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TITLE: ASSESSING CLIMATE CHANGE AND VARIABILITY IMPACTS ON WATER RESOURCES AND SMALLHOLDER AGRICULTURE IN THE OFFIN SUB BASIN OF GHANA

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DEDICATION

This work is dedicated to my dad, mum, and siblings

PAN AFRICAN UNIVERSITY

STATEMENT OF THE AUTHOR

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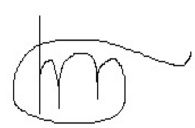

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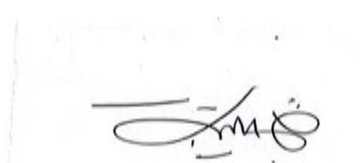

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LIST OF ABBREVIATIONS

AGRA: Alliance for a Green Revolution in Africa

AIDS: Acquired Immune Deficiency Syndrome

℃: Degree Celcius

CIGI: Centre for International Governance Innovation

CSIR: Council for Scientific and Industrial Research

CSIR: Council for Scientific and Industrial Research

ENSO: El Nino – Southern Oscillation

FAO: Food and Agriculture Organization

GDP: Gross Domestic Product

GIZ: Deutsche Gesellschaft für Internationale Zusammenarbeit

GMET: Ghana Meteorological Agency

GNCCAS: Ghana National Climate Change Adaptation Strategy

GSS: Ghana Statistical Service

GWCL: Ghana Water Company Limited

HIV: Human Immunodeficiency Virus

IFPRI: International Food Policy Research Institute

IPCC: Intergovernmental Panel on Climate Change

IWRM: Integrated Water Resource Management

m^3/s: Cumec

mm: Millimeter

NEPAD: New Partnership for Africa's Development

NOAA: National Oceanic and Atmospheric Administration

PAUWES: Pan African University Institute of Water and Energy sciences

SAI: Standard Anomaly Index

SDG: Sustainable Development Goals

SDG: Sustainable Development Goals

SEI: Stockholm Environmental Institute

SPSS: Statistical Package for the Social Science

UN: United Nations

UNDESA: United Nations Department of Economic and Social Affair

UNDP: United Nations Development Programme

UNESCO: United Nations Educational, Scientific, and Cultural Organization

UNFCCC: United Nations Framework Convention for Climate Change

UNFPA: United Nations Populations Fund (formerly, the United Nations Fund for Population Activities)

US-EPA: United State Environmental Protection Agency

WHO: World Health Organization

WHO: World Health Organization

WMO: World Meteorological Organization

WRC: Water Resource Commission

WWF: World Wide Fund for Nature

ABSTRACT

Climate change and variability is becoming an issue of global and regional concern as its impacts are increasingly taking hold of diverse sectors of the world. Temperatures increasing and rainfall becoming highly variable have had major impacts globally, with Africa faced with the harshest conditions. Although the continent's contribution to global warming and subsequently climate change is the lowest, Africa's low adaptive capacity tend to put the continent at the forefront of the battle with climate change and variability. Several studies have stated explicitly that climate change tends to increase the demand on the limited useful freshwater resources in the continent, even as the populations are increasing and the water demand for agriculture, industry and domestic purposes keep increasing. The over-dependence of Ghana and other African countries on climate-sensitive sectors such as water and agriculture has greatly contributed to the high vulnerability of the continent. Water resources and agriculture inevitably do contribute largely to socio-economic development in Ghana. These sectors are however exposed to first-hand harshness from climate change and variability, nullifying gains made by the country to attain sustainable development. This study was geared towards assessing climate change and variability impact on water resources and smallholder agriculture in the Offin sub-Basin of Ghana, which is of high socio-economic value. In order to detect possible changes in the climate of the basin, a 46-year daily rainfall and temperature data was analysed. It was revealed that temperatures had been on the rise, whereas rainfall had been diminishing over the years. Analysis of a daily 40-year streamflow data also revealed a decreasing trend. In order to determine the strength of the influence of rainfall and temperature on streamflow in the basin, the Pearson Correlation Coefficient was used. To assess the impacts climate change and variability have had on smallholder agriculture in the basin, a semi-structured questionnaire was administered. It was observed that farmers and indigenes do have a general knowledge of climate change and the challenges it poses on their farming activities. Various means by which these farmers had been coping with the impacts of climate change and variability were also assessed, even as a means of contributing to building resilience in these climate sensitive sectors. Developing and enhancing these adaptive measures in crop-production dominant rural areas, would foster resilience to climate change and variability in the agriculture sector of the country, reduce rural poverty as well as boost economic growth in Ghana and Africa at large.

RÉSUMÉ

Le changement climatique et la variabilité deviennent un sujet de préoccupation mondiale et régionale, car ses impacts s'emparent de plus en plus de divers secteurs du monde. L'augmentation des températures et la forte variable pluviométrie ont eu des répercussions majeures à l'échelle mondiale, l'Afrique faisant face aux conditions les plus difficiles. Bien que la contribution du continent au réchauffement de la planète et, par la suite, au changement climatique soit la plus faible, la faible capacité d'adaptation de l'Afrique tend à mettre le continent à l'avant-garde de la lutte contre le changement climatique et la variabilité. Plusieurs études ont explicitement déclaré que le changement climatique tend à augmenter la demande sur les ressources limitées d'eau douce utiles sur le continent, alors même que les populations augmentent et que la demande en eau pour l'agriculture, l'industrie et les buts domestiques croissant. La dépendance excessive du Ghana et d'autres pays africains à l'égard de secteurs sensibles au climat tels que l'eau et l'agriculture a grandement contribué à la grande vulnérabilité du continent. Les ressources en eau et l'agriculture contribuent inévitablement en grande partie au développement socio-économique au Ghana. Ces secteurs sont cependant exposés à la dureté de première main du changement climatique et de la variabilité, annulant les gains réalisés par le pays pour atteindre le développement durable. Cette étude visait à évaluer l'impact du changement climatique et de la variabilité sur les ressources en eau et l'agriculture des petits exploitants dans le sous-bassin offin du Ghana, qui a une grande valeur socio-économique. Afin de détecter d'éventuels changements dans le climat du bassin, des données quotidiennes sur les précipitations et la température sur 46 ans ont été analysées. Il a été révélé que les températures avaient augmenté, alors que les précipitations avaient diminué au fil des ans. L'analyse d'une moyenne quotidienne de flux de 40 ans a également révélé une tendance à la baisse. Afin de déterminer la force de l'influence des précipitations et de la température sur le débit des cours d'eau dans le bassin, le coefficient de corrélation Pearson a été utilisé. Pour évaluer les impacts du changement climatique et de la variabilité sur l'agriculture des petits exploitants du bassin, un questionnaire semi-structuré a été administré. On a observé que les agriculteurs et les indigenes ont une connaissance générale du changement climatique et des défis qu'il pose sur leurs activités agricoles. Divers moyens par lesquels ces agriculteurs avaient dû faire face aux impacts du changement climatique et de la variabilité ont également été évalués, même comme un moyen de contribuer au renforcement de la résilience dans ces secteurs sensibles au climat. L'élaboration et le renforcement de ces mesures d'adaptation dans les zones rurales dominantes en matière de

production agricole favoriseraient la résilience au changement climatique et à la variabilité du secteur agricole du pays, réduiraient la pauvreté rurale et stimuleraient la croissance économique au Ghana et en Afrique en général.

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CHAPTER ONE

1. INTRODUCTION

1.1 Background of the study

The climate of an area is the average weather conditions that prevail over the area. This is influenced by a number interacting factors such as latitude, vegetation, topography, ocean currents among others. The two most important factors in the climate of an area are rainfall and temperature (American Geosciences Institute, 2019). When there is a long or short term change in the main climatic variables such as rainfall and temperature in an area, then the topic of climate change and variability comes up. Climate Change, according to IPCC (2007) is a change in the state of the climate, identified by changes in the mean and the variability of its properties like rainfall and temperature, which persists for extended periods of decades and more. This phenomenon according to IPCC (2007), is caused by global warming, which is due to the greenhouse effect. Human activities have fueled the greenhouse effect by the increase in the emission of greenhouse gases, which subsequently heightens global warming. According to UNFCCC (2011), climate change and variability is masterminded directly and indirectly by human activities altering the composition of the atmosphere, coupled with natural climate variability. Kankam-Yeboah et al. (2010) instigated that the increasing trend in the emission of carbon dioxide into the atmosphere, subsequently causing an increase in temperature of the earth's atmosphere, is the cause of today's climate change. Climate variability is a term used to describe temporal and spatial variations in the average state of the climate of an area, going beyond discrete weather events. This is attributed to both natural and anthropogenic processes (IPCC, 2013).

Climate variability and change impacts are becoming more evident by the day. Nan et al. (2011) iterated that climate change effects are multi-scale and broad, encompassing both positive and negative effects. Moreover, beyond the hydrological, biological and ecological consequences of climate change, economic growth and development are highly threatened. Several studies (eg. Kurukulasuriya and Mendelsohn 2007; Thornton et al. 2008) have concluded that the impacts of climate change are not shared equally globally, thus some areas experience harsher conditions than others. The effects of climate change and variability are significantly evident especially in Sub Saharan Africa, Ghana inclusive, where resources are not sufficient for effective adaptation and mitigation strategies (IPCC 2014; Niang et al. 2014). Sub-Saharan Africa countries continue to exhibit vulnerability to variability and change in climatic factors such as temperature, rainfall, as well as extremities bringing events like droughts, dry spells, and floods, which are becoming highly pronounced in the region with time.

Climate change and variability pose threats to communities in developing countries, whose livelihoods are interconnected with the natural environment (Boon and Ahenkan, 2012). It has the potential to worsen poverty and food insecurity levels in various regions of the world, particularly in sub-Saharan Africa, where other factors have created the perfect atmosphere for climate variability and change impacts to be highly felt. Ghana, as a country, relies heavily on ecosystem services, in terms of food, water, raw materials, and others. These services are disadvantaged and limited by climate change impacts (Boon and Ahenkan, 2012). It is therefore evident that climate change and variability affects people and livelihood, hence the more reason why its studies should be given the due attention required.

Water resources and agriculture have shown extreme vulnerability to climate change and variability in developing countries (Tyhra et al., 2017). Meanwhile, water serves as the basis of life and the precondition of human existence playing key roles in socio-economic development, via its multipurpose use in areas such as agriculture, industry, domestic, transportation, welfare, tourism, energy among others. Socio-economic development processes are therefore closely related to the water resource because of the diverse range of interactions between water and human activities. This inevitably points out to the fact that realizing Sustainable Development Goal Six, which calls for clean water and sanitation for all, would propel the attainment of other SDGs (UNESCO, 2017).

Africa, which is home to over 900 million people, is characterized by abundant water resources as there are over 50 significant river basins across the continent. Key among them are the Congo, Volta, Nile, Niger, Zambezi, Senegal, Orange, Okavango Rivers and others (Shahin, 2006). Uneven distribution of water resources, poor water development, climate change among other challenges have made Africa the continent with the most water-related problems. This ranges from water shortage and scarcity to poor sanitation and waterborne diseases (Serdeczny et al., 2015). Pressing of these issues is climate change, whose impacts are being felt globally, however, sub-Sahara Africa countries have exhibited high vulnerability to climate change and variability due to geographical factors coupled with weak adaptation capacity (IPCC 2014; Niang et al. 2014). Due to low adaptive capacity, Ghana and other Sub Saharan regions continually exhibit vulnerability to variability and change in climatic parameters such as temperature and rainfall. According to Fosu-Mensah (2012), climate change and variability in Ghana have been marked mainly via decreasing average annual rainfalls characterized by high variability, rising temperatures, increase in extremities, such as droughts and floods, among others.

The impacts of this phenomenon are felt across diverse sectors in the country, however, this research particularly seeks to investigate the impact that climate change and variability have on water resources and agriculture in Ghana. Kankam-Yeboah et al (2011) mentioned that in the face of climate change and variability bringing about the increase in the frequency and severity of extremities, rivers and other water resources in Ghana would be impacted negatively. Several studies (eg. Nan et al., 20ll; Dumenu and Obeng, 2016) have indicated as well that climate change and variability tends to increase water demand, whiles decreasing water supply. Increase in temperatures and shifts in patterns of precipitation, influencing the occurrence of floods and droughts, are some effects of climate change which are becoming evident in Ghana (Asante and Amuakwa-Mensah, 2015). These occurrences tend to have adverse effects on water resources, food, energy production and the socio-economic development of the country at large.

Existing literature has pointed out that Ghana could become a water stress country by 2025 (Kankam-Yeboah et al., 2011), and climate change and variability together with other predominant water issues in the country might provide the right environment for the nurturing of this water stress situation. Ghana is a country whose economy is strongly supported by agriculture. This sector is steered by reliable water supplies, making the country more vulnerable to water and food insecurity caused by climate change and variability.

The Offin River serves as the main source of water supply for populations in and beyond the catchment, 80% of whom are into agriculture (Gyampoh et al., 2007). This study, therefore, sought to assess the impacts of climate change and variability on water resources and smallholder farming in the Offin River basin, which tends to massively support livelihoods of the communities in the basin. This study, through semi-structured questionnaires and key personnel interviews, also assessed farmers and water users' perception of climate change and variability. Moreover, their vulnerabilities to the impacts and various means by which climate change and variability were being coped with, in the basin were assessed.

1.2 Problem Statement

The Offin River, located in Kumasi is the main source of potable drinking water for the residents of Kumasi, the second-largest city in Ghana with a population estimated at about two million. This river provides over 80 percent of the total pipe-borne water to Kumasi and surrounding areas through the Barekese and Owabi dams with a key percentage of the population living in the catchment relying directly on the river to meet their water demands. This river basin as well serves as the main support for livelihoods in the basin, ranging from fishing, farming, and transport, among others, with agricultural activities being the key sources of livelihood in the catchment (Gyampoh et al., 2007). This river basin is plagued by persistent degradation via human activities throughout the catchment (Tyhra et al., 2010), therefore it is most likely that climate change and variability would further stress the water resources in the basin. This implies that climate variability and change assessments in the basin cannot be taken lightly, lest the platform for bigger issues related to water resources and water availability in the country be established.

A number of studies carried out in this catchment have focused more on water quality assessment than climate change and variability assessments. However, climate change is significantly becoming evident in Ghana. Kankam et al (2011) mentioned that in the face of climate change and variability bringing about the increase in the frequency and severity of extremities, rivers and other water resources in Ghana would be impacted negatively. This inevitably takes a toll on the livelihoods of the people as their livelihoods are interconnected with areas that are negatively impacted by climate change, such as water and agriculture. Agriculture, being climate-sensitive and also steered by the availability of water, makes it more vulnerable to climate change, although it is a major backbone of Ghana’s economy.

Low river flows during the dry season may serve as a stumbling block to the river meeting the water demand of the population. Climate change and variability coupled with the already existing magnitude of demand on freshwater resources by many sectors is set to further stress water resources and various water-dependent sectors. Therefore, bringing about uncertainty pertaining to water availability in the future (US-EPA, 2017). In light of already existing water challenges such as pollution (mainly ‘galamsey’) and population growth, climate change and variability is set to further jeopardize the state, availability, and sustainability of water resources in Ghana and Sub-Saharan African at large. Amisah et al (2010), assessed the livelihood trends in the forest communities of the Offin sub-Basin in response to climate change. Gyampoh et al (2007) as well examined how watersheds of the basin can be adapted to climate change and variability.

This study however, seeks to assess the impact the impact of climate change and variability on water resources and smallholder agriculture the Offin sub-basin and then present views on strategies that would foster climate variability and change adaptation among households, farmers and policy makers at large, taking clues from already existing adaptation practices undertaken by smallholder farmers and water users in the communities in the catchment. In a country as Ghana, where water resources and rain-fed agriculture is principal, climate change and variability assessments are key in building resilience and propelling development.

1.3 OBJECTIVES

1.3.1 Main Objective

The main objective of this study is to assess the impact of climate change and variability on water resources and smallholder farming in the Offin sub-basin, looking on to reccommend adaptive strategies to cope with climate change and variability impacts in the above sectors.

1.3.2 Specific Objectives

- To evaluate climate trends and smallholder farmers' perceptions of climate change and variability in the Offin sub-basin.
- To examine the effects of rainfall and temperature on river flow for the period of 1980 to 2009 at annual and monthly scales.
- To identify challenges faced by smallholder farmers due to the changing climate and evaluate adaptation strategies practiced in water management and smallholder agriculture in the basin.

1.4 Research Questions

- What have been the trends and changes pertaining to rainfall and temperature in the basin from 1970 to 2015 and how has smallholder farmers' perceived climate change and variability?
- What have been the effects of rainfall and temperature on river flow at annual and monthly scales in the Offin sub-basin?
- Which challenges do smallholder farmers in the basin face due to this changing climate and which measures have been put in place to foster climate change and variability adaptation, with respect to water management and smallholder agriculture in the basin?

1.5 Hypothesis

- Climate variables like rainfall and temperature in the river basin are influenced by climate change and variability.
- River flow, indirectly referring to water availability, is sensitive to fluctuations and changes in temperature and rainfall in the Offin sub-basin.
- Climate change and variability can be best be adapted to if there is an increase in knowledge of climate change and its impacts among various stakeholders and climate-dependent sectors.
- Assessing and building on existing practices by communities to adapt or cope with climate change is a key means of integrating the grass-root level into climate change adaptation issues, which would in turn foster adaptation and improve livelihoods at large.

1.6 The relevance of the Study

Ghana, as well as most sub-Saharan African countries, are not spared the hazards of climate change and variability (Cudjoe and Owusu, 2011; Serdeczny et al). The reliance of Ghana's economy on climate-sensitive sectors have made the country even more vulnerable to the impacts of climate change and variability (Kankam-Yeboah et al., 2010). Water serves as a fundamental input to most economic activities in the country, yet water resources have experienced first-hand harshness from climate change and variability. This study focused on how climate change and variability influences river flows in the country, using the case of the Offin River basin, whose water resources are responsible for supplying water to the township of Kumasi and its environs through the Barekese and Owabi dams. The Offin River most importantly directly serves as the source of water and livelihood for the populations in the basin. Adaptive strategies based on water management in the basin have been coined to foster climate change and variability adaptation in the basin and in the country at large. Residents in the river basin are predominantly into agriculture, a sector which is highly exposed to climate change and variability. Nelson et al (2009), affirmed that the agricultural sector is extremely prone to the hostile impacts of climate change and variability.

De Pinto et al (2012), also clearly inferred that the agricultural sector in the country has the potential to develop at a high rate of 6%, however, climate change and variability plays such a big hindrance to this growth, threatening Ghana's advancements at enhancing food security. Therefore, this study, through semi-structured questionnaires and key personnel interviews, sought to investigate existing schemes farmers employ to cope with climate change impacts in the basin, based on which further measures have been recommended. This study as well aims to inform policies, decision-makers and various sectors of interest about climate change and its impacts. This study also serves as a point of reference for future studies and as well as contribute to the Pan African University of Water and Energy Sciences (PAUWES) database.

1.7 Thesis Outline

This study is structured into five chapters. The first chapter, which is the chapter of introduction outlines the background of the research. It throws light on the aim and relevance of the study and introduces the concept of climate change and its impacts in Ghana and Africa at large. In chapter two, the existing literature relevant to this study is reviewed. This includes an account of climate change in Ghana and its impacts of key sectors such as water resources and agriculture, and other key subjects of interest. The third chapter emphasizes on the methodology employed to attain the various objectives of the study. Chapter four showcases and interprets the results of the study, with the fifth chapter presenting the conclusions and recommendations.

CHAPTER TWO

2. LITERATURE REVIEW

2.0 Introduction

Climate change being a global issue, with impacts cutting across most sectors, has seen a good number of studies done concerning it. Water resources and smallholder agriculture are two key sectors experiencing first-hand harshness from climate change impacts. Several studies, with regards to wthis, has been conducted, with the aim of arriving at relevant policies and strategies geared at adapting to, and mitigating climate change impact on these sectors. This chapter contains both empirical and theoretical reviews of existing studies done in the area of climate change and its impacts, particularly on water resources and agriculture. Studies done globally, in sub-Saharan African and Ghana are reviewed with key conclusions arrived at by researchers in the area of this study are highlighted.

2.1 Climate Change and Global Warming

Climate change according to IPCC (2007) is a change in the state of the climate, identified by changes in the mean and the variability of its properties like rainfall and temperature, which persists for extended periods of decades and more. Similarly, Doll (2002) defined climate change as “changes in the long-term averages of precipitation and temperature”. It has been a topic of global concern seeing international and local leaders as well as key institutions coming together to deliberate on the way forward. Wang and Qin (2017), asserted that over the century, global climate change manifests itself via a rise in temperatures, an increase in precipitation variability, and reduction in snow and glacier covers. Greenhouse effect bringing about global warming has been identified scientifically as the main reason for this fast-changing climate. Human activities, increasing the concentrations of atmospheric carbon dioxide among other greenhouse gases have been primarily responsible for the greenhouse effect. These gases trap energy from the sun, subsequently and gradually causing the temperature of the earth surface to rise, referred to as global warming (Hansen et al., 2010). According to the WMO, the net effect of the increase in greenhouse gases in the atmosphere is the warming of the lower atmosphere and the earth surface, due to these gases absorbing and re-radiating a portion of the outgoing long-wave radiation from the earth surface (UNFCCC, 2011).

Root et al (2003), mentioned that the past century has seen a temperature rise of approximately 0.6 ℃ and this trend is projected to continually rise rapidly. This has been accompanied by high variability in precipitation, with some regions experiencing a net decrease in precipitation as well as extreme events. Wu et al (2010) stated that inasmuch as the temperature in Northwest China has been changing in the past 200 years, the past 50 years has recorded a significant warming trend. Recent climate change cannot be explained by natural factors such as solar radiation and volcanic eruption alone as compared to centuries ago, as research has proven that a greater percentage of the observed warming cannot be explained by these natural factors (USA-EPA, 2017). The figures below represent the trend of annual global temperature and the levels at which climate change is influenced by human and natural factors.

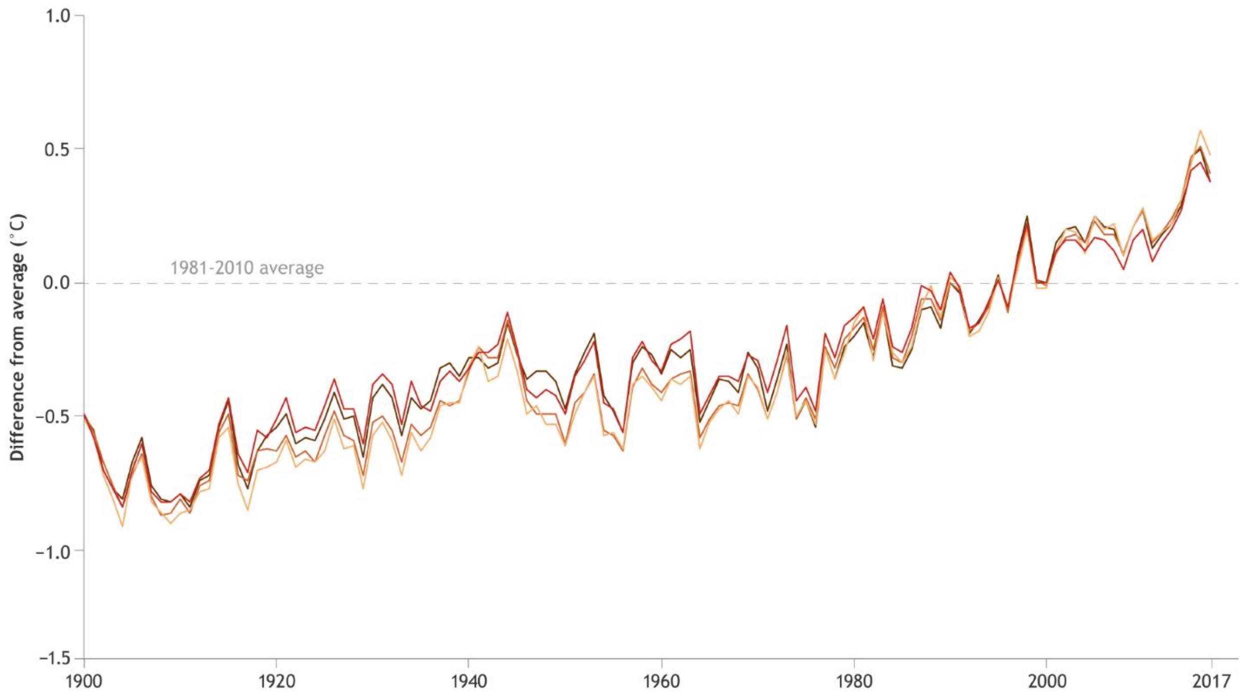

Figure 1: Trend of annual global temperature

Source: (NOAA, 2018)

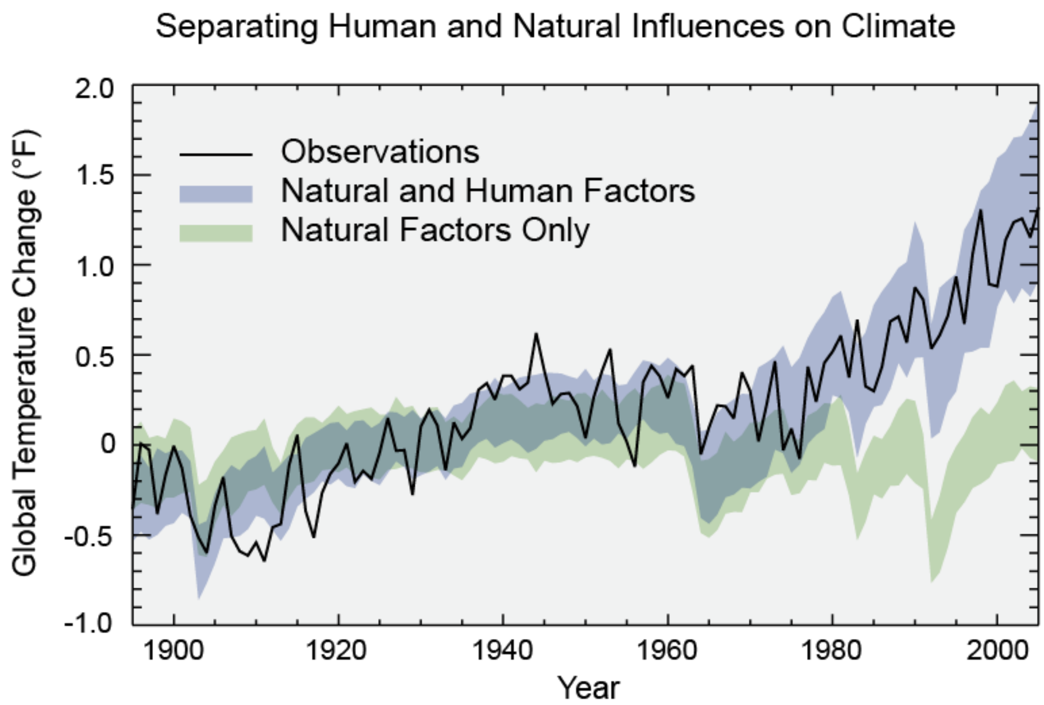

Figure 2: The extent of human and natural influences on global warming

Source: (Skeptical Science, 2015)

2.2 General Impacts of Climate Change and Variability

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change highlighted the actuality of climate change and its serious environmental and socio-economic impacts (IPCC, 2007). Climate change impacts are multi-scale and broad, encompassing both positive and negative effects (Nan et al., 2011). These effects cut across physical, biological, human systems among others. Boon and Ahenkan (2012), insinuated that climate change is the greatest present and future threat consuming ecosystems, biodiversity, resources, and livelihoods at large if nothing is done about it. Climate change and variability have been responsible for changes in precipitation, temperature balance of the earth, sea level, frequency and intensity of extreme events, ice and glacier cover, among other consequences. These changes have had extensive effects on humans and the environment at large, in the sense that they have further influenced areas such as human and environmental health, food and water security, loss of biodiversity and human security in general.

