckinnonsc.vic.edu.au/vceit/infodata/primarysecondary.htm
London: Sage Publications.

Kennedy, J, Ramasamy, S, Andrew, R, Arico, S, Bishop, E & Braathen, G. (2019). *WMO statement on the State of the Global Climate in 2018.* Geneva: Chairperson, Publications Board, World Meteorological Organization. p. 6. ISBN 978-92-63-11233-0.

Kenny, J. F., Barber, N. L., Hutson, S. S., Linsey, K. S., Lovelace, J. K., & Maupin, M. A. (2009). Estimated use of water in the United States in 2005. USGS Circular 1344, U.S. Department of the Interior, U.S. Geological Survey (USGS), Washington, DC, USA, 52 pp.

Kivunja, C. (2018). Distinguishing between Theory, Theoretical Framework, and Conceptual Framework: A Systematic Review of Lessons from the Field. International Journal of Higher Education. 7. 44. 10.5430/ijhe.v7n6p44.

Klein, R. J. T., Schipper, E. L., & Dessai, S. (2003). Integrating mitigation and adaptation into climate and development policy: three research questions. Tyndall Centre for Climate Change Research, Working Paper 40.

Klein, R. J. T., Huq, S., Denton, F., Downing, T. E., Richels, R. G., Robinson, J. B., & Toth, F. L. (2007). Inter-relationships between adaptation and mitigation. *Climate Change* 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Klein, R. J. T., Midgley, G. F., Preston, B. L., Alam, M. G. H., Berkhout, K., Dow, K., & Shaw, M. R. (2014). Adaptation opportunities, constraints, and limits, in *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* edited by C. B Field, V. R Barros, D. J Dokken, K. J Mach, M. D Mastrandrea, T. E Bilir, M. Chatterjee, K. L Ebi, Y. O Estrada, R. C Genova, B. Girma, E. S Kissel, A. N Levy, S. MacCracken, P. R Mastrandrea & L. L White. Cambridged; Cambridge University Press, pp. 899-943.

Kortum, S. S., & Weisbach, D. A. (2017). The design of border adjustments to carbon prices. *National Tax Journal*, 70(2):421–446, Working paper. Available at: http://www.rff.org/files/document/file/RFF-DP-16-09.pdf.

Kruger, R. (2017). Evaluating Africa's largest hydropower projects. Available at: www.hydroworld. com/articles /2018/08/

Kuklicke, C. & Demeritt, D. (2016). Adaptive and risk-based approaches to climate change and the management of uncertainty and institutional risk: the case of future flooding in England. *Global Environmental Change* 37: 56–68.

Kumar, R. (2011). *Research methodology: a step by step guide for beginners*. 3rd edition. London: Sage Publications.

Kwadijk, J. C., Haasnoot, M., Mulder, J. P., Hoogvliet, M., Jeuken, A., Van der Krogt, R. A., Van Oostrom, N. G., Schelfhout, H. A., Van Velzen, E. H., Van Waveren, H., & De Wit, M.J. (2010). Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. *Climate Change* 1(5): 729–740.

Lal, P. N., Mitchell, T., Aldunce, P., Auld, H., Mechler, R., Miyan, A., Romano, L. E., & Zakaria, S. (2012). National systems for managing the risks from climate extremes and disasters: a special report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge: Cambridge University Press, pp. 339-392.

Lamperti, F., Dosi, G., Napoletano, M., Roventini, A., & Sapio, A. (2018). Faraway so close: coupled climate and economic dynamics in an agent-based integrated assessment model. *Ecological Economics*, 150: 315-339.

Landry, S., (2017). Policy implementation: a synthesis of the study of policy implementation and the causes of policy failure. OCP Policy Center, Rabat, Morroco.

Laukkonen, J., Blanco, P. K., Lenhar, J., Keiner, M., Cavric, B., & Kinuthia-Njenga, C. (2009). Combining climate change adaptation and mitigation measures at the local level. *Habitat International* 33: 287–292.

Lauren, R., John, W. & Yoshi, K. (2014). *Barriers to effective climate change mitigation: the case of senior government and business decision makers*. New York: John Wiley & Sons. Vol. 5, 5:753–773. doi: 10.1002/wcc.305

Lavell, A., Oppenheimer, M., Diop, C., Hess, J., Lempert, R., Li, J., Muir-Wood, R. & Myeong, S. (2012). Climate change: new dimensions in disaster risk, exposure, vulnerability, and resilience, in *Managing the risks of extreme events and disasters to advance climate change adaptation: a special report of Working Groups I and II of the Intergovernmental Panel on Climate Change* edited by CB Field, V Barros, TF Stocker, D Qin, DJ Dokken, KL Ebi, MD Mastrandrea, KJ Mach, G-K Plattner, SK Allen, M Tignor & PM Midgley. Cambridge: Cambridge University Press, 25-64.

Lesnikowski, A. C., Ford, J. D., Berrang-Ford, L., Barrera, M., Berry, P., Henderson, J., & Heymann, S. J. (2013). National-level factors affecting planned, public adaptation to health impacts of climate change. *Global Environmental Change*, 23(5), 1153-1163.

Lindseth, G. (2004) The cities for Climate Protection Campaign (CCPC) and the framing of local climate policy. *Local Environment: The International Journal of Justice and Sustainabiliy* 9(4):325-336.

Locatelli, B., Evans, V., Wardell, A., Andrade, A., & Vignola, R. (2011). Forests and climate change in Latin America: linking adaptation and mitigation. *Forests* 2: 431-450.

Long, T., & Johnson, M. R. (2000). Reliability and validity in qualitative research. *Clinical Effectiveness in Nursing* 4(1):30-37.

Longhurst, R. (2003). Semi-structured interviews and focus groups, in *Key methods in geography* edited by N Clifford and G Valentine. London: Sage Publications, 117-132.

Luber, G., & McGeehin, M. (2008). Climate change and extreme heat events. *American Journal of Preventive medicine*, 35(5): 429-435.

Macnee, L. C., & McCabe, S. (2008). Understanding nursing research: Using research evidence-basedpractice. Philadelphia, PA: Lippincott Williams & Wilkins).

Marfo, E., Adam, K. A., & Darko-Obiri, B. (eds). (2009). Ghana country case study report on chainsaw milling.Developing alternative to illegal chainsaw milling through multistakeholder dialogue in Ghana and Guyana project. SIR-Forestry Research Institute of Ghana/Tropenbos International, Netherlands.

Massetti, E., & Mendelsohn, R. (2018). Measuring climate adaptation: methods and evidence. *Review of Environmental Economics and Policy* 12.2: 324-341. DOI: 10.1093/reep/rey007

Matland, R. E. (1995). Synthesizing the implementation literature: the ambiguity-conflict model of policy. *Journal of Public Administration Research and Theory* 5 (2): 145–74.

Mazmanian, D. A., & Sabatier, P. A. (1983). *Implementation and public policy*. 1st edition. Northbrook, Ill: Scott Foresman.

Mazmanian, D. A., & Sabatier, P. A. (1989). *Implementation and Public Policy.* Revised edition. Latham, Md.: University Press of America

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., & White, K. S. (eds). (2001). *Climate change 2001: impacts, adaptation, and vulnerability*. Cambridge University Press, Cambridge.

McKibbin, W., & Wilcoxen, P. (2002). The role of economics in climate change policy. *Journal of Economic Perspectives* 16(2): 107-130.

Mendelsohn, R. (2013). Climate change and economic growth, commission on growth and development. Working paper no.60. Climate Change and Economic Growth.

Meige, P., Blewitt, R., & Van Aalst M., (2020) A humanitarian recipe for a green, resilient and inclusive recovery from COVID-19, Solferino Academy, Leadership voices. Available at: https://future-rcrc.com/2020/07/03/a-humanitarian-recipe-for-a-greenresilient-and-inclusive-recovery-from-covid-19/

MESTI (2015). Ghana National Climate Change Master Plan. Action Programmes for Implementation: 2015–2020, Ministry of Environment, Science, Technology and Innovation: Accra

Meyers, M., & Nielsen, V. (2012). Street-level bureaucrats and the implementation of public policy. In The SAGE Handbook of Public Administration, 305–18. 1 Oliver's Yard, 55 City Road, London EC1Y 1SP United Kingdom: SAGE Publications Ltd. Available at: http://knowledge.sagepub.com/view/the-sage-handbook-ofpublic-administration-

Milly, P. C. D. (2008). Stationarity is dead: whither water management? *Science:* 319, 573-574.

Mjimba, V., & Sibanda, G. (2019). Biomimicry, Big Data and Artificial Intelligence for a Dynamic Climate Change Management… DOI: Michael Jakob and Jan Christoph Steckel http://dx.doi.org/10.5772/intechopen.84406

Nordhaus, W. D. (2017). Social cost of carbon in DICE model. Proceedings of the National Academy of Sciences. 114 (7): 1518-1523.

Moomaw, W. R., Moreira, J. R., Blok, K., Greene, D. L., Gregory, K., Jaszay, T., Kashiwagi, T., Levine, M., McFarland, M., Siva Prasad, N., Price, N., Rogner, H-H., Sims, R., Zhou, F., & Zhou, P. (2001). Technological and economic potential of greenhouse gas emissions reduction, climate change 2001: Mitigation. Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 167-299.

Morrison, A., French, P., Stewart, S., Birchwood, M., Fowler, D., Gumley, A., Jones, P., Bentall, R., Lewis, S., Murray, G., Patterson, P., Brunet, K., Conroy, J., Parker, S., Reilly, T., Byrne, R., Davies, L., Dunn, G. (2012). Early detection and intervention evaluation for people at risk of psychosis: Multisite randomised controlled trial. BMJ (Clinical research ed.). 344. e2233. 10.1136/bmj.e2233.

