UNIVERSITY OF GHANA

COLLEGE OF HUMANITIES

DEPARTMENT OF GEOGRAPHY AND RESOURCE DEVELOPMENT

CLIMATE CHANGE AND VARIABILITY AND WATER INSECURITY IN THE SUDAN SAVANNAH ZONE OF GHANA: THE CASE OF GARU-TEMPANE

BY

DINKO HANAAN DINKO

(ID. NO. 10343859)

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN PARTIAL FULFILMENT OF THE AWARD OF DEGREE OF MASTER OF PHILOSOPHY IN GEOGRAPHY AND RESOURCE DEVELOPMENT

JULY, 2017

Declaration

I hereby declare that this thesis is the result of my own independent investigation towards the award of a Master of Philosophy Degree in Geography and Resource Development. Where other sources of information have been used, they have been acknowledged.

Name of Candidate Dinko Hanaan Dinko

Student Number: 10343859

………………………… ………………….

Signature Date

Principal supervisor: Prof. Joseph Awetori Yaro

………………………… ………………….

Signature Date

Co-Supervisor: Dr. John Manyimadin Kusimi

………………………… ………………….

Signature Date

Abstract

Climate change and variability has been a major cause of water insecurity in drylands of Africa. This study seeks to understand the dynamics and lived experience of climate-induced water (in) security in four agro-pastoral rural savannah communities in north- eastern Ghana, using mixed methods. The study shows that rainfall and temperature were the two main climatic elements that significantly influenced water security. The study observes a 2^0C rise in temperature 1983-2013. The shift coincides with the severe drought years. Temperature is thus critical in determining water insecurity though a mediating factor is runoff. Statistically observed meteorological changes translate into crop failures thus undermining food and income securities. Livelihoods are almost exclusively rain-dependent except in Worikambo and Denugu where small numbers of households are engaged in irrigation. Rainfall variability is thus a major constraint to agricultural and household water use. Households with the means of transport to collect water were more water secure than those who had to walk and carry water in small vessels. It also emerged that access to irrigated land was a function of one's position in the society. Powerful individuals and institutional coalitions often determined access albeit there may exist an open and universal usufruct rights to irrigated lands by the dams. The study shows that vulnerability of a household is contingent on two factors: location and endowments. Household responses of water insecurity are enveloped in the institutions and fluid resources available to them. Wealth enhances water security in several ways. Wealthier households tend to own a means of transport such as donkeys or bicycles, making water collection easier in times of drought. It also enables them to benefit from hiring and thus empowering them to accumulate more resource to invest in irrigation and storage capacity. The key adaptation strategies used by household to deal with water insecurity resulting from climate and variability in the study area are predominantly *ex ante*. These coping strategies include irrigation, planting drought-resistant crops, delaying planting and using early-maturing varieties. Depending on remittances or migrating are the most important *ex post* options that household adopted. Water management is critically important to the success of food production in the future. This calls for robust investment in resilient water storage systems and use of underground water.

Dedication

To my mother, Manshiakya Sadia Dinko

Acknowledgement

My profound gratitude to my supervisors Prof. Joseph Yaro and Dr. John Manyimadin Kusimi, whose constructive guidance has immensely shaped my life and enabled me to conduct this research. I thank Peri Peri U for providing financial support in collecting data for this thesis.

A special thanks to my grandmother, Hajia Ajara Dinko and my mother for their constant support and prayer. A special appreciation to my brothers Ralph Dinko and Nazeer Dinko for the encouragement- thanks for being there. Kamilo Dinko and Francis Asigri, I appreciate your efforts. I further want to thank PeriPeri U for partially funding my studies. My journey could not have been this far without the support of GETFund and Mr. Alexis Kwabena Asuinura in particular.

To Mabel Lariba Awuni, for her enduring friendship - God bless you. To John Narh, Moses Mosonsieyiri Kansanga, Charles Kwowe Nyaaba and all my friends and classmates in the University of Ghana who helped in shaping my thoughts.

I am grateful to Dr. Gerald Yiran who generously gave me climate data for the study area.

To Francis Tokoli, you are a true definition of friendship. I am eternally grateful to the farmers and women of the Denugu, Worikambo, Kolmasug and Bugwia who are at the forefront of dealing with water insecurity and climate change!

Finally and most importantly, I thank God Almighty for His tender care and mercy. I would not have made it without His blessing.

They thought they buried me, they didn't I was a seed!

Sponsor

This thesis was sponsored by Peri Peri U-Ghana a USAID funded project.

I am most grateful to Prof. Jacob Songsore and Prof. Martin Oteng-Ababio for their support. Dear Dr. Osman Alhassan, I am highly indebted to you as your tireless efforts made this funding possible.

Table of Contents

List of tables

List of figures

List of boxes

List of maps

List of Equations

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Background

Livelihoods in semi-arid regions of the world face an historic water insecurity challenge than ever before. This historic challenge has thrust water security at the nexus of global issues including health, hunger, economic growth, agriculture and human development (Falkenmark, 2001; GWP, 2013; Intelligence Community Assessment, 2012; World Economic Forum, 2011). The undeniable seriousness of the situation is captured in the fact that water underpins all life and living activities. Livelihoods activities especially in the semi-arid regions of Africa are carved around water (Braune & Xu, 2010; Lapworth et al., 2017; Wossen & Berger, 2015). Some scholars have characterized the endemic poverty in these regions as a direct consequence of physical water insecurity (Bonsu & Asare, 2004; Cook & Bakker, 2012; Xiao-jun et al., 2014). Globally, one billion people are water insecure - more than the entire population of Europe (UN-Water, 2013b). This situation is projected to worsen in the future as a result of urbanization, population growth, an increasing consumption of water per capita and climate change (Hope, Foster, & Thomson, 2012; Hope, Hansen, Mutembwa, & Schlessingen, 2012; Loftus, 2015). Further complicating the situation is the fact that water insecurity is expanding globally in countries that are already considered water insecure, threatening to further undermine important development progress (Bigas, 2012). Global food security is the first causality of water insecurity. About 70 percent of all freshwater withdrawals are used for food production(FAO, 2011). With water variability inevitable, food security gains could be reversed in already food stressed regions such as sub Saharan Africa.

Although there is enough freshwater on the planet to grossly meet current population demand, they are spatiotemporally unevenly distributed. While endowed with large freshwater bodies, Africa is the second driest continent in the world with about 9% of global freshwater resources (The World Water Council, 2016).. There is marked intracontinental distribution of water resources, with 54% of the continent’s water resources concentrated in only six countries while the driest twenty countries hold only 7% (The World Water Council, 2016). Statistically, about 64% of Africa's population is rural (UNHABITAT, 2010), whose earn their livelihood directly from subsistence agriculture. Agriculture remains almost exclusively rain-fed, making much of the population highly dependent on rainfall. For small farmers, regular and adequate rains are vital to livelihood and food security. In rural Ghana, where agriculture is the main employer, regular rainfalls are critical to the entire economy. The challenge is more pronounced in semi-arid regions where water is the lifeblood of agriculture and livelihoods (GWP, 2013; Solh & Saxena, 2011). Improving access to household water use requires adoption of an integrated approach to water management at basin and local levels.