A UNFCCC report indicated that numerous regions of the earth, in 2010, had experienced extreme weather-related events with large parts of Central Europe and Asia experiencing various forms of floods and the world's largest nation, Russia experiencing extensive heatwaves and droughts, along with china having mudslides (UNFCCC, 2011). Inasmuch as the planet-warming has not been uniform, the globally averaged temperature trend points to more areas getting warmer than cooler, with a nearly doubled rate of warming over the last 50 years (Lindsey and Dahlman, 2018). This finding is in agreement with NOAA (2017), reporting that global temperatures have not been any cooler than the twentieth-century average since 1976. Increasing global temperatures depicts reduction in snow covers, shrinking of glaciers, and a subsequent rise in the sea level. IPCC Report (2007), indicated that the Himalayan glaciers are shrinking due to these increase in temperatures.

The past century has as well seen a rise in the sea level, with the current rate standing 0.13 inches per year as indicated in figure 3 (NOAA, 2019). Far from the melting of the glaciers, the main issue has to do with the challenges this poses downstream, bearing in mind that millions of the world's population are located in these downstream coastal areas. This increases the exposure and vulnerability to coastal flooding due to deadly and destructive storm surges. Hirsch and Ryberg (2012), iterated that floods have been responsible for over 500,000 deaths and affected over 2.8 billion people between the year 1980 and 2009, worldwide. It can therefore be said that climate change, without a shadow of a doubt, is and would be a major threat to human security. Precipitation across the globe has been highly variable, with some regions experiencing higher than normal precipitation and vice versa, as previous studies have indicated that regional precipitation responses to climate change vary. Some regions of the world like Central Asia have been experiencing an increase in annual precipitation, a trend which is set to continue (Huang et al (2014). Other regions like Western Africa is set to continue in its decreasing precipitation trend.

Global climate change and variability, apart from influencing climatic variables have also had major impacts on key sectors such as water resources, agriculture, health, education, environment and livelihoods at large. Water resources across the globe have had their share of impacts of global climate change and variability. Guo et al (2015) discovered that the water level of Bosten Lake in China experienced a reduction due to increased lake evaporation, reduced water supply from the Tarim River and reduced precipitation from 1956 to 2010. It is stipulated that as glaciers continue to shrink and precipitations remain highly variable, water inflows will ultimately decrease and subsequently the water level of the rivers, lakes, etcetera, will continue to decrease. This reduction in river flows coupled with droughts and other factors like pollution tend to affect water availability.

The ability to ensure global food security is majorly threatened by climate change and variability (FAO, 2018). Agriculture remains the backbone of many economies in the world, contributing to major developments and acting as a major tool for curbing poverty in the world. However, the sector is highly exposed to the impacts of climate change and variability, leading the developing world to a future of poverty and high food security risks. Chhogyel and Kumar (2018), attested to the fact that agricultural production and food security is most likely to be met with great challenges in this century as far as climate change is concerned. Some parts of the world are already experiencing this bizarre impact of climate change on agriculture and food production. Developing countries who mostly rely on rainfall for crop and livestock production highly disadvantaged, due to the unreliability of rainfall in these past years. This is a more reason why research must be conducted and appropriate adaptation strategies developed, to enhance improvements in food production and security.

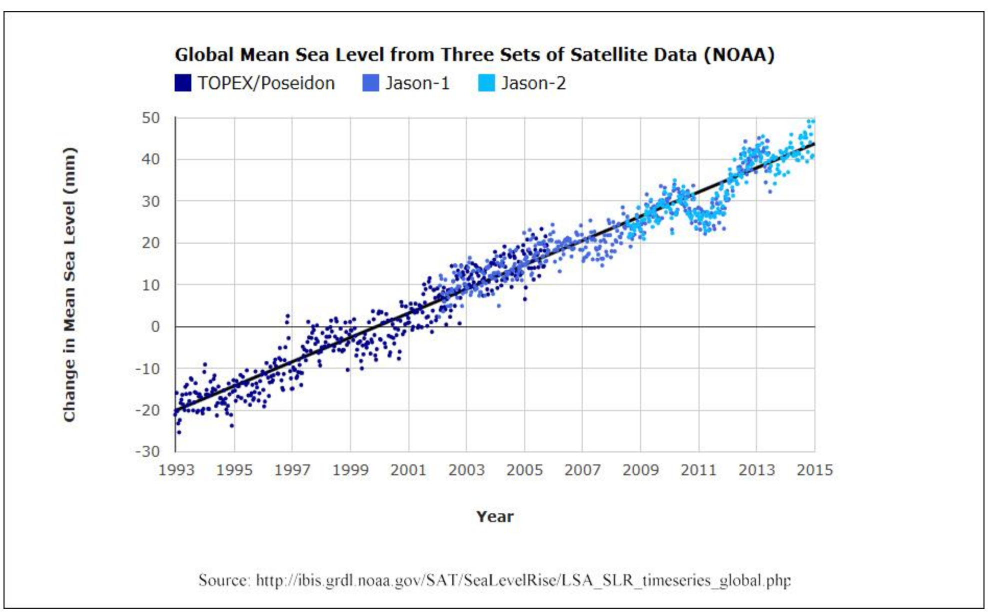

Figure 3: Trend in Global Sea-level rise. Source: (NOAA, 2015)

2.3 Climate change and variability impacts in Africa

Africa being the world's second-largest continent, with the second-highest population following Asia, has been identified as the continent most vulnerable to climate change and its impacts (IPCC, 2014). Studies have shown that weighty costs are associated with climate variability due to intermittent droughts and floods which tend to aggravate losses in key sectors of development (SEI, 2009). As of 2009, a report by CIGI, also attributed Africa's proneness to climate change and variability vulnerabilities to the inability of the continent to cope with the human, physical, and socio-economic consequences of climate extremes such as floods and droughts. This phenomenon is extremely real in this part of the world, as undeniably evident is its impacts such as increasing temperatures, highly variable rainfalls, and increase in weather extremities (WWF, 2006; Hansen et al., 2006). Africa, though the least contributor to global warming, has been the continent with the greatest climate change burden (Fields, 2005). This can be attributed to high exposure and vulnerability coupled with a low adaptation capacity as a result of inefficient and inadequate resources.

According to IPCC (2006), inadequate institutional, economic and developmental capacity has made African countries the most vulnerable to change in climate impacts. According to Collins (2011), there is a significant increasing trend in the temperatures of all regions of the continent as shown in figure 4. Collins (2011) went ahead to conclude that the change in climate over Africa is most likely not predominantly as a result of variations in ENSO, but more of natural and human-induced changes. Furthermore, climate change projections for Africa point to a warming trend (Sanderson et al., 2011), with the Western Sahel region set to go through the driest conditions, coupled with irregular rainfalls and frequent dry spells (Niang et al., 2014; Serdeczny et al., 2015; Sanderson et al., 2011).

Rainfall trends in the continent have been highly variable with some regions like West, East and Southern Africa experiencing declining rainfalls and more episodes of droughts and dry spells (Nicholson et al., 2018). On the broader scale, it can be said that there is not a single "African Climate Change Effect", because as some areas are set to be wetter, others are getting drier and whiles some areas are trailing, others are profiting (Hoste and Vlassenroot, 2009). However, for most areas in the continent, climate change is a real threat and challenge. There have also been increased flooding hazards for developing countries pertaining to sea level rise, (McGuigan et al.,

2002) as some coastal cities such as Lagos, Dar es Salaam and Darkar are already facing devastating impacts of coastal flooding, (Adelekan, 2016), with West Africa facing consequences of severe coastal erosion (Olympio and Amos-Abanyie, 2013).

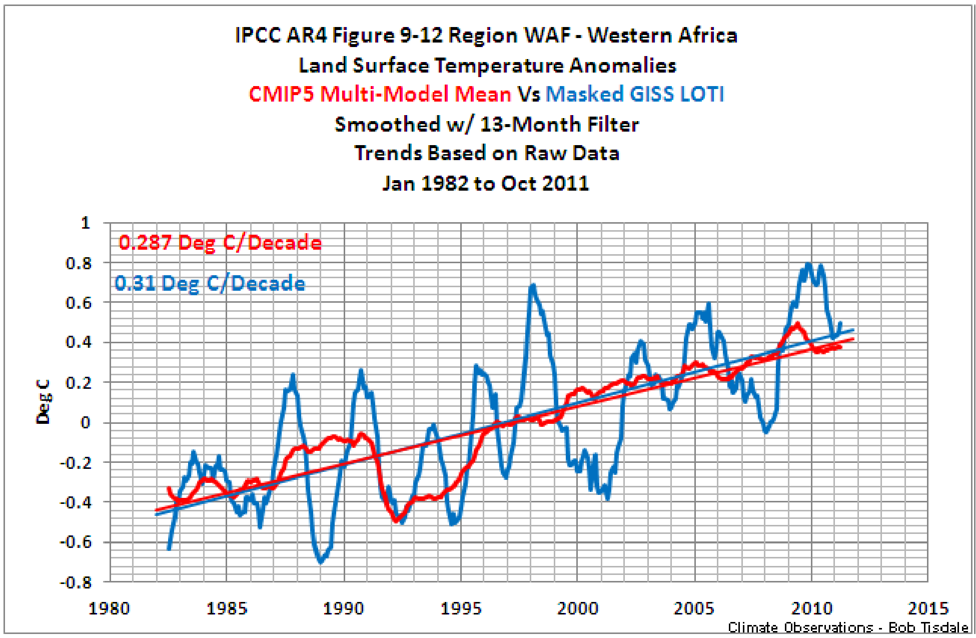

Figure 4: Increasing temperature trend over West Africa.

Source: (Tisdale, 2012).

Changes in these climate variables tend to impact a broad range of sectors such as water resources, agriculture, energy, health, sanitation, among others. Climate extremes coupled with food and water security have been a cause for both internal and international migration (Stapleton et al, 2017). The continent's reliance on climate-dependent sectors is a major contribution to its susceptibility to climate change impacts. In addition, the continent's low level of development bringing about a high adaptation deficit continuously leaves the continent vulnerable to climate change (Adger, 2005).

Other non-climatic stressors further contributing to the vulnerability of the continent to climate change include diseases such as HIV and malaria, poverty, chronic conflicts, which tend to further weaken the adaptive capacity of the continent (Osman-Elasha, 2009). Individuals, societies and countries tend to develop ample social resilience in light of increasing threats of climate change when there is a reinforced response to HIV, AIDS and other infectious diseases (UNFPA, 2009). With the population of the continent projected to get to 2 billion by 2050, (UN Department of Economic and Social Affairs 2013), it is clear that without proper adaptation and coping strategies, climate change impacts would take a worse turn in the continent, as resources might not be sufficient to meet the needs of the ever-growing population

2.3.1 Climate Change, Variability, and Water Resources in Africa

The African continent has a rich store of water resources comprised of both surface and groundwater resources. About 85% of these water resources are large river basins which are mostly shared by a number of countries (Ashton, 2002). Groundwater as well has been a significant source of water for the continent, as it estimated that over 40% of Africans rely on groundwater sources to fulfill their consumption needs (Donkor and Wolde, 2011). Inasmuch as Africa has abundant water resources, the continent tends to be the second driest continent in the world, with over 300 Million inhabitants of sub-Saharan Africa living water-stress and water-scarce areas (UNDESA, 2013).

This shortcoming is first and foremost attributed to the highly unequal distribution of water resources in space and time, as some areas have more water supply with low demand and other less water supply with high demand (Ashton, 2002). Beyond the disproportional distribution of water resources across the continent, most areas in Africa suffer from economic water scarcity, looking at the fact that water resources are not absent in most areas physically. However, poor water infrastructure development has been a stumbling block to fully exploit water resources in Africa, to meet the demands of the ever-growing population. Water systems and infrastructure in the continent are highly overburdened as populations are expanding at a fast rate. Moreover, already existing water resources are being stressed due to pollution and over-exploitation schemes such as mining, which is one of the key issues, destroying freshwater resources in Africa. Other factors such as urbanization, deforestation, industrial processes, and agriculture have also been undeniable water pollution sources in the continent.

Surface waters, which are supposed to serve as key water sources are increasingly being polluted, rendering them less useful. Looking at the fact that about two-thirds of the sub-Saharan population relies entirely on surface waters to meet their demands, water pollution does put more areas and people at risk of water scarcity (IFPRI, 2013). The continent has reasonable amount of water resources, so mostly the problem does not come from lack of water, but rather the unavailability of clean drinking water, which is key to survival. It is estimated that over 40% of sub-Sahara Africa has no access to clean water which inevitably puts the continent in the forefront of water-related health issues, poverty, poor sanitation as well as resource-driven conflicts. This makes groundwater the only source of safe and clean drinking water among the majority of rural sub-Saharan Africa population (MacDonald et al., 2009). Other issues making Africa a water-stress continent has to do with inadequate and corrupt management of resources on the side of governments, key organizations, and individuals. The lack of coordination among key authorities, in that roles are not clearly defined is as well a setback for the continent in terms of water resource development.

Among the numerous challenges facing water resources in Africa is climate change and variability, which is increasingly becoming evident in the continent by the day. Several studies (Serdeczny et al., 2015; Hoste and Vlanssenroot, 2009; Ashton, 2002; MacDonald et al. 2009) have stated explicitly that climate change tends to increase the demand on the limited useful freshwater resources in the continent, even as the populations are increasing and the water demand for agriculture, industry and domestic purposes keep increasing. Climate change is set to exacerbate the water situation in Africa, with regards to the already existing challenges facing water resources in the continent unless appropriate steps are taken to make necessary corrections.

The decreasing precipitation trend in most regions of sub-Sahara Africa tends to subsequently reduce the streamflows for rivers in the region (Mahe et al. 2013; Amogu et al. 2010). With low flows, seasonal water shortages and droughts are inevitable (Niang et al. 2014). Increasing temperatures in the continent tend to also increase the temperatures of surface water resources, implying a higher rate of evaporation, frequent algal blooms, reduced oxygen levels, bringing harm to the aquatic ecosystem and subsequently threatening water efficiency and availability. Ashton (2002), indicated that by 2025, the total area of African countries measured to have water abundance would have decreased to 35% as compared to an area of 53% in the year 2000. Studies show that climate extremes such as droughts and floods tend to be linked to poor water and sanitation conditions, accounting for over 20% of the disease burden in the continent (WHO, 2008). The impact of climate change and variability on water resources are expected to intensify in the years ahead. This, coupled with population growth, poor water management, among other challenges, would serve as a huge threat to water security and sanitation in Africa (Serdeczny et al., 2016).

2.3.2 Climate Change and variability Impact on Agriculture in Africa

Agriculture forms a vital component of economic development in Africa, as most countries in the continent have agriculture to be the backbones of their economy. Two-thirds of livelihoods in Africa is dependent on agriculture, providing close to 70% of all jobs in the continent (Gollin, 2014). Rural smallholder farmers, majority of whom are women, make up a greater percentage of the farming population in Africa, yet this group has been given little attention and deprived of resources and investments (AGRA, 2018). The continent has the greatest potential to produce food, looking at the fact that about 25% of the world's agricultural lands are located here. This potential is unfortunately not explored due to low levels of productivity as a result of low technology levels, weak institutional and ineffective policies, inefficient irrigation systems, less support and market for small-holder rural farmers, lack of farmer incentives, among others (AGRA, 2018). Although the population of the continent is ever-growing, food production, on the other hand, is not meeting up to the population growth rate. Agriculture, if managed well, would serve as a firm foundation upon which the transformation of Africa would be built, as more jobs would be created, poverty would be reduced drastically, and livelihoods would generally get better.

Undeniably, the future of African economies depends on a strong, vibrant and resilient agriculture sector. However, the sustainability of the sector is hindered by climate change, as climate change poses various threats and challenges to agriculture across the continent. According to FAO (2018), agriculture development in Africa is slowed down by climate change, as climate change tends to worsen challenges facing the agriculture sector in the continent, further reducing food crop yields, intensifying hunger and malnutrition across the continent. Several studies (Lloyd et al. 2011; Serdeczny et al., 2016; UNDP 2007) found a correlation between low agricultural yields and under-nutrition, which tends to create a platform for other health implications, reducing the working force of populations (WHO, 2008).

What majorly makes agriculture in the continent susceptible to climate change is the fact that it is to a greater extent, rain-fed. Rainfall however, is one climate variable that is highly impacted by climate variability and change, in the sense that its onset, cessation, duration, intensity and amount is impacted by climate change and variability (Yorke and Omotosho, 2010). A highly unreliable rainfall pattern tends to affect various farming activities, such that the time of planting all through to harvesting are impacted, subsequently crop yields gained as well are lower than expected. Cereals to a large extent are grown in almost every part of the continent, serving as the main staples for most areas, especially sub-Saharan Africa. According to IFPRI (2014), about half of the daily calorie intake across the continent is accounted for by cereals. Several studies (eg Pereira, 2017; NEPAD 2013) observed that high temperatures and variable rainfall patterns tend to reduce the productivity of cereal crops and perennial crops across the continent, intensifying hunger and under-nutrition, which also comes along with various consequences. According to Goebel and Cilas (2015), climate change poses the risk of an increase in the burden crop pests and diseases, as the phenomenon modifies the behavior and distribution of pests and diseases. Increase in local-level understanding of climate change impacts in agriculture is key to enhancing the continent's adaptive capacity.

2.4 Climate Change and Sustainable development

Climate change by the day, is becoming an issue of global and regional concern as its impacts are increasingly taking hold of diverse parts of the world. Global temperatures increasing and rainfall becoming highly variable have had major impacts globally, with Africa faced with the harshest conditions. Although the continent's contribution to global warming and subsequently climate change is the lowest, yet Africa's low adaptive capacity tend to put the continent at the forefront of the battle of climate change and variability. Osman-Elasha (2009), addressed climate change as an equity issue, indicating that the poorest people in the world who most definitely contribute least to the buildup of atmospheric greenhouse gases are the ones who are least prepared to handle to negatives of climate change. According to IPCC (2007), sub-Saharan Africa is the region expected to bear the maximum consequence of climate change with regards to low agricultural yields, food, and water insecurity, climate extremities, among other developmental pressures. Thus for a region as this climate change inevitably poses a threat to sustainable development, as Munasinghe (2011), addresses climate change as the "ultimate risk multiplier", hyping already existing risks.

Sustainable development, according to the International Institute for Sustainable development, is "development that meets the needs of the present without compromising the capacity of the future generations to meet their own needs". Sustainable development is meant to bring long-term solutions to the world's problems, evident via the creation of the Sustainable Development Goals (SDGs). This is to tailor the world into a better place, where poverty, discrimination, environmental degradation among others would be at the lowest possible levels (United Nations, 2015). Sustainable development, however, tends to be challenged globally due to factors cutting across environmental, social, economic, financial, political, technical and institutional frames. According to World Bank (2014), the most significant hindrance to achieving sustainable development is climate change, as it keeps ushering millions of people all over the world, especially least developed countries into poverty. A number of studies (eg Osman-Elasha, 2009; Yohe et al., 2007; Bhatasara and Nyamwanza, 2018; Lutz, 2011) have as well gone ahead to establish a strong relationship between climate change and sustainable development. Climate sensitive sectors happen to be the main sectors that drive economic development in most parts of Africa. Hence in the quest of Africa to pursue sustainable development, appropriate climate actions need to be undertaken.

Moreover, in taking climate actions in the form of adaptation, vulnerability reduction and mitigation sustainable development must be a key concern, (Munasinghe, 2011), as some climate actions might seem perfect for the present, however for the future, it might be deteriorating to the environment. The relationship between climate change and sustainable development is therefore a two-way affair. According to UNFCCC (2017), challenges of climate change and sustainable development are interconnected and ought to be addressed with all earnestness, in order to enhance a safe and healthy world, even for the generations yet to come. Increasing temperatures coupled with high evaporation and decreased water availability due to climate change is set to reduce crop yields. Moreover, with agriculture being the backbone of African economies, the pursuit for sustainable development as a continent, is severely constrained. In the same light, the role of water resources in building a sustainable environment is brought under scrutiny due to this changing climate. It is as well a big challenge if the population who stand as a vital component of sustainable development are faced with food and water insecurity, health problems, increased migration among others. With climate change posing a massive threat to growth and development in Africa, working towards SDG 13 especially in Africa, undeniably lays a firm foundation for other SDG goals geared towards growth to be fulfilled. Asante and Amuakwa-Mensah (2015), argued that not taking appropriate climate actions could offset development progresses made in other areas.

2.5 Climate Change and Variability and its Impacts in Ghana

2.5.1 General Description of Ghana

Ghana can be found between latitudes 4.50°N and 11.50°N, and longitude 3.50°W and 1.30°E. Ghana, located in West Africa is among the countries sited along the northern coastline of the Gulf of Guinea and has its capital city to be Accra. To the north, it is bordered by Burkina Faso, to the West, Ivory Coast and East, Togo and to the south, the Gulf of Guinea. The country is predominantly characterized by low-lying savannah regions, with the highest point of elevation being the mountain Afadja (height of 885m above sea level), located in the Volta region of Ghana. Ghana as well is blessed with rich forests, covering a tenth of the total land surface, serving as habitats to various species. Ghana typically is characterized by a tropical (warm and humid) climate, because of its low-lying elevations and proximity to the equator. The two wet seasons in Ghana are from April to July (the major rainy season) and September to October (minor rainy season), with an exception of Northern Ghana, which has a single rainy season from May to October, after which there is a long dry season. Mean annual temperatures range from 27℃ in the South to 35℃ in the North. Annual rainfall also ranges from about 2100 mm in the south-eastern part to 1100 mm in the northern part, depicting a decreasing trend from the south to the north. The entire land area is 238,535 Km^2, with a water area of 8520 Km^2.

With a population density of 129 per Km^2, the population as at 2018 was **29,395,406**, out of which a percentage of 54.4 is located in the urban areas indicating that most Ghanaians tend to live in the cities (GSS, 2018; World Bank 2018). Ghana has a vibrant working force, as the greatest part of the population are youths. The economy of the country is dominated by agriculture, as more than half of the population are employed in this sector. Over the years, exports have had a positive impact on the gross domestic product of the country, as the main export goods of the country include cocoa, gold, bauxite, manganese, bauxite, mineral oils, timber, nut, and fruits, among others (World Bank, 2018).

2.5.2 Climate Change and Variability in Ghana

Climate change and variability are already happening and causing dire consequences in climate-sensitive sectors of the Ghana economy. This urgent developmental issue is highly evident in

Ghana, via increasing temperatures, reduced and erratic rainfalls, and increase in weather extremities. A number of studies carried out in the country reported increases in temperatures along with highly variable rainfalls where the onsets, duration and cessation patterns of the rains had changed. McSweeney et al (2008) reported that temperatures of the country since 1960 had seen a rise of 1.0 ℃. A temperature rise as this has a lot of negative implications across diverse sectors. The Environmental Protection Agency of Ghana led a Climate change impact and Vulnerability study in 2008, after which it was reported that the average annual temperature in five of the six Agro-ecological zones (Sudan Savannah, Guinea Savannah, Coastal Savannah, Savannah transitional zone, Deciduous Forest zone and the Rain Forest zone) of Ghana saw a steady rise within a period of 40 years, that is from 1960 to 2000. A 20% reduction in the mean annual rainfall of the country was observed as well. Climate analysis conducted over the Volta river basin, which extends to about 70% of the country's land area, recorded an increasing trend in temperatures and significant decreases in annual rainfall (Kankam-Yeboah et al., 2013). Yorke and Omotosho (2010), affirmed a high variability and unreliability of rainfalls in the country, with respect to their onset, duration, and cessation.