Moser, S. C., & Boykoff, M. T. (2013). Successful adaptation to climate change linking science and policy in a rapidly changing world. London: Routledge.

Moser, S. C., & Ekstrom, J. A. (2010). A framework to diagnose barriers to climate change adaptation, PNAS, Available at: http://www.pnas.org/content/107/51/22026.

Mouton, J. (2002). *Understanding social research.* Pretoria: Van Schaik Publishers.

Nachmany, M., Fankhauser, S., Davidová, J., Kingsmill, N., Landesman, T., Roppongi, H., Schleifer, P., Setzer, J., Sharman, A., Singleton, C., Sundaresan, J., Townshend, T. (2015). The 2015 Global Climate Legislation Study - A Review of Climate Change Legislation in 99 Countries (summary for policymakers). Available at: http://www.lse.ac.uk/GranthamInstitute/.

New UN Report Synthesizes National Climate Plans from 146 Countries, UNFCCC (2015). Available at: http://newsroom.unfccc.int/unfccc-newsroom/indc-synthesis-report-press-release/ (Retrieved online August 19, 2016)

Niang, I., Ruppel, O. C., Abdrabo, M. A., Essel, A., Lennard, C., Padgham, J., & Urquhart, P. (2014). 'Africa', in *Climate change: Impacts, adaptation, and vulnerability. Part B: Regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC*, edited by VR Barros, CB Field, DJ Dokken, MD Mastrandrea, KJ Mach, TE Bilir, M Chatterjee, KL Ebi, YO Estrada, RC Genova, B Girma, ES Kissel, AN Levy, S MacCracken, PR Mastrandrea and LL White. Cambridge and New York: Cambridge University.

Noble, H., & Smith, J. (2015). Issues of validity and reliability in qualitative research. Evidence-Based Nursing, 18(2), 34-5. Available at: https://doi.org/10.1136/eb-2015-102054

North, D. (1990). Institutions, Institutional Change and Economic Performance. Cambridge: Cambridge University Press.

Nortey, E., Doku-Amponsah, K., & Ocran, E. (2017). Estimating exceedance probability of extreme water levels of the Akosombo dam. *CBAS Journal: Science and Development* 1: 59-67.

Nyong, A., Adesina. F., & Osman E., B. (2007). *The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel*. Springer Science+Business Media B.V. 12:787–797. DOI 10.1007/s11027-007-9099-0.

Onwuegbuzie, A. J., & Leech, N. L. (2007). Validity and qualitative research: an oxymoron? *Quality and Quantity* 41: 233–249. doi: 10.1007/s11135006-9000-3.

Osbahr, H., Twyman, C., Adger, W. N., & Thomas, D. S. (2008). Effective livelihood adaptation to climate change disturbance: scale dimensions of practice in Mozambique. *Geoforum* 39 (6): 1951–1964.

Osberghaus, D., Finkel, E., & Pohl, M. (2010). Individual adaptation to climate change: the role of information and perceived risk. ZEW - Centre for European Economic Research Discussion Paper No. 10-061. Available at SSRN: https://ssrn.com/abstract=1674840 or http://dx.doi.org/10.2139/ssrn.1674840

Osman-Elasha, B., Goutbi, N., Spanger-Siegfried, E., Dougherty, B., Hanafi, A., Zakieldeen, S., Sanjak, A., Atti, H., & Elhassan, H. (2006). *Adaptation strategies to increase human resilience against climate variability and change: lessons from the arid regions of Sudan*. AIACC Working Paper 42, International START Secretariat, Washington, District of Columbia, 42 pp.

O'Sullivan, E., & Rassel, G. (1999). *Research methods for public administrators.* 3rd edition. New York: Longman.

Owusu, J. G. K., Daasebre Osei Bonsu II, Djokotoe, E. Y., Adam, A. K., & Osiakwan, K. (2006). Benefit sharing of revenues derived from natural forest reserves. Executive summary of the Committee's report. Prepared for the Ministry of Lands, Forestry and Mines, July 2006.

Owusu, K., Waylen, P., & Qiu, Y. (2008). Changing rainfall inputs in the Volta basin: implications for water sharing in Ghana. *GeoJournal* 71: 201-210. 10.1007/s10708-008-9156-6.

Paige-Green, P., Verhaeghe, B., & Head, M. (2016). Climate adaptation: risk management and resilience optimisation for vulnerable road access in Africa. AfCAP Project Report GEN2014C.

Phyper, J., & MacLean, P. (2009). *Good to green: managing business risks and opportunities in the age of environmental awareness.* Ontario, Canada: Wiley.

Pizer, W. A. (2002). Combining price and quantity controls to mitigate global climate change. *Journal of Public Economics* 85: 409-434.

Porta, M. (2008). *A dictionary of epidemiology*. 5th edition. Oxford: Oxford University Press. 320 p

Rabe, B. (2007). Race to the top: the expanding role of U.S State Renewable Portfolio Standards." Sustainable Development Law & Policy, Spring 2007, 10-16, 72.

Ramana, M. V. (2009). Nuclear power: economic, safety, health, and environmental issues of near-term technologies Annu. Rev. Environ. Resour. 34 127 – 52

Rasch, E. D., & Köhne, M. (2016). Micropolitics in resistance: the micropolitics of large scale natural resource extraction in South East Asia. Social Natural Resources. 9 (4): 479 – 492.

Ravitch, S. M., & Riggan, M. (2017). Reason & Rigor: How Conceptual Frameworks Guide Research, (Edited) 2nd Edition (2017): 264 pp., Soft Cover, ISBN: 9781483340401, SAGE Publications, Inc., Thousand Oaks, CA, Price: $64.00. Occupational Therapy In Health Care. 31. 1-2. 10.1080/07380577.2017.1360538.

Reid, H., Alam, M., Berger, R., Cannon, T., Huq, S., & Milligan, A. (2009). Community-based adaptation to climate change: an overview. In: *Participatory Learning and Action*, issue 60, pg. 13, IIED.

Renaud, K., Ming, T., Davies, P., Liu, W., Caillol, S. (2017). Removal of non-CO_2 greenhouse gases by large-scale atmospheric solar photocatalysis. *Progress in Energy and Combustion Science* 60: 68-96, ISSN 0360-1285, Available at: https://doi.org/10.1016/j.pecs.2017.01.001.

Ribot, J. (2010). Vulnerability does not fall from the sky: toward multi-scale pro-poor climate policy, in *Social dimensions of climate change: equity and vulnerability in a warming world,* edited by R Mearns & A Norton. Washington, DC: World Bank.

Richter, B. D., Postel, S., Revenga, C., Scudder, T., Lehner, B., Churchill, A. & Chow, M. (2010). Lost in development's shadow: the downstream human consequences of dams. *Water Alternatives* 3(2): 14-42.
Robert, H., Jared, B., Sara, C., Ohrel, B., Ragnauth, S., Ogle, S., Li, C., Ingraham, P., & Salas, W. (2015). *Journal of Integrative Environmental Sciences* 12, Iss. sup1.

Roel, D., Micheal, H., Jan, J., H., Lia, J., Henk,J., M., Dennis, P., & Peter, L., (2014). Commodity risk mitigation: A survey report. Nicole Hartung.

Rojas-Solórzano, L., Rahmaputro, S., Ruiz, C., & Anaglate, S. A. (2012). Comparison between landfill gas and waste incineration for power generation in Accra, Ghana. *International Journal of Environmental Science and Engineering Research* 3: 35-44.

Romero-Lankao, P., Wilbanks, T., & Gnatz, D. (2011). Chapter 7: Conclusion: Linkages between climate change responses, research and policy directions, UN-Habitat 2011, Human Settlements Report on Cities and Climate Change. Earthscan April 2011.

Rose, S., Ahammad, H., Eickhout, B., Fisher, B., Kurosawa, A., Rao, S., Riahi, K., & Van Vuuren, D. (2008). Land in climate stabilization modeling: initial observations. (Energy Modeling Forum (EMF) No. 21). Stanford University; [cited 2008 Jul]. Available at: http://www.stanford.edu/group/EMF/home/index.htm

Rotter, M., Hoffmann, E., Hirschfeld, J., Schröder, A., Mohaupt, F., & Schäfer, L. (2013). Stakeholder Participation in Adaptation to Climate Change – Lessons and Experience from Germany. Available at: http://www.umweltbundesamt.de/publikationen/stakeholder-participation-inadaptation-to-climate

Rubin, H. J., & Rubin, I. S. (2005). *Qualitative interviewing: the art of hearing data*. 2nd edition. London & New York: Sage Publications.

Sam, F., Alina, A., & Jared, F. (2018). Policy brief 10 years of the UK Climate Change Act (43 pp), available at: www.lse.ac.uk/GranthamInstitute/publication/10-years-climate-change-act /

Sanou, H., Kambou, S., Teklehaimanot, Z., Dembélé, M., Yossi, H., Sina, S., Djingdia, L., & Bouvet, J. (2004). Vegetative propagation of Vitellaria paradoxa by grafting. *Agroforestry Systems* 60(1): 93–99.

Schaeffer, R. (2012). Energy sector vulnerability to climate change: a review. *Energy* 38, 1-12.