Observed climatic records have consistently concluded that climate change is altering the hydrological cycle through precipitation and temperature. Precipitation changes show substantial spatial and inter-decadal variability (Bates, Kundzewicz, Wu, & Palutikof, 2008b) which results in some places having abundant freshwater while others have very limited water to meet increasing demands (Kankam-Yeboah et al. 2013). Climate change particularly affects water security by increasing the frequency and severity of floods and droughts, increase in temperature and intensity of precipitation. These have negative repercussions on water quality and quantity which in turn affects food availability, access, stability, and utilization. Increasing global surface temperatures are likely to increase evapotranspiration and the capacity of the atmosphere to hold water. In sum, climate change presents new constraints and amplifies existing vulnerabilities in fragile zones.

This study seeks to understand the dynamics and lived experience of climate-induced water (in) security at the local level in Ghana, in particular the study investigates the nature and dimensions of water insecurity, identify household vulnerability and analyse the causes of water-related risk and explore how different households respond to changing water availability for agricultural and household uses.A spatial analysis of water insecurity reveals that water-insecure communities are often in socioecological peripheries - regions without sufficient access to water because of a lack of political power and infrastructural connection as well as geographical constraints. The Sudan savannah of Ghana embodies this assertion. The Sudan savannah is considered the most ecologically fragile vegetation zones in Ghana and is threatened by desertification, environmental degradation, rapid population growth and declining soil fertility (Yaro and Hesselberg 2010; Glazebrook 2011; Yiran, Kusimi, and Kufogbe 2012). It is also a stack reflection of deep poverty and deprivation (Cooke et al 2016; GLSS 2014). Hence understanding the strategies that farmers and households adopt in negotiating access to secured water is essential for policy planning. The above scenario brings to the fore three sets of questions. First, how does the emerging problem of water insecurity shape adaptation options? Are adaptation strategies expanding opportunities, or they are a constrained response to a diminished set of opportunities? Second, what determines access to new and resilient options and opportunities? Thirdly, have traditional rules of access and structures of inequality simply been reproduced and propagated or they are crumbling? And how can more equitable access be encouraged?

The study also seeks to contribute knowledge to the changing discourse on environmental change in the Sudan savannah. Gaining an understanding of how climate change impact water security for both household and agricultural water in an already water-stressed ecosystem such as the Sudan savannah is, therefore, crucial.

1.2 Problem statement

The northern savannah regions of Ghana are considered to be the least developed with livelihoods largely dependent on the natural environment (Bawakyillenuo et al., 2014; Whitehead, 2002). Agriculture is almost exclusively rain-fed with just 0.4 percent of arable land under irrigation (MOFA, 2013). A full understanding of the endemic poverty and low human development in these regions is impossible without understanding the crucial role of water insecurity resulting from climate change and variability.

The nexus of water, climate change and development continue to generate enquiry. Recent literature on the causes of water insecurity in semi-arid regions is in twofold. While some scholars attribute the debacle to physical characteristics of the environment, others attribute the insecurity to socio-economic and cultural choices. The latter integrates physical scarcity with human agency, legal and institutional constraints to explain water insecurity (Zeitoun et al., 2016). An emerging dimension to the debate is climate change. Kankam-Yeboah et al. (2013) in examining the impact of climate change on streamflow in the White Volta basin have projected a 50% decrease by 2050. Similarly, Barron et al. (2015) have discussed how agricultural water management interventions for smallholders in the Volta and Limpopo basins could be best utilized to build resilience against climate change. Climate change impact on floods and droughts in terms of vulnerability and disaster risk reduction in the northern savannah have also been examined (Armah, Yawson, Yengoh, Odoi, & Afrifa, 2010; Douxchamps et al., 2014; Poussin et al., 2015).

With climate change intensifying weather extremes and shifting raining seasons, the impact on agricultural output is projected to be severe. For instance, maize, a major staple food in the Sudan Savannah, is projected to decline by 40% by 2030 while millet, sorghum and tubers are also projected to decline by more than half the current output attributable to declining precipitation and increasing temperatures (Mawunya & Adiku, 2013). In contrast, the population is projected to grow at 5% annually and doubling by 2030 (Berazneva & Lee, 2013; Strzepek & Boehlert, 2010). Ghana's high population growth of 2.7% (Ghana Statistical Service, 2012) with high urbanization rates of 3.4% (Fuseini & Kemp, 2015; UNHABITAT, 2010) puts tremendous pressure on agricultural production and water requirements which are already stressed due to poor water resource management systems. The situation is of particular worry in regions with savannah ecological areas experiencing further water stress due to climate change and related human activities. According to the IPCC, the impact of climate change on water is three-fold: increasing temperature will increase the evapotranspiration rate, reduce ground water recharge and significantly affect runoff (IPCC, 2013). This has significant ramifications on agriculture in Sub-Saharan Africa (SSA) where declining soil fertility, increasing population and limited technology makes food and livelihood systems sensitive to least variability in climate (Barron et al., 2015). The frequency and intensity of climatic extremes such as dry spells and droughts, as well as floods cause substantial losses in yields (Barron et al., 2015; ISDR, 2015; Mârza, Angelescu, & Tindeche, 2015; Molle & Mollinga, 2003) thus affecting household income and overall national growth. According to Barron et al.(2015), although yields of smallholder farmers have generally increased in Africa, it is less than a quarter of the biophysical potential of the land. Hence SSA is a net importer of food (OECD/FAO, 2016). It has been argued that sustainable agricultural water management interventions for crop and livestock production in arid and semi-arid regions are critical to reversing this trend (Barron et al., 2015; De Bruin et al., 2015; Grey & Sadoff, 2007; Pérez Blanco & Gómez, 2014; Rousset & Brown, 2007). But how effective are these interventions in semi-arid Ghana?

The importance of water security is better revealed through direct impact on food security, health, economic development and poverty alleviation (Schultz and Uhlenbrook 2007). There is a robust empirical correlation between water security and resilient economic development. Water-related hazards such as floods, droughts, and disease cause damages to economies through the destruction of physical property and infrastructure, the loss of human capital, and the disruption of economic activities (Sadoff et al. 2015). Using panel data, Sadoff et al. (2015) established that countries most economically vulnerable to hydro-climatic effects are those that are poor, water stressed, and/or dependent on agriculture. But the relationship between hydro-climatic variability and water security has been a subject of controversy. On the global level, both empirical and climate change projections conclude there is a strong correlation between climatic variability and water security as climate affects the supply-side of water. However, the relationship at the local level is unclear.