This has brought about high unpredictability when it comes to droughts and floods, which tend to have adverse impacts on key sectors of development (De Pinto et al. 2012). These trends in climate change are however projected to continue and even become more severe and attention capturing in the near future (IPCC, 2013). Future projections for the mean annual temperature of Ghana points to rises of 0.6, 2.0 and 3.9 ℃, by 2020, 2050, and 2080, respectively (EPA, 2011).

2.6 Overview of Water Resources in Ghana

Water is a vital natural resource, serving as the bedrock for life, development and the environment at large. Ghana like most West African countries at large is endowed with both surface and groundwater resources. Whereas rural areas in the country mostly rely on groundwater via boreholes, the urban population, to an extent of about 95% relies on surface water for their water needs (Akumiah, 2007; Sarpong 2005). For surface waters, there are three main rivers draining the entire country. They are the Volta river system, covering 70 percent of the country area. The southwestern river system, secondly, covers about 22 percent of the area of Ghana. Lastly, there is the coastal river system, which drains about 8 % of Ghana's surface area. (Ministry of Water Resources, Works and Housing, 2007).

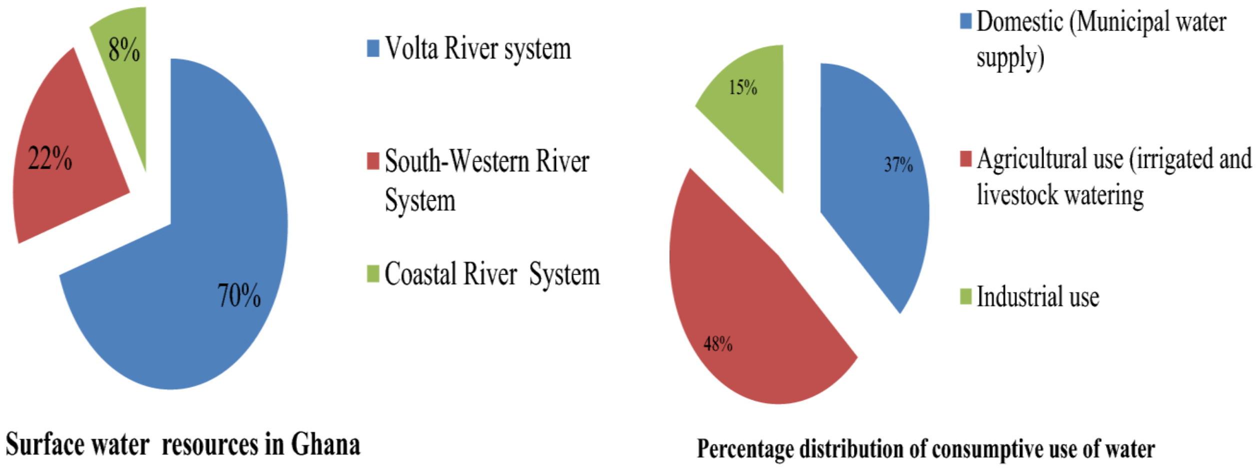

Figure 5 (a) Surface water resources in Ghana (b) Percentage distribution of consumptive water use. Source: (Yeleliere, 2018)

Water use in the country is classified under consumptive (in-situ) and non-consumptive (ex-situ) use. Consumptive water usages are those uses that require that water be withdrawn from their main sources like the rivers, groundwater, and etcetera. These water uses are mostly classified under community use (water supply) which stands at approximately 37%, industrial, standing at 15% and agriculture (livestock and irrigation) which uses 48%. The key non-consumptive usages of water include transport, local fisheries, hydropower generation, and tourism, as Ghana is well known for beautiful waterfalls, and ecosystem support services. Recharge to water resources here in the country is predominantly rainfall, depicting how important rainfall is to livelihoods in Ghana.

The total renewable water resources are approximated at 53.2 km^3/yr, more than half of which is generated internally, with the rest being contributions beyond the borders of the country, particularly from Togo, Burkina Faso, and Cote d'Ivoire. Rainwater harvesting which provides access to clean water, is a crucial to increasing water availability in the country, especially in Northern Ghana, which is relatively dry. A number of studies have indicated that with the right bases and technologies, rainwater harvesting could reduce the demand pressure on the available surface and groundwater resources (Zakaria, 2011; Naik and Pradeep, 2008). The Water Resource Commission of Ghana has undertaken projects aimed at collecting, storing and purifying rainwater collected from rooftops. However, rainwater harvesting is lacking owing to inadequate resources and technologies and hence is not done on a commercial basis. On the brighter side, it provides hope when looking at water scarcity especially in Africa (Ghana ministry of water, works, and housing, 2007).

Table 1: A summary of yearly renewable water resources in Ghana. Source: (FAO, 2005)

Renewable water resources	Amount
Average precipitation	283.1×10^{9} m3/yr
Internal renewable water resources	30.3×10^{9} m3/yr
Contributions from outside the country	22.9×10^{9} m3/yr
Total actual renewable water resources	53.2×10^{9} m3/yr

Another rich water resource in Ghana is groundwater, with generally good quality, if not for intense pollution due to mining activities, leachates from dumpsites, and high mineral pollution destroying the water quality in some areas in the country. There is also the issue of minimal saltwater intrusion in some parts of the nation like Ada (Ministry of Water Resources, Works and Housing, 2007). The incident of groundwater in Ghana is connected to three geological creations; the basement complex, the Mesozoic and Cenozoic sedimentary rocks; and the consolidated sedimentary formations beneath the Volta basin (Yeleliere et al, 2018; WRC, 2018). Groundwater abstraction systems in the country include hand-dug wells, boreholes, and dugouts and it is generally cost-effective and safe for agricultural and domestic purposes (Kortatsi, 1994).

Reservoirs, both large and small are increasingly becoming a vital water resource in the country as they support the socio-economic development of Ghana. Small reservoirs are beneficial in diverse ways to populations (Krol et al., 2011), positively influencing rural communities (Acheampong et al., 2018). They tend to improve water availability for domestic, commercial, environmental, social and agricultural purposes. In a country as Ghana where the non-uniform distribution of water resources coupled with other conditions establishes a foundation for water shortages, small reservoirs play a huge role in ensuring adequate water supply.

Although the country has abundant water resources, the deficit in coverage and underdevelopment of infrastructure for treating and dispensing water have been hindrances in ensuring adequate water supply across the country (Yeleliere, 2018). These hindrances coupled with challenges such as population pressures, pollution, rapid industrialization, and urbanization, are set to decrease water availability, while water demand across various sectors in the country increase. Additionally, current and future climate variability and changes tend to exacerbate various challenges facing water resources in the country (Ministry of Water Resource, Works and Housing, 2007; Kankam-Yeboah et al, 2011; Owusu et al, 2016).

An estimation by the Water Resource Commission (WRC) of Ghana indicated that water use in irrigated agriculture would almost be doubling by 2020, relative to the demand in 2010. An increasing trend was recorded for domestic and industrial uses among others. Padi, (2016) hints that although there are a reasonable amount of rivers in the country, if necessary measures are not taken to protect these water bodies, they will dry up, and the remaining few will be highly polluted, leaving us with the option of importing water from other countries for consumption.

2.7 Threats to Water Resources in Ghana.

Water is indispensable to life, community and the functioning of the economy of a country. Over the years, the utilization and management of water resources in the country have been characterized by problems cutting across political, economic, environmental, and socio-cultural spheres. Some of these challenges tend to nullify advancements of the nation in its pursuit to manage and utilize water resources sustainably. Adjomah (2010), instigated that the challenges many countries are encountering in their quest for developments are increasingly associated with water. This undeniably points out to the fact that water plays a central role in socio-economic development and thus need to be given the accorded attention. According to Egyin (2011), rainfall is not scarce in Ghana and rivers flow ceaselessly, but clean water is not readily available to thousands of people, due to a gross inadequacy in supply and distribution. Research has shown that more than 40% of Ghana’s 29 million population do not have readily accessible safe water (Safe water network, 2018). These challenges are impeding Ghana’s effort at attaining various sustainable development goals and with climate change becoming highly evident in the country, there is no doubt that water resources would be further stressed. Some of these challenges are outlined below.

2.7.1 Pollution

Pollution, which stems from agricultural, industrial and domestic sources has been a serious issue threatening water resources in Ghana. Threats of water pollution have been continually increasing over the years due to rapid population growth coupled with poor sanitation systems that arise due to peri-urbanism (Akoto et al., 2017). Majority of the water resources in the country have been heavily polluted with inorganic fertilizers, rubbish, oils, chemicals used during mining and others. These pollutants not only destroy water resources, but contribute to environmental degradation as well, endangering ecosystems and livelihoods. According to CSIR (2017), about 60% of water bodies in Ghana are polluted, with most of them being in critical condition. Indiscriminate disposal of wastes from industries, organic wastes from homes, illegal mining and agricultural activities have contributed intensively to the contamination of water sources in Ghana. Persistent of these is illegal mining popularly referred to as 'galamsey', which has gained a great deal of attention in Ghana.

This activity has had effects on agriculture production, the environment, and livelihoods at large, and it is as well projected to have detrimental impacts on the lives in concerned communities. Harmful chemicals used in this type of mining, such as mercury, cyanide, and others pose serious threats to water quality, making the water resources tougher to treat (Hogarh et al, 2016). Due to the magnitude of this pollution of surface waters, the majority of the population in rural areas tend to rely on groundwater. Some of these water resources have been polluted beyond treatment or are too expensive to treat, hence they are just left to die. This puts a significant burden on populations who rely directly and indirectly on these water resources for various purposes. Poor sanitation practices in Ghana such as open defecation, incorrect disposal of garbage and sewage also influence the pollution of these water bodies.

Most streets and drainages are filled with garbage and after the rains come down, this garbage find their way into water sources that people rely on for daily supply, bringing down diseases like typhoid, cholera, diarrhea and other water-related diseases. Due to unclean water and improper sanitation, Ghana has 1,000 kids under five years old dying each year from diarrhea (CSIR, 2017). Studies have indicated that climate change and variability would definitely worsen the effect of pollution on water resources in the country. Increasing temperatures would increase evaporation rates and this coupled with decreasing rainfalls would reduce water availability in Ghana's rivers.

Less water available in rivers imply that pollutants cannot be diluted easily. CSIR (2017), warned that with this rate of water pollution in the country, there might be no treatable water, be it surface or groundwater by 2030. Although water would be available, its quality would be at the least level. This would have consequences on livelihoods and agriculture, bearing in mind that contaminated water has the potential to kill off crop seedlings.

2.7.2 Population Growth

Ghana's population growth rate which stands at 2.5% per year is becoming alarming as this has resulted in pressure on various sectors and facilities such as housing, health, education, food production, roads, and water resources among others (National Population Council, 2018). Owusu et al (2016), mentioned that there is urgent need to adequately manage water resources in view of the point that the rapid growth of populations in developing countries poses a huge threat to the sustainability of water resources. Okello et al (2015) had also stated that demand on readily available freshwater resources has risen with increasing population, as water consumption across economic sectors like agriculture and industry increase. This brings about cases of water shortages, as noticed in various suburbs of the country. Urbanization increases the creation of impervious surfaces, minimizing infiltration and recharge to groundwater resources, reducing water availability in the long run.

Population growth coupled with poverty brings about poor sanitation services and poor environmental practices at large, which tend to deteriorate water quality. This was confirmed by Altiera (2016), who deduced that water resources are stressed beyond their limits, as a consequence of rapid population growth and urbanization, which brings about increase in water pollution, and subsequent decrease in water quality. Research has projected that about half of the populations around the globe would be water-stressed by 2030, relative to a figure of 15% as of 2013 (United Nations, 2013). This water stress could either be due to the lack of water altogether or the presence of highly polluted water resources. Rapid population growth implies a high demand for food crop production. This comes along with high irrigation demand, looking at the unreliability of rainfall patterns in the country over the past years.

2.7.3 Inadequate Management of Water Resources

Water resources in Ghana are failed to be managed moderately. There are extensive policies, legislations, laws and other institutional frameworks to ensure water resources are managed sustainably, yet water resources in the country continue to face harsh conditions and detrimental utilization. This tends to interfere with the economic growth of the country, as sustainable use of water resources is key to socio-economic development. Existing policies such as the polluter pays principle, which is meant to put polluters under check is inadequately enforced. Therefore industries, miners, textile companies and the population at large, without treating their wastes, comfortably discharge them into water bodies. This is one of many problems that could be curbed if there was keen management of water resources and sturdy enforcement of laws.

One major hindrance to the sustainable management of water resources in Ghana is the lack of training and capacity building. Communities, especially the rural ones tend to lack the basic knowledge and capacity in adequately managing water resources in their locations. Boreholes, wells, ponds, small reservoirs, etcetera, created to supplement want supplies in these areas, get broken down over time due to poor practices. Poor sanitation and waste management, leave water resources highly polluted, leaving people who rely on them very vulnerable to water-borne and water-related diseases (Owusu, 2010), out of which Ghana lost many lives. According to the United Nations (2006), a strong political will of the government is required in the management of water resources in a country. However, For Ghana and other sub-Saharan African countries, the political will is absent or weak.

Another key management issue is the lack of adequate financial commitments in the water sector, in that policies meant to ensure advancements in the sector are hardly implemented to the fullest (WaterAid, 2013). Corruption as well is one hindrance to proper water management in Ghana as Van Rooijen (2008), identified the said to be a key challenge to effective water management in the country. One would realize that there are bans on illegal mining in water resources across the country, yet partly due to bribery and corruption, these activities still go on, destroying water bodies. The lack of technical expertise in the water sector cannot be overlooked as a management challenge. According to Ainuson (2010), in most African countries, the workforce in the water sector lack the essentials on how to ensure sustainability in the sector. To close this labour gap, there should be capacity building coupled with proper training sessions for workers. Finally Integrated Water Resource Management (IWRM) should be strengthened in the country, to improve the management of water resources in the country (UNESCO, 2013).

2.7.4 Climate Change and Variability

Climate change is a phenomenon that cannot be denied, as its effect has increasingly become evident. In many areas, Ghana inclusive, climate change tends to increase water demand, whiles decreasing water supply (Dumenu and Obeng, 2016). Looking at the widespread areas where water is needed, coupled with climate change, it is undeniable that water resources are further being stressed (US-EPA, 2017). Increase in temperatures and shifts in patterns of precipitation is influencing the occurrence of floods and droughts, which tend to have adverse effects on water resources. Several studies have concluded that there has been a net reduction in rainfall, coupled with high evaporation, implying reduced water availability (Yorke and Omotosho, 2010; Baidu et al, 2017; Kamkam-Yeboah, 2013). Extreme climate events such as floods and droughts have dire consequences on the water quality of water resources. Streamflow analysis performed over large river basins in the country revealed a decreasing trend. For instance, the 2020 average annual streamflow estimated for the White Volta basin and the Pra river basin showed reductions of 22% for both basins. This is undoubtedly a threat to water security in Ghana.

These challenges are impeding Ghana’s effort at attaining various sustainable development goals, pressing of them is climate change and variability due to its complexity and the absence of strong and long-term adaptation strategies, hence the existence of a wide adaptation deficit in the country (FitzGibbon and Mensah, 2012; Kamkam-Yeboah, 2013).

2.8 Agriculture in Ghana

The agricultural sector of Ghana is made up of four sub-sectors, thus livestock, crop farming, forestry, and fisheries. This sector is undoubtedly a pillar of the economy of Ghana, as it serves as the greatest employer in the country, employing about 60% of the population, the majority of whom are small-scale farmers (Dafour and Rosentrater, 2016). Irrefutably, Ghana can be perceived as a nation that thrives on agriculture. Meanwhile, a greater percentage of agriculture in the country can be attributed to smallholder farmers who are to a large extent women, mainly based in the rural areas with a lesser percentage in the urban settings as well. These type of farmers make up about 70% of the farming population in the country, and they are largely faced with challenges cutting across land, labour, finance, market, climate among others (Von Loeper et al. 2016). According to FAO (2017), smallholder agriculture is notable for small farms coupled with small production volumes, which tend to reflect the low support rendered to this group.

Agricultural activities in Ghana is predominantly geared towards fishing and crop production. This is characterized by a wide range of food crops and fishes. Major staples in the country include maize, rice, sorghum, millet, yam, cassava, cocoyam, plantain, groundnut, cowpea, and soyabean. With livestock production covering cattle, sheep, goats, pigs, and poultry (Ministry and Food and Agriculture, 2016). The forestry and fishing sub-sectors also do contribute massively to food production and socio-economic development in the country. The major crops exported include cocoa, cotton, and oil palm. For the purpose of this work, food crop production would be highlighted. Agriculture in Ghana, like most sub-Saharan countries is largely pivoted by rainfall, considering that not up to two percent of the total cultivated land in the country is irrigated, revealing a low irrigation development in the country (IFPRI, 2013).

Inasmuch as agriculture is a major sector as far as development in the country is concerned, there are some factors disrupting growth and sustainability in the sector. The Ministry of Food and Agriculture (2007), observed and documented some factors contributing to draw-backs in the sector. Some of these factors are as follows:

- Unsustainable management of natural resources
- Inadequate information dissemination among stakeholders
- Inadequate access to robust planting materials and seeds as well as lack of incentives.
- Pest infestations and Increased post-harvest losses
- Poor soil and water management and low irrigation development
- Poor roads and inadequate transport infrastructure
- Limited market accessibility and lack of capacity development
- Climate change and variability

Research has shown that climate change and variability would leave the agricultural sector of the country more vulnerable to existing challenges hence posing a threat to food security in Ghana. The Ministry of Food and Agriculture is the parent institution responsible for the growth and progress of agriculture in the country. Its mission is to "promote sustainable agriculture and thriving agribusiness through research and technology development, effective extension and other support services to farmers, processors, and traders for improved livelihood". Primarily, it sets out to formulate key policies, plan, coordinate, monitor and evaluate activities within the agricultural sector, under the national economic development framework. The ministry achieves its aims via power-sharing to four sub-sectors which are; the Fishers Commission; the Veterinary Council; Grains and Legumes Development Board and Ghana Irrigation Development Board (Ministry of Agriculture, 2007).

2.9 The Role of Water Resources and Agriculture in the Socio-Economic Development of Ghana

2.9.1 Water Resources and Socio-Economic Development

Water resources have been of tremendous importance in Ghana, as they contribute majorly to the economic and social development of inhabitants. Some of these significances are seen in the transportation of people and goods, food and raw materials production, revenue generation for the government and the people, domestic functions, tourism, hydropower generation among others. Limited or inadequate water resources, according to Malsy et al (2013), tends to hamper socio-economic development of countries, using the instance of Mongolia which has records of high water scarcity owing to a semi-arid climate. Dei (2011) instigated that water resources play central roles in sustaining various economic ventures that provide jobs and livelihoods for people, especially the poor and vulnerable groups in the country, thus fostering economic development. Therefore neglecting water resource management could have bizarre impacts for any country. SDG 6, which calls for optimizing the availability and sustainable management of water has been found to be related many other sustainable development goals, in that it provides the foundation for other goals to be achieved (United Nations, 2015).

Ghana to a large extent relies on hydropower for her electricity needs. The Akosombo hydroelectric dam built on the Volta River for hydro-power generation tends to basically support domestic and industrial activities, another key sector which irrefutably contributes to the development of the economy (Adusei, 2018). A research conducted on the water flow into the hydropower dam indicated that Poor water flows from the river to the dam has been the root cause of shortage in electricity generation in the country (Joy Online, 2014). For instance, in 2015 the dam functioned at just half of its capability, causing the whole nation to go through serious power crises. The persistence in the blackouts brought about unfavorable situations like people being laid off from their jobs, food insecurity, industry shutdowns, and many other problems. Somewhere in May 2015, thousands of Ghanaians paraded the streets of the capital, Accra to campaign against these persistent blackouts, locally known as 'dumsor', and translated as "on and off" (GhanaWeb, 2015).

This predicament shed light on the essence of managing water resources for socio-economic development, as 2015 saw a reduction in the growth rate of the country (Cosgrove and Loucks, 2015). Advancements and investments in safe drinking water have been proved to facilitate socio-economic development, as water is figuratively a source of life and wealth, and a healthy and well-fared population is able to work to make great strides (United Nations, 2015; Goswami and Bisht, 2017). It can therefore be said that socio-economic development strides are inter-related to effective water resource management due the variety of interactions between water and human engagements, as Water serves as a key input for numerous activities (UNESCO, 2017).

2.9.2 Agriculture and Socio-Economic Development

Agriculture plays a strategic role in the socio-economic development process of a country. Research has shown that increased output and productivity in the agricultural tends to contribute majorly to the overall economic welfare of a country (Armah et al., 2011). This is because emphasis on agriculture tends to increase per capita income and revenue as well as the general wellbeing of countries, especially less developed countries. According to FAO (2017), least developed countries have agriculture to be their bulwark, bracing food security, foreign exchange, and overall development of these countries. A sustainable agricultural sector implies adequate food and raw materials to other economic sectors. Not forgetting that the agricultural sector has the greatest percentage of the workforce employed in sub-Saharan Africa, with Ghana being a typical example.

This sector creates a world where a population that is uneducated, unskilled and untrained can have the opportunity of being employed, thus contributing their quota to economic development together with the educated and skilled across various sectors. Moreover, the socio-economic growth of a country is impacted adversely when the food production of the agricultural sector fails to meet up to the rising demand for food as a result of increasing population. Agriculture acts as a key source by which a country earns foreign exchange which undeniably pushes a country forward in terms of development. Ghana's GDP is fuelled by three main sectors namely, agriculture, services, and industry. The agricultural sector accounts for a key part of Ghana's gross domestic product. As of 2017, the GDP composition by sectors saw agriculture contributing 18.3% to the total GDP, with industry contributing 25.5% and services, 56.2%, with agriculture having the highest growth rate from the previous year (from 3.0 in 2016 to 8.4 in 2017) (GSS, 2018).

As at the third quarter of 2018, the contribution of agriculture to the GDP was 19.2%, showing an improvement from the previous year. The growth rate, however, dropped to 5.5%, as a result of a negative growth rate in the fisheries sub-sector and other climate factors (GSS, 2018). Agriculture further contributes to the progress of industry through the sourcing of materials for production. Ghana is the next principal manufacturer of cocoa in the world, making the cocoa industry inevitable in the strengthening of the economy, as about 1.5 million citizens are employed in its production and transport. Agriculture development hence, is a powerful weapon countries can arm themselves with, in the fight against extreme poverty, as the sector is two to four times more effective in enhancing livelihood among the poorest (World Bank, 2019). Impact of agriculture on Ghana's GDP has mostly been a positive one, as envisaged in the chart below.

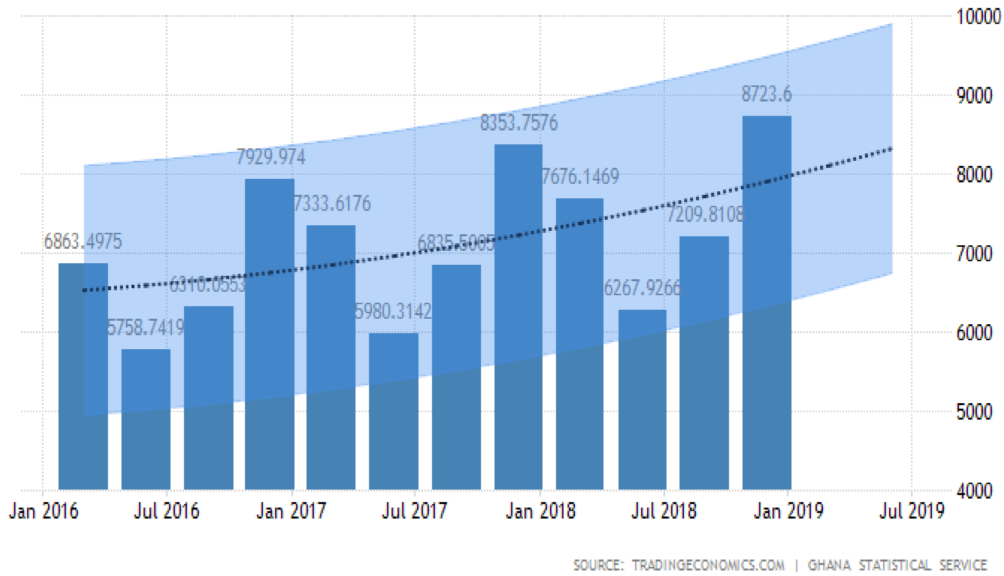

Figure 6: The trend of the agriculture sector contribution to Ghana's GDP over recent past years

Source: (GSS, 2019).

2.10 Climate Change Impact on Water Resources and Agriculture in Ghana

Climate change being a defining issue in this century, is undoubtedly evident in Ghana with significant impacts across vital sectors including water and agriculture. These sectors are both key contributors to the gross domestic product of the country, hence playing roles as backbones of socio-economic development in Ghana. However, water resources and agriculture, both being climate-sensitive sectors exhibit an alarming vulnerability to climate change in Ghana and Africa at large. According to Nan et al (2011), studying the impacts of climate change on water resources is important in understanding and solving water resource and hydrology problems, as there is a direct link between water resources and agriculture, industry and economic development at large. The reason for the concern in this area is the changes in the water and its quality as a result of climate factors, mainly temperature and rainfall, impacting runoff, streamflow, evaporation, and etcetera (Nan et al, 2011). Ma et al (2015), also indicated that climate change impacts water resources via precipitation, river flow, and groundwater recharge changes.