Scott, C. E., Monks, S.A., Spracklen, D.V., Arnold, S. R., Forster, P. M., Rap, A., & Wilson, C. (2018). Impact on short-lived climate forcers increases projected warming due to deforestation. *Nature communications*, *9*(1): 157. doi:10.1038/s41467-017-02412-4

Sharma, B. (2019). Literature Review—The Springboard for Research. Homœopathic Links 2019; 32(02): 049-050. DOI: 10.1055/s-0039-1692679

Siders, A. R. (2019). Adaptive capacity to climate change: a synthesis of concepts, methods, and findings in a fragmented field. *Wires Climate Change* 10(3). Available at: https://doi.org/10.1002/wwc.573

Singal, S. K., Saini, R. P., & Raghuvanshi, C. S. (2010). Analysis for cost estimation of low head run-of-river small hydropower schemes. Energy for Sustainable Development. 14. 117–126. 10.1016/j.esd.2010.04.001.

Singh, S. P., Raghuvanshi, A., & Sharma, P. (2007). Comparative performance study of QN and LM algorithms in predictive control for NNARX-identified model of hydropower plant. *Engineering With Computers* 23: 71-78. 10.1007/s00366-006-0024-z

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H. H., Kumar, P., Mccarl, B., Ogle, S., O'mara, F., Rice, C., Scholes, R. J., Sirotenko, O., Howden, M., Mcallister, T., Pan, G., Romanenkov, V., Schneider, U., & Towprayoon, S. (2007). Policy and technologicalconstraints to implementation of greenhouse gas mitigation options in agriculture. *Agriculture, Ecosystems and Environment* 118, 6–28.

Smit, B., & Pilifosova, O. (2001). Adaptation to climate change in the context of sustainable development and equity, in *Climate change 2001: impacts, adaptation, and vulnerability, contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel*

on Climate Change, published for the Intergovernmental Panel on Climate Change edited by JM McCarthy, N Canziani, A Leary, DJ Dokken & KS White KS. Cambridge University Press, Cambridge. Available at http://www.grida.no/ publications/other/ipcc_tar/

Smit, B., & Pilifosova, O. (2003). From adaptation to adaptive capacity and vulnerability reduction, in *Climate change, adaptive capacity and development* edited by JB Smith, RJT Klein, S Huq. London: Imperial College Press.

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* 16:282–292.

Solaun, K., & Cerdá, E. (2017). The Impact of Climate Change on the Generation of Hydroelectric Power—A Case Study in Southern Spain. Energies. 10. 1343. 10.3390/en10091343.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Avery, K., Tignor, M., & Miller, H. (2007). Technical summary, in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*

Spriestersbach, A., Röhrig, B., Du Prel, J. B., Gerhold-Ay, A., & Blettner, M. (2009). Descriptive statistics: the specification of statistical measures and their presentation in tables and graphs. Part 7 of a series on evaluation of scientific publications. *Deutsches Arzteblatt International*, *106*(36), 578–583. doi:10.3238/arztebl.2009.0578

Stake, R. E. (1995). *The art of case study research*. Thousand Oaks, CA: Sage Publications.

Stecko, S., & Barber, N. (2007). Exposing Vulnerabilities: Monsoon Floods in Mumbai, India. Case study prepared for Revisiting Urban Planning: Global Report on Human Settlements 2007 Available from http://www.unhabitat.org/grhs/2007

Stern, N., & Stiglitz, J. E. (2021). The social cost of carbon, risk, distribution, market failures: an alternative approach. Working Paper 28472. Available at: http://www.nber.org/papers/w28472

Stern, N., Peters, S., Bakhshi, V., Bowen, A., Cameron, C., Catovsky, S., Crane, D., Cruickshank, S., Dietz, S., Edmondson, N., Garbett, S., Hamid, L., Hoffman, G., Ingram, D., Jones, B., Patmore, N., Radcliffe, H., Sathiyarajah, R., Stock, M., Taylor, C., Vernon, T., Wanjie, H., & Zenghelis, D. (2006). *The Economics of Climate Change" Cabinet Office – HM Treasury*. Cambridge: Cambridge University Press.

Sterman, J. D. (2011). Communicating climate change risks in a skeptical world*. Climatic Change 108:811*–826*.*

Stiglitz, J. E. (2019). Addressing climate change through price and non-price interventions. *European Economic Review*, 119, 594-612.

Sundararajan, V. (2007). Discrimination and health outcomes: a secondary analysis of hospital data from Victoria, Australia*. Diversity in Health and Social Care*. 4:21–32

Swanson, R. A. (2013). *Theory building in applied disciplines*. San Francisco, CA: Berrett-Koehler.

Swart, R., Robinson, J., & Cohen, S. (2003). Climate change and sustainable development: expanding the options. *Climate Policy* 3S1:S19–S40.

Swart, R., & Raes, F. (2007). Making integration of adaptation and mitigation work: mainstreaming into sustainable development policies? *Climate Policy*, 7(4): 288-303.

Systemiq (2020). The Paris Effect: How the Climate Agreement is Reshaping the Global Economy. Available at: https://www.systemiq.earth/paris-effect/

Tanaka, S. T., Zhu, T., Lund, J. R., Howitt, R. E., Jenkins, M. W., Pulido, M. A., Tauber, M. E., Ritzema, R. S., & Ferreira, I. C. (2006). Climate warming and water management adaptation for California. *Climatic Change* 76(3–4):361–387.

Thomas, D. R. (2006). A general inductive approach for analyzing qualitative evaluation data. *American Journal of Evaluation*, *27*(2): 237–246. Available at: https://doi.org/10.1177/1098214005283748

Thorlakson, T. (2011). Reducing subsistence farmers' vulnerability to climate change: the potential contributions of agroforestry in western Kenya. ICRAF Occasional Paper

Tol, R. (2005). Adaptation and mitigation: Trade-offs in substance and methods. Environmental Science & Policy. 8. 572-578. 10.1016/j.envsci.2005.06.011.

Tompkins, E., Day, S., Hurlston, L. A., Boyd, E., Hodge, G., Clarke, J., Trotz, N., & Varlack, L. (2005). Surviving climate change in small islands: a guidebook, Tyndall Center for Climate Change Research, United Kingdom.

Triscos, C. H., Merow, C., & Pigot, A. L. (2020). The projected timing of abrupt ecological disruption from climate change. *Nature*, 580: 496–501.

United Nations Sustainable Development Goals (2015). Available at https://sdgs.un.org/goals

UNEP (United Nations Environment Programme) (2019) Global Environment Outlook – GEO-6: Summary for Policymakers. Available at: https://www.unenvironment.org/resources/assessment/global-environment-outlook-6-summarypolicymakers

UNEP (United Nations Environment Programme) (2007). Beijing 2008 Olympic Games: an environmental review.

US Department of the interior Report, Bureau of reclamation, Power Resources Office (2005). Reclamation: Managing Water in the West, Hydroelectric Power.

Valadez, J., & Bamberger, M. (2004). Monitoring and evaluating social programs in developing countries: a handbook for Policy Makers, Managers and Researchers. Washington: World Bank.

Venturini, T., Bounegru, L., Gray, J., Rogers, R. (2018). A reality check(list) for digital methods. New Media & Society. 20. 146144481876923. 10.1177/1461444818769236.

Veronesi, G., and Kevin K. (2015). Patient and public participation in the English NHS: an assessment of experimental implementation processes. *Public Management Review* 17 (4): 543–64. doi: 10.1080/14719037.2013.822526.

Vicedo-Cabrera, A. M., Guo, Y., Sera, F., & 49 other Authors (2018). Temperature-related mortality impacts under and beyond Paris Agreement climate change scenarios. Climatic Change 150: 391– 402.

Vicuna, S., Leonardson, R., Hanemann, M. W., Dale, L. L., & Dracup, J. A. (2008). Climate change impacts on high elevation hydropower generation in California's Sierra Nevada: a case study in the Upper American River. *Climatic Change* (2008) 87 (Suppl 1):S123–S137

Vij, S., Moors, E., Ahmad, B., Arfanuzzaman, M., Bhadwal, S., Biesbroek, R., Gioli, G., Groot, A., Mallick, D., Regmi, B., Saeed, B., Thapa, B., Werners, S., Wester, P., Lead, I., Agricultural Pakistan & Council Research & Ishaq, S. (2017). Climate adaptation approaches and key policy characteristics: Cases from South Asia. Environmental Science & Policy. 78. 10.1016/j.envsci.2017.09.007.

VRA. 2018. Newsletter Volume 14: April - May - June.

Vogel, C. (1998). Vulnerability and global environmental change. LUCC Newsletter 3, 15–19

Walsh, T. (2006). Climate change: business risks and solutions. Vol. 5(2) **Marsh.**

Whitmarsh, L. (2009). Behavioural responses to climate change: asymmetry of intentions and impacts. *Journal of Environmental Psychology*, 29:13–23.

Wilby, L., Dawson, W., & Barrow, M. (2002). SDSM: a decision support tool for the assessment of regional climate change impacts. *Environmental and Modelling Software* 17.

Wilby, L., & Dessai, S. (2010). Robust adaptation to climate change. *Weather* 65(7): 180-185.

Willows, R., & Connell, R. (2003). Climate adaptation: risk, uncertainty and decision making UKCIP Technical Report May.

Winter, S. C. (2011). Implementation, in *International Encyclopedia of Political Science*, edited by Bertrand Badie, Dirk Berg-Schlosser, and Leonardo Morlino. Thousand Oaks, CA: Sage Publications, Inc. Available at: http://knowledge.sagepub.com/view/intlpoliticalscience/SAGE.xml.

Wise, R. M., Fazey, I., Smith, M. S., Park, S. E., Eakin, H. C., Van Garderen, E. A., & Campbell, B. (2014). Reconceptualising adaptation to climate change as part of pathways of change and response. *Global Environmental Change* 28, 325–336.

Worldwatch Institute, ed. State of the World 2012: Moving Toward Sustainable Prosperity. Washington: Worldwatch Institute, 2012.