Previous studies on climate change in semi-arid regions of West Africa have primarily focused on food security and adaptation. Liehr, Drees, & Hummel (2016) contend that climate-induced changes and deteriorating environmental conditions have led to a new migration trend. Similarly, Reid et al. 2007 observed an increased frequency of dry spells and a shift in the start of the rainfall season. It has also been acknowledged that African countries are the most vulnerable to climate change due to climate dependent economies (UNFCCC 2007; Gregory et al., 2005; Thompson, Berrang-Ford, and Ford 2010), poverty and low human development (Eguavoen, 2013; Mosha, 2011) and limited adaptive capacity (Archer, Oettlé, & Louw, 2008; UNFCCC, 2007).

Climate change/variability and livelihoods studies in Ghana have corroborated the above findings. It has been established that climate change through its influence on hydrological cycle represents the most potent obstacle to development in the northern savannah regions of Ghana where poverty is endemic. For instance, Yaro (2013) suggests climate change has acted as multiple stressors in conjunction with existing socio-politico policy choices to stagnate agriculture and livelihood improvement. Using 30 years historical weather data, crop characteristics and management practices to simulate, MacCarthy et al. 2013) reveals *a* reduction of maize grain yield by 19-41% between 1980-2010. A study by Tachie-Obeng et al. (2014) confirms EPA (2000) findings that the onset of the rainy season has shifted while the rains are now more intense and unpredictable. Although these studies do not explicitly examine water security, water security can be seen as the principal underlying driver of these findings.

An increasing volume of research has investigated water security in Ghana. Within this inquiry focus, three points of concentration can be identified; the first strand examines sustainable approaches to water resource management and concentrates on physical availability, climate change and pollution (Bonsu & Asare, 2004; Douxchamps et al., 2014; Evans, Giordano, & Clayton, 2012; Kankam-Yeboah et al., 2013); the second explores water delivery systems and is primarily concerned with how infrastructure, policy and water governance structure and institutions gives rise to water insecurity (Addo, 2010; Ainuson, 2010; Beck, Harris, & Luker, 2016; Osumanu, Abdul-Rahim, & Songsore, 2010) ; the third strand considers access outcomes for different segments of society. This third strand argues that existing societal structures of inequalities and politics are the main drivers of water insecurity. Thus water insecurity is a reflection of power imbalance in society (Ainuson, 2010; Grönwall, 2016; Yussif, 2012).

Few studies have however, examined the impact of climate change on water availability for household and agricultural use in Ghana's Sudan Savanah. In the few studies, the conceptualization water security has been fixated by its physical absence or destructive presence. The securitization of water as an outcome of social and economic interactions is often overlooked or is subsumed under the physical absence of water. In cases where economic or social are examined, the emphasis is either on household water use or water availability for non-household use.

Again, previous studies show effects of floods and droughts on production. This study seeks to show the multiple uses of water and how these are affected by climate change in Garu-temapne. It further seeks to assess the socio-political dimensions of water use in local communities and how these interact with broader climate changes in producing outcomes for different segments of society. In a nutshell, this study seeks to contribute to the growing knowledge and information network thereby enhancing further policy studies.

1.3 Research objectives

The main objective of the study is to assess the impact of climate change and variability on water security for agricultural production.

The specific objectives are:

1. Assess the nature of changes in the climate of the Sudan Savannah.
2. Describe the nature and dimensions of water insecurity.
3. Identify household vulnerability and analyse the causes of water-related risk.

1.4 Proposition:

Drought risk is higher for poorer households.

1.5 Justification of study

Water is an essential element for human survival and development. With a changing climate, an appropriate understanding of its impact on water resources and sustainable livelihoods in semi-arid regions, especially in Sub-Saharan Africa, is crucial to sustainable economic development and social transformation. This research is particularly important as it contributes not only to the impact of climate change on household water shortages but it also focuses on the socioeconomic effects of agricultural water security on food production. Such a blend of environmental studies and sociological impact is essential to a social enquiry.

By employing mixed methods, this empirical study gives a good foundation for explaining the multifarious socio-biophysical context of water security while giving the research both solid positivist grounding and revealing the human agency. It thus focuses on discovering and understanding the experiences, perspectives and thoughts of participants by exploring meaning, purpose, or reality towards understanding the lived worlds of people. These are crucial ingredients for theory building. Such a methodological approach could serve as a guide for future research in social science-oriented water security studies.

In line with the reasoning above, this thesis seeks to contribute to the unsettled debate about definition of water security. Unlike previous studies, this thesis adopts an anthropocentric perspective to water insecurity analysis to highlight adequately the complex system of interactions that gives rise to household water insecurity. Such an approach makes play for a socially-constructed definition of water security that encompasses the vast range of interests that society has in water. It thus deconstructs water insecurity from aggregate indices to lived experiences where human agency wrestles with micro and macro level structures to shape vulnerability and adaptation outcomes.

This research seeks to highlight how structure and processes shape vulnerability and adaptation options. By highlighting how social barriers amplify vulnerabilities and constrains adaptation and resilience, the thesis generates debate that will resonate beyond academic cycles to policy implementation. The findings of the thesis are therefore essential for a better understanding of the climate-water-development nexus and thus facilitate better transmission from academia to policy implementation.

In a nutshell, this study will contribute to the debate on the impact of climate change and options for adaptation and building resilient communities in Sub-Saharan Africa in particular and the developing world in general.

CHAPTER TWO: LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.1 Introduction

This section addresses the evidence about changing climate and its relationship with declining water resources, declining water availability in arid regions in general and the Sudan Savannah in particular. The last subsection outlines the theoretical and conceptual framework that guides this study. It begins by exploring the multiple and fluid conceptualisations of water security.

2.2 Contested meaning of the concept of water security

Over the past two decades, the securitization of water has shaped the discourse on water resource management although there is no universal consensus on what the term means. Again, what contextual variables should trigger the use of the term? And does the variation in usage of the term blur decision making? Unravelling the meaning of water (in)security is crucial to defining the boundaries of what Fischhendler (2015) describes as "the securitization enigma". The natural resource governance and management literature recognise the indispensable role of linguistic framing in shaping and promoting the discourse of environmental issues (Grey & Sadoff, 2007; Intelligence Community Assessment, 2012; Schultz & Uhlenbrook, 2007; Zimmer & Renault, 2003; Zimmerman, 2000).