Several studies conducted in the country have confirmed the manifestation of climate change and its impacts on water resources. The Water Research Institute of Ghana, in the year 2000, conducted a study on annual river flows and groundwater recharge and found out that by the year 2020 and 2050, there would be an annual streamflow reduction of 15-20 % and 30-40 % respectively. Additionally, groundwater recharge would decrease by 5-22 % and 30-40% by 2020 and 2050 respectively. This would unquestionably increase water stress and bring about a reduction in hydropower production coupled with water demand across sectors, complicating livelihoods in the country (Kankam-Yeboah et al, 2011). This agrees with studies undertaken in other areas regarding water resources, where it was found out that climate change tends to decrease runoff and streamflow, as a result of which the salinity of rivers and other water resources will, especially in semi-arid areas (IPCC, 2018; Chang and Bonnette, 2016; Serdeczny et al, 2016; Amogu et al. 2010).

Awotwi et al (2015), on assessing the impact on climate variability on water balance in the White Volta Basin revealed an increase in evaporation and a decrease in surface and groundwater runoff, implying reduced water availability. Climate change impacts water resources as well via changes in the quality of water. Increase in intense rainfall coupled with floods ends up polluting surface water and shallow groundwater resources, due to the conveying of pollutants into them. These situations coupled with the increasing population, bringing about cases of water shortages as already seen in some parts of Ghana and sub-Saharan Africa at large. According to IPCC (2016), increase in the intensity of precipitation is linked directly to declining in water quality, as pollutants from urban centers, agricultural fields, mining sites, etcetera, find their way into water bodies, reducing their resourcefulness. Increasing temperatures together with unpredictable rainfall in the Northern part of Ghana, tends to trigger evapotranspiration, increasing crop water demands (Mbinji, 2010; Asante, 2009).

There is more than enough evidence pointing out the vulnerability of water resources in Ghana to climate change, hence the need to take necessary actions. The Water Research Institute of Ghana has indicated that Ghana could become a water stress country by 2025 as a result of non-climatic factors, therefore in view of climate change being highly pronounced in the country, water resources will be further stressed. Socio-economic development of the country will thus be threatened. Studies have shown that in this era of climate change, the agriculture sector tends to take the hardest blow, due to its excessive climate sensitiveness. Agriculture in Ghana, being a key economic sector bears the maximum consequence of climate change and variability, as rainfall is increasingly becoming variable (UNDP, 2012). Yorke and Omotosho (2010), instigated that the sector is pivoted by mostly rainfall, which tends to be highly variable in terms of its onset, cessation, duration, intensity and amount, due to climate change and variability. This coupled with major food crop's sensitiveness to the increasing temperatures, makes the agriculture sector highly vulnerable to climate change (Asseng et al. 201l; Serdeczny et al, 2016). This is already manifesting via declining yields of major food crops like maize, cocoa, sorghum, among others in the country (Boateng, 2016).

De Pinto et al (2012), clearly inferred that the agricultural sector in the country has the potential to develop at a high rate of 6%. However, climate change and variability plays such a big hindrance to this growth, threatening Ghana's advancements at enhancing food security and achieving major developmental goals. According to Armah et al (2010), drought conditions coupled with bushfires and soil erosion have been a great challenge facing agriculture in the Northern part of the country, as these conditions bring about reduced income, famine, malnutrition, and loss of livelihoods. In the quest to survive, some indigenes of Northern Ghana tend to move to the Southern part of the country in search of better livelihoods.

Some farming communities in the country have complained of high-intensity rains, which brought about floods, consequences of which included food crops getting rotten on the farms, seedlings dying off, erosion and low harvest in general (Codjoe and Owusu, 2011). Maize is one of the common cereals grown in all the agro-ecological zones of the country and an assessment of climate change impact on maize yields revealed low yields during periods of low rainfall and vice versa. In order to secure food supply in the country, various coping mechanisms to facilitate crop growth during dry periods would have to be developed.

2.11 Institutional Framework for Water Resource Management in Ghana

Inadequate fresh water resources to meet economic, domestic, environmental and developmental needs places constraints on health, sanitation, productivity and development (Cosgrove and Loucks, 2015). Increasing demand on freshwater due to population expansion, coupled with other challenges such as climate change and variability require water resources to be adequately and efficiently managed in order to sustain water resources for present and future use. Water requirements across various sectors keep increasing, yet water supply is hardy meeting up to all of these requirements partly due to the deteriorating quality of the available fresh water, poor water infrastructure, among others, leaving less than sufficient water to meet diverse needs (Yeleliere et al, 2018). Water resource management is therefore key in enhancing adequate water availability for diverse purposes, thus the mainstay of socio-economic development. 70% of freshwater globally, is used in agriculture, and agriculture being the pillar of most economies requires that there be efficient crop water management to secure food production.

The overall ministry with a mandate for the water supply sector in the country is the Ministry of Sanitation and Water Resources. The principal institution involved in water management is the Water Resources Commission (WRC). The WRC which was established in 1996 has been in charge of the regulation and management of the consumption of water resources. The commission is also responsible for coordinating water policies, developmental plans, data dissemination, pollution control, monitoring and evaluation among other functions, all geared towards sustainable management and utilization of water resources. Membership of this commission is taken the environmental Protection Agency (EPA), the Ghana Water Company (GWCL), Community Water and Sanitation Agency (CWSA), the Public Services Regulatory Commission (PURC), the Volta River Authority (VRA), the Irrigation Development Authority (IDA), Ghana Meteorological Services (GMET), the Minerals Commission, Water Research Institute, the Hydrological Service Department, the Forestry Commission and various organizations producing potable water (Water Resource Commission, 1996).

There are institutional frameworks established to create an enabling environment for the management of water resources in the country, key of them being the National Water Policy. The National Water policy is established to provide a basis for the sustainable development of water resources in Ghana, directed at water managers, decision-makers, investors among others (Ministry of Water Resources, Works and Housing, 2007). Integrated Water Resource Management is also being implemented in some river basins across the country, with the aim of addressing water resource availability, ecosystem sustainability and water quality (WRC, 2012). Statistics show the presence of enough water in Ghana, but supply and delivery are very much inadequate. With overpopulation and urbanization and rapidly increased water demands, such as water for irrigation, hydro-power, industrial processes etcetera, the resource is becoming increasingly scarce, hence the need for an integrated approach to ensure that water does not become a barrier to economic development. (Manu, 2015).

2.1.3 Ghana National Climate Change Policy

The Ministry of Environment, Science, and Technology in 2012 coined the Ghana National Climate Change Policy mainly under the supervision of key national and international institutions which made up the National Climate Change Committee (NCCC). Members of the committee represented these institutions: Ministry of Food and Agriculture: Ghana Meteorological Agency, Ministry of Energy: Ghana Health Services: National Development Planning Commission: the Dutch Embassy: Ministry of Foreign Affairs: Energy Commission: Forestry Commission: Friends of the Earth: DFID: Conservation International and other key related organizations. With climate change posing threats to various developmental sectors, the policy sought to make available key strategies to manage climate change challenges in the country. The policy is geared towards building a climate-resilient economy by mainstreaming climate change into national development and pooling resources to fight against the phenomenon thus the vision of the NCCP. In addition, the vision of the NCCP seeks to reduce the carbon footprint of the country whiles ensuring sustainable development. To achieve this vision, three objectives and four thematic areas were identified.

The objectives of the NCCP incorporates constructive adaptation, mitigation, and public growth. Accordingly, areas of interest set to foster these objectives include natural resource management, disaster management, energy and infrastructure, and food security. Through effective governance and coordination, international cooperation, capacity building, education, evaluation, and monitoring, among other key pillars, progress is being made towards the objectives of the NCCP. Key policy areas of the NCCP aligned with the cores of this study include developing resilient food systems and alleviating the impact of climate change and variability on water resources. Various ministries and responsible organizations have been in partnership to ensure and enhance the implementations of policy actions for a resilient economy.

2.12 Climate Change and Variability Adaptation in Ghana

Climate change and variability being key environmental challenges have taken tolls on developmental sectors and livelihoods in Ghana and the world at large. This has required that measures be put in place to respond to this phenomenon actively and proactively, thus enhancing adaptation measures. According to IPCC (2007) adaptation refers to responding to the actual or anticipated change in climate by regulating natural or human systems in such a way that harms and losses are reduced and gains are enhanced. Enhancing adaptation implies that climate change and variability would not erase gains made by the country to attain sustainable development. Various adaptation measures with respect to water resources have started taking grounds in Ghana. A typical example is the small reservoir project mainly being implemented in the Northern part of the country, where rainfall regimes are uni-modal. This implies a greater vulnerability in terms of agriculture and water availability. Small reservoirs in the region do serve as an important means of adapting to climate change and variability in terms of water storage and availability for diverse use (Acheampong et al., 2018). This study investigated adaptation practices with regards to smallholder farming and water management in the Offin sub-Basin of Ghana.

CHAPTER THREE

3. METHODOLOGY

3.0 Introduction

This chapter describes the study area along with the methodology used for achieving various objectives of this study. Both secondary and primary data were employed in this study. Published articles, theses, reports from government institutions and non-governmental organizations, proceedings of conferences and forums, among other key sources concerning the subject matter were studied and incorporated to buttress findings from the field.

3.1 Research Approach

A mixed-method research approach was employed in this study. According to Johnson et al, (2007), the research approach whereby researchers, in the same study, collate and analyze both quantitative and qualitative study is known as mixed-method approach. Research has indicated that this approach offers a better approach to understanding the research problems, as the potential strengths of both methods are exploited (Creswell and Plano Clark, 2007; McKim, 2017). Mixed method research as well provides a good avenue to better understand a study, should there be any contradictions and similarities between qualitative and quantitative data (Wisdom and Creswell, 2013). In this research, the mixed-method approach used was beneficial in getting to know the perceptions of the population to climate change, their vulnerabilities and how they have been coping in their own way to climate change in the river basin.

3.2 Study Area Description

3.2.1 Location

The Offin sub-basin is located entirely in Ghana and it is a key tributary of the Pra Basin, which is the largest river basin of the south-western river system in the country, spanning across four regions in Ghana. The total basin area of the Pra Basin is approximately 23,200 km^2 cutting across 7% of the Western, 23% of Eastern, 15% Central and 55% of the Ashanti Regions, comprising of four, eleven, six, and twenty administrative districts respectively. Situated in south-central Ghana, the Pra Basin can be identified between Latitudes 5º N and 7º 30’ N, and Longitudes 2º 30’ W, and 0º 30’ W. It takes its source from the highlands of the Kwahu Plateau in the Eastern Region and after flowing for about 240km, it finally enters the Gulf of Guinea in the Western part of the country (WRC, 2012).

The Offin River basin is located within 5º 30’ to 6º 54’ North and Longitude 1º 30’ to 2º 15’ West. The river and its tributaries originate from the Eastern part of the country and flow Southward through the Ashanti plateaus in the Ashanti region and finally discharges into the Pra River in the Central Region before entering the Gulf of Guinea (Mensah-Brako et al, 2018). The Offin sub-basin is predominantly located in the Ashanti Region, which is the part of the river basin under consideration for this study.

3.2.2 Climatology of the Offin sub-basin

The Offin river basin has a semi-humid tropical climate and moist semi-deciduous forests, with an average minimum temperature of 22 ℃ and a maximum temperature of 33.2 ℃. The basin, like most parts of the country is characterized by two rainy seasons thus a major (April - July) and a minor season (September – October). Average annual rainfall levels range from 1250 mm to 1700 mm, with June being the month with highest levels of rainfall. Humidity levels as well range from 48 % to 88 %, with average a five hour per day sunshine. The Offin Basin has its highest elevation being 550 m and the lowest being 100 m above sea level.

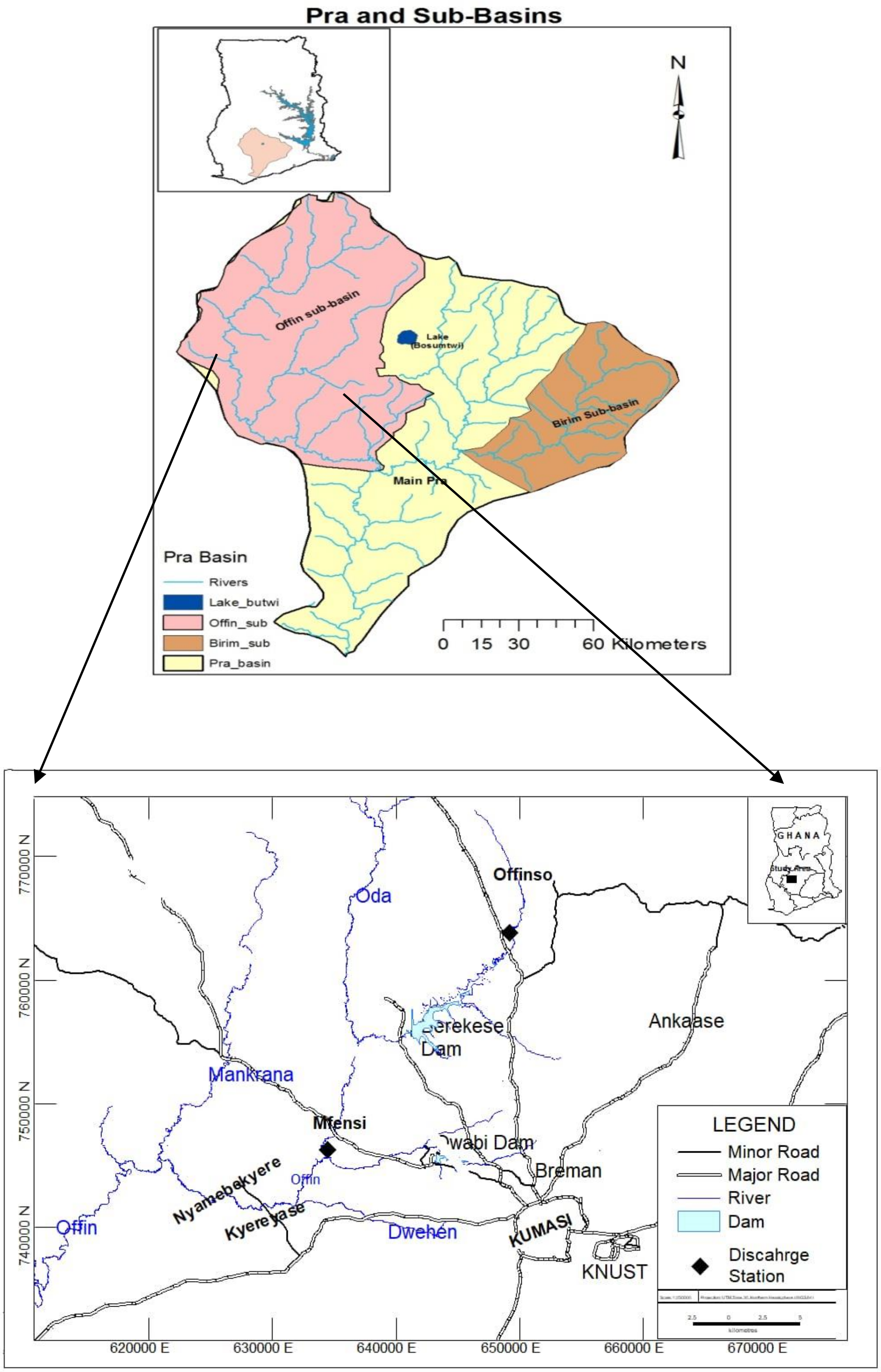

Figure 7: Study area

3.2.3 Water Use and Socio-Economic Activities

The Offin basin is the main source of water supply to Kumasi and its environs through the Barekese and the Owabi dam, (Gyampoh et al, 2007), however a significant percentage of residents in the rural areas of this river basin lack access to potable water to meet their daily needs. Water uses in the basin majorly cut across urban water supply, rural water supply, irrigation, industrial work, fishing, transport and other related purposes (Amisah et al. 2010). Studies have indicated that most populations in the Offin basin are primarily rural subsistence farmers who rely on the catchment for their livelihoods (Amisah et al. 2010; Gyampoh et al, 2007). The basin provides water transport for the communities and their farm produce. The basin as well provides forest resources like timber, firewood, medicinal plants, game, and etcetera. Mining activities, as well as logging, are comprehensive in the catchment, bringing various consequences to the water resources. Indiscriminate felling of trees, sand winning and illegal mining activities have degraded a portion of the natural forest. These coupled with unsustainable agricultural practices tend to subject water resources to pollution (Mensah-Brako et al, 2018). One area this study is focused on is farming in the catchment which is to a large extent smallholder and rain-fed.

3.2.4 Water Resource Management Challenges in the Offin sub-basin

Water resources of the Offin River have been faced with various challenges that tend to interfere with their adequate management. Some of these challenges as identified by the Water Resource Commission include water pollution as a result of excessive deteriorating activities, high concentration of iron in groundwater, flooding, seawater intrusion, and water shortage. This brings about inadequate water to meet increasing demands across domestic, industrial, agricultural, and related sectors. Another issue highlighted is a weak response to climate change and variability, making water resources, agriculture and other climate-sensitive sectors in the basin more vulnerable to climate change impacts (WRC, 2012). This study sought to assess climate change impacts in the Offin river basin, looking forward to developing strategies in responding better to climate change in terms of water resources and agriculture.

3.3 Data Collection

3.3.1 Hydro-climatic data

A 46 year daily data from 1970 to 2015 on rainfall, maximum and minimum temperature, covering 2 stations in the basin (Mfensi and Offinso) was acquired from the Ghana Meteorological Agency databases. Temperature and rainfall data were employed in this study due to them being weather variables most likely to reveal changes in the climate within the period of study, as several studies (IPCC, 2007; Root et al. 2003; Kankam-Yeboah et al. 2010). Mean daily river flow data for the period of 1980 to 2009 for gauges at Mfensi and Offinso were acquired as well from the Ghana Hydrological services. Analyzing these data showed how climate change had impacted the water resources of the basin. Research has implied that climate change does impact water resources through changes in river flow, which is as a result of changes in rainfall coupled with changes in temperatures. These changes tend to influence water availability (Ramirez-Villegas and Challinor, 2012; Wangchuk and Siebert, 2013).

3.3.2 Socioeconomic Survey

A semi-structured questionnaire was issued to smallholder crop farmers and household water users in four communities (Mfensi, Nyame Bekyere, Kyereyase, and Offinso) in the Offin River catchment in the Ashanti region of Ghana. The questionnaire sought to assist in developing measures to foster climate change and variability with respect to water management and smallholder farming in the Offin catchment in Kumasi and Ghana at large. In order to achieve this goal, the survey amassed information on the level of awareness of climate change and variability as well as the impacts on water resources and smallholder agriculture in the catchment. The survey went on to identify the vulnerability of the above sectors to changes and variability in climate and also to gain information regarding various means by which farmers and households cope with these changes. Open-ended questions were issued in addition the close-ended questions in order to get an in-depth understanding of the subject matters of interest as it pertains to the people in the communities. Within the first week of July 2019, 35 (40, 29, 25) respondents were interviewed at Mfensi, (Offinso, Kyereyase, Nyamebekyere) amounting to 130 questionnaires in all being administered, mostly on a one on one basis, as a portion of the respondents could not read and write.

Purposive sampling was employed in the qualitative survey to select these 4 communities in the river basin. This sampling type is a non-probabilistic approach where the objective of the study and the characteristics of the population are the basis on which sample areas or towns are selected. Therefore the study areas were selected based on their situation in the Offin catchment and their reliance on the Offin River for their livelihood needs, and the extent of smallholder farming practiced in the basin. Simple random, snowball, and convenience sampling techniques were employed as well in selecting participants of the survey.

3.4 Data Analysis

Obtained secondary data were organized using pivot tables and analyzed using Python Software and Microsoft Excel. Rainfall and temperature data were analyzed to establish historical trends. River flow data was also analyzed to indicate the trend and the rate of change per year. The mean monthly rainfall, temperature, and discharge were plotted as well to investigate their variability across the years. Trend analysis as well as Standardized Anomaly Index (SAI) was employed to further elaborate yearly variability in rainfall, temperature and river flow in the basin. Decadal changes were carried out to quantify the changes in rainfall and temperature as well as river flow within the years of study.

3.4.1 Trend Analysis

The least-squares method was used to determine the lines of best fit for the various time series data sets in this study (rainfall, temperature, streamflow). The equation of the best fit line or the trend line equation takes the form of a line equation as shown below.

$$Y = ax + b \qquad \text{(Equation 3.1)}$$

Where,

$$a = \frac{\sum_{i=1}^{n}(xi - x_{mean})(yi - y_{mean})}{\sum_{i=1}^{n}(xi - x_{mean})} \qquad \text{(Equation 3.2)}$$

$$b = Y_{mean} - a * X_{mean} \qquad \text{(Equation 3.3)}$$

The non-zero slope from the equation indicates the rate at which the measured parameter has changed (increased or decreased) per annum in the study area. Beyond this, the linear regression analysis was used to determine if the various trends were statistically important or not. This was done by calculating the value of R^2 and R^2 adjusted, which tends to quantify the fraction or percentage of variance or inconsistency represented by the trend. Generally R^2 values are between 0.0 (0 %) and 1.0 (100 %). Trends are however significant when $R^2 > 0.5$ (50 %). A hypothesis testing was performed to further assess the trend significance of the mean annual variables assessed in the study area, where the null hypothesis indicated no significant trend, and the alternative hypothesis indicated a significant trend. Therefore with a P-value greater or lesser than 0.05, the null hypothesis can be accepted or rejected.

3.4.2 Correlation between Climate Variables and Streamflow

A correlation coefficient is a statistical measure used to determine the extent to which one of the extent to which one variable relates to another, in the sense that a change in one variable causes a change in the other (Werner et al., 2009). The Pearson correlation coefficient (r), as well as the coefficient of determination (R2), were engaged to determine the strength of the linear relationship between the climate variables (rainfall and temperature) and streamflow at monthly and annual scales. The various data sets were checked for normality, as the use of the Pearson correlation and other statistical analysis requires coefficient requires that data sets be normally distributed. The coefficient values range from -1 to 1, with 1 representing a flawless positive relationship and -1, a flawless negative relationship as well.

3.4.3 Standardized Anomaly Index (SAI)

The Standardized Anomaly Index was used to throw more light on the inter-annual variability and fluctuations of rainfall, temperature and streamflow in the in the basin. Yearly summations of the above data were used in estimating the SAIs. Equation 3.4 was used for the calculation of the standardized Anomaly Index, which is deduced by dividing the anomalies (yearly value minus the long-term mean) by the standard deviation. The Standardized Anomaly Index is calculated as shown below.

$$SAI = \frac{x'}{\sigma} \qquad \text{(Equation 3.4)}$$

Where, x' is the departure from the mean value and σ is the standard deviation.

$$\sigma = \sqrt{\frac{\sum(x-X)^2}{N-1}} \qquad \text{(Equation 3.5)}$$

Where, x is the total rainfall, temperature or streamflow value for each year and;

X is the long-term mean rainfall, temperature or streamflow and;

Nis the number of years.

This provides a general understanding of how rainfall, temperature, and streamflow from 1970 to 2015 has been varying about the mean for the period. This is indicated graphically via significant troughs and peaks. Years of rainfall above or below the mean are displayed, corresponding to periods of wetness or dryness. The SAI ranges and their corresponding descriptions are indicated in table 2.

Table 2: SAI ranges and description. Source: (McKee et al, 1993).

SAI range	Description
≥ 2.0	Extremely warm
1.50 to 1.99	Severely warm
1.00 to 1.49	Moderately warm
0.99 to -0.99	Near normal
-1.00 to -1.49	Moderately cool
-1.50 to -1.99	Severely cool
≤ -2.0	Extremely cool

3.4.4 Decadal Changes

This analysis is key to investigating the decadal variability of rainfall, temperature, and streamflow over the study period, in the basin. The decadal means of the various parameters were calculated and the differences between them noted. The total change in the parameters over the entire 46 years (for rainfall and temperature) and 40 years for streamflow was also computed by splitting the data into two equal periods. The percentage change in each parameter was calculated by deducting the mean of the second set of data (y) from the mean of the first set (x). The value gotten was divided by the mean of the first data set and then multiplied by 100 %.

Thus, Change = $\frac{x-y}{x}$ x 100 (Equation 3.6)

3.4.5 Questionnaire Data Analysis

The quantitative data obtained from the survey were analyzed using SPSS Statistics 20, together with Microsoft Excel. Appropriate graphs, charts, and tables were used to represent findings. The qualitative data, on the other hand, was analyzed by the briefing, recounting, interpreting and referencing with respect to quantitative data. Common themes and trends in the survey were identified, drawn-out and interpreted.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.0 Introduction

The results of the study are presented in this section. The results are presented and discussed based on each research objective. Firstly, the trends, changes, and variability in rainfall and temperature in the basin were presented and discussed. Secondly, the trend of river flow and the interrelation between the river flow and rainfall were presented and critically examined. Lastly, the results of the qualitative study were presented and some strategies to foster climate change adaptation with respect to water management and smallholder agriculture in the basin coined. Appropriate tables, charts, and graphs were used to support findings.

4.1 Climate Trends and Smallholder Farmers' Perceptions on Climate Change in the Offin sub-Basin

Rainfall and temperature data were prepared and analyzed for annual and decadal changes as well as monthly and annual variability over the study period and results illustrated via graphs, trend lines, and tables.

4.1.1 Historical Trends, Changes and Variability in Rainfall

The 46-year daily rainfall data from the Mfensi, Offinso and Dunkwa gauge stations were computed for the monthly and annual scales from 1970 to 2015 with the results shown in figure 7 and figure 8 respectively. At monthly scale, the rainfall showed a gradual increase from January and a significant peak in June, with rainfall amounts decreasing till August, where a sharp trough is seen. Following a short period of dryness in August, rainfall increases through September to October, after which there is a fall in rainfall amount through to December. The Offin sub-basin is therefore characterized by two rainy seasons; a major season from April to July and a minor season from September to October.