Worrell, E., Bernstein, L., Roy, J., Price, L., & Harnisch, J. (2009). Industrial energy efficiency and climate change mitigation. *Energy Efficiency* 2:109–123 DOI 10.1007/s12053-008-9032-8

Wu, J., & Zhang, Y. (2008). Olympic Games promote the reduction in emissions of greenhouse gases in Beijing. *Energy Policy* 36: 3422–3426.

Yohe, G., & Tol, R. S. J. (2001). Indicators for social and economic coping capacity: moving toward a working definition of adaptive capacity. *Global Environmental Change* 12: 25-40.

Yohe, G. (2001). Mitigative capacity: the mirror image of adaptive capacity on the emissions side. *Climatic Change*, 49: 247-262.

Yin, R. K. (2003). *Case study research: design and methods.* 3rd edition. Thousand Oaks, CA: London: Sage Publications.

Yin, R. K. (2006). *Case study research: design and methods.* 4th edition. Thousand Oaks, CA: Sage Publications.

Yin, R. K. (2018). *Case study research and applications: design and methods.* London: Sage publications.

Zhan, X., Lo, C. W., & Tang, S., (2014). Contextual changes and environmental policy implementation: a longitudinal study of street-level bureaucrats in Guangzhou, China. *Journal of Public Administration Research and Theory* 24 (4): 1005–35. doi:10.1093/jopart/mut004.

Zhang, H-B., Dai, H-C., Lai, H-X., Wang, W-T. (2017). US withdrawal from the Paris Agreement: reasons, impacts, and China's response. *Advances in Climate Change Research* 8:220–225.

Zhao, J. (2011). Climate change mitigation in Beijing, China. Available at: http://www.unhabitat.org/grhs/2011) retrieved online on July 4, 2017

Zhu, X, Linham, MM & Nicholls, RJ. (2010). Technologies for climate change adaptation-coastal erosion and flooding. UNEP Risø Centre on Energy, Climate and Sustainable Development, Roskilde, Denmark.

APPENDIX A: ETHICAL CLEARANCE APPROVAL

UNISA university of south africa

CAES RESEARCH ETHICS REVIEW COMMITTEE

National Health Research Ethics Council Registration no: REC-170616-051

Date: 02/03/2017

Ref #: **2017/CAES/037**
Name of applicant: **Mr EK Acquaah**
Student #: **58545573**

Dear Mr Acquaah,

Decision: Ethics Approval

Proposal: The impact of climate change on hydro-power generation: A case study of Ghana's Akosombo Dam

Supervisor: Dr V Mjimba

Qualification: Postgraduate degree

Thank you for the application for research ethics clearance by the CAES Research Ethics Review Committee for the above mentioned research. Approval is granted for the project.

Please note that the approval is valid for a one year period only. After one year the researcher is required to submit a progress report, upon which the ethics clearance may be renewed for another year.

Due date for progress report: 28 February 2018

Please note point 4 below for further action.

The application was reviewed in compliance with the Unisa Policy on Research Ethics by the CAES Research Ethics Review Committee on 01 March 2017.

The proposed research may now commence with the proviso that:

1) *The researcher/s will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.*

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

2) *Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should be communicated in writing to the CAES Research Ethics Review Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.*
3) *The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.*
4) *The consent form lists incentives to be given to participants. The researcher is advised to remove mention of the incentives from the consent form to prevent participation purely to receive these incentives. The incentives may still be given after participation but participants should not be informed of this beforehand.*

Note:
The reference number [top right corner of this communiqué] should be clearly indicated on all forms of communication [e.g. Webmail, E-mail messages, letters] with the intended research participants, as well as with the CAES RERC.

Kind regards,

Signature
CAES RERC Chair: Prof EL Kempen

Signature
CAES Executive Dean: Prof MJ Linington

Note 4

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

UNISA university of south africa

CAES HEALTH RESEARCH ETHICS COMMITTEE

Date: 09/04/2019

NHREC Registration # : REC-170616-051
REC Reference # : 2017/CAES/037
Name : Mr EK Acquaah
Student #: 58545573

Dear Mr Acquaah

Decision: Ethics Approval Renewal after Second Review from 01/04/2019 to 31/03/2020

Researcher(s): Mr EK Acquaah
58545573@mylife.unisa.ac.za

Supervisor (s): Dr V Mjimba
vmjimba@hsrc.ac.za; 073-354-0590

Dr AO Agyepong
agyepao@unisa.ac.za; 072-525-4080

Working title of research:

The impact of climate change on hydro-power generation: A case study of Ghana's Akosombo Dam

Qualification: PhD Environmental Science

Thank you for the submission of your progress report to the CAES Health Research Ethics Committee for the above mentioned research. Ethics approval is renewed for a one-year period. After one year the researcher is required to submit a progress report, upon which the ethics clearance may be renewed for another year.

Due date for progress report: 31 March 2020

*The **low risk application** was **reviewed** by the CAES Health Research Ethics Committee on 01 March 2017 in compliance with the Unisa Policy on Research Ethics and the Standard Operating Procedure on Research Ethics Risk Assessment.*

The proposed research may now commence with the provisions that:

1. The researcher(s) will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
2. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study should be communicated in writing to the Committee.
3. The researcher(s) will conduct the study according to the methods and procedures set out in the approved application.
4. Any changes that can affect the study-related risks for the research participants, particularly in terms of assurances made with regards to the protection of participants' privacy and the confidentiality of the data, should be reported to the Committee in writing, accompanied by a progress report.
5. The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study. Adherence to the following South African legislation is important, if applicable: Protection of Personal Information Act, no 4 of 2013; Children's act no 38 of 2005 and the National Health Act, no 61 of 2003.
6. Only de-identified research data may be used for secondary research purposes in future on condition that the research objectives are similar to those of the original research. Secondary use of identifiable human research data require additional ethics clearance.
7. No field work activities may continue after the expiry date. Submission of a completed research ethics progress report will constitute an application for renewal of Ethics Research Committee approval.

Note:
*The reference number **2017/CAES/037** should be clearly indicated on all forms of communication with the intended research participants, as well as with the Committee.*

Yours sincerely,

Prof EL Kempen
Chair of CAES Health REC
E-mail: kempeel@unisa.ac.za
Tel: (011) 471-2241

Prof MJ Linington
Executive Dean : CAES
E-mail: lininmj@unisa.ac.za
Tel: (011) 471-3806

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

UNISA university of south africa

UNISA-CAES HEALTH RESEARCH ETHICS COMMITTEE

Date: 19/05/2021

Dear Mr Acquaah

NHREC Registration # : REC-170616-051
REC Reference # : 2017/CAES/037
Name : Mr EK Acquaah
Student #: 58545573

Decision: Ethics Approval Confirmation after Third Review from 19/05/2021 to 31/05/2022

Researcher(s): Mr EK Acquaah
58545573@mylife.unisa.ac.za

Supervisor (s): Prof KF Mearns
mearnkf@unisa.ac.za; 082-337-0074

Dr AO Agyepong
agyepao@unisa.ac.za; 072-525-4080

Working title of research:

The impact of climate change on hydro-power generation: A case study of Ghana's Akosombo Dam

Qualification: PhD Environmental Science

Thank you for the submission of your yearly progress report to the Unisa-CAES Health Research Ethics Committee for the above mentioned research. Ethics approval is confirmed to continue for a one-year period, **subject to submission of yearly progress reports. Failure to submit the progress report will lead to withdrawal of the ethics clearance until the report has been submitted.**

The researcher is cautioned to adhere to the Unisa protocols for research during Covid-19.

Due date for next progress report: 31 May 2022

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

*The **low risk application** was originally **reviewed** by the UNISA-CAES Health Research Ethics Committee on 01 March 2017 in compliance with the Unisa Policy on Research Ethics and the Standard Operating Procedure on Research Ethics Risk Assessment.*

The proposed research may now commence with the provisions that:

1. The researcher will ensure that the research project adheres to the relevant guidelines set out in the Unisa Covid-19 position statement on research ethics attached.
2. The researcher(s) will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
3. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study should be communicated in writing to the Committee.
4. The researcher(s) will conduct the study according to the methods and procedures set out in the approved application.
5. Any changes that can affect the study-related risks for the research participants, particularly in terms of assurances made with regards to the protection of participants' privacy and the confidentiality of the data, should be reported to the Committee in writing, accompanied by a progress report.
6. The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study. Adherence to the following South African legislation is important, if applicable: Protection of Personal Information Act, no 4 of 2013; Children's act no 38 of 2005 and the National Health Act, no 61 of 2003.
7. Only de-identified research data may be used for secondary research purposes in future on condition that the research objectives are similar to those of the original research. Secondary use of identifiable human research data require additional ethics clearance.
8. No field work activities may continue after the expiry date. Submission of a completed research ethics progress report will constitute an application for renewal of Ethics Research Committee approval.

Note:
*The reference number **2017/CAES/037** should be clearly indicated on all forms of communication with the intended research participants, as well as with the Committee.*

Yours sincerely,

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

Prof MA Antwi
Chair of UNISA-CAES Health REC
E-mail: antwima@unisa.ac.za
Tel: (011) 670-9391

Prof SR Magano
Executive Dean : CAES
E-mail: magansr@unisa.ac.za
Tel: (011) 471-3649

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

APPENDIX B: INFORMED CONSENT FORM

PARTICIPANT INFORMATION SHEET

Ethics clearance reference number: 2017/CAES/037

April 5, 2017

Title: THE IMPACT OF CLIMATE CHANGE ON HYDROPOWER GENERATION: A CASE STUDY OF GHANA'S AKOSOMBO DAM IN GHANA

Dear Prospective Participant

My name is Ezekiel Kojo Acquaah and I am doing research with Prof. K. Mearns and Dr. Nana Agyepong, a lecturer in the Department of Environmental Science towards a PhD at the University of South Africa. We are inviting you to participate in a study entitled "The Impact of Climate Change on Hydropower Generation: A Case Study Of Ghana's Akosombo dam In Ghana"

WHAT IS THE PURPOSE OF THE STUDY?