This approach of framing is grounded on the social construction tradition which recognises that reality is not absolute but is continually being shaped and reshaped by multiple subjective realities. In other words, the social constructivist argues that there is no monocausal, mono explanatory and universal understanding of a phenomenon but recognises that all phenomena are filtered through a wider social, political and economic context. Social constructivists contend that researchers must describe reality in all its complexity and diversity (Danermark, Ekström, Jakobsen, & Kar, 2002). Such a framing of reality with a linguistically-powerful scope determines the willingness of policy makers at both local and international levels to act on pressing issues as security. Securitization assumes threats and survival which border directly on human safety and wellbeing. Hence, securitising water and establishing the complex and intertwined linkages with other sectors and its potential detrimental outcomes could elevate water discourse to high politics (Fischhendler, 2015; Global Water Partnership, 2012; Naidoo, 2001). Once an issue is securitized, it exacts exceptional measures to prevent an existential threat. Hence, environmentalists often view it as means to creating public awareness and causing urgent mobilisation of resources and funds.

Water security, which basically describes the nexus between water availability, access and use, has been variously defined. For instance Ndaruzaniye (2011, p. 2) opines that water security refers to " availability of, and access to water in sufficient quantity and quality to meet livelihood needs of all households throughout the year, without compromising the needs of other users". The definition has been criticised by sustainability scientists for being human-centric and ignoring the ecosystem water use. In other words, it does not incorporate the multiple uses of water by different actors in the water equation. It ignores the environmental services provided by water which is an important part of the water security equation. Quantitatively, Falkenmark (1989) argues that an area is water insecure if its per usage of water is less than 1700m^3/capita/year. Table 1 gives that threshold for measuring water security according to Falkenmark (1989).

Table 1: Water barrier differentiation proposed by Falkenmark (1989)

Index	
(m^3 per capita per year)	**Category/Condition**
>1,700	No Stress
1,000-1,700	Stress
500-1,000	Scarcity
<500	Absolute Scarcity

Source: Falkenmark (1989)

This metrics famously known as the *Falkenmark indicator* has been widely used to measure water. Proponents of this metrics argue that it enables for a measure of individual use of water and consequently allows for distinguishing climate and human-induced water insecurity.

Again, it provides a scale for assessing national scale water insecurity thus revealing the broader picture of the extent of insecurity. But critics raise three principal charges against its use. First, the use of national averages masks local insecurities. Again, the use of thresholds is mechanistic and thus ignores important variations in demand among and within countries due to the diversity of culture, affluence and climate. Simply put, it assumes homogeneity in a heterogeneously complex real world. Thirdly, the metric has been accused of under-measuring local scale impact. In sum, this definition of water security merely emphasises the physical availability of water.

In view of these criticisms, there were calls for a more inclusive and comprehensive definition that encapsulates the multiple uses of water. In response to this call, Sadoff et al. (2015) used a risk-based approach to define water insecurity. To them "water security is tolerable water-related risk to society". Although this definition conveys a simple framing of water security, it risks being vague and open to almost limitless interpretation. Again, what is *tolerable* can be different to different people within the same place depending on resilience and wealth base. The use of society as a measure ignores inter and intra-household differences to vulnerability.

Schultz & Uhlenbrook (2007, p. 1), suggests "water security involves the sustainable use and protection of water systems, the protection against water-related hazards (floods and droughts), the sustainable development of water resources and the safeguarding of (access to) water functions and services for humans and the environment." This definition appears comprehensive by recognising the duality of water security. The definition views water security from a development approach rather than Sadoff et al's (2015) risk-based approach to water security. It recognises both scarcity and the undesirable and destructive presence of water in the form of floods.

Similarly, Beek & Arriens (2014) insist that water security must be defined from three dimensions. To them water security is an outcome which lies in:

- *ensuring the availability of adequate and reliable water resources of acceptable quality to provide water services for all social and economic activity in a manner that is environmentally sustainable;*
- *mitigating water-related risks such as floods, droughts, and pollution; and*

• *addressing the conflicts that may arise from disputes over shared waters, especially in situations of growing stress, and turning them into win-win solutions.* (Beek & Arriens, 2014)
The Competing definitions and indicators of water security reflect unsettled conceptual and methodological issues (Garrick & Hall, 2014).

Table 2: Contrasting definitions of water security.

Notes	Definition of water security	source
The Hague Ministerial Declaration on Water Security in the 21st Century had social equity and the environment at its heart	ensuring that freshwater, coastal and related ecosystems are protected and improved; that sustainable development and political stability are promoted, that every person has access to enough safe water at an affordable cost to lead a healthy and productive life and that the vulnerable are protected from the risks of water- related hazards	The Hague Ministerial Declaration (2000)
It is the most comprehensive and most cited definition of water security seek from within an otherwise reductionist qualitative 'acceptable risk' framing:	the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies	Grey & Sadoff (2007)
This definition appears comprehensive by recognising the duality of water security. This definition defines water from a development approach	water security involves the sustainable use and protection of water systems, the protection against water-related hazards (floods and droughts), the sustainable development of water resources and the safeguarding of (access to) water functions and services for humans and the environment	Schultz & Uhlenbrook (2007)
It is the preferred definition of DFID. It emphasises equity and access	sustainable and equitable access to water of appropriate quantity and quality for all users (e.g. for drinking water & sanitation, agriculture, energy, industry and ecosystems) whilst reducing the impact and costs of water shocks and stresses including floods, droughts and pollution to an acceptable level	Penrose (2012)
It is the most preferred definition amongst most institutions	the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability	UN-Water (2013)
Pro-poor oriented and suitable for suitable framework for microanalysis of water security	reliable access to water of sufficient quantity and quality for basic human needs, small-scale livelihoods and local ecosystem services, coupled with a well-managed risk of water-related disasters	(Dessalegn et al., 2013)
Very short and based on conceptualization of water security from a risk-based approach	a tolerable level of water-related risk to society	(Sadoff et al., 2015)

Source: Zeitoun et al. (2016)

2.3 Dimensions of water security

Water security is not only limited to having enough water. It involves all issues related to water. To recapitulate Beek & Arriens (2014) "water security addresses the '*too little', 'too much', and 'too dirty*' issues of water management". Three dimensions of water security emerge: social equity, environmental sustainability, and economic efficiency. These dimensions have been alluringly phrased as people, planet, and profit (UN-Water, 2013).

2.3.1 Social dimension

The social dimension is concerned with affirmative action that advocates for equity in access to water services and resources to all people regardless of their social background. It involves taking down discriminatory barriers and building bridges which ensure all people have access to water. The UN-Water (2013) sums it up that all people, whatever their stage of development, have the right to have access to water in quantities and of a quality equal to their basic needs. Also embedded in the social dimension of water security is resilience. This involves making and building the resilience of communities to withstand and recover from water-related risks such as climate change-induced floods and droughts and pollution.