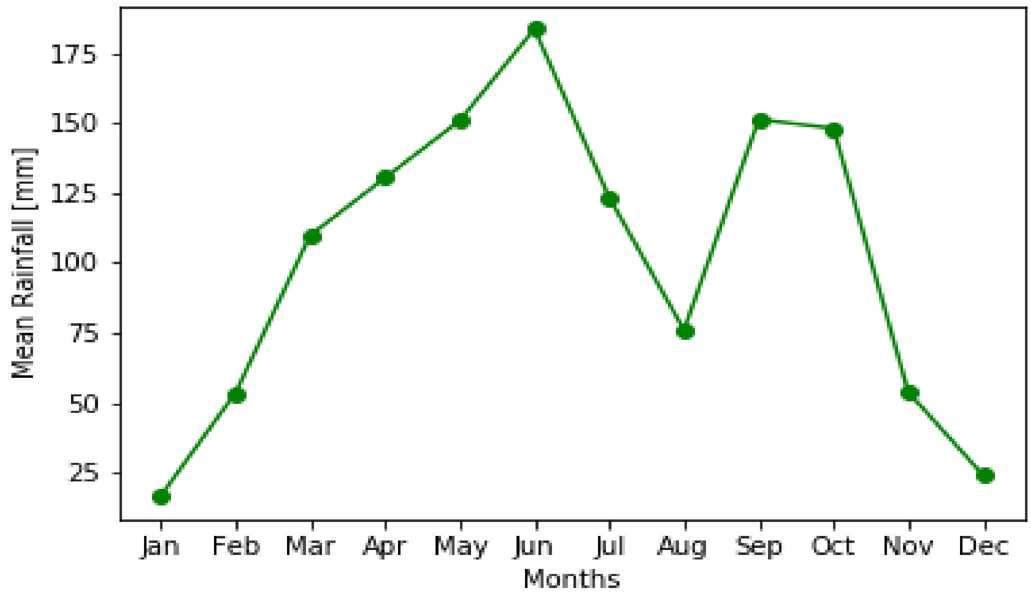

Figure 8: Mean monthly rainfall in the Offin sub-basin (1970 -2015)

At annual scale, the highest rainfall, being 1468.00 mm was recorded in 2002 and the lowest of 896.00 mm was recorded in 1983. The mean annual rainfall recorded within this period was 1221.30 mm. The trend of the total annual rainfall for the basin is presented in the graph below. The mean annual rainfall was found to be on the decreasing trend at a rate of 1.04mm/year over the study period.

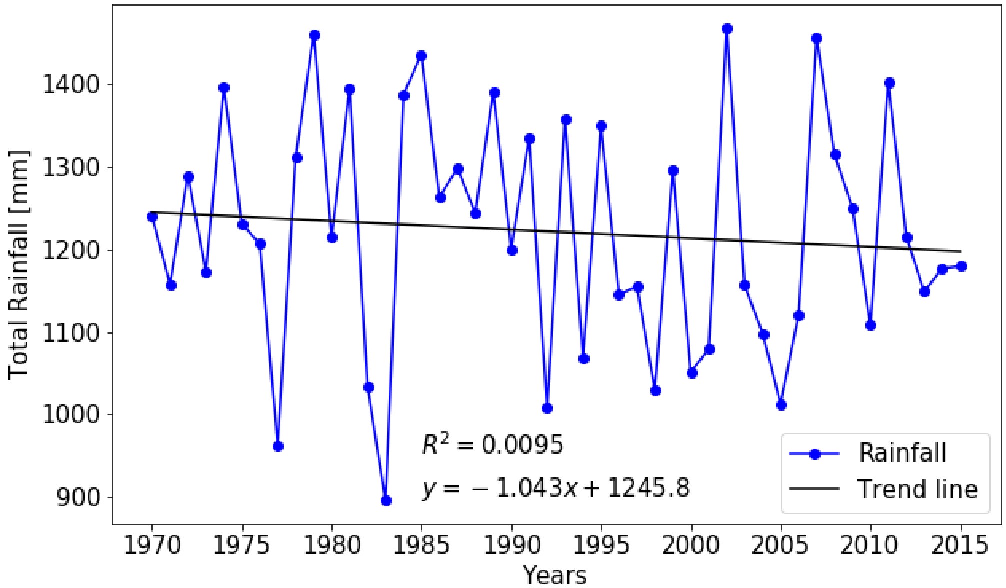

Figure 9: Trend in total annual rainfall in the Offin sub-basin (1970 -2015)

This reduction in rainfall in the Offin sub-basin confirms several studies undertaken in the country indicating the net reduction in the rainfall amounts in the country. The rainfall pattern as shown in the graph above indicates a high inter-annual variability with a number of sharp peaks and troughs. The general linear regression analysis was used to further investigate the trend in rainfall in the study area. The R squared values being lesser than 50% indicated that the trend was insignificant. The P-value also being greater than 0.05 further confirmed the insignificance of the trend.

4.1.2 Standardized Anomaly Index for Mean Monthly Rainfall and Inter-Annual Rainfall Variability in the Basin.

The Standard Anomaly Index was computed for the mean monthly and annual rainfalls over the study period as indicated in figures 9 and 10. This was to assess the monthly and annual variability of rainfall about the normal in the river basin. The results show that rainfall seasonality in the basin was within the range of moderately dry to moderately wet. January, February, August, November, and December are months with negative SAIs, thus dry months. However, January and December tend to be the driest months, as the other months below the mean do fall within the normal range.

June has the highest SAI above the mean, indicating moderately wet conditions. March to April as well as July, September, and October have rainfalls that fall within the normal range from the mean. At annual scale, rainfall variability about the mean value of 1221.30 mm can be seen in the graph below, where it is evident that most of the data points fall within the normal range, with relatively lesser data points falling below or above the normal.

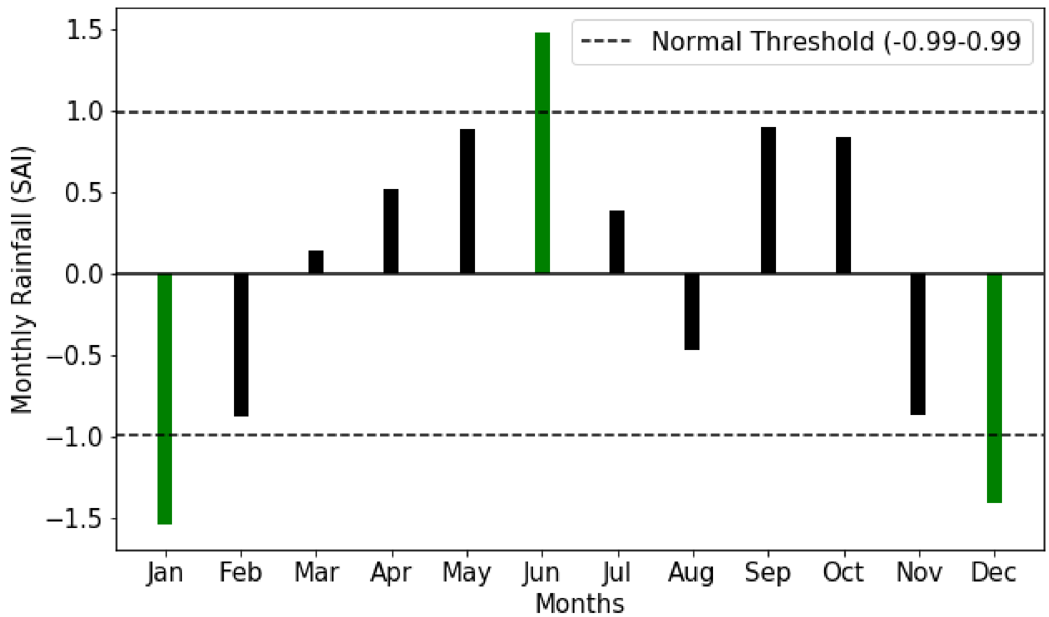

Figure 10: Monthly Rainfall Anomaly Index (1970 – 2015

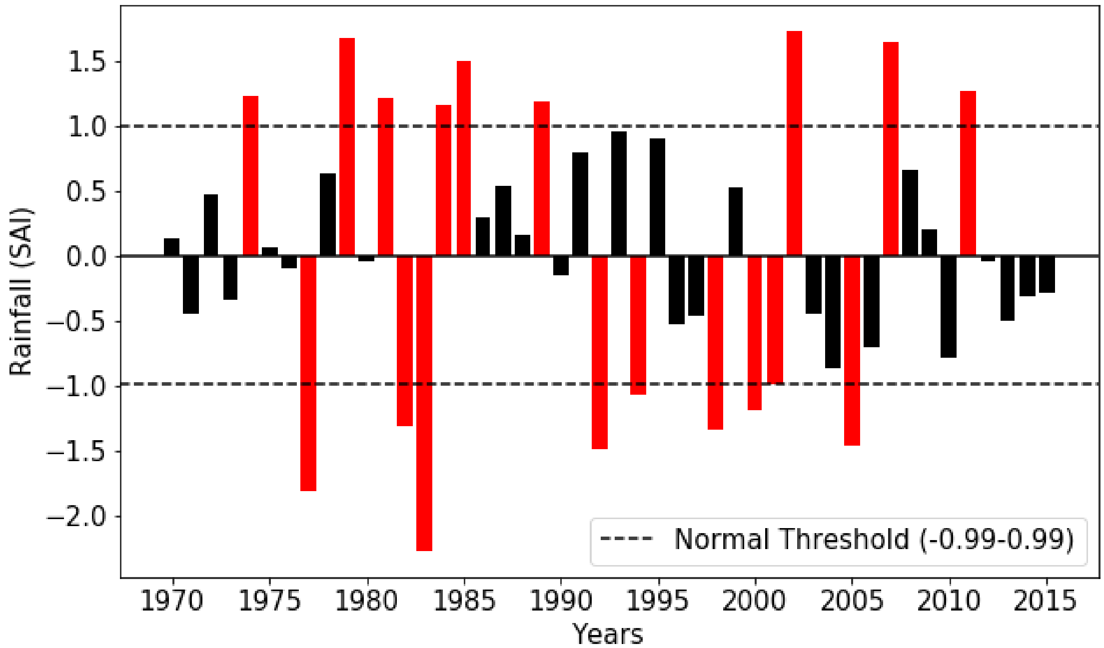

Figure 11: Annual Rainfall Anomaly Index (1970 – 2015)

High inter-annual variability of rainfall in the basin was observed which tends to agree with reports of erratic rainfalls experienced in the basin and the country at large. According to the SAI analysis, most rainfall years in the catchment have been in the near-normal range, with a relatively significant number of years being moderately wet (1974, 1981, 1984, 1989, 1993, 2011) and moderately dry (1982, 1987, 1992, 1994, 1998, 2000). A few years experienced severely wet and severely dry conditions. There had not been any extremely wet year within the time frame of the studies. However, the year 1983 experienced extremely dry conditions. 1983 is a year described as one of the harshest in Ghana due to devastating prolonged drought and famine, bringing about national economic crises.

4.1.3 Decadal Changes in Rainfall

This was computed using the decadal means of all four decades within the study period. The results are indicated in the table 3.

Table 3: Decadal Variability of Rainfall in the Offin sub-basin (1970 -2015)

Decade		Mean Rainfall (mm)	Changes in Rainfall (mm)
1	1970 – 1979	1242.99	
2	1980 – 1989	1256.03	13.04 (Increase)
3	1990 – 1999	1194.83	-61.20 (Decrease)
4	2000 – 2009	1201.02	6.19 (Increase)

Due to the available data not being up to five decades, four decades (1970 – 2009) were considered out of the study period (1970 – 2015). From the table, there has been an increase of 13.04 mm in rainfall amount from decade 1 to decade 2. Rainfall amount decreased by 61.20 mm from decade 2 to 3 and increased by 6.19 mm from decades 3 to 4. This shows variability in rainfalls over the basin, as rainfalls did increase and decrease on an irregular basis, increasing the unpredictability of rainfall trends in the country. The total change in rainfall over the study period was computed to quantify the change in rainfall amount in the river basin from 1970 to 2015. The result is presented in table 4.

Table 4: Total change in rainfall (1970 -2015)

Mean rainfall (1970 – 1992)	1240.64 mm
Mean rainfall (1993 -2015)	1201.96 mm
Change in rainfall (1970 -2015)	**-38.68 mm (3.21%) (Decrease)**

From the table, it can be seen that rainfall in the basin is generally decreasing. Within the period of study, rainfall has decreased by 3.21 %. Research has further predicted that rainfall across the country is set to continue to reduce (UNDP, 2012).

4.1.4 Historical trend, Changes and variability in Mean Air Temperature

The monthly and annual scale of temperature from 1970 to 2015, obtained from the Mfensi and Offinso gauge stations were computed using a 46-year daily temperature data. The results have been indicated in figure 12 and figure 13. At monthly scale, temperatures were seen to rise from January and on peaking in February at a value of 28.08 ℃ it slowly decreased till it got to a lowest of 24.66 °C in August, after which it rose gradually and then peaked minimally at a value of 26.73 °C in November. However, mean monthly temperatures over the study period in the Offin sub-basin did not vary much throughout the year.

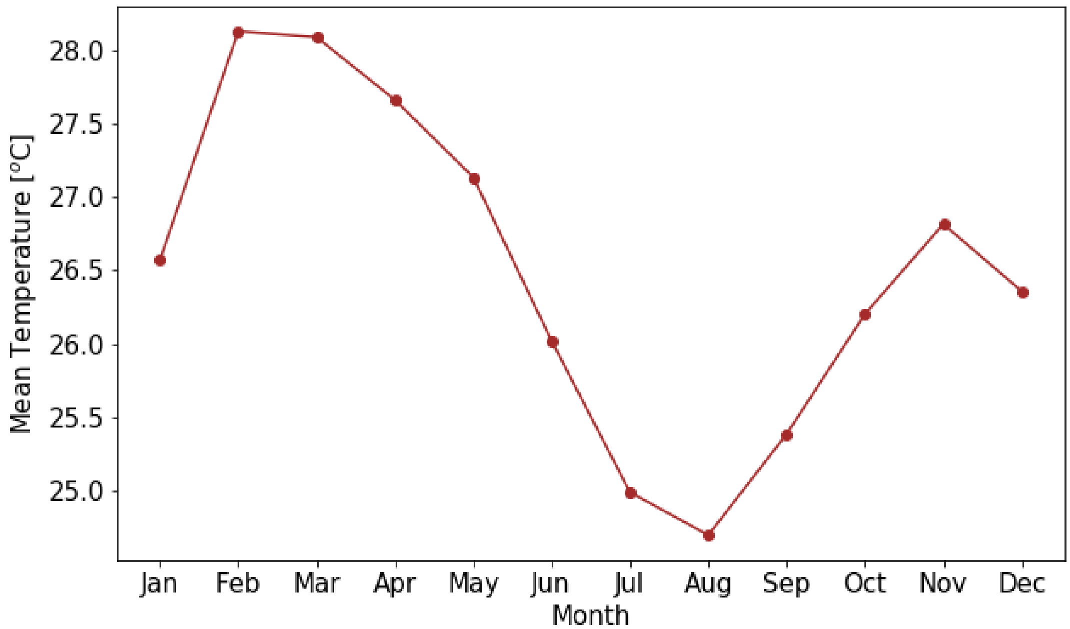

Figure 12: Mean Monthly Temperature in the Offin sub-basin (1970 -2015)

The mean annual temperatures over the study period were computed and plotted to view the trend over the study period. On an annual scale, temperature values also did not vary much as the values were between the ranges of 25 °C to 27 °C. The year 2010 had the highest computed mean temperature valued at 27. 35 °C and 1976 had the lowest temperature valued at 25. 4°C, which was just slightly lower than mean temperatures of 1971, 1972, and 1975. The mean temperature computed for the study period was 26.34 °C. The trend of mean annual mean temperature in the basin during the study period is illustrated in the graph below.

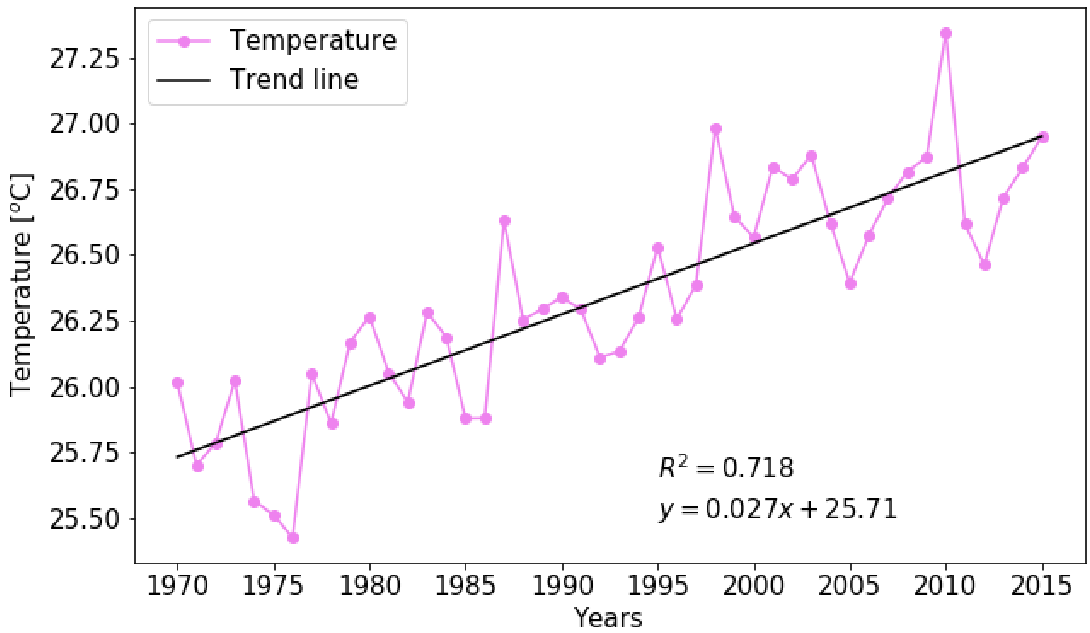

Figure 13: Trend in mean annual temperature in the Offin sub-basin (1970 -2015)

The mean annual temperature trend equation was deduced by the use of the least-squares method as shown in equations 3.1, 3.2, and 3.3. This method basically found the line of best fit for the data set, approximating the change in mean annual temperature per year. Most significantly, the mean annual temperature was found to be on the increasing trend at a rate of 0.027 ℃ per year over the study period, implying that temperatures have been increasing as hinted by a number of studies in the country. This increase in temperature tends to have impacts on climate-sensitive sectors such as water resource management and smallholder agriculture. The general linear regression analysis was used to further investigate the trend in rainfall in the study area. From the results, R^2 and R^2 adjusted were 71.8 % and 71.2 % respectively, indicating that the temperature trend is significant, as both values are greater than 50 %. Moreover, the P-value deduced was 0.00, further depicting a significant trend.

4.1.5 Standardized Anomaly Index for Inter-Annual Temperature Variability in the Basin

SAI was used to assess the inter-annual variability of mean temperature in the Offin basin, as indicated in figure 12. Temperature variability about the mean for the study period, which was

26.34℃ was assessed for the inter-annual variability of the mean temperatures over the years. This would help inform decisions and policies in climate-sensitive sectors. From the graph, it can be seen that most of the years fall within the normal temperature range, with a few being moderately cool or warm to extremely warm or cool. Extremely warm and extremely cool conditions were recorded in 2010 and 1976 respectively. Notably, beyond 1996, temperatures recorded were mostly above normal, as compared to the period from 1970 to 1975, where temperatures recorded were significantly below normal.

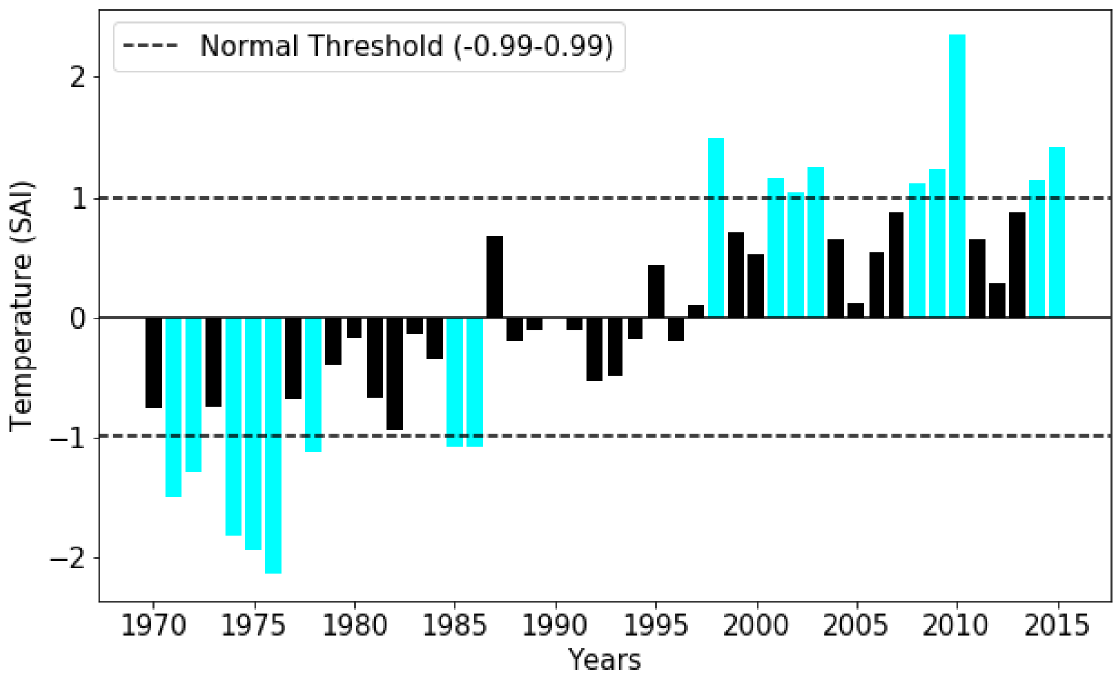

Figure 14: SAI for mean temperature in the Offin sub-basin (1970 – 2015)

4.1.6 Decadal Changes in Temperature

The decadal change and the change over the entire study period was computed as indicated in table 5. It can be seen from the table below that mean temperatures over the decades had been constantly increasing. Decade 1 to 2 recorded the highest increase in temperature (0.36℃), whereas the decades in 2 to 3 recorded the least increase in temperature (0.22 ℃). There was a temperature rise of 0.32 ℃ from decades 3 to 4. The highest and lowest mean temperatures were recorded in decades 4 and 1 respectively. Steady rises in temperatures do have impacts on water resources, agriculture, the environment and livelihoods at large.

Table 5: Decadal Variability of Temperature in the Offin sub-basin (1970 -2009)

Decade		Mean Temperature (℃)	Decadal Change (℃)
1	1970 – 1979	25.81	
2	1980 – 1989	26.17	0.36 (Increase)
3	1990 – 1999	26.39	0.22 (Increase)
4	2000 – 2009	26.71	0.32 (Increase)

The total change in temperature in the Offin sub-basin over the study period was computed as 0.637 ℃ as indicated in table 6. The period of 1993 to 2015 recorded a higher mean annual temperature, relative to the period of 1970 to 1992, confirming reports of increasing trend of temperature in the country.

Table 6: Actual change in temperature over the study period

Mean temperature (1970 – 1992)	26.023 ℃
Mean Temperature (1993 -2015)	26.660 ℃
Change in Temperature (1970 -2015)	**0.637 ℃ (Increase)**

4.1.7 Smallholder Farmers' Perceived Changes in Climate

This section looked at the awareness and perceptions of smallholder farmers on climate change and variability, their sources of weather and climate change information among other key information. 130 farmers made up of 61 (46.9%) and 69 (53.1%) were interviewed from four different towns in the Offin sub-basin.

4.1.7.1 Demographic Information of Respondents

The age of respondents ranged from 30 years to 72 years. Majority (43.1%) of the respondents were between the ages of 30 to 39, followed by the ages of 40 to 49 (22.3%) and the ages of 60 and above (19.2%). The least (15.4%) respondents were between the ages of 50 to 59. The results as well revealed that a greater proportion (52.3 %) of the farmers had received junior or senior secondary school education, while 31% had received basic or primary education. Only 8% of the respondents had tertiary education and 23% had received no formal education at all. Furthermore, considering the years of farming, 39.2% and 27.7% of the respondents had been farming for 10 to 20 and 20 to 30 years respectively. 18.5 % of the farmers have had 1 to 10 years' experience with the least percentage spending over 30 years in farming. The details of the respondents demographic information is shown in table 7.

Table 7: Demographic Information of Farmers (N=130)

Variable	Categories	Frequency	Percent
Age (years)	30-39	56	43.1
	40-49	29	22.3
	50-59	20	15.4
	60 and above	25	19.2
Level of education	None	23	17.7
	Basic education	31	23.8
	JSS/SSS	68	52.3
	Tertiary	8	6.2
	Vocational	0	0
Farming Experience (years)	1-10	24	18.5
	10-20	51	39.2
	20-30	36	27.7
	Over 30	19	14.6

Smallholder farmers in the surveyed towns are mostly into maize, plantain, cassava, cocoyam, yam, palm nut, pepper, and vegetables cultivation. The major cash crops cultivated in the surveyed areas are cocoa and rice.

4.1.7.2 Sources of Climate Information and Awareness on Climate Change and Variability

Farmers were questioned on their access to weather and climate information, and further on their knowledge on climate change and variability as indicated in table 8. Majority of the respondents (94.6%) had access to weather and climate information, and were aware of changes in climate (98.5%). 61.5% of the respondents access weather and climate information via the radio while 10.8% of them accessed weather information through television. Meanwhile 26% of smallholder farmers interviewed professed the reliance on their own perceptions for weather information. Older folks and friends made up 0.8% and 1.5% of sources of weather information among farmers in the basin. 5.4% of the respondents had no access to weather and climate information. Although majority of the respondents had their source of weather information being the radio, it was realized that when it comes to knowledge or awareness in climate change, a large portion of smallholder farmers relied on their own perceptions as their source information as shown in figure 15.