I am conducting this research to find out how climate change has affected hydropower generation using Ghana's Akosombo dam as a case steady

WHY AM I BEING INVITED TO PARTICIPATE?

You are being invited to participate in this study because I believe with your status and having worked with your organization whose operations are related to the Akosombo dam and Climate Change Policies and having stayed around the catchment area of study for some time, you may have an extensive knowledge on how climate change might have affected the efficiency of the Akosombo dam and its surrounding area.

I sought permission from the Head of organization/opinion leader to select some personnel to participate in this study and you were part of the chosen participants. In all five participants have been chosen from your organization. The organizations expected to participate in this study include the Volta River Authority, the Energy Commission, the Water Research Institute, the Ghana Meteorological Agency and

approximately hundred inhabitants (participants) living around the catchment area of study. All the chosen participants were selected because it is believed they have the requisite knowledge when it comes to the topic under study.

WHAT IS THE NATURE OF MY PARTICIPATION IN THIS STUDY?

Your role as a participant in the study is to help provide answers to the questionnaire and interview that will help fulfill the research questions of this study. The study involves answering of questionnaires and semi-structured interviews. The kinds of questions to be asked are based on climate change particularly on its impact on the power generation capacity of the Akosombo dam. It will also be based on policies that has been adopted or being adopted to adapt or mitigate the climate change effect. The expected duration of participation is approximately fifty (50) minutes, twenty-five (25) minutes to complete the questionnaire and another twenty-five (25) to complete the interviews. Thus the time allocated to conduct the interviews and the questionnaires is approximately twenty-five (25) minutes each.

CAN I WITHDRAW FROM THIS STUDY EVEN AFTER HAVING AGREED TO PARTICIPATE?

Participating in this study is voluntary and you are under no obligation to consent to participation. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a written consent form. You are free to withdraw at any time and without giving a reason. But once the questionnaire has been completed and submitted, you will not be able to withdraw it. The questionnaire however will not have your name on it.

WHAT ARE THE POTENTIAL BENEFITS OF TAKING PART IN THIS STUDY?

The potential benefit of taking part in this study is that under the acknowledgement section of the report, acknowledgements will be given to participants of the various organizations. Your organizations will also be acknowledged including the community. The community, society and the country as a whole will benefit in that the information gathered after the report will be used by policy makers in mitigating the effect of climate change on the hydropower generation of the Akosombo dam. This will ensure that the power generation of the dam is not interrupted as much as possible. It will also ensure that the dam be made adaptable to climate change to ensure its continuous power generation.

ARE THEIR ANY NEGATIVE CONSEQUENCES FOR ME IF I PARTICIPATE IN THE RESEARCH PROJECT?

The potential inconvenience has to take approximately fifty minutes of your time to answer the questionnaire and the interviews. It will be a little discomfortable having to take you to a different location for the answering of the questionnaire and the interviews.

Among other foreseeable risk in participating in this research project may be:

- It is possible that you may divulge some information that may be seen as institutional secrets and are not to be put in the public domain
- You may give an information about yourself, families or the institutions that they are not to be made known
- It is possible that you may feel obliged to give responses and may not have your freedom during the data collection
- I the researcher may be tempted to take more of your time than stipulated
- I the researcher may contravene some cultural values of yours or your institution.
- There may be a risk of associating you with this research project when others identify you as the person participation in this research

However there are measures that will be taken to forestall the above risk, these include:

- As the answering of questionnaire and interview goes on, I will remind you periodically not to be tempted in divulging certain information that is seen as institution secrets thereby acting contrary to their institutional policies.
- I will ensure you go through your own answers at the end of the questionnaire and the interview to ensure every information is suitable and can be used for the research purposes
- I will state the end of every page of the questionnaire that respondents are not obliged to give responses and may feel free to opt out of the research process if they want to.
- I will be cautions to do away with irrelevant chats so as not to eat into the allowed time of the respondents
- I will ensure that all allowable and unallowable procedures of the institutions to carry out the research are known so as not to contravene any during the research
- Confidentiality will be high and names will not be written on any questionnaire

WILL THE INFORMATION THAT I CONVEY TO THE RESEARCHER AND MY IDENTITY BE KEPT CONFIDENTIAL?

Your name will not be recorded anywhere and no one will be able to connect you to the answers you give. Your answers will be given a code number or a pseudonym and you will be referred to in this way in the data, any publications, or other research reporting methods such as conference proceedings.

Your answers may be reviewed by people responsible for making sure that research is done properly, including the transcriber, external coder, and members of the Research Ethics Review Committee but because your answers are coded they will not be able to link the answers to you. In anycase, records of this research will be available only to people working on the study, unless you give permission for other people to see the records.

A report of the study may be submitted for publication, journal article, conference proceedings or a research report but individual participants will not be identifiable in such a report since their answers are coded and names kept confidential.

HOW WILL THE RESEARCHER(S) PROTECT THE SECURITY OF DATA?

Hard copies of your answers will be stored by the researcher for a period of five years in a locked cupboard/filing cabinet in the researcher's office for future research or academic purposes; electronic information will be stored on a password protected computer. Future use of the stored data will be subject to further Research Ethics Review and approval if applicable. After the five years of locking the data hard copies will be shredded and electronic copies will be permanently deleted from the hard drive of the computer through the use of a relevant software program.

WILL I RECEIVE PAYMENT OR ANY INCENTIVES FOR PARTICIPATING IN THIS STUDY?

There will be no anticipated cost incurred by the participant.

HAS THE STUDY RECEIVED ETHICS APPROVAL

This study has received written approval from the Research Ethics Review Committee of the College of Agriculture & Environmental Sciences, Unisa. A copy of the approval letter can be obtained from the researcher if you so wish.

HOW WILL I BE INFORMED OF THE FINDINGS/RESULTS OF THE RESEARCH?

If you would like to be informed of the final research findings, please contact Mr. Ezekiel Acquaah on +233 277493259 and on the email: ezeake@yahoo.com. The findings are accessible for five years. Should you require any further information or want to contact the researcher about any aspect of this study, please contact me with the same contact information as above.

Should you have concerns about the way in which the research has been conducted, you may contact Prof. Kevin Mearns, on +27 82 337 0074 and on email: mearnkf@unisa.ac.za
Contact the research ethics chairperson of the Research Ethics Review Committee of the College of Agriculture & Environmental Sciences**,** Dr M Togo on +27 11 471 3934, togom@unisa.ac.za if you have any ethical concerns.

Thank you for taking time to read this information sheet and for participating in this study.
Thank you.

Mr. Ezekiel Acquaah

CONSENT TO PARTICIPATE IN THIS STUDY

I, _____ (participant name), confirm that the person asking my consent to take part in this research has told me about the nature, procedure, potential benefits and anticipated inconvenience of participation.

I have read (or had explained to me) and understood the study as explained in the information sheet.
I have had sufficient opportunity to ask questions and am prepared to participate in the study.
I understand that my participation is voluntary and that I am free to withdraw at any time without penalty (if applicable). I am aware that the findings of this study will be processed into a research

report, journal publications and/or conference proceedings, but that my participation will be kept confidential unless otherwise specified.

I agree to the recording of using a mobile phone recorder.

I have received a signed copy of the informed consent agreement.

Participant Name & Surname……

Participant Signature……..Date……

Researcher's Name & Surname: Mr. Ezekiel Acquaah

Researcher's signature Date: May 4, 2017

APPENDIX C: PERMISSION LETTERS FROM INSTITUTIONS FOR DATA COLLECTION

ENERGY COMMISSION

Ghana Airways Avenue, Airport Residential Area (behind Alliance Française)

Private Mail Bag
Ministries Post Office
Accra - Ghana

Tel: 0302 813756/7
Fax: 0302 813764
IDD Code: (233-302)
E-mail: info@energycom.gov.gh
Website: http://www.energycom.gov.gh

EC/SPPD/USA/2017

January 6, 2017

Mr. Ezekiel Acquaah
PhD Student Researcher
University of South Africa
Preller Street, Muckleneuk Ridge
City of Tshwane
P.O. Box 392 UNISA 0003
South Africa

Dear Sir,

RE: REQUEST FOR PERMISSION TO CONDUCT RESEARCH AT THE ENERGY COMMISSION

Reference is made to your letter dated December 19, 2016 requesting for permission to conduct research with the Energy Commission.

I am glad to inform you that the Commission has accepted your request for that matter approval has been granted for your research work at the commission.

Regarding nominating specific contact persons, we suggest that you visit our office and we will introduce you to the team assigned to help you with your research.

Yours Sincerely

Dr. Joseph Essandoh-Yeddu
Ag. Director (SPPD)

GHANA METEOROLOGICAL AGENCY

P. O. Box LG 87, Legon-Accra, Ghana
Tel: +233-21-701 2520/1
Fax: +233-21-701 2519
E-mail: meteo@africaonline.com.gh
Website: www.meteo.gov.gh

Our Ref.: Met-9/Vol.20/15
Your Ref. No. .....

22nd **December, 2016**

MR. EZEKIEL ACQUAAH
PhD STUDENT RESEARCHER
UNIVERSITY OF SOUTH AFRICA
P. O. BOX 392
SOUTH AFRICA

RE- REQUEST FOR PERMISSION TO CONDUCT RESEARCH AT THE GHANA METEOROLOGICAL SERVICES

Your letter dated 19th December, 2016 refers.