2.3.2 Economic dimension

Water has an inherent economic potential. In fact, there is scarcely any productive activity that does not require usage of water. Increasing water productivity and conservation in all water-using sectors is the primary concern of the economic dimension of water security. It also involves sharing the economic benefits in managing transboundary rivers, lakes, and aquifers.

2.3.3 Environmental dimension

The environmental dimension of water security recognises the importance of water in the provision of ecosystem services. It is thus concerned with managing water in a sustainable manner in the context of green economy.

Despite their seeming differences, the key dimensions of water security are related, interdependent and mutually reinforcing web. They can therefore not be treated in isolation. Thus, a change in one dimension of water security may simultaneously change (increase or decrease) security in another dimension. This has a net effect on the overall water security in a particular area.

2.4 The linkages between water scarcity, water stress and water security

Related to water security are the concepts of water scarcity, water risk and water stress. Although these terms have been used interchangeably, there exist apparent and latent differences in these terms (Calow, Macdonald, Nicol, Robins, & Kebede, 2006; GWP, 2014; Mason & Calow, 2012).

2.4.1 Water scarcity

According to White (2012), there is no universal definition of water scarcity owing to pluralistic methods for scarcity measurement. These different measurements capture different aspects of the pressures on water resources. For instance, the 'Falkenmark indicator' argues that water scarcity arises when the amount of renewable water in a country is below $1000m^3$ per person per year. However, this measure ignores cultural and regional differences in water uses of water. The International Water Management Institute (IWMI) conceives water scarcity as the inability of an individual or group to meet their consumptive use of water. In summary, water scarcity is the volumetric availability or lack of water supply. It is, therefore, different from water stress.

2.4.2 Water stress

In contrast with water scarcity, water stress is demand driven. Water stress arises from the inability to meet human and ecological water demand. The European Environmental Agency contends that water stress occurs when the demand for water exceeds the available amount of water during a certain period or when poor quality restricts its usage (European Environmental Agency, 2016). Water stress is the product of socio-economic or environmental problems that restrict the use of available water. For instance, although water resource or the connection may be near a household, social rules or low income may prevent them from accessing this source despite its proximity. On the other hand, wealthy households may be water-stressed if the physical distance is too long to guarantee access. Within a community, access may be uneven, because access to water often reflects socioeconomic status and existing inequalities. While water scarcity, may tend to be universal across space, vulnerability to water stress is mediated by social rules, wealth and pollution. Water stress is thus felt disproportionally in disadvantaged communities (Adger, Brooks, Bentham, & Agnew, 2004).. In sum, water stress is the unmet demand for water.

2.4.3 Water risk

Water risk is another concept with expansive interpretation. It covers challenges of over-abundance as well as insufficiency (Mason & Calow, 2012). Water risk recognises uncertainties in the face of global change. These changes interact with the hydrological cycle, climate, ecosystems and ultimately human settlement which affect water quantity and quality for water use on earth. Water risk concept in water security is future-oriented in comparison to water stress and scarcity. To recapitulate the World Water Assessment Programme (2012, p. 237), "it is impossible to fully predict how well any water resource system will perform in the future. Such systems are subject to changing and uncertain inputs, and serve changing and uncertain demands". These risk uncertainties permeate social, political and physical change.

Water security encapsulates its inherent risks, stress and scarcity. Understanding risk, scarcity and stress are imperative as water security is "the gossamer that links together the web of food, energy, climate, economic growth, and human security challenges the world economy faces over the next two decades" (World Economic Forum, 2011, p. 1). The interaction of risk, scarcity and stress collectively defines water security. Climate change lies at the heart of water security discourse due to its role as a threat multiplier in water security. Climate change amplifies scarcity and insecurities by altering and or accelerating elements of the hydrological cycle.

2.5 Water security and development trajectories

Sustainable growth, development and poverty reduction in every country hinges largely on its ability to achieve water security. A robust parallel can be drawn between poverty and water security. Water was a prerequisite for growth in industrial countries and continues to sustain growth achieved (Sadoff et al. 2015). Water has been harnessed to these countries to drive agriculture, hydroelectric power, and industry. In contrast, developing countries, especially in Sub-Saharan Africa, endure poverty, deprivation, and disease due to alternating episodes of scarcity or excess of water.

Statistically, marked variation in precipitation in semi-arid regions has acted as a natural barrier to agriculture (Falkenmark, 1989).. The Sudan savannah of Ghana is a classic example. Consequently, development and poverty reduction efforts have been limited by inter-annual and intra-annual variation of precipitation (GWP, 2013; Hope, Hansen, et al., 2012; Smakhtin, 2015). Climate-induced water scarcity combined with high levels of poverty continues to pose a formidable long-term challenge to food and livelihood security in the semi-arid north of Ghana. There is an emerging consensus linking water security and poverty in arid regions although the flow of link remains contested. The link between water security and development is found the critical role it plays in food, energy and health cycles (Beek & Arriens, 2014).

Industrial countries realized the relevance of water to growth and development at an early stage. Sustained investments in water management infrastructure, institutions, and competent human capacity to manage the infrastructure propelled growth and secured development gains made. These investments ensured they achieved water security hence providing them an effective tool for agricultural transformation, and generation of energy to support industrial growth. Industrial countries harnessed the productive potential of water while mitigating its destructive capability (Harrington & Harrington, 2013). In contrast, Sub-Saharan countries have been hampered by or are held hostage by water.

There is unequivocal evidence of investment irrigation and water poverty. Better water resource management has been found to similarly have a significant impact on poverty reduction and an empowered livelihood. However, initial investments remain prohibitive. The consequence is that water insecurity continues to constrain or stall growth in Sub-Saharan Africa. The nexus of water security and development in semi-arid is not only revealed in food security but also through its role in energy generation, health promotion, and ecosystem services. Hence, discourse on development and poverty alleviation in the semi-arid regions cannot be properly understood without uncovering the role of water security in perpetuating poverty in these regions. As water becomes scarce relative to demand, there is an emerging concern that recent gains on poverty reduction could be reversed. The concern is further compounded by projected impact of climate change on water. Hydrological variability and extremes are at the heart of the challenge of achieving basic water security as it affects the supply side of freshwater.

2.6 Contested views of vulnerability

The concept of vulnerability provokes competing conceptualisations and framings that defy a straightforward and universal characterisation. It basically implies the degree to which individuals, communities and systems are likely to suffer harm or injury to a specific devastating event or process. It invokes images of harm, weakness and incapability in the face of latent or real threat. Different scholars from diverse fields have pronounced different interpretations of vulnerability. The seeming lack of universal consensus on vulnerability has resulted in a definitional deficiency in vulnerability literature. Social scientists and climate scientists usage of vulnerability often connote different things. The former tends to construe vulnerability as a mixed set of social, political and economic factors acting in part or in unison to undermine people's ability to cope with or withstand adverse change. The climate scientist, on the other hand, interprets vulnerability in relation to the probability of occurrence and impact of weather and climate-related events such as flood, drought, storms and water stress. The climate scientist tends to highlight the physical elements of exposure, probability and impact of the hazards of nature in their definitional shift.