Table 8: Access to Weather and Climate Information and Changing Climate Awareness

		Name of community				Total
		Mfensi	Nyamebekyere	Kyereyase	Offinso	
Access to weather and	Yes	31(%)	25	29	38	123
climate information	No	4	0	1	2	7
Total		35	25	30	40	130
Awareness of change	Yes	33	25	30	39	127
in climate	No	2	0	0	1	3
Total		35	25	30	40	130

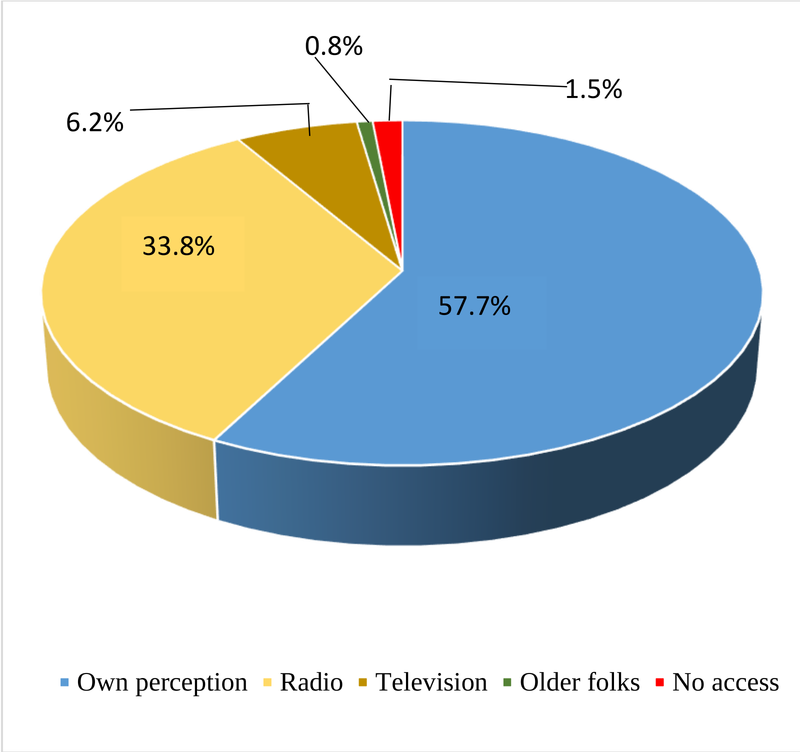

Figure 15: Source of Smallholder farmers Knowledge on Climate Changing

4.1.7.3 Perception of Changes in Rainfall

Farmers were queried about changes they had noticed in rainfall over the past 5 or more years. Firstly, the survey inquired whether the respondents had noticed a change in rainfall, of which 96.2% responded affirmatively. 30% of respondent farmers stated that rainfalls had increased whiles 65.4% of them responded that rainfall had decreased over the years as indicated in figure16. Furthermore, about 61% of these smallholder farmers indicated that a change in the onset and the cessation of rainfall had also been observed in addition to the rains increasing or decreasing. 4.6% (6) of the respondents had not observed any change in rainfall. The detailed results of this part of the survey is indicated in table 9.

Table 9: Rainfall Changes Observed

Count		Name of Community				Total
		Mfensi	Nyamebekyere	Kyereyase	Offinso	
Rainfall changes observed	Increased	15	6	7	11	39
	Decreased	16	18	23	28	85
Total		31	24	30	39	124

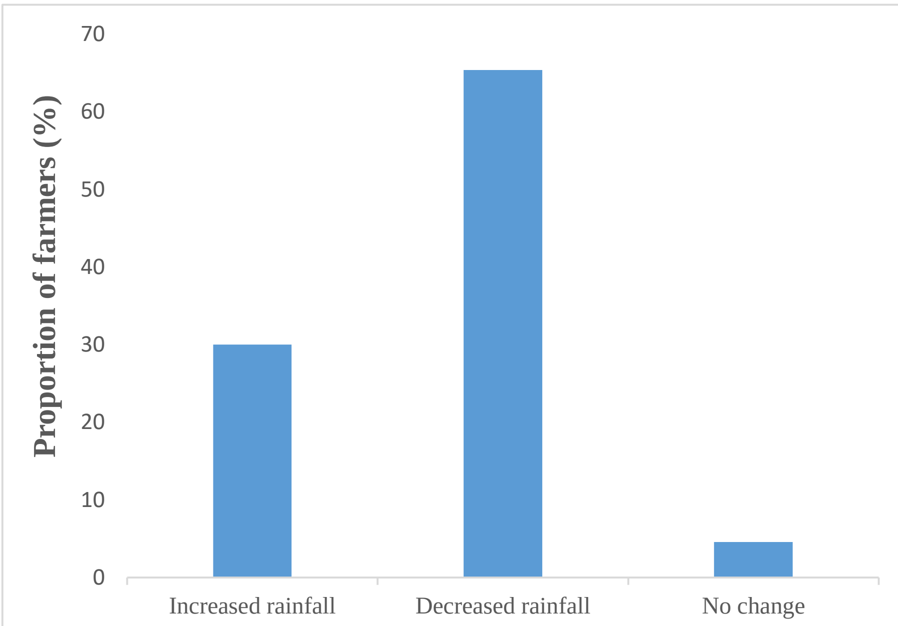

Figure 16: Perceived Changes in Rainfall over the past 5 and more years

The result of the statistical analysis of the daily rainfall used for this study pointed to a decreasing trend in rainfall, which most certainly correlates with the view of the majority of smallholder farmers respondents. This decline in rainfall and variability in the onset and cessation periods tend to impede development in the smallholder agriculture sector as attested to by a majority of the respondents.

4.1.7.4 Perceived Changes in Temperature

Smallholder farmers were inquired on their observations in temperature over the past 5 or more years, being given the options of temperatures increasing, decreasing or remaining the same. 34 (26.2%) of the respondents observed a decreasing trend in temperature whereas 86 (66.2%) of the respondents observed an increasing trend in temperature. Meanwhile, 10 (7.7%) stated that temperatures have not changed over the years as shown in figure 17. There was consistency in the observations of farmers across all four sampled towns in the Offin sub-basin as indicated in table 10.

Table 10: Observed changes in temperature

Categories		Name of Community				Total
		Mfensi	Nyamebekyere	Kyereyase	Offinso	
Observed changes in temperature	decreased	9	4	6	15	34
	increased	21	20	21	24	86
	not changed	5	1	3	1	10
Total		35	25	30	40	130

According to the respondents, these high temperatures mostly do not favour their crops as the crops tend to lose water at a high rate, causing them to die off.

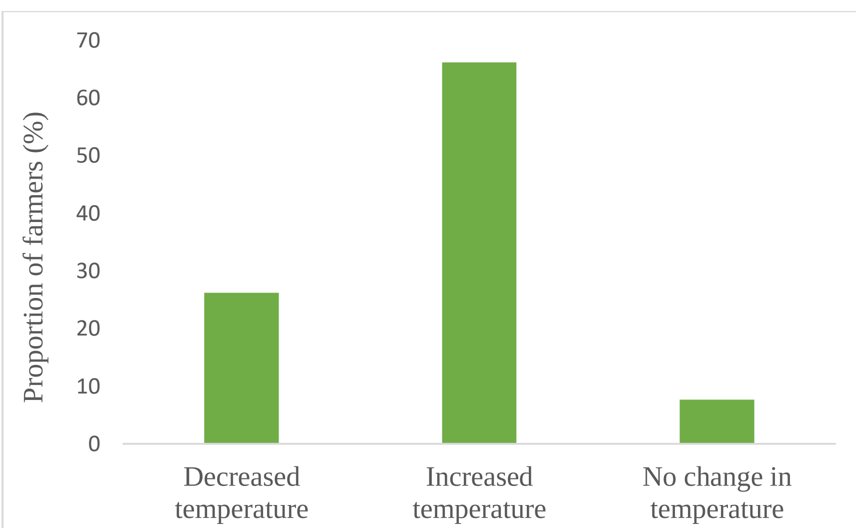

Figure 17: Perceived Changes in Temperature in the past 5 and more years.

Respondents were now asked on their general observations of the climate over the years. This saw 68.5% of farmers asserting that the climate is getting warmer and drier and 31.5% affirming that the climate is getting cooler and wetter. The frequency of flood events over the years according to 50 % of the respondents have increased. 27.7% of the respondents however, observed that the frequency of floods remained the same and 4.6% indicated a decrease in the occurrence of floods. In addition, 5.4% and 47.7% of the farmers stated that droughts and dry spells had decreased and increased respectively over the past 10 years. However, a significant portion of farmers noted that the frequency of droughts and dry spells had been normal. According to a section of the respondents, high temperatures do cause some of their crops to get rotten.

"Sometimes the weather gets so hot that our cocoa gets burnt literally, but this was not so at first. The cutting of trees from the farms tends to heighten the sun's intensity on our crops, causing our crops not to do well and subsequently reducing our yields". These were the worries of the chief of Mfeni who is senior farmer, concerning the increase in temperatures over the years. Notably, most of the respondent's observations were in line with the senior farmer's views.

4.1.8 Discussion

4.1.8.1 Rainfall and Temperature Changes and Variability in the Offin sub-basin

Water resources and agriculture, especially smallholder agriculture, tend to face harsh conditions as a result of climate change and variability. Analysis of the secondary data indicated increases in the mean annual maximum and minimum temperatures as well as highly variable and decreasing rainfall trend. These changes most certainly do affect the water resources of the basin. Moreover, Populations in the basin are predominantly into agriculture which being highly rain-fed makes it vulnerable to climate change and variability. Generally, about 80% of the population in the basin also do rely on the water resources for their livelihoods with a percentage depending on the river as their sole source of water supply (Gyampoh et al. 2007). The Offin River also serves extensively as the raw water which is treated and distributed to consumers in Kumasi and beyond.

Rainfall and temperature have been the major climate variables engaged to detect and measure the changes and variability in the climate of an area (IPCC, 2007). In a country as Ghana, where some major economic and development sectors are climate-sensitive, assessing climate change and variability, and their impacts on key areas in the country is crucial to seasoned policy-making and socio-economic development at large. Water resources and smallholder agriculture do contribute massively to economic growth and development in the country, yet they remain two sectors facing the first-hand harshness from climate change and variability. This study assessed the variability and changes in rainfall and temperature in the Offin sub-basin from 1970 to 2015.

Rainfall in the basin was found to be characterized by high seasonal and inter-annual variability, as its seasonality alternated between near normal to moderately wet and moderately dry conditions, as per the SAI computations. The Offin River sub-basin, however, has bimodal rainfall regimes with the major season being from March to July and the minor, from September to October. Accumulated mean monthly rainfall in the basin ranged from 183 mm in June to 16 mm in January, indicating a significant gap between the maximum and minimum rainfall. The December-January-February was recorded as the season with the least rainfall in the basin, indicating the potential of droughts and dry spells in this season, whereas March-April-May marked the onset of the rainy season. The trend, decadal and total changes in total annual rainfall in the basin were analyzed, as several studies have indicated that long-term changes and trends in climate variables are indicators of potential change. Total annual rainfalls in the basin over the study period have shown high variability. The deduced trend depicted a statistically insignificant negative one, where rainfalls were seen to reduce at a rate of 1.04 mm per year.

The insignificance of the trend can be attributed to the high inter-annual variability of the rains, thus a high level of annual rainfall dispersion around the mean. Decline in rainfalls has been recorded in most parts of West Africa over the past years (Weldeab et al., 2007). Similar studies carried out in various parts of Ghana also did find negative trends in rainfall. Baidu et al, (2017) reported a negative trend in total annual rainfall in all agro-ecological zones of the country, except the Coastal Zone, which experienced an increased rate of 0.16 mm per year. Owusu and Waylan, (2009), also recounted a decreasing trend in the total annual rainfalls in four agro-ecological zones, along with high inter-annual variability and a corresponding decrease in agricultural productivity over recent decades.

The SAI indicated that rainfall in the basin over the study period have varied from severely wet conditions to extremely dry conditions. Nonetheless, rainfall in the basin, over the period of 1970 to 2015 had decreased by 38 mm (3.21 %). This decline and irregularity in rainfall have been proven detrimental to agricultural practices and water resources, in terms of availability and quality and management at large. Therefore assessing and understanding the distribution, changes, and variability in rainfall is key to socio-economic areas like hydropower and agriculture in Ghana, due to the sector's high reliance on rainfall (Yorke and Omotosho, 2010). According to Philip et al (2014), agriculture stands as the most vulnerable sector to climate change as a result of the susceptibility of temperature and rainfall, to agriculture. These two variables, however, happen to be two of the major inputs in agriculture. Moreover, knowledge in rainfall variability and changes is key to understanding and realizing effective water resource planning, development, and management, as well as serving as a key tool for water balance modeling (Zhao et al, 2013).

Mean daily temperature in the basin ranges from 24 ℃ to 28.13 ℃. February and August were recorded as the months with the highest and lowest temperatures respectively. Mean annual temperature in the Offin sub-basin depicted a statistically significant positive trend pointing to a warming climate, as temperatures were seen to increase at a rate of 0.03 ℃ per year. Mean annual temperatures in the basin have been between 25 ℃ and 28 ℃. The decadal mean temperatures computed showed a steady rise in temperatures, with the period of 1993 to 2015, recording a higher mean temperature as compared to the period of 1970 to 1992. This was as well made evident in the SAI for the period, where above-normal temperatures were mostly within the period 1993 to 2015. Most notably, temperatures over the entire period (1970 – 2015), were observed to have increased by 0.637 ℃, and this tends to confirm various scientific reports, implying that temperatures in the country have been on the rise. According to Kuuzegh et al (2007) and EPA (2000), temperatures would have increased by about 0.6 ℃, 2.0 ℃, and 3.9 ℃ by the years 2020, 2050 and 2080 respectively. Several other studies (UNDP, 2012; Kankam-Yeboah et al., 2013; Fosu-Mensah, 2012; Codjoe and Owusu, 2011) have as well indicated that climate change and variability in Ghana have been made manifest mainly via diminishing average annual rainfall which is characterized by high variability, rising temperatures, increase in extremities, among others. This increase in temperature, coupled with declines in rainfall pose serious threats to water resources as well as water-dependent sectors in the country.

4.2 Effects of Rainfall and Temperature on Streamflow for the Period of 1970 to 2009 at Annual and Monthly Scale

4.2.1 Historical Trends, Changes and Variability in River Flow in the Offin sub-basin

The 40-year (1970 – 2009) streamflow data acquired from the Hydrological Services of Ghana, was computed and analyzed for trends, monthly and inter-annual variability and changes. The mean annual values, monthly means, decadal and total changes within the study period were computed and analyzed. As indicated in figure 18, at monthly scale streamflow was observed to rise gradually from February through to April, increasing steadily till a minor peak in June. Following this peak is a steady decrease till a major trough is established in August, after which there is a stable rise till a major peak is reached in October, decreasing steadily through to January. February and October were observed as the months with the lowest and highest streamflows respectively.

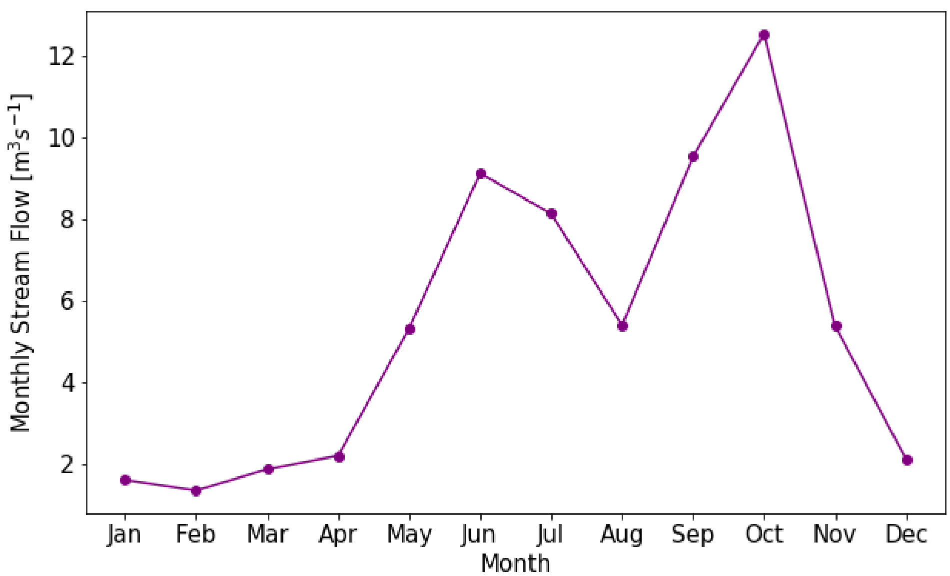

Figure 18: Mean Monthly Stream Flow in the Offin sub-basin.

At annual scale, the highest mean annual discharge, being 11.26 m^3/s was recorded in 1974, which happened to be a moderately wet year. The lowest, valued at 1.88 m^3/s was recorded in 2001, which was almost a moderately dry year. The mean discharge recorded for the period of study was

5.68 m^3/s. The mean annual streamflow was found to be on a decreasing trend at a rate of 0.107 m^3/s per year, implying stream flow had generally been reducing over the years. This reduction in streamflow poses challenges to water resources and climate-sensitive livelihoods at large. The annual trend depicted in figure 19 indicates a significant inter-annual variability hence the general linear regression analysis was used to further investigate the trend in streamflow in the study area. R squared (R^2) was valued at 0.307 (30.7%) implying that amidst this high inter-annual variability, there could still be a significant trend. The P-value however depicted a significant trend as it was valued at 0.0001 ($P < 0.05$).

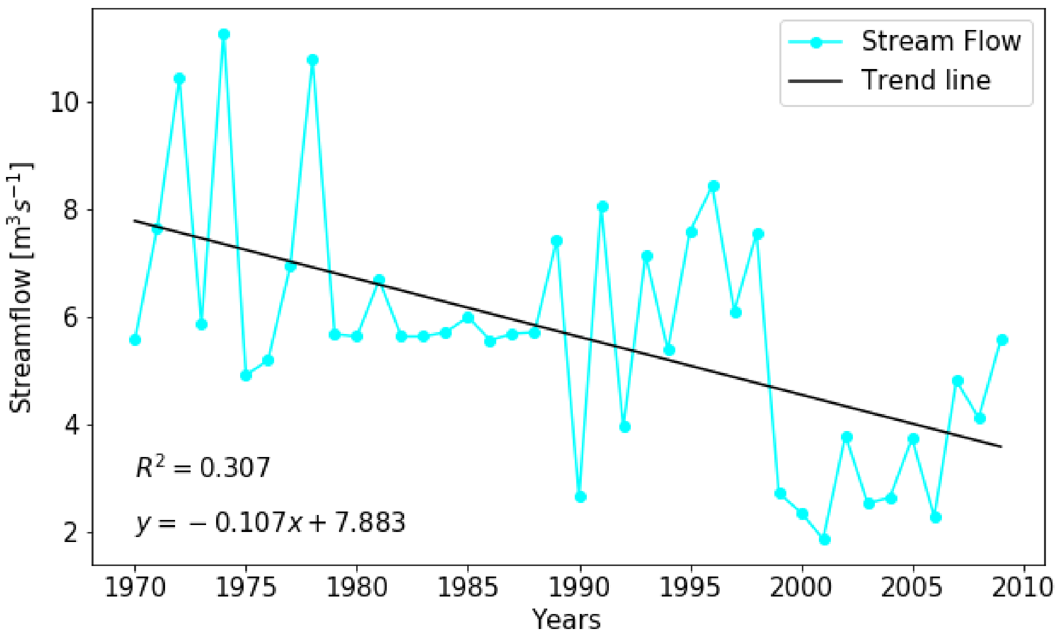

Figure 19: Trend of Streamflow in the Offin sub-Basin (1970-2009)

4.2.2 Decadal Changes in Stream Flow (1970 – 2009)

The decadal means and changes over the study period were computed and analyzed as indicated in table 11.

Table 11: Decadal Changes of Stream Flow in the Offin sub-basin (1970 -2009)

Decade		Mean Streamflow (m^3/s)	Decadal changes (m^3/s)
1	1970 – 1979	7.43	
2	1980 – 1989	5.97	-1.46
3	1990 – 1999	5.95	-0.02
4	2000 – 2009	3.38	-2.57

From the computations, 1970 to 1979 recorded the highest mean stream flow, followed by the decade of 1980 to 1989 with the period of 2000 to 2009 recording the least mean streamflow. From decade 1 to 2 mean streamflow reduced by 24% with a decrement of 0.34% observed from decades 2 to 3. The most significant reduction in mean streamflow was observed from decade 3 to 4 where streamflow reduced by 76%. On the whole, streamflow over the study period had decreased by 43.41% as indicated in table 12. It is therefore evident that streamflow had been decreasing over the years, posing major threats to water resources and water-dependent sectors at large.

Table 12: Actual Change in Stream Flow in the Offin sub-basin from 1970 to 2009

Mean Streamflow (1970 – 1989)	6.696 m^3/s
Mean Streamflow (1990 -2009)	4.669 m^3/s
Change in Streamflow **(1970 -2009)**	**-2.027 (43.41 %)** m^3/s

4.2.3 Standardized Anomaly Index for Historic Stream Flow in the Offin sub-basin

Standardized anomalies were used to further describe and characterize the inter-annual variability of streamflow in the Offin sub-basin. Streamflow variability and fluctuations about the mean for the study period (1970 – 2009), which is 5.68 m^3/s, was evaluated and presented in figure 20. It can be seen that normal and above normal streamflows were majorly recorded from the 1970s till the late 1990s, after which mostly lower than normal flows were recorded. Most years within the study period had normal flows with a few years recording moderately wet (1991 and 1996) and moderately dry (1990, 1999, 2003 and 2004). There were extremely wet years (1972, 1974, 1978) and severely dry years (2000, 2001, 2006) as well.

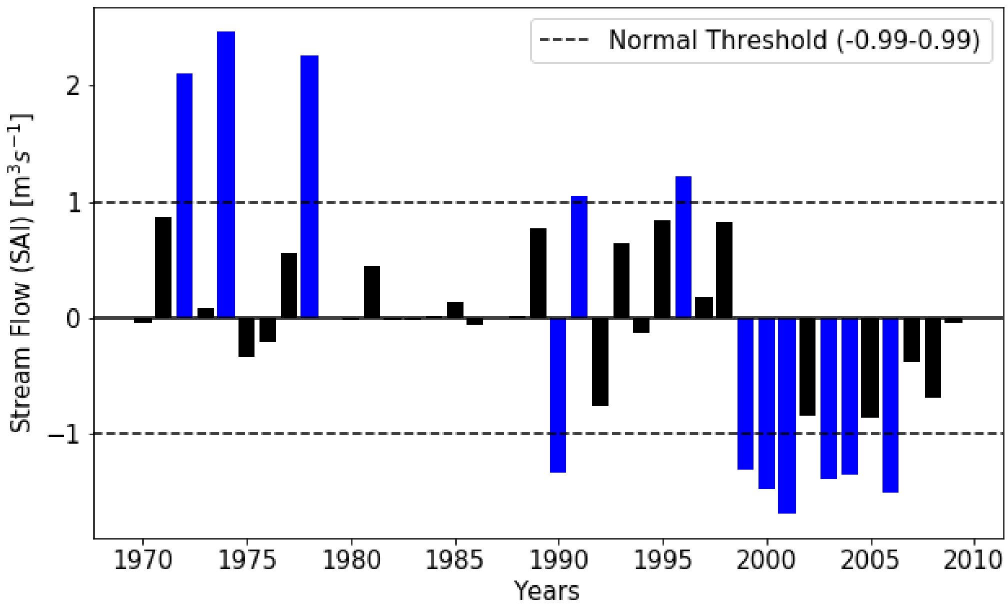

Figure 20: SAI for Streamflow in the Offin sub-basin.

4.2.4 Influence of Rainfall and Temperature Changes on Stream Flow in the Offin sub-basin at Monthly and Annual Scales

Changes and variability in climate tend to have effects on water resources. According to Chang et al (2016) and Chien et al (2013), water resources of river systems do respond to changes in climate variability through Changes in precipitation and potential evaporation. Ma et al (2015), also indicated that climate change and variability impact water resources via precipitation, streamflow, and groundwater recharge changes. A decreasing precipitation trend tends to subsequently reduce the streamflows for rivers (Mahe et al. 2013; Kankam-Yeboah et al. 2013). According to USA-EPA (2012), streamflows increase during thunderstorms and decline during the dry periods and periods of high temperatures. Knowledge on how climate change and variability impacts streamflow is key planning water developments and enhancing resilience in across water sectors.

This section of the results focused on the impact rainfall changes do have on streamflow at monthly and annual scales. Monthly variability of rainfall and streamflow in the basin were analyzed as indicated in figure 21, to compare their patterns. On a monthly scale, rainfall is observed to influence streamflow as both variables peaked in June and declined majorly in August. Though rainfall peaked minimally in September, the major streamflow peak occurred in October. This is attributable to the ground getting close to saturation due to the earlier rains, hence when the September rains occur, more water is available as runoff as a minimal portion of the rains infiltrate the ground.