I have the pleasure to inform you that approval has been given you to undergo your research with the Agency.

The under listed Officers are authorised to participate in the research.

1. Mr. Charles K. Yorke
2. Mrs. Francisca Martey
3. Mr. Edward Osei Akoto
4. Mr. Robert Cudjoe
5. Mr. Richmond Obeng.

Counting on your cooperation in this regard.

Yours faithfully,

FOR: DIRECTOR-GENERAL
ERIC ASUMAN
DEPUTY DIRECTOR-GENERAL (SS)

VOLTA RIVER AUTHORITY

Our Ref: F:D/HSM/190/023/17

Your Ref:

Date: January 17, 2017

Mr. Ezekiel Acquah
University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
P. O. Box 392 UNISA 0003
South Africa

Tel: 0277493259

Dear Sir

RE: REQUEST FOR PERMISSION TO CONDUCT RESEARCH AT THE VOLTA RIVER AUTHORITY

We write to acknowledge receipt of your letter dated December 19, 2016 on the above-mentioned subject.

Please be advised that your request for the Volta River Authority (VRA) to participate in your research work towards a PHD at the University of South Africa in a study titled "***The Impact of Climate Change on Hydropower Generation: A Case Study of Ghana's Akosombo Dam in Ghana***" has been accepted.

Your contact person in VRA shall be Ben A. Sackey, Manager, Environment & Social Impact, and he shall be responsible for coordinating your activities with other staff members in VRA. Mr. Sackey can be reached through email: ben.sackey@vra.com or Mobile +233-24-334-4779.

Yours faithfully

Ing Theo Nii Okai
DIRECTOR, ENVIRONMENT & SUSTAINABLE DEVELOPMENT

Electro Volta House - P. O. Box MB 77, Accra, Ghana. Phone: +233-30-2664941-9 FAX: +233-30-2662610
Website: www.vra.com

COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH
WATER RESEARCH INSTITUTE

Our Ref: CSIR/WRI/AD.38/SF.2/Vol.5/119 6th January, 2017

Mr. Ezekiel Acquaah
University of South Africa
Preller Street, Muckleneuk Ridge
City of Tshwane
P. O. Box 392 UNISA 0003
South Africa

Dear Sir,

RE: REQUEST FOR PERMISSION TO CONDUCT RESEARCH AT THE WATER RESEARCH INSTITUTE

I acknowledge receipt of your letter dated 19th December, 2016 on the above-mentioned subject.

I wish to inform you that your request has been approved to conduct a research work on the topic: "The Impact of Climate Change Hydro-power Generation: A case study of Ghana's Akosombo Dam in Ghana" in our Institute. In addition, Dr. Emmanuel Obuobie, Senior Research Scientist of our Institute will assist you to carry out your research work.

Thank you.

Yours faithfully,

Dr. Osmund D. Ansa-Asare
Director

Head Office: P. O. Box AH 38, Achimota. Ghana Or P. O. Box M 32, Accra
Tel: (+233-302) 775352, 779514/5
Fax: (+233-302) 777170. Email: info@csir-water.com

Location: CSIR Premises, Airport Res. Area
Behind Golden Tulip
Off 37 - Achimota Road

APPENDIX D: SURVEY QUESTIONNAIRE

QUESTIONNAIRE
(For Energy Commission)

The bearer of this questionnaire is a doctoral student of the University of South Africa, Department of Environmental Sciences. He is carrying out a research on "**THE IMPACT OF CLIMATE CHANGE ON HYDROPOWER GENERATION: A CASE STUDY OF GHANA'S AKOSOMBO DAM IN GHANA.**

The purpose of the research is to investigate and determine the extent and form to which climate change has impacted the water levels in the Akosombo dam and its energy generating capabilities. This is expected to be done by determining the nature and extent of changes in rainfall quantities and patterns in the Akosombo dam catchment area, identify changes in the Akosombo dam features that may have affected the dam's electricity generation activity and determine the nature of climate change adaptation policies and practices adopted and their impact on water inflows into the dam.

Participants are assured of confidentiality and that all information gathered will be used for research purposes and possible publication of academic papers only. Issues of privacy with regards to participants and data will be observed at all times during the research and publication processes at any time without giving reasons.

..... ……

Sign: Student Researcher Sign: Respondent

Thank you for your cooperation.

A. Participant's Information

Date		Place			
Respondent's work designation		Male		Female	
Period in this role					

Scope of responsibility	

B. Climate Information

1. Is climate change critical to the operations of the Energy Commission (E.A)? Yes [ ] No [ ]

2. If "Yes" what role does climate change play in the operations of the E.A.? ……

……

……

……

3. If 'No', why is it so? ……..

……

……

……

4. Does the Commission collect climate data? Yes [ ] No [ ]
Explain why is acting this way
…….....

……..

……

……

5. In the Table below indicate how Ghana's weather patterns have changed from 1970 to 2016

Parameter	Decrease	Increase	No change
Rainfall quantities			
Flood frequencies			
Hail storm frequency			
Heat wave frequency			

Cold spell frequency			
Wild fires			
Other			

6. What do you think has caused the changes mentioned in question 5?

……

……

……

……

7. Do you think or know if and how these changes mentioned in question 5 have affected Ghana's electricity generating capacity especially in hydropower generation?

……..

……..

……...

……

8. Does the Energy Commission directly monitor the changes mentioned in question 5 in the catchment areas of Ghana's hydropower facilities?

Yes		No	

If 'Yes', what aspect of changes mention in question 7 does it monitor and how is it carried out and if 'No' how does it get its information about the changes?

……

……

……

……

9. In the table below indicate the total hydropower generation in Ghana output in the specified periods.

Time period	Power output (MW)

1970 - 1979	
1980 - 1989	
1990 - 1999	
2000 - 2009	
2010 – Date	

10. Indicate how the following have changed in the catchment areas of Ghana's hydropower facilities from 1970 to date (2017)

Parameter	Decrease	Increase	No change
Human population			
Livestock population			
Urban settlements			
Rural Settlement			
Agricultural activities			
Vegetation cover			
Soil erosion			
Number of dams, lakes and other water surface water storage facilities			
Other			

11. Are the changes mentioned in question 10 critical for the Energy's Commission's mandate?
Yes [ ] No [ ]

12. If "Yes", how has the changes mentioned in question 10 affected the Commission's mandate?

……

……

……

……

13. Do you think the changes mentioned in question 10 have affected the electricity generation of hydropower plants in particular?

Yes		No	

14. If “Yes” in what way have the changes mentioned in question 10 affected electricity generation of hydropower plants?

……

……

……

……

……..

15. How is the Commission addressing the impacts of the changes mentioned in question 10?

……

……

……

……

16. Does the Energy Commission collaborate with other departments (Ministries) to manage the climate change challenge? Yes [ ] No [ ]

17. If ”Yes” what are these departments (Ministries), their roles and how is the collaboration carries out? ……..

……

……

……

18. If ‘No’ why is the Commission not collaborating with departments (Ministries)?

……

……

……

……

19. Does the Energy Commission collaborate with the private sector and international organization to manage the climate change challenge? Yes [ ] No [ ]

20. If ”Yes” who are these private sectors and international organizations, their roles and how is the collaboration carried out?

……

……

……

……

21. What major policy changes (if any) has the Commission engaged with to manage climate related issues affecting energy production in hydropower facilities from 1970 to date (2017):

Period Policy Was Developed	Name of Policy	Observed Impact of policy
1970 - 1979		
1980 - 1989		
1990 - 1999		
2000 - 2009		
2010 – Date		

22. What top five policy and practical actions has the Commission engaged with to manage the climate change challenge?

Policy Name/Action	Practical Action

23. What is the nature of these policy actions?

……

……

……

……

24. How are the climate change policies expected to minimize the impact of climate change on the country's energy production especially hydropower energy?

……

……

Thank You!

QUESTIONNAIRE
(For Ghana Meteorological Agency [GMA])

The bearer of this questionnaire is a doctoral student of the University of South Africa, Department of Environmental Sciences. He is carrying out a research on "**THE IMPACT OF CLIMATE CHANGE ON HYDROPOWER GENERATION: A CASE STUDY OF GHANA'S AKOSOMBO DAM IN GHANA.**

The purpose of the research is to investigate and determine the extent and form to which climate change has impacted the water levels in the Akosombo dam and its energy generating capabilities. This is expected to be done by determining the nature and extent of changes in rainfall quantities and patterns in the Akosombo dam catchment area, identify changes in the Akosombo dam features that may have affected the dam's electricity generation activity and determine the nature of climate change adaptation policies and practices adopted and their impact on water inflows into the dam.

Participants are assured of confidentiality and that all information gathered will be used for research purposes and possible publication of academic papers only. Issues of privacy with regards to participants and data will be observed at all times during the research and publication processes at any time without giving reasons.

..... ……
Sign: Student Researcher Sign: Respondent

Thank you for your cooperation.

A. Participant's Information

Date		Place			
Respondent's work designation		Male		Female	
Period in this role					
Scope of responsibility					

B. Climate Information

1. Is climate change critical to the operations of the Ghana Meteorological Agency (GMA)?
   Yes [ ] No [ ]

2. If “Yes”, why and how is it critical in the operations of the GMA and if “No” why is it not critical?

……

……

……

3. Does the GMA collect climate data? Yes [ ] No [ ]

4. If “Yes” where does the GMA collects its climate data and if “No” why is it not collecting the data?

……

……..