To Chambers (1989), vulnerability to harm inherently has two strata; internal incapacity (the original in-built characteristics of the individual) and external influences including the wider political economy of things.

As Chambers summarises;

> It means not lack or want, but defencelessness, insecurity, and exposure to risk, shocks and stress . . . Vulnerability here refers to exposure to contingencies and stress, and the difficulty in coping with them. Vulnerability thus has two sides: an external side of risks, shocks, and stress to which an individual or household is subject: and an internal side which is defencelessness, meaning a lack of means to cope without damaging loss (Chambers, 1989, p. 1).

Essentially three themes emerge from Chambers' definition that needs to be filtered out:

1. The risk of exposure to crises, stress and shocks
2. The risk of inadequate capacities to cope with stress, crises and shocks
3. The risk of severe consequences of, and the attendant risks of slow or limited poverty (resiliency) from, crises, risk and shocks.

In sum, vulnerability of an individual, community or system is a reflection of its characteristic features and circumstances that may put it in harm's way which renders it unable to cope with and or recover from the damaging effect of the hazard or perturbation.

Gallopín (2006) in discussing the linkages between the vulnerability, resilience and adaptive capacity describes perturbation as the major disturbance within a system beyond the normal variability the system is used to. It is often sudden and external to the system although unstable internal elements may trigger it. For instance, a rainstorm in a nearby community may pollute the only surface drinking water source with debris leading to water insecurity. Unlike perturbations, stresses are slow and continuous variability which may be imperceptible at the beginning. Drought and population growth embody good examples of stressors. However, the distinction between stressors and perturbation can sometimes be blurred by geography, scale, time and the field of study. The twin concepts of perturbation and stress are conceptually bounded by the fact that they induce alterations in a community.

The degree of susceptibility of a community to damage is a function of its ability to respond to perturbation and return to its original status prior to the disturbance. Adger (2006) refers to this ability as sensitivity. He defines sensitivity as "the degree to which a system is modified or affected by perturbations" (Adger, 2006, p. 270). This general conceptualisation of sensitivity latently limits sensitivity to the adverse effects of perturbation. In climate change literature, the IPCC describes sensitivity as the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli (Bates, Kundzewicz, Wu, & Palutikof, 2008a). To illustrate, a decline in crop yields in response to a decline in mean rainfall in a season or a poor household losing their last stock of livestock in a major flood. In other times, the effects may be indirect. A case in point is losing seasonal household income in the dry season due to a shortage of water in the village dam for dry season farming.

Gallopín (2006) clarifies and summarises sensitivity as the degree to which a system, for example, community and livelihoods are modified by internal or external disturbance or a set of disturbances. Yaro (2004) argues that any attempt to distinguish between internal and external sensitivity is artificial and arbitrary. There is a constant flux of exchanges and interactions between both internal and external sensitivity. Measuring vulnerability using an "either or approach" is unnecessarily restrictive and buries the multiplex of interactions that gives rise to vulnerability. He proposes a more comprehensive approach that captures fully household inability to avoid a negative outcome such as water insecurity. This view of vulnerability and its measurement enables a deeper understanding of the varying degrees of vulnerability amongst the different layers of society.

Yaro (2004) concludes that:

> Appropriately, we can talk of the risk of being food insecure, which is dependent on the general vulnerability status of the unit of analysis. Vulnerability should be seen as the risk that the household's entitlements would fail to buffer against hunger, famine, dislocation or other losses. It encapsulates the growing recognition that the extent to which people suffer from calamities of any kind depends on both their likelihood of being exposed to hazards or shocks and their capacity to withstand them, which is related to their socio-economic circumstances.

In contributing to the categorisation for factors that influence vulnerability, Cutter, Boruff, & Shirley (2003), identifies four interlocking and mutually interacting factors that influence vulnerability. This dynamic quartet of lack of access to resources, limited access to political power, social capital and physical capital determines vulnerability.

2.7 Water security and climate change

There is an emerging picture of the intricate relationship between climate change and water security as knowledge and information about the linkages evolve. Water security in a given area is largely linked to the hydrological cycle (see figure 1) which is shaped by the balance of precipitation, temperature, runoff and evaporation. It is the interactions of these processes that largely determine the type of water resources that an area may be endowed with. Specifically, the role of precipitation and temperature are crucial.

According to the IPCC (2008), warmer temperatures increase evaporation rates while drying certain parts and effecting increases in precipitation in other regions. While the exact outcome of climate change is a subject of controversy in climate science, rising temperature will naturally increase evapotranspiration rate. Key climatic elements that affect evapotranspiration are temperature which positively linked, relative humidity (negatively correlated) and wind speed (positively correlated) (UNFCCC, 2011).

The IPCC (2013) opines that the global increase in temperature (this decade) is 0.5 degrees higher than the average warming between the years 1960 and 1990. Similarly, the world metrological organisation (WMO, 2016) concludes that:

*"*2016 will be the hottest year on record; with global temperatures even higher than the record-breaking temperatures in 2015...Global temperatures for January to September 2016 were approximately 1.2°C above pre-industrial levels and 0.88°C (1.58°F) above the average for the 1961-1990 reference period*"*.