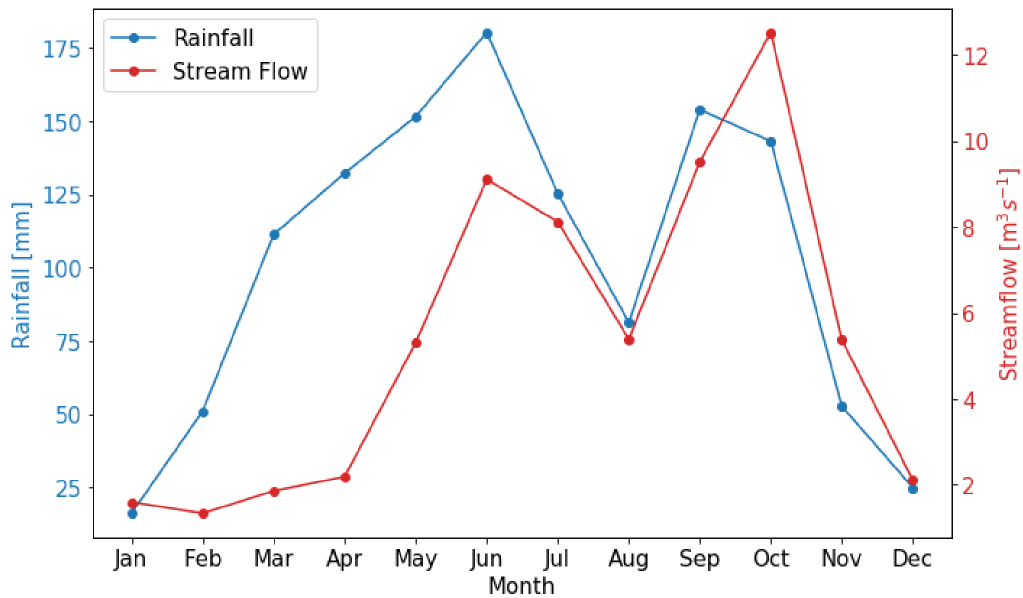

Figure 21: Total Monthly Rainfall and Mean Monthly Streamflow in the Offin sub-Basin

There is however a lag time between the minor peak of the rains and the peak streamflow in the basin. The Pearson correlation coefficient being a measure of the strength of a linear relationship between two variables was employed in measuring the effect of rainfall on streamflow on both monthly and annual scales. At monthly scale, a Pearson correlation coefficient of 0.68 was found, indicating a moderate positive linear relationship between rainfall and streamflow. The R squared value being 0.46 indicates that 46% of the variation in mean monthly streamflow can be accounted for by variations in total monthly rainfalls. The trends of rainfall and streamflow at annual scales were compared as indicated in figure 22.

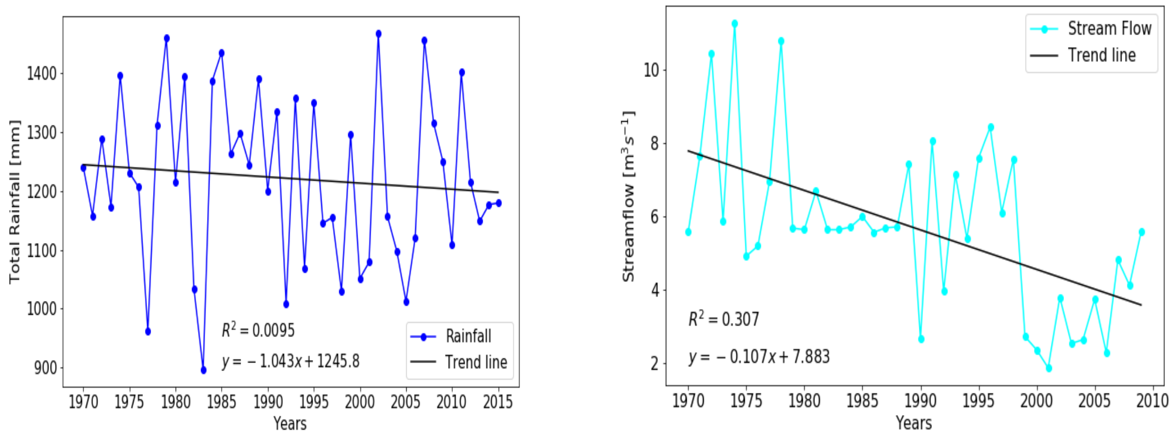

Figure 22: Comparing Trends of Total Annual Rainfall and Mean annual Streamflow

Both annual trends were observed to be on the decreasing end. Though the trend of rainfall has not been significant, that of streamflow was significant ($P < 0.05$). At annual scale, the Pearson correlation coefficient was found to be 0.29, indicating a positively weak relationship. R squared as well, being 0.08 shows that only 8% of the inter-annual variations in streamflow can be attributed to the inter-annual variations in rainfall. Therefore it can be said that on a monthly scale, rainfall has much impact on stream as compared the annual scale. Comparing the decadal changes of rainfall and streamflow from 1970 to 2009 revealed a significant decrease in both parameters in the last two decades of the study period.

Increasing temperatures have been noted to impact streamflow via an increase in evapotranspiration. Previous studies in the Pra and Volta basins of Ghana found out that a steady rise in temperature contributed to a decline in streamflow in both basins. Mean monthly temperature and streamflow in the basin were analyzed as indicated in figure 23, to compare their patterns. The highest temperature and the lowest mean flow was recorded in February. August being a short dry period was seen to have the lowest temperature. Although temperatures begin to rise again through to October, the rains cause streamflow to peak majorly in October, as the rate of evaporation is nullified by the abundant rainfall. At monthly scale, The Pearson correlation coefficient between mean temperature and streamflow was -0.61 ($R^2 = 0.37$), implying a moderate negative relationship. This indicates that as temperature increases, streamflow tends to decrease due to high rates of evaporation as a number of studies have hinted.

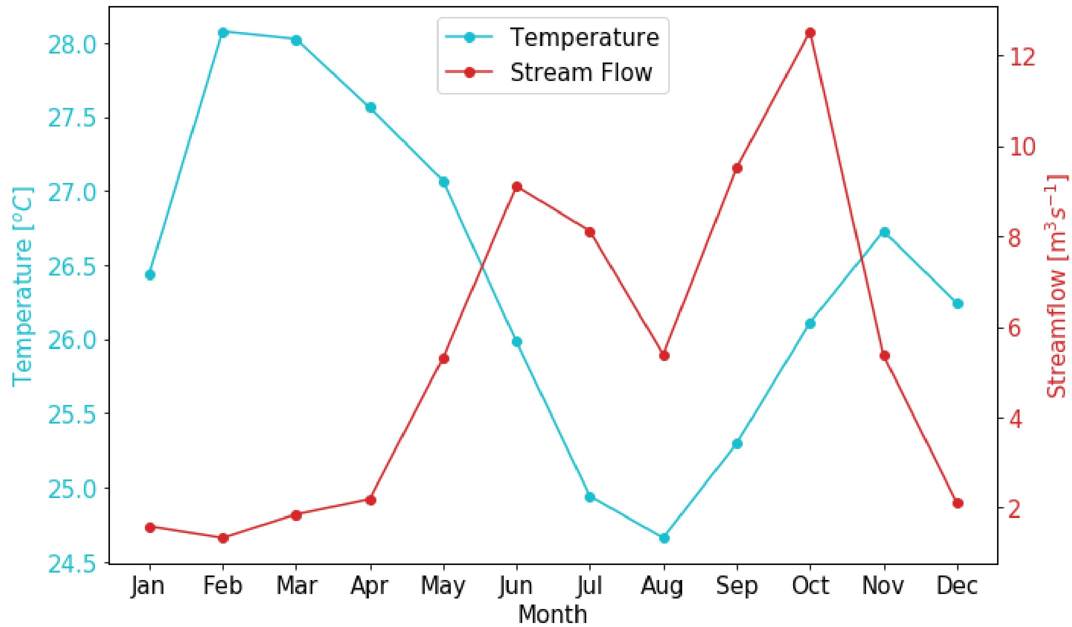

Figure 23: Mean Monthly Temperature and Mean Monthly Streamflow in the Offin sub-Basin

At annual scale, streamflow trend was decreasing significantly with that of temperature also increasing significantly (P< 0.05) as indicated in figure 24. The Pearson correlation coefficient at the annual level was found to be -0.51, implying a moderate negative linear relationship. The coefficient of determination being 0.26, denotes that 26% of the variance in mean annual streamflow can be explained by the changes in annual temperature as indicated in table 14.

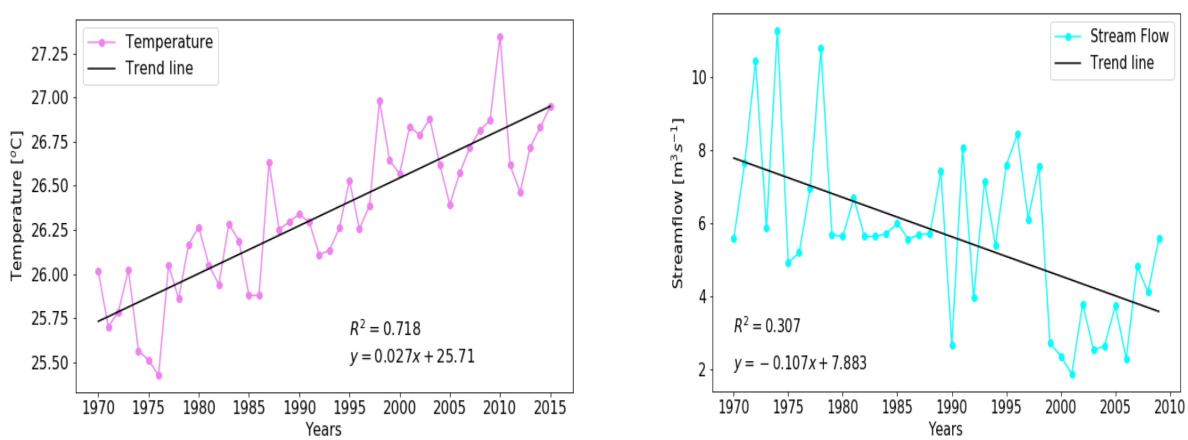

Figure 24: Comparing Trends of Total Annual Rainfall and Mean annual Streamflow

Furthermore, comparing the decadal means of temperature and streamflow from 1970 to 2009 revealed a notable decrease in mean streamflow and increase in temperature in the last 2 decades of the period relative to the means of the first 2 decades as shown in table 13.

Table 13: Comparing Mean Rainfall and Mean Streamflow in the Offin sub-Basin (1970-2009)

Decades	Rainfall Mean (mm)	Temperature Mean (℃)	Streamflow Mean (m^3/s)
1970 -1989	1249.52	25.99	6.696
1990 -2009	1197.92	26.55	4.669

Table 14: Result of Correlation between Rainfall, Temperature and Streamflow at Monthly and Annual Scales (1970-2009)

Variables	Correlation Coefficient (r)	Strength of Linear Relationship	Coefficient of determination (R^2)
Rainfall – streamflow (monthly)	0.68	Moderately positive	0.46
Rainfall – streamflow (annual)	0.29	Positively weak	0.08
Temperature – streamflow . (monthly)	-0.61	Moderately negative	0.37
Temperature – streamflow (annual)	-0.51	Moderately negative	0.26

4.2.5 Discussion

4.2.5.1 Historical Trends, Changes and Variability in Streamflow in the Offin sub-Basin

Mean streamflow in the basin ranged from 1.59 to 12.52 m^3/sec, with February and October recording the lowest and the highest stream flows respectively. Average annual streamflow analyzed within the study period revealed a significant negative trend, where streamflows declined at a rate of about 0.1 m^3/sec per year. It was found that streamflow in the Offin sub-basin decreased by about 44 % over the study period. This results tend to agree with a number of studies in the country where remarkable reductions in streamflow were recorded across various river basins. According to Gyau-Boakye (2001), between 1971 and 1990, the mean stream flow of the Oti River had decreased by 32.5 %. Boon and Ahenkan (2011), further iterated that rivers, streams and other surface freshwater resources, being the key sources of drinking water in Ghana, are continually becoming unreliable as a result of declines in rainfalls and increase in the frequency of droughts and dry spells. These conditions create the platform for extremely low flows, threatening water quality and availability. Population growth over the years has increased the demand for water across various sectors and food production as well. Climate change and variability impact on streamflow coupled with the increase in water withdrawals for industrial and agricultural purposes would further deplete streamflow.

From the questionnaire administration, it was revealed that 76.3% of the respondents do rely on the Offin River for their livelihoods and water needs, with 58.5% of them relying on the river for their crop irrigation purposes. These figures are set to increase with the population on the rise, creating a suitable platform for climate change and variability to have detrimental impacts on water resources, and the environment at large. Hence, there is the need to put up measures to nurture resilience of water systems in the country.

4.2.5.2 Relationship between Climate Variables and Streamflow in the Offin sub-basin of Ghana

The Pearson correlation coefficient was used to measure the strength of the connection between rainfall, temperature, and streamflow. It was realized that at monthly scale, rainfall and temperature did have a stronger influence on streamflow than at annual scales. Increase in rainfall resulted in higher or even excess streamflows, which is good for the river system, yet detrimental in terms of flood hazards. Moreover, the decreasing trend in rainfall is set to further deteriorate streamflow and pose challenges to water supply and the environment at large. A section of respondents pointed out that most trees that used to shade the river had been cut down, causing the sun to have a direct impact on the river. Higher temperatures have been associated with an increase in evaporation rates. This emphasizes the need for measures to be put in place to enhance effective water resource management in the Offin basin.

4.3 Challenges due to Climate Change and Variability and Adaptation Strategies practiced in water management and smallholder agriculture in the basin

This section, firstly looked at some challenges facing smallholder farming in the basin due to the changing climate after which various means by which they tend to adapt to some of these problems are discussed.

4.3.1 Challenges Facing Smallholder Farming in the Offin sub-Basin According to Field Survey

Several studies have established the basis that climate change and variability do have consequences for agriculture and do unfairly impact the poor and sidelined groups who depend on the sector for their sustenance (Zougmore et al., 2018). The respondent farmers interviewed identified a number of problems they face currently due to the changing climate. These problems have been identified into common themes such as pest infestations, low yields, low income, increase in flood frequency, and others and then discussed.

4.3.1.1 Increased Flood and Erosion frequency

Floods and droughts are increasing the rate at which crops and farm harvests get ruined, particularly in developing countries such as Ghana. In 2018, hundreds of smallholder farmers in the Bawku area of Northern Ghana were ushered into great losses due to floods engulfing vast farmlands, destroying crops and farm structures (Modern Ghana, 2018). Similarly, 2009 also recorded River Offin flooding and displacing over a thousand people at Amaada, a farming community in the basin.

During the survey, 61.5% of the respondents identified that the frequency of floods had increased in the past 10 years, having detrimental effects on their crops. Many respondents pointed out that floods do occur in the rainy season, causing lots of crops to be washed away. The few left behind tend to get rotten due to the loss of soil oxygen resulting in overwhelming. Others complained of their seedlings getting destroyed, thus the need to replant them, putting strains on available resources. Vegetable farmers interviewed exhibited even more susceptibility to flooding by virtue of their farming along the banks of the Offin River. As a result of the need for continuous irrigation, most of these farmers situate their farms close to the river. Therefore anytime the river floods, their farmlands are certain to get flooded. Notwithstanding this exposure, only 13.1% of the respondents attempt to protect their farms from the devastating effects of floods. One older female farmer recounted “There is nothing I can do about the floods, I just start counting my losses when it happens”.

Due to increase in the frequency of floods, erosions have also been on the rise as 56.9% of the respondents consented to experiencing frequent erosion. This percentage majorly was made up of vegetable farmers who farm closer to the Offin River, as the farmers whose farms were away from the river and those whose farms were situated on higher grounds do not get their farms easily flooded. These floods, according to respondents tend to wash away all the topsoil, leaving the soil bare and unfertile.

4.3.1.2 Reduction in Soil Fertility

Research has shown that climate change and variability impact soil fertility through changes in, soil temperature, carbon dioxide levels and most importantly soil moisture (Pareek, 2017). Therefore as part of the field survey, respondents were queried on the state of their soil’s fertility over the years, given the options of soil fertility decreasing, or being unaffected. 61.5% of the smallholder respondents indicated that the fertility of the soil is decreased with 37.7% stating that it has been unaffected. Increased erosion in the catchment over the years has been a key contributing factor in this as the rich healthy topsoils are mostly destroyed. Due to a reduction in soil fertility, a key portion of the respondents stated that crops do not do very well compared to previous times due to the soil losing its strength. A section of farmers complained of having to replant crops sometimes due to crops dying after the initial planting. This has increased fertilizer usage in the basin. A senior farmer recalled, “Early on, we could grow maize without fertilizer use, however, due to the soil getting hardened with less moisture in recent times, we go in for fertilizers to aid even maize growth”. Studies have also attributed the decrease in soil fertility to the diminishing fallow periods and intense cropping activities, giving the soil very limited or no time to undergo restoration (Vanlauwe et al., 2015).

4.3.1.3 Decline in Rainfall Totals and Changes in Rainfall Pattern

Changes in rainfall pattern coupled with declines in rainfall amount, as reported by several studies have been key evidence of climate change and variability in Ghana. McSweeny et al (2010) indicated a high inter-annual and inter-decadal variability in rainfall in the country, a deduction which has been confirmed by the findings of this study. This research as well revealed that rainfall over the study period (1970-2015) had decreased by 38.68 mm (3.21%). Affirmatively, the field survey also saw 65.4% of the respondent farmers inferring that rainfall had decreased over the years with 61.5% indicating that there had been changes in the onset and cessation of rainfall.

Yorke and Omotosho (2010), affirmed a high variability and unpredictability of rainfalls in the country, with respect to their onset, duration, and cessation. Studies show that extremely variable climate settings such as changes and variability in rainfall onset and cessation times tend to aggravate soil fertility and food production challenges. About two-thirds of respondent farmers' detailed that delays in the onset of rains tend to disrupt farming activities in that planting time is delayed, thus production is also delayed. Majority of the farmers stated that their crops get destroyed due to the expected rains not forthcoming and the soil surface being very hard such that crops like cassava which thrives even in harsh conditions are not able to grow well. Due to this most of them like to wait for the onset of the rains before going on ahead to plant. These farmers, on the other hand, complained of their crops getting rotten should the onset of the rains be characterized by high-intensity rainfalls leading to floods. The respondents also made it clear that the frequency of dry spells and droughts had increased over the years and gave a typical example of how July was supposed to be a wet month yet due to early cessation, they were not getting the rains as expected. A senior male farmer recounted;

"Our planting dates have shifted a lot. Even for this year, the rains delayed our cropping activities in the sense that we used to plant rice twice a year, but due to the delay of rainfall, we planted only once". A section of rice and maize farmers recounted that delays in the rains after planting mostly cause their crops to become chaff instead of yielding food. The decline and changes in rainfall onset times have affected crop production and yields among farmers in the basin, as 71.5% of the respondents mentioned a reduction in their crop yields over the years.

4.3.1.4 Increase in Temperature

This studies revealed a positive trend in temperature in the basin where temperature increased at a rate of 0.03 ℃ per year and increased by 0.637 ℃ over the entire period of study. Agreeably, 66.2% of the respondents had observed an increase in temperature over the years. This increase in air temperature has been proven to have adverse influences on plant growth. According to Serdeczny et al (2015), the net effect of increasing temperatures on crop yields in Africa is negative. Moving forward, Dell et al (2012) estimated a decrease of 2.66 % in crop output per a temperature rise of 1℃ in developing countries.

From the field survey, a greater proportion of respondent farmers complained of how these high temperatures diminish the water retainability of the soil and cause crops to lose water at unusual rates, destroying crops eventually. Cocoa farmers reported the numerous times their cocoa trees got destroyed due to very high temperatures causing them to run into losses, as cocoa is one of the major cash crops cultivated in the basin. High temperatures coupled with dry conditions have been observed to cause increased cocoa tree mortality and highly decreased yields (Gateau-Rey et al., 2018).

4.3.1.5 Increased Pest Infestation

A number of studies revealed that increased temperatures bring about a rise in pest infestations as well as crop diseases, which has detrimental effects on food crop yields. Especially, that of cereals such as rice, maize and wheat, which is grown in tropical regions (Serdeczny et al., 2015; Appiah et al., 2018). Nelson et al (2009) noted that higher temperatures heighten weed and pest spread, subsequently leading to crop yield reduction. A section of the respondents, mostly the maize and rice farmers recounted increases in pest infestations over the years which cause them to cut some crops down. According to them, maze thrives less these past years relative to previous years as a result of pest and weed infiltration even in the face of highly variable rains and increased temperatures. One of the respondents iterated, “If we grow crops such as rice and maize and we do not apply pesticides, we do not get a single grain to harvest at the end of the day. In addition to this, weeds have invaded our rice farms”. This pest and weed excessiveness has caused them to spend more resources on pesticides, taking a toll on their incomes.

4.3.1.6 Decreased Income

All the above mentioned challenges lead to crop yield reduction, implying fewer crops available for sale thus lessened income, as pointed out by 76.9% of the respondents. Resources spent to control pest and weed infestations as well, consumes a percentage of smallholder farmer’s income. Weeds, when cleared and used as mulch, is able to enhance soil fertility. However, according to farmer's heads, lack of money to hire labourers to clear weeds on farms causes farmers to highly patronize weedicides which in turn hardens the soil and depletes its fertility, in addition to posing health risks to farmers. A section of farmers made mention of their inability to sell some of their produce for income due to low yields leaving them with only what they have to consume with their family.

4.3.2 Adaptation Strategies practiced in water management and smallholder agriculture in the basin

This study investigated the various means which by changes and variability in climate are adapted to in terms of smallholder farming and water management. The field survey revealed that majority of the respondent smallholder farmers had clear perspectives on climate trends and a few had put in measures to reduce the impacts of climate change and variability on their livelihoods as discussed below.

4.3.2.1 Water Management Strategies

Communities surveyed in this study mostly sourced their water for domestic use from boreholes placed at vantage points. According to the older respondents, the communities used to rely on the Offin River even for drinking until the quality of the water started deteriorating. The traditional leader of Mfensi recounted that a few years ago, a group of health workers analyzed the water quality of the river in their town, after which the water was declared unfit for consumption in its raw state. However, a small proportion of the respondents still drink from the river with greater percentage of them relying on the river for their crop irrigation purposes. This river as well provides potable water to Kumasi and surrounding towns through the Owabi and Barekese dams. The river serving a number of key purposes, coupled with climate change and variability implies increased water stress.

It was found that over 50% of respondent farmers relied on the river for the sustenance of their farming activities. This number would inevitably increase in the face of highly variable and decreased rainfall, coupled with high temperatures and increasing population.

Rainwater harvesting has been established over the years as a sustainable water management approach under a changing climate and a water stress environment (Kaushik et al., 2006). The field survey revealed that rainwater harvesting has been extensively practiced in the basin. 96.9% of the respondents responded affirmatively to harvesting rainwater as indicated in table 15.

Table 15: Respondents who harvest rainwater

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	yes	126	96.9	96.9	96.9
	no	4	3.1	3.1	100.0
	Total	130	100.0	100.0	

Most respondents indicated that harvested rainwater (nyankonsuo, in local dialect) provided them with a cleaner and tasty source of drinking water compared with the borehole and river. Moreover, they are provided with water for various domestic purposes and small-scale irrigation. Rainwater harvesting, without doubt, plays a vital role in supporting water supply in the basin. Several studies (Bates et al., 2008; Ojwang et al., 2017) have detailed rainwater harvesting as a key climate change adaptation measure for complementing water for drinking or irrigation. One key challenge facing surveyed communities is the increased flood frequency which tends to destroy their homes and their crops as well as erode the fertile top soils in their farms, eventually leading to losses. Further investments in rainwater harvesting in the surveyed communities and the basin at large would not only increase water availability but also reduce stress on ground and surface water resources. Moreover, enhancing rainwater harvesting could provide ample water for irrigation purposes, further reducing demand on available water resources. Research shows that about 70% of freshwater withdrawn globally is used for agricultural purposes. Therefore rainwater harvesting has the potential to reduce this figure and also increase crop yield in the basin as the consequences of erratic rainfall on crop production in the basin would be alleviated. A typical rainwater harvesting system in the surveyed towns in indicated in figure 25 below.

Figure 25: A typical rainwater harvesting system at Nyamebekyere (Field Survey, 2019)

4.3.2.2 Adaptation Strategies Practiced in Smallholder Agriculture (Crop Production) in the basin

This study explored various means by which smallholder farmers have been adjusting to climate change and variability in the basin. The field survey revealed that farmers in the basin had noticed changes in the climate and a percentage of them put in measures to avoid the consequences that come thereof as indicated in table 16.

Table 16:Adaptation strategies Adopted by smallholder farmers in surveyed Communities

Strategy	Response	
	Yes (%)	No (%)
Usage of irrigation	76 (58.5)	54 (41.5)
Water and soil moisture conservation	32 (24.6)	98 (75.4)
Practice of crop diversification	112 (86.2)	17 (13.1)
Flood protection	17 (13.1)	112 (86.2)

Tree planting on farms	58 (44.6)	72 (55.4)
Planting some climate resistant crops	65 (50)	65 (50)
Changing planting dates	113 (86.9)	17 (13.1)
Alternative income source	65 (50)	65 (50)

The erratic nature of rainfall in the basin and the country at large coupled with high temperatures have heightened smallholder farmers' reliance on irrigation in enhancing crop production. Through the field survey, it was realized that vegetable farmers mostly pumped water from the Offin River for their crop irrigation, whereas other farmers, especially those who farm away from the river solely relied on the rains. A section of the respondents complained of not having the resources to source water from the river to irrigate their crops even in the face of dry spells and droughts implying low production. Developing and enhancing irrigation systems in these crop-production dominant rural areas inevitably would foster resilience to climate change and variability in the agriculture sector of the country as well as boost economic growth. Irrigation is therefore a vital input to crop production and a key to alleviating rural poverty (Lipton et al., 2003).

Water and soil moisture conservation practices have been established as a means of responding to high rainfall variability as well as increasing temperatures. According to Derpsch et al (2014), low yields are rather associated with inadequate soil moisture as opposed to highly erratic and decreased rainfall. The field survey revealed that a relatively lesser percentage of respondents (24.6%) practiced soil moisture conservation mainly via mulching. This according to them not only helps to retain soil moisture, but enhances normal soil temperature, lessen weed growth and promote soil fertility. Mulching is not extensively practiced in the surveyed communities due to the widespread use of weedicides which ends up drying and ridding the soil of moisture.