……

5. In the Table below indicate how the ff weather parameters have changed particularly within the Akosombo catchment area from 1970 to 2016

Parameter	Decrease	Increase	No change
Rainfall quantities			
Flood frequencies			
Droughts			
Hail storm frequency			
Heat wave frequency			
Cold spell frequency			
Wild fires			
Other (if any)			

6. What do you think has caused the changes?

……

……

……

……

7. Do you think or know if and how these changes have affected Ghana's electricity generating capacity especially in hydropower generation?

……..

……..

……...

8. Does the Ghana Meteorological Agency have any climate change policies? Yes [ ] No [ ]

9. If 'Yes' what are the major focus areas of these policies and if 'No' why not?
……

……

……

10. What major policy changes (if any) has the GMA engaged with to manage climate related issues affecting energy production in hydropower facilities from 1970 to date (2017):

Period Policy Was Developed	Name of Policy	Observed Impact of policy
1970 - 1979		
1980 - 1989		
1990 - 1999		
2000 - 2009		
2010 – Date		

11. What top five policy and practical actions has the GMA engaged with to manage the climate change challenge?

Policy Name/Action	Practical Action

12. Indicate the level of intensity of the ff weather parameters from 1970 to 2016 and their impact at the Akosombo dam area.

Parameters	Intensity				Observed Impact
	Very High	High	Low	Very Low	
Flooding					
Hail storm					
Heat wave					
Cold					
Droughts					

13. Averagely how often has the listed weather condition been occurring from 1970 to 2016 at the Akosombo dam area.

Weather condition	Frequency		
	None at all	Seldom	Often
Flooding			

Hail storm			
Heat wave			
Cold spell			
Wild fires			
Drought			

14. Why do you think these weather events are occurring at the indicated frequencies?

……

……

……

15. Were these frequencies predicted?
Yes [ ] No [ ]

If 'Yes' what signs led to the predictions and if 'No' why was it not predicted?

……

……

……

……..

……

16. Recounting from 1970 to 2016 how long does the following weather condition stay on when they occur?

Weather condition	Duration	
	Short	Long

Heat waves		
Cold spell		
Drought		

17. Are there any other reasons apart from climate change attributable to the current weather conditions? Yes [ ] No [ ]

If yes what are the other reasons and if “No” what explains these conditions?

……

……

……

……

Thank you!

QUESTIONNAIRE
(For Volta River Authority [VRA])

The bearer of this questionnaire is a doctoral student of the University of South Africa, Department of Environmental Sciences. He is carrying out a research on "**THE IMPACT OF CLIMATE CHANGE ON HYDROPOWER GENERATION: A CASE STUDY OF GHANA'S AKOSOMBO DAM IN GHANA.**

The purpose of the research is to investigate and determine the extent and form to which climate change has impacted the water levels in the Akosombo dam and its energy generating capabilities. This is expected to be done by determining the nature and extent of changes in rainfall quantities and patterns in the Akosombo dam catchment area, identify changes in the Akosombo dam features that may have affected the dam's electricity generation activity and determine the nature of climate change adaptation policies and practices adopted and their impact on water inflows into the dam.

Participants are assured of confidentiality and that all information gathered will be used for research purposes and possible publication of academic papers only. Issues of privacy with regards to participants and data will be observed at all times during the research and publication processes at any time without giving reasons.

..... …….....

Sign: Student Researcher Sign: Respondent

Thank you for your cooperation.

:

A. Participant's Information

Date		Place			
Respondent's work designation		Male		Female	
Period in this role					
Scope of responsibility					

B. Climate Information

1. Is climate change critical to the operations of the VRA? Yes [ ] No [ ]

2. If 'Yes', what role does climate change play in the operations of the VRA? And if "No' why is is it not critical?

……

……

……

3. Does the VRA collect climate data? Yes [ ] No [ ]

If "Yes" where does the VRA collects its climate data? And if "No" why does it not collect this data and where does it get its data from?

……..

……

……

4. In the Table below indicate how Ghana's weather patterns have changed from 1970 to 2016.

Parameter	Decrease	Increase	No change
Flood frequencies			
Drought frequencies			
Hail storm frequency			
Heat wave frequency			
Cold spell frequency			
Wild fires frequencies			
Other (specify)			

5. What do you think has caused these changes in question 4?

……

……

……

6. Does the VRA monitor these changes mentioned in question 4 in the catchment areas of Ghana's hydropower facilities?

Yes		No	

7. If 'Yes', what aspect of changes does it monitor and how is it carried out and if "No" why does it not monitor these changes?

……

……

……

……

8. Do you think or know if and how these changes have affected Ghana's electricity generating capacity especially in hydropower generation?

……..

……..

……...

……

9. In the table below indicate the total hydropower generation in Ghana output in the specified periods.

Time period	Power output (MW)
1970 - 1979	
1980 - 1989	
1990 - 1999	
2000 - 2009	
2010 – Date	

10. Indicate how the following have changed within and around the Akosombo hydropower facility from 1970 to date (2017)

Parameter	Decrease	Increase	No change
Human population			
Live stock population			
Urban settlements			
Rural Settlement			
Agricultural activities			
Vegetation cover			
Soil erosion			
Number of dams, lakes and other water surface water storage facilities			

Do you think these changes have affected the electricity generation of the Akosombo power plant in particular?

Yes		No	

11. If 'Yes' in what way have these affected electricity generation of the Akosombo power plant and if 'No' why have these changes not affected electricity generation at the Akosombo power plant

……

……

……

……

12. How is the VRA addressing the impacts of the changes mentioned in question 10?

……

……

……

13. Are the changes mentioned in question 10 critical for the VRA's mandate?

Yes		No	

If ‘Yes’, how are they critical and if “No” why are they not critical?

……

……

……

……

14. Does the VRA collaborate with other departments (Ministries) to manage the climate change challenge? Yes [ ] No [ ]

If ‘Yes’ what are these departments (Ministries), their roles and how is the collaboration carries out and if “No” why is the VRA not collaborating with other departments (Ministries) to manage the climate change challenge

……

……

……

……

15. Does the VRA collaborate with the private sector and international organizations to manage the climate change challenge? Yes [ ] No [ ]

If ‘Yes’ who are these private sectors and international organizations, their roles and how is the collaboration carried out? If “No” why is the VRA not collaborating with private sector and international organizations to manage the climate change challenge?

……

……

……

……

16. What major policy changes (if any) has the VRA engaged with to manage climate related issues affecting energy production in hydropower facilities from 1970 to date (2017):

Period Policy Was Developed	Name of Policy	Observed Impact of policy
1970 - 1979		
1980 - 1989		
1990 - 1999		
2000 - 2009		
2010 – Date		

17. What top five policy and practical actions has the VRA engaged with to manage the climate change challenge?

Policy Name/Action	Practical Action

18. What is the nature of these policy actions?
……

……

……

……

19. How are the climate change policies expected to minimize the impact of climate change on the country's energy production of the Akosombo dam?

……

……

……

……

20. Provide any other observed changes in the features of the Akosombo dam over the stated period, the possible reason(s) attributed to the changes and the response action taken by management:

Period of Change Occurrence	Change in Feature	Reasons attributed to the Change	Action taken by Management
1970 – 1979			
1980 - 1989			
1990 - 1999			
2000 - 2009			
2010 - Date			

How have these changes affected the operating efficiency of the Akosombo dam

……

……

……

……

……

21. How have the changes affected the country (Ghana) as a whole?

……

……

……

……

……

Thank You!

QUESTIONNAIRE
(For Water Research Institute[WRI])

The bearer of this questionnaire is a doctoral student of the University of South Africa, Department of Environmental Sciences. He is carrying out a research on "**THE IMPACT OF CLIMATE CHANGE ON HYDROPOWER GENERATION: A CASE STUDY OF GHANA'S AKOSOMBO DAM IN GHANA.**

The purpose of the research is to investigate and determine the extent and form to which climate change has impacted the water levels in the Akosombo dam and its energy generating capabilities. This is expected to be done by determining the nature and extent of changes in rainfall quantities and patterns in the Akosombo dam catchment area, identify changes in the Akosombo dam features that may have affected the dam's electricity generation activity and determine the nature of climate change adaptation policies and practices adopted and their impact on water inflows into the dam.

Participants are assured of confidentiality and that all information gathered will be used for research purposes and possible publication of academic papers only. Issues of privacy with regards to participants and data will be observed at all times during the research and publication processes at any time without giving reasons.

..... …….....
Sign: Student Researcher Sign: Respondent

Thank you for your cooperation.

A. Participant's Information

Date		Place			
Respondent's work designation		Male		Female	
Period in this role					
Scope of responsibility					

B. Climate Information

1. Is climate change critical to the operations of the Water Research Institute (WRI)?
   Yes [ ] No [ ]

2. If ‘Yes’, what critical role does climate change play in the operations of the WRI? ……

……

……

……

3. If ‘No’, why is it so? …….

……

……

……

4. Does the WRI collect climate data? Yes [ ] No [ ]

If ‘Yes’ where does the WRI collects its climate data and if ‘No’, why is the WRI not collecting climate data?

……..

……

. …….....

……..

……

5. Is the WRI concerned about climate change? Yes [ ] No [ ]

If ‘Yes’, what concerns WRI on climate change? ……..

……

……

……

……

6. What is the WRI doing to address the climate change concerns? ……

……

……

……..

7. Does the WRI have climate change Policies? Yes [ ] No [ ]

8. If 'Yes' what are the major focus areas of these policies? ……

……

……

……

9. If 'No', any reasons for not having? ……

……

……

10. What major policy changes (if any) has the WRI engaged with to manage climate related issues affecting energy production in hydropower facilities from 1970 to date (2017):

Period Policy Was Developed	Name of Policy	Observed Impact of policy
1970 - 1979		
1980 - 1989		
1990 - 1999		
2000 - 2009		
2010 – Date		

11. What top five policy and practical actions has the WRI engaged with to manage the climate change challenge?

Policy Name/Action	Practical Action

12. Provide any observed changes in the water level of the Akosombo dam over the stated period, the possible reason(s) attributed to the changes and any scientific advice given to reverse any negative change.

Change in Water Level				Reasons attributed to the Change	Period of Change Occurrence	Scientific advice given to reverse negative change in water level
V. H	High	Low	V. L			
					1970 - 1979	
					1980 - 1989	
					1990 - 1999	
					2000 - 2009	
					2010 - Date	

V.H = Very High, V.L = Very Low

13. Apart from climate change would you say there are any other things that cause low levels of water in the Akosombo dam?

……

……

……

14. How do the following conditions affect the water levels in general?

Condition	Impact on Water bodies
Rainfall quantities	
Flood frequencies	

Hail storm frequency	
Temperature/ Heat wave frequency	
Cold spell frequency	
Wild fires	
Siltation	
Human Activities (fishing, farming etc.)	

Thank You!

APPENDIX E: INTERVIEW GUIDE

INTERVIEW GUIDE
(For Inhabitants in Akosombo Area)

The bearer of this interview guide is a doctoral student of the University of South Africa, Department of Environmental Sciences. He is carrying out a research on "**THE IMPACT OF CLIMATE CHANGE ON HYDROPOWER GENERATION: A CASE STUDY OF GHANA'S AKOSOMBO DAM IN GHANA.**

The purpose of the research is to investigate and determine the extent and form to which climate change has impacted the water levels in the Akosombo dam and its energy generating capabilities. This is expected to be done by determining the nature and extent of changes in rainfall quantities and patterns in the Akosombo dam catchment area, identify changes in the Akosombo dam features that may have affected the dam's electricity generation activity and determine the nature of climate change adaptation policies and practices adopted and their impact on water inflows into the dam.

Participants are assured of confidentiality and that all information gathered will be used for research purposes and possible publication of academic papers only. Issues of privacy with regards to participants and data will be observed at all times during the research and publication processes at any time without giving reasons.

..... …….....
Sign: Student Researcher Sign: Respondent

Thank you for your cooperation.

A. Participant's Information

Date		Place			
How long have you lived in the Akosombo area (in years)		Male		Female	
Age (years)	18 – 20 [ ] 20 – 30 [ ] 30 – 40 [ ] 40 – 50 [ ] 50 – 60 [ ] 60+				
Level of education	Primary [ ] Secondary [ ] Vocational [ ] Tertiary [ ]				
Occupation					

1. What are the most common means of livelihood (i.e. fishing, farming, livestock rearing, hunting etc) in this area?

2. Indicate how these livelihood activities mentioned in question 1 changed (increased, decreased or no change) from the time it started up to date?

Livelihood activities	Change		
	Increased	Decreased	No change
Fishing			
Livestock rearing			
hunting			
Farming			
Other (Specify):			

3. What might be the cause of any change in the livelihood activities?

B. Climate Information

4. State any observations in the changes of weather patterns (eg. heavy rainfall, droughts, very high or low temperatures, etc.) you might have made over the past ten (10) years.

5. In the table below indicate the frequency of extreme weather events in the area over the last 10 to 30 years.

Weather Event Occurrence	Frequency				
	Once a week	Once in two weeks	Once in three weeks	Once a month	None at all in a year
Heavy Rainfall					
Flooding					
Hail storm					
Heat waves					
Cold spells					
Wild fires					
Others (Specify):					

6. What is and has been the intensity of these extreme weather events from 1970 to date (2017)?

Climate Event	Intensity				
	Very high	High	Low	Average	Very low
Rainfall					
Droughts					
Flooding					
Hail storm					
Heat waves					
Cold spells					
Wild fires					

7. What do you think has caused the kind of frequency and intensity of the extreme weather events mentioned in questions 5 and 6?

8. What are some of the traditional ways residents use to predict future weather events if any?

9. How are you managing the changes of these extreme weather events?

10. How is the Government or any organization assisting residents to manage these extreme weather events if any?

11. Indicate how the following have changed within your area from 1970 to date (2017)

Parameter	Decrease	Increase	No change
Human population			
Livestock population			
Urban settlements			
Rural Settlement			
Agricultural activities			
Vegetation cover			
Soil erosion			
Number of dams, lakes and other water surface water storage facilities			
Other			

12. What do you think is the cause of these changes mentioned in question 11?

13. What have you done to cope with all or some of the changes above?

14. Please explain what you understand by climate change:

15. Which dam/lake/reservoir or river do you depend on in the area for your activities (eg. washing, drinking, bathing etc.)

16. When was that dam/lake/reservoir or river do you depend on built? .....

17. Who build the dam/lake or water reservoir?
Government [ ] Community [ ] NGO [ ] other [ ], specify……..

18. Explain how you think your water sources could be affecting other water sources downstream?

19. What advice would you give to those that leave downstream of your water source?

20. Explain how you think your activities (eg. washing, drinking, bathing etc.) would either have or not have impact on the Akosombo dam.

21. Why is the Akosombo dam important to Ghana?

22. Which activities do you think have the highest impact on the Akosombo dam?

23. What can be done to reduce the adverse impacts of some of the activities in your area on the Akosombo dam?

24. What are you doing to reduce the adverse impacts of some of the activities in your area on the Akosombo dam?

25. Explain how you think your answers in question 24 will reduce the adverse impacts in the dam?

26. Any additional comments?

Thank you!

APPENDIX F: RESPONSE FROM THE WORLD METEOROLOGICAL AGENCY

Re: E-mail from WMO Catalogue for Climate Data2
Yahoo/Inbox

-----Original Message-----
From: Ezekiel via WMO Catalogue for Climate Data <gabor@ooxo.nl>
Sent: donderdag 30 januari 2020 19:00
To: Siegmund, Peter (KNMI) <peter.siegmund@knmi.nl>
Subject: E-mail from WMO Catalogue for Climate Data

Submitted on Thursday, January 30, 2020 - 17:59 Submitted by anonymous user: 197.255.127.134 Submitted values are:

E-mail: ezeake@yahoo.com
Name: Ezekiel
Message: I would be grateful to receive rainfall data (2000 to 2020) within the catchment areas of the Akosombo dam. These areas are in Ghana West Africa.
Thanks

The results of this submission may be viewed at:
https://climatedata-catalogue.wmo.int/node/6/submission/12

Peer Hechler <phechler@wmo.int>
To:Ezekiel
Cc:climate-data@wmo.int,wcdmp wcdmp
Fri, Jan 31, 2020 at 2:41 PM
Dear Ezekiel,

Thank you very much for your request.
The best way to receive these data is to contact your National Meteorological Service: https://www.meteo.gov.gh/gmet/
You may also wish to explore our World Data Centre at ncdc.noaa.gov/data-access for data that have been shared internationally.

Best regards;

Peer.

Peer HECHLER (Mr.)
Scientific Officer
Climate Monitoring and Policy Services Division
Services Department

World Meteorological Organization
7 bis, avenue de la Paix
Case postale 2300
CH 1211 Genève 2
SUISSE
Tel.: +41 (0)22 730 8224
phechler@wmo.int

APPENDIX G: SUMMARY OF SURVEY RESULTS ON THE DEALINGS OF CLIMATE CHANGE BY THE GOVERNMENT AGENCIES AND ASSESSMENT OF COMMUNITY KNOWLEDGE ON CLIMATE CHANGE

Questions	Agency			
	EC	**GMA**	**VRA**	**WRI**
Are climate change issues integral part of the agency	No	Yes	Yes	Yes
Are the operations of the agency affected by climate change	Yes	Yes	Yes	Yes
Does the agency have climate change policies	No	No	Yes	No
Does the agency monitor trends in climate change	No	Yes	Yes	No
Do human activities affect operations of the agency	No	No	Yes	Yes
Does the agency collaborate with other agencies (local or international) in dealing or conducting climate change research	Yes	Yes	Yes	Yes
	Assessment of community knowledge on climate change			
Comments by members of community in relation to climate change	*"Sometimes we experience low rainfalls and some other times we experience high volumes of rainfall. We see these as normal and depends on when God wants to release more rains or not."*			
	"I don't think falling of trees has anything to do with the rainfall."			
	"Since I came to live here in 1962, the rainfall has been the same, I don't see any difference".			
	"To me climate change is a change in the weather conditions."			
	"I a farmer and have never engaged in tree planting exercise before."			
General comments by the agencies and community members indicating the impact of climate change				
There are cases of intense flooding that sometimes destroys our farm crops. This makes us lose money because there is no crop to sell.				
Most of the times we experience more flooding in June to the extent of having to relocate to stay at a place on a high-level ground to avoid being swallowed in the floods.				
Most of the times we shut down some of the turbines due to low water levels resulting from prolonged dry periods. This subsequently leads to suboptimal operation of the dam.				
The water in our fishponds is drying up gradually because the rains are not falling as expected these days.				
One of the worst performances of the Akosombo dam occurred around 2010. The energy production of dam was reduced to 175MW per day instead of the expected 1020MW per day.				
The surrounding rivers and other sources of water used for irrigation are drying up. This is negatively affecting the growth of our plants.				
There seems to be a lot of drying up of our water bodies which must be tackled swiftly otherwise there would be dire consequences on hydropower production and other sectors of the economy.				
The dam has been experiencing some sort of climate change-linked water shortages leading to fluctuating water levels particularly in-between the rain and dry season.				
EC = Energy Commission	GMA = Ghana Meteorological Agency	VRA = Volta River Authority	WRI = Water Research Institute	