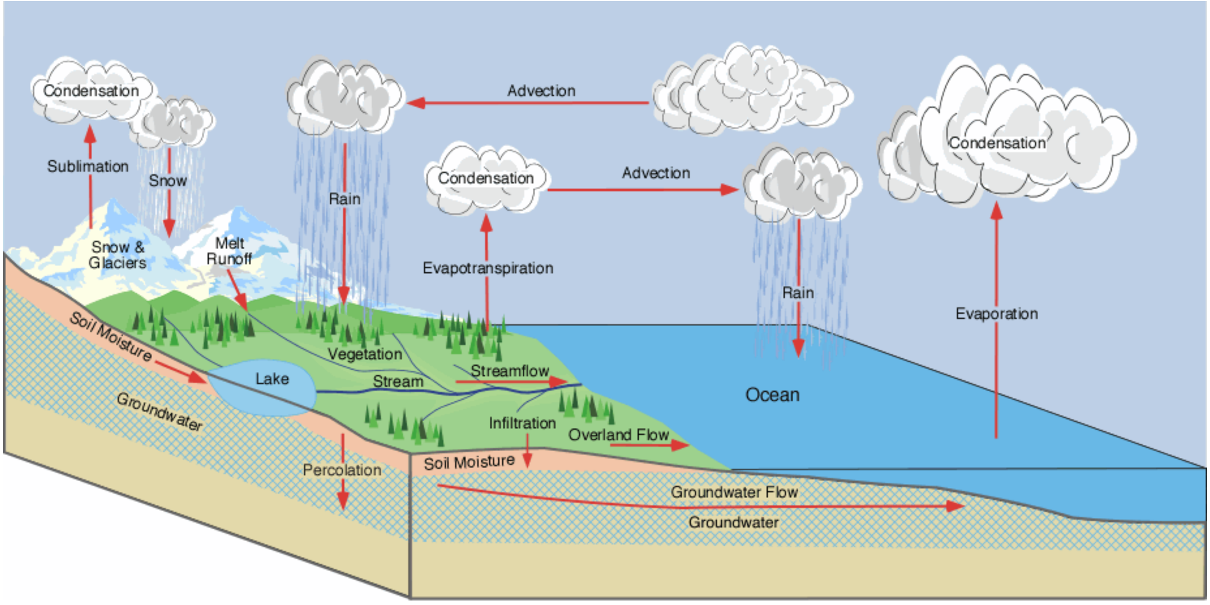


Figure 1: The hydrologic cycle

Attribution studies show that most of the observed increase in global temperatures (see figure 2) since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations (Bates et al., 2008a; IPCC, 2013; UN-Water, 2013b; UNFCCC, 2015).

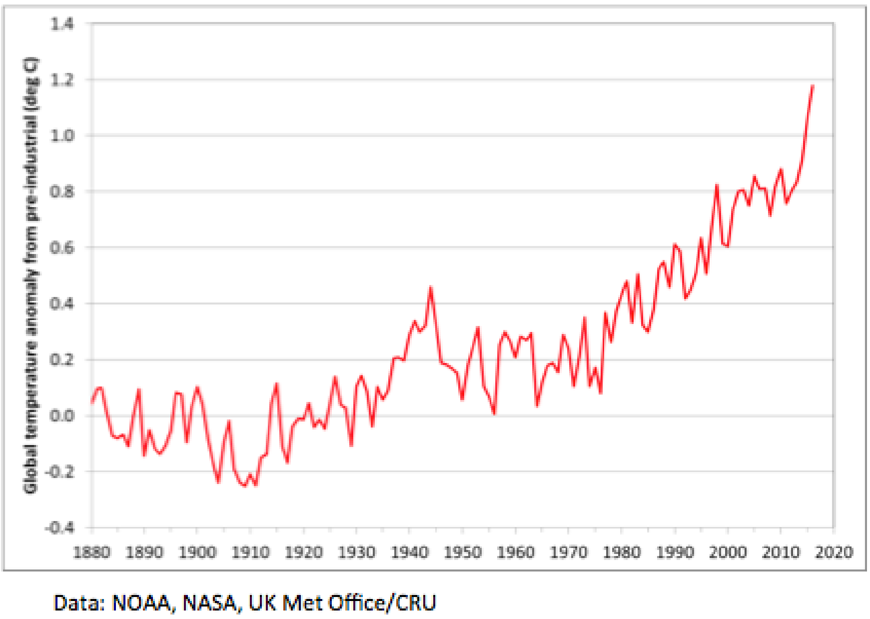


Figure 2: Global temperature changes from pre-industrial levels

Given the delicate automatic relationship between temperature changes and evapotranspiration, temperature rise could lead to surface and soil water evaporation and consequently the amount of water available to support human and ecosystem services.

The impact of climate change on precipitation remains unsettled. The controversy is partly due to varying methodological and data challenges. Recent studies linking climate change and water security shows that climate change impact on water resources shows both spatial and temporal variation. In analysing five climate models, Bates et al. (2008) found that precipitation across Africa except southern Africa will experience a significant reduction in stream flow. Riede, Posada, Fink, & Kaspar (2016) also reports that the onset of the rainy season has not significantly shifted, although the length of the Sahelian rainy season reveals an increasing trend of 2–3 days per decade. This assertion is supported by the IPCC finding that drought has, and floods have, become common in West Africa.

The importance of climate change in relation to water security pivots around its overarching influence on river flow or discharge. It is particularly highlighted in arid and semi-arid regions (Intelligence Community Assessment, 2012; Misra, 2014). In arid and semi-arid regions, the small difference between precipitation and evaporation makes slight reduction in precipitation have pronounced impact river flow and surface water availability (UNFCCC, 2011). For example, Ojo, Gbuyiro, & Okoloye (2004) demonstrates that in arid regions of Africa with less than 500mm of rain a year, a 10 percent reduction in precipitation could induce up to about 50 percent reduction in runoff. Similarly, any small increase in precipitation could create new floodplains. Similarly, in Ghana, Kankam-Yeboah et al (2013) in simulating streamflow in the Volta and Pra basins projects that the mean stream flow could reduce by between 21.6% and 50.1% and 2.2% and 46.2% respectively by 2050. These observed and projected changes have negative impact on water availability and may interact with existing social, political and economic rules and institution to complicate access and use of water resources especially for the vulnerable in society. Table 3 shows Africa has the most vulnerable socioeconomic systems susceptible to water-related stress as a result of climate change. Recent projections indicate that there may be 50 million refugees by 2020, hit and affected by severe droughts in and across the African continent (Brown & Hammill, 2014; IPCC, 2008, 2013; UNFCCC, 2007). These projected changes add to the pre-existent stress amplifying vulnerability of livelihoods.

Table 3: Impact of Climate Change Worldwide

North	Reduced snow in the West
	Increased frequency and intensity of heat waves in cities
	Reduced yield of rain-fed crops - only up to 20% yield
Latin	Replacement of tropical forest by Savannah in Eastern Amazonia
	Significant biodiversity loss through extinction
	Changes in water availability for utilisation - low availability
Europe	Frequent flooding of inland and coastal regions - Increase in flash floods
	Sea level rise
	Glacial melts in mountainous regions
	Reduced snow cover
	Loss of biodiversity
Africa	Water stress will impact 75 to 250 million by 2020
	Reduced yield of rain-fed crops/ agricultural produce by up to 50%
	Overall reduction of agricultural production and access to food
Asia	Major reduction in freshwater availability - projected to decline all over
	Increased coastal flooding - during monsoons and storms
	Increased death and disease - related to droughts and floods
	Increase in drying/droughts - increase in drying index percent

Source: Compiled from IPCC, 2009

The IPCC concludes that a warmer climate, with its increased climate variability, will increase the risk of both floods and droughts (IPCC, 2008). Arid and semi-arid regions around the world such as the Sudan Savanah in Ghana face an alternating double jeopardy of floods and droughts. Both ISDR (2008) and Intelligence Community Assessment (2012) reports asserts that there is incontrovertible evidence that drought-affected areas will likely become more widely distributed. Hydrometeorological events are likely to increase both in intensity and frequency leading to higher flood risks. By mid-century, water availability will likely decrease in mid-latitudes. Sub-Saharan Africa is particularly vulnerable to these changes and variabilities due to a complex interaction of endemic poverty, weak institutions, and dependence of livelihoods on the natural environment (Yaro & Hesselberg, 2016). These interactions of misfortunes act to constrain adaptive capacity and weaken resilience to the multiple shocks and stresses of climate change.

Climate change-induced droughts affect the supply side of water security. Droughts offset scarcity by prolonging the distance and non-availability of surface water, compromising storage levels through lack/reduction of rains. It may also cause stress by making water inaccessible and unusable through contamination. These could be exacerbated by existing social domains.

2.8 The nexus of climate change, water and food securities

There is compelling evidence emerging that link climate change-related water insecurity to agriculture and food security. (GWP, 2013; Tandon, 2007; Wiltshire, Kay, Gornall, & Betts, 2013). Naturally, where precipitation is expected to decline, rain-fed agricultural production will take a hit. Projections of increased aridity across already arid and semi-arid regions appear to be robust across different climate models. Increasing aridity has a direct impact on water availability for irrigation.

Even areas where expected increased precipitation could boost yields are likely to be vulnerable to crop damages associated weather extremes such as heavy storm events and flooding.

Again, comprehensive modelling studies have consistently shown that beyond a certain level of warming (2–3 °C), yields are likely to decline (Blanc, 2012; Nelson et al., 2010).

Globally, about 70 percent of all freshwater withdrawals are used for food production involving crop and livestock productions. In regions of low agricultural technology such as Sub-Saharan Africa, agriculture is almost exclusively rain-fed. Rivera (2011) projects that climate change will not only influence the supply of water, modifying the regional distribution of freshwater resources, but will also influence the demand for water. The FAO, 2011; Shepherd et al., 2013; WMO, 2016 and World Economic Forum, 2011 also make similar conclusions. For instance, higher temperatures and changes in precipitation patterns are expected to increase irrigation water demand for crops (FAO, 2011). Again, changing demographic dynamics will increase the competition for water between irrigation needs and non-agricultural users due to population and economic growth (World Economic Forum, 2011).

Studies (Alcamo et al., 2003; Awotwi, Yeboah, & Kumi, 2015; Ojo et al., 2004; Riede et al., 2016) forecast that by the year 2050 the rainfall in West Africa decline by 10%, prompting major water shortages. They further reason that the 10% decrease in precipitation would translate into between 17%-20% reduction in drainage while the regions which are receiving 500–900 mm/year such as the Sudan Savannah in Ghana may experience a reduction by 50–30% respectively in the surface drainage. With a population growth above 2.7% (Bongaarts & Casterline, 2013; Yansaneh, 2005), competition and pressure on water resource could double within this same period in the Sudan Savannah. This could lead to a decline in agricultural production and significantly affect food inflation and thus affecting food availability, access and stability. The northern savannah belt faces an even more serious dilemma. The region is already experiencing a decline in soil fertility, declining yields and environmental desertification. Declining precipitation could exacerbate these stresses and throw poverty reduction efforts out of gear.

Linking climate change with ongoing demographic and agricultural land expansion in arid areas highlights the scope and nature of future vulnerability to climatic shocks and stress. Grazing land and livestock production are vulnerable to climate change for three plausible reasons. First, decreasing precipitation and increasing evaporation due to rising temperatures in arid regions could potentially reduce the primary productivity of grazing land and accompanying livestock carrying capacity. Again, prolonged droughts could directly lead to loss of herds. The third reason is a loss of biomass. Repeated and prolonged drought could decimate the capacity of soil to regenerate sufficient biomass to sustain growing livestock. This may leave the soil unable to recover even during wetter periods.

With more than 80 percent of the global agricultural land being rain-fed, the projected changes in water quality and quantity due to climate change are expected to have a significant impact on the agriculture sector in terms of agricultural productivity, hence affecting food security. The complex relationship between water security, energy, and food security poses the most formidable counter force in the struggle of developing countries to achieve sustainable development. To keep up with the growing population, food production will need to increase by 50 percent by 2030 (UNFCCC, 2011). Adding climate change to the equation makes this projection even harder to achieve particularly in South Asia and Sub-Saharan Africa (UNFCCC, 2011).

In the last decade, regional food production and distribution systems were significantly disrupted due to a simultaneous combination of drought and financial crisis with a ripple effect on other sectors of production and trade. In an interconnected and interdependent globalised world, failure of the monsoon in India or a major storm in China affects regional food production. This has a scaler effect on the prices of imported rice in Ghana. Between 2006 and 2008, global basic food staple prices skyrocketed dramatically, especially in food insecure endemic regions such as sub-Saharan Africa. The dramatic rise was attributable to, among other factors, a prolonged drought that plagued Australia compelling wheat production to plummet. As a result of this crop failure and others, food prices doubled in some countries.

2.9 Nature of climatic change in Ghana

Climate change literature in Ghana has expanded tremendously over the past decade. The increased interest is partly due to the ravaging impact of climate change on agriculture which remains the largest employer of the 28 million population (Ghana Statistica Service, 2012). It has been observed that both temperature and rainfall regimes have significantly changed since the 1960s. According to Ghana's Third National Communication Report to the UNFCCC, observed historical minimum temperatures have increased by 2% in the south (rainforest, coastal agro-ecological zones, deciduous and transition zones) and 37% in the north (Guinea and Sudan savannah zones). The mean monthly temperature maximum temperatures are projected to increase by 2.1^0C by 2060. The changes are not uniform across the country. It exhibits latent spatial and agro-ecological variation.

Table 4: Spatial variations in temperature increases in the various agro-climatic zones

Zone	**Increase in Mean Maximum Temperature by 2100 (°C)**	**Increase in Mean Minimum Temperature by 2100 (°C)**
Sudan	3	2.5
Guinea	2.5	2.5
Transitional	2.5	3
Deciduous	2.5	2.5
Rainforest	2.5	2
Coastal savannah	2.5	No Data

Source: Amlalo & Oppong Boadi (2015)

The Sudan savannah is the zone likely to experience highest temperature changes. This has significant ramifications for water resource availability and subsequent livelihoods options in the future. Climate change studies have unequivocally established that rainfall pattern has changed over the last half century. However, the extent and nature of change have been a subject of competing claims. Amlalo & Oppong Boadi (2015) observed a decline in rainfall amount while EPA (2000) and MacCarthy, Adiku, & Yangyuorul (2013) observes a shift in