86.2% of respondent farmer indicated their involvement in crop diversification which is also geared towards increasing production as pests and weeds are controlled and soil fertility is enhanced. Therefore under a changing climate, promoting crop diversification will help build resilience in smallholder farming. A few of the farmers' (13.1%) put in basic measures such as creation of gutters on farms, to alleviate the effect of floods on their farms. Enhancing small scale flood control measures in the basin and rural Ghana at large would go on to secure food production, considering the intensity of yield loss due to flooding in the basin.

Tree planting has been a major means of mitigating against climate change as it serves as a means to remove CO_2 from the atmosphere, thus offsetting greenhouse effect (Hof et al., 2017). Beyond this, trees according to the respondents provide shades on the farms, thus preventing the direct impact of the increasing temperature on the crops. Cocoa farmers recounted that their cocoa was doing quite well till most of the trees on their farms were cut, leading to their cocoa yields reducing due to the harsh temperatures.

50% of the farmers planted some climate-resistant crops such as cassava, plantain, palm nut, and coconut. According to them, they are able to count on these crops should there be rains or not, or should there be high temperatures. Providing farmers with climate-resistant varieties and high yielding seeds would secure food production even in this changing climate. Changing planting dates have been a means by which farmers reduce losses as a result of delayed rains. 86.9% of respondent farmers attested to changing their planting dates to suit the onset of the rains as planting before the onset time resulted in plants or seedling destruction and possibly replanting. Adapting alternative livelihood sources is key to enhancing the resilience of rural farmers to climate change and variability impacts. 50% of the respondents were involved in other income-earning activities such as trading, teaching, and crafting.

Finally, respondent farmers consented to the increased use of fertilizers and pesticides as they play a central role in maintaining the fertility of the soil and the general wellbeing of crops, thus facilitating crop yields. Studies have elaborated the use of highly improved fertilizers and pesticides as a means of adapting to the impacts of climate change and variability. Respondent farmers went on to propose the subsidization of fertilizers and pesticides to increase their use, take some pressure off their incomes and enhance agricultural efficiency.

Meanwhile, smallholder farmers have been urged to adopt more sustainable farming practices as unsustainable practices such as the use chemical fertilizers, pesticides and weedicides tend to exert detrimental pressures on the environment (Fadina et al., 2018).

CHAPTER FIVE

5. SUMMARY, CONCLUSION, AND RECOMMENDATION

5.1 Summary

Climate change and variability have undoubtedly taken grounds in Ghana and Africa at large as previous studies have indicated significant changes in rainfall and temperature across various regions of the country. Two sectors most vulnerable to the impacts of climate change and variability are the water and agriculture sectors. Meanwhile, these sectors are the backbones of the economy of Ghana, playing central roles in socio-economic development. This implies research on climate change and variability impact on these sectors should not be taken lightly. This study assessed the impact of climate change and variability on water resources and smallholder agriculture in the Offin sub-Basin of Ghana, which is responsible for supporting livelihoods in and beyond the basin.

This study analyzed 46-year (1970-2015) temperature and rainfall data, as well as a 40-year streamflow data for the trends, anomalies, decadal changes, and correlations. It was realized that temperature increased significantly over the study period whereas rainfall decreased insignificantly over the years. Rainfall in the basin was found to be characterized by high seasonal and inter-annual variability, as its seasonality alternated between near normal to moderately wet and moderately dry conditions, as per the SAI computations. Most notably, temperatures over the entire period (1970 – 2015), were observed to have increased by 0.637 ℃, and this tends to confirm various scientific reports, implying that temperatures in the country have been on the rise. As a way of confirming these findings and knowing how people in the basin have been exposed to climate change, the perceptions of farmers and households were assessed as well. Assessing the perceptions of smallholder farmers' on changes in the climate indicated that most farmers had indeed observed changes in rainfall and temperature, which have been having dire consequences on their farming activities and yields over the years.

Changes in rainfall and temperature implied possible changes in streamflow as well. Therefore on analyzing streamflow data, it was observed that streamflow in the basin had been on a significant decreasing trend. Since other factors could be contributing to these changes, the correlation between streamflow and rainfall and temperature were found, in order to know the extent of the influence of the climate variables on streamflow. This study finally looked into challenges farmers in the basin had been facing due to climate change and variability and various means by which they had been coping with these challenges.

5.2 Conclusion

This study was geared towards assessing climate change and variability impact on water resources and smallholder agriculture in the Offin sub-Basin of Ghana. This basin is to a large extent responsible for supporting the livelihoods of indigenes in the basin in terms of irrigation for food crop production, fishing, transport, and water for domestic and industrial purposes. Aside this basin being a major area for agricultural production in the region, it also supports the provision of potable water to Kumasi and its environs. Meanwhile, recent and past studies have highlighted changes and variability in the climate of the country and their dire effects on these climate-sensitive sectors.

In order to detect possible changes in the climate of the basin, the trends of rainfall and temperature in the basin were assessed, coupled with recounts by indigenes in the Offin sub-Basin. A significant increasing trend (0.027℃/year) was detected for temperatures in the basin, whereas an insignificant decreasing trend (1.04mm/year) was recorded for rainfall in the basin over the study period (1970-2015). On interviewing smallholder farmers in the basin, 26.2% of the respondents indicated an observed decrease in temperatures, whereas 66.2% had observed increased temperatures over the years. 7.7% reportedly observed no changes in temperature. Changes in these climate variables implied possible changes in streamflow in the basin. Significantly, streamflow in the basin was on a decreasing trend at the rate of 0.107 m^3/s per year. The Pearson Coefficient was employed to determine the strength of the influence of rainfall and temperature on streamflow in the basin. This revealed a moderately positive and moderately negative relation between streamflow and rainfall and temperature respectively at monthly scales. At annual scale, rainfall had a positively weak relationship with streamflow, whereas temperature had a moderately negative relationship with streamflow.

This research went on to find out some challenges facing farmers and water users in the basin as a result of these changes. Smallholder farmers made mention of challenges such as floods and increased soil erosion, high temperatures destroying crops, low yields and income, increased pest infestations and many more. Notably, these farmers had developed a few strategies geared towards reducing the effect of climate change and variability impact on their livelihoods. These include rainwater harvesting, the usage of irrigation, the increased use of fertilizers, crop diversification tree planting, and alternative income sources, among others. Developing and enhancing these adaptive measures in crop-production dominant rural areas inevitably would foster resilience to climate change and variability in the agriculture sector of the country, reduce rural poverty as well as boost economic growth in the country at large. Teaching and learning processes between policymakers, governmental and non-governmental organizations, individuals, community water managers, farmers, and other concerned groups should be enhanced. This would inevitably serve as a major step to building resilience in the management of water resources in the country as well as foster resilience in the agriculture sector.

5.3 RECOMMENDATIONS

The impacts of climate change and variability on water resources and smallholder agriculture is set to continue as far as the climate keeps changing. Future projections of climate change and variability do point out even harsher conditions, hence the more reason for pooling resources together to enhance adaptation to climate change and variability in the country. Based on field data, reviewed literature, and personal views, the following recommendations have been drawn.

Robust administrative systems comprising of key stakeholders and individuals or groups at the grassroots level should be set up to ensure effective coordination and management of water resources across the country. There should be sensitization about the effects of unsustainable agricultural practices and activities that deteriorate water resources among communities, farmers and water users.

Populations should be sensitized and prompted on water conservation strategies, to avoid practices that lead to wastage, as water is a finite resource. Moreover, there should be stern enforcement of the law against small and large-scale activities such as ‘galamsey’ destroying water resources

Water retention ponds should be created at vantage points to manage storm runoffs which potentially cause floods in these study areas as well as other flood-prone areas.

Knowledge on the perceptions and vulnerabilities of local populations about climate variability should be amassed in other areas of the country, along with various means by which climate change and variability are being adapted to in the communities. This would serve as a means of integrating rural and indigenous knowledge into developing sustainable adaptation strategies which would enhance resilience in the country.

Indiscriminate deforestation should be discouraged, whiles encouraging afforestation. Incentives should be made available to individuals and groups who are pursuing the act of deforestation, to serve as a means of getting more tree planters on board.

There should be flood and soil erosion control programs in various communities to serve as a means of reducing farm losses and sedimentation of water bodies.

Rainwater harvesting should be facilitated in households, to support water availability. Policies geared towards ensuring sustainable agriculture should be implemented and enforced in the country.

Supports in diverse forms should be made available to farmers. Pesticides and fertilizers being the most widespread needs of respondent farmers should be made easily accessible and affordable, in order to enhance yields and alleviate poverty in farming communities.

Farmers should be educated on key issues, as a number of respondents complained of not receiving any education, hence causing them to commit some mistakes, such as planting a crop in the wrong soil type.

Research on newly emerging pests and diseases should be undertaken by the responsible agencies.

Farmers should be educated on climate-resistant crop varieties and how to enhance their resilience to this changing climate.

Climate change study should be included in educational curricula of basic and secondary schools, as well as universities in order to make its social and economic impacts known, even as a way of building resilience.

Farming very close to water bodies should be discouraged, as this poses threats to both water resources, the farmer and the environment on a whole.

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APPENDICES

Appendix I: Mean Monthly Rainfall, Temperature and Streamflow (1970-2009)

Month	Rainfall	Temperature	Streamflow
January	16.15845	26.43593011	1.594715323
February	50.9705	28.07519971	1.33743125
March	111.29695	28.0238293	1.855803226
April	132.244	27.56272639	2.189139167
May	151.5529	27.06925	5.305541129
June	180.30955	25.98373611	9.104390833
July	125.2832	24.94147177	8.116694355
August	81.28015	24.66015995	5.385974194
September	153.9529	25.29665833	9.511890833
October	143.11315	26.11263172	12.52372605
November	52.68185	26.72771389	5.368120833
December	24.8751	26.2427621	2.104226613

Appendix II: Total Annual Rainfall, Mean Annual Temperature and Streamflow (1970-2015)

Year	Rainfall	Temperature	Streamflow
1970	1240.194	26.01493151	5.576753425
1971	1158.06	25.70248493	7.633353425
1972	1289.442	25.78729508	10.42025137
1973	1173.6	26.02471781	5.863906849
1974	1397.014	25.5669863	11.2635589
1975	1231.098	25.51409589	4.916706849
1976	1206.564	25.42810929	5.193431694
1977	961.514	26.04965205	6.942843836

1978	1312.024	25.86154795	10.76400274
1979	1460.476	26.16932877	5.678421918
1980	1214.828	26.26680328	5.634778082
1981	1394.9	26.05349863	6.683476712
1982	1033.902	25.94123288	5.634778082
1983	896.36	26.2828	5.634778082
1984	1387.824	26.18917486	5.711723288
1985	1436.076	25.87889315	5.993364384
1986	1263.234	25.88013425	5.566043836
1987	1298.426	26.63047397	5.684783562
1988	1244.374	26.25290984	5.711751366
1989	1390.402	26.2948137	7.419950685
1990	1200.658	26.33980274	2.674654795
1991	1334.742	26.29375616	8.042517808
1992	1008.914	26.1109235	3.95904918
1993	1357.996	26.1340411	7.136191781
1994	1069.324	26.26074795	5.393484932
1995	1349.946	26.53012877	7.581457534
1996	1145.24	26.25701913	8.422147541
1997	1155.226	26.38651507	6.108753425
1998	1030.246	26.98217534	7.54750137
1999	1295.996	26.64471233	2.7296
2000	1051.356	26.56713115	2.370584699
2001	1079.198	26.83572603	1.878175342
2002	1468.808	26.78646575	3.798087671
2003	1156.506	26.87975342	2.540432877
2004	1098.402	26.61945355	2.645663934
2005	1012.736	26.39490411	3.741630137
2006	1119.91	26.57565205	2.295328767
2007	1457.31	26.71715068	4.812980822

2008	1315.314	26.81598361	4.125311475
2009	1250.608	26.8697726	5.576257534
2010	1108.544	27.34633151	
2011	1401.598	26.61758082	
2012	1215.47	26.46270219	
2013	1148.778	26.71827671	
2014	1176.912	26.83057808	
2015	1179.722	26.94839726	

Appendix III: SAI for Total Annual Rainfall, Mean Temperature and Streamflow (1970-2015)

Year	Rainfall	Temperature	Streamflow
1970	0.131970961	-0.763139684	-0.04683521
1971	-0.441719252	-1.492965769	0.862211497
1972	0.47595878	-1.294862589	2.094060375
1973	-0.333175337	-0.740280422	0.080090723
1974	1.227328536	-1.80946927	2.466814403
1975	0.068437148	-1.933012956	-0.338585267
1976	-0.102928129	-2.133864139	-0.216268915
1977	-1.814555306	-0.682037942	0.556996352
1978	0.633689712	-1.121419573	2.246003412
1979	1.670598415	-0.402491954	-0.001896278
1980	-0.045205677	-0.174806817	-0.02118748
1981	1.212562652	-0.673052946	0.442352361
1982	-1.308939031	-0.935288099	-0.02118748
1983	-2.26964348	-0.137440991	-0.02118748
1984	1.163138151	-0.356134593	0.012823406
1985	1.500169102	-1.080903899	0.137312811

1986	0.292900935	-1.078004895	-0.051569002
1987	0.538710294	0.674670757	0.00091566
1988	0.161167458	-0.207259715	0.012835816
1989	1.181144986	-0.109378879	0.767884424
1990	-0.144180405	-0.004291551	-1.329604444
1991	0.792370578	-0.111849113	1.043068025
1992	-1.483475411	-0.538917483	-0.761883697
1993	0.954795301	-0.484918407	0.642458917
1994	-1.061523166	-0.188951124	-0.127842514
1995	0.898567598	0.440280131	0.839272769
1996	-0.531264489	-0.197661061	1.210869814
1997	-0.461514197	0.104821106	0.188316423
1998	-1.334475489	1.496189872	0.824263657
1999	0.521737211	0.707929319	-1.305317875
2000	-1.187026194	0.526711875	-1.464007789
2001	-0.992555173	1.154107293	-1.68165979
2002	1.728795834	1.039043037	-0.833030994
2003	-0.452573643	1.256948372	-1.388932457
2004	-0.858418922	0.648928787	-1.34241882
2005	-1.456779476	0.124416587	-0.857986034
2006	-0.708189673	0.546615375	-1.49727199
2007	1.648484513	0.877133932	-0.384433659
2008	0.65666973	1.107992101	-0.688393377
2009	0.20471075	1.233634741	-0.047054401
2010	-0.787579	2.34680143	-0.04683521
2011	1.259346895	0.644554384	0.862211497
2012	-0.04072143	0.282782236	2.094060375
2013	-0.506552239	0.879764155	0.080090723
2014	-0.310041653	1.142082502	2.466814403
2015	-0.290414343	1.417289582	-0.338585267

Appendix IV: The Offin River, Kyereyase

Appendix V: Questionnaire

This questionnaire seeks information for academic purposes on **"**Climate Change and Variability Impacts on Water Resources and Smallholder Agriculture in the Offin Sub-Basin of Ghana**"**. Respondents are free to respond to the questions or ignore.

Introduction

This research is being conducted by an MSc. Student of the Pan African University Institute of Water and Energy Science, reading Water Policy. As part of a thesis, this field survey is being conducted to amass information on the level of awareness of climate change and variability, as well as the impacts on water resources and smallholder agriculture in the basin. This survey would go on to assess the communities' vulnerability to climate change and variability with regards to the above sectors of interest. Lastly, this questionnaire also seeks to gain information regarding various means by which the people in the communities are coping with the impacts, in order to finally outline key measures to adapt to climate change and variability in the basin.

Your assistance is humbly requested in this survey as your contributions are key to making this study significant. The outcomes of this survey would help to inform decisions, policies and actions in the water and agriculture sectors of communities and the country at large, as far as climate change and variability is concerned thus building resilience and promoting sustainable development.

You are not required to reveal your identity and your responses would be handled discretely.

Thank you for your time and contributions.

I hereby consent to voluntarily participate in this survey ☐

NB: Questions not relevant to you can be left out

Target groups: Smallholder farmers, Household water users, Community leaders,

Name of community…………………………………………………………………………..

Name of interviewer ……………………………………………………………………….

Date of interview ………………………………………………………………………..

DEMOGRAPHICS

1. Age (a) 30-39 [ ] (b) 40-49 [ ] (c) 50-59 [ ] (d) 60 and above [ ]
2. Sex (a) Male [ ] (b) Female [ ]
3. Marital Status; (a) Married[ ] (b) Single[ ] (c) Divorced[ ] (d) Widow/Widower [ ]
4. Educational status
   (a) None [ ]
   (b) Basic education [ ]
   (c) JSS/SSS [ ]
   (d) Tertiary [ ]
   (e) Vocational [ ]

5. Are you a native of this town? (a) Yes [ ] (b) No [ ]
6. If yes, how long have you lived here? **(In years)**
   (a) Under 20 [ ] (b) Between 21-49 [ ] (c) Over 50 [ ]
7. Are you the head of your household? (a) Yes [ ] (b) No [ ]
8. What is the number of dependents in your household?
9. What is your main occupation?
   (a) Farming [ ] (b) Trading [ ] (c) Public Servant [ ] (d) Miner [ ]
   (e) Fishing [ ] (f) logger [ ] (g) others ……………….

10. How long have you been working?
    (a) 1-10 years [ ] (b) 10-20years [ ] (c) 20 – 30years [ ]
11. Who makes rules and decisions concerning water resources within the community?
    (a) Traditional leaders [ ] (b) Assemblyman/woman [ ] (c) District Assembly [ ]

    (d) Others, please specify …………………………………..

12. Are the people in this community involved in the management of the river basin?

(a) Yes [ ]   (b) No [ ]

PART A: AWARENESS ON CLIMATE CHANGE AND VARIABILITY AND ITS IMPACTS

13. Do you have access to weather and climate information? (a) Yes [ ] (b) No [ ]
14. What is the source of your information concerning the weather and climate?
    a. Own perception
    b. Radio
    c. Television
    d. Local information services
    e. Newspaper
    f. Older folks
    g. Other, please state.

15. Are you aware or have you heard that the climate is changing? (a) Yes [ ] (b) No [ ]
16. If yes, state the source.
    a. Own perception
    b. Radio
    c. Television
    d. Newspaper
    e. Local information services
    f. Older folks
    g. others

17. Have you noticed changes in rainfall over the past 5 or more years? (a) Yes [ ] (b) No[ ]
18. If yes, what are the changes in rainfall you have noticed?
    (a) Rainfalls have increased
    (b) Rainfalls have decreased
    (c) Rainfalls have not changed.
    (d) The onsets and cessation of rainfalls have changed

19. What have you observed about temperatures in the last 5 or more years?
    (a) Temperatures have decreased
    (b) Temperatures have increased
    (c) Temperatures have not really changed.

20. Has there been any flood (s) over the past 10 years? (a) Yes [ ] (b) No [ ]

21. If yes, what has been the frequency of floods in the past 10 years?
    a. Decreased b. Normal c. Increased d. No idea

22. Which month and years did you experience these floods?

23. Has there been droughts and dry spells in the last 10 years? ? (a) Yes [ ] (b) No [ ]

24. If yes, what has been the frequency of droughts and dry spells in the past 10 years?
    a. Decreased b.Normal c. Increased d. No idea

25. Which months and years did you experience these droughts and dry spells?

26. Have u noticed changes in the climate over the years as a farmer? Yes [ ] No [ ]
27. If yes, please give an account. ....
    …………………………………………………………………………………………
28. What can you generally say about the climate in the area
    (a) Getting hotter and drier
    (b) Getting cooler and wetter

PART B: KNOWLEDGE ON CLIMATE CHANGE VULNERABILITY IN THE BASIN

29. Do you consider the population of your town as increasing? Yes [ ] No [ ]
30. If yes, do you know this has the tendency to increase the demand on water and food in the community? Yes [ ] No [ ]
31. Do you rely on the river for your livelihood and water needs? Yes [ ] No [ ]

32. If yes, is water available from the Offin River all year round? Yes [ ] No [ ]
33. If no, what is your source(s) of water supply?

    ……………………………………………………………………………………………

34. If the answer to question 32 is no, when is water available and when is it not in the Offin river? ……………………………………………………………………………………

35. Do you think this changing climate impacts water availability from the river?

    Yes [ ] No [ ]

36. If yes, can you give some details?

    …………………………………………………………………………………………………

37. What are some activities in the community that you think are further deteriorating the river and affecting its availability for use?

    …………………………………………………………………………………………………

38. Do you think these changes and variability in climate is affecting farming activities and yields in the community? Yes [ ] No [ ]
39. If yes, give an account. ……………………………………………………………………

    …………………………………………………………………………………………………

    …………………………………………………………………………………………………

40. What crops do you cultivate and how has the changing climate affected your farming activities? ……………………………………………………………………………….

    ………………………………………………………………………………………………..

41. Has there been any shift in cropping systems over the years? Yes [ ] No [ ]
42. If yes, what was the reason for the change and give details of the crops.

    …………………………………………………………………………………………………

43. Have your yields over the years increased decreased or remained the same?

    …………………………………………………………………………………………………

44. Do you experience frequent erosion? Yes [ ] No [ ]
45. Do you perceive that the fertility of the soil has also been affected by climate change and variability?

…………………………………………………………………………………………………

46. Is the rainfall in the basin enough to sustain your crop growth? Yes [ ] No [ ]
47. Can you give your opinion about how rainfalls in the past years has influenced your farming activities ………………………………………………………………………

…………………………………………………………………………………………………

48. Give a general account on how this variability in climate has affected water availability and farming practices in the community.

………………………………………………………………………………………………

…………………………………………………………………………………………………

49. Has this variability in climate affected your income in any way? Yes [ ] No [ ]
50. If yes, elaborate. ……………………………………………………………………….

…………………………………………………………………………………………………

51. Do you receive early warning about extreme events like floods? Yes [ ] No [ ]

SECTION C: VARIOUS MEANS BY WHICH CLIMATE CHANGE IS BEING ADAPTED TO, IN THE COMMUNITY

52. How do you ensure adequate water supplies during periods of low rainfalls and low river flows as well as droughts? ……………………………………………

…………………………………………………………………………………………………

53. Do you re-use water during periods of inadequate supply? Yes [ ] No [ ]
54. Is the local community involved in the management of the river? Yes [ ] No [ ]
55. If yes, what role does the local community play in the management of the river?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

56. Do you harvest rainwater? Yes [ ] No [ ]
57. If yes, how does it make things different? ……………………………………………….

…………………………………………………………………………………………………

58. Do you rely on the river for your crop irrigation purposes? Yes [ ] No [ ]
59. How do you generally cope with the perceived changes in rainfall patterns?
60. Do you practice any water and soil moisture conservation practices? Yes [ ] No [ ]

    If yes, do give an account. ………………………………………………………………..

61. Do u practice mixed cropping?

…………………………………………………………………………………………………

62. How do you protect your farm against flooding?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

63. Do you protect your farm against erosion? Yes [ ] No [ ]
64. If yes, give details ………………………………………………………………………

…………………………………………………………………………………………………

65. Do you plant trees on your farm? Yes [ ] No [ ]
66. Do you plant some climate resistant crops? Yes [ ] No [ ]
67. Do you sometimes change your planting dates? Yes [ ] No [ ]
68. Have there been any form of sensitization and capacity building with respect to climate change in the community? Yes [ ] No [ ]
69. If yes, then by which organization or group? …………………………………………..
70. Do you think being enlightened more on climate change and variability, and its impact can enhance a better adaptation? Yes [ ] No [ ]
71. Is there a farmers union in this community? Yes [ ] No [ ]
72. If yes, what role does it play in sustaining smallholder farming in the community?

…………………………………………………………………………………………………

………………………………………………………………………………………………..

73. Have you adopted an alternative source of income aside that from farming? Yes [ ] No [ ]
74. If yes, state them ………………………………………………………………….
75. What do you recommend to be added to the policy framework for climate change adaptation, in order to enhance the resilience of the water and agriculture sectors in the country? ………………………………………………………………………………….
76. What do you think the government and responsible agencies can do to help you adapt adequately to climate change and variability?

THANK YOU FOR YOUR TIME AND PARTICIPATION

Appendix VI: Budget for Thesis

S/No	Item	Unit	Quantity	Amount (Gh)	Amount (dz)	Amount (USD	Link
1.	Return Flight from Algiers to Accra		Return		137268.00	1159.00	Case studies Location
2.	Taxi from Tlemcen to Algiers		1		4000.00	33.44	To pick flight to Accra
3.	Taxi from Oran to Tlemcen		1		2750.00	23.71	Transport to Larocade
4.	Insurance		1	200		44.45	Insurance
5.	Printing of questionnaires			150.00		33.33	Primary data collection
6.	Internet	Monthly(30 USD)+ oredoo 2000	4	576.00	2000	132	To gain access to internet- based resources.
7.	Meteorological Data (Rainfall, Temperature)		46	1380.00		307.00	Climate change analysis
8.	Discharge data		40	900.00		200.00	Streamflow analysis
9.	External storage for data backup		1 Terabyte	320.00		71.11	External storage for data backup
10	Research Assistants		2	1326		294.00	Data collection
	Transport from Tema to Kumasi		1	120.00		27.00	Research area is in Kumasi which is far from Accra
11	Transport from Kumasi to Accra		1	115.00		26.00	Transport from study area
12	Fuel		1	500.00		111.11	Fuel for hired vehicle for questionnaire distribution
13	Car rental and driver charges		1	1000.00		222.22	questionnaire distribution
14	Printing and binding of thesis	950.00	4		3800.00	33.00	Thesis printing
15.	Publication					250.00	

	TOTAL (Plus flight)					2968.70	
	Total (minus flight)					1809.70	
	Amount given (1st 50%)					920.66	
	Balance					889.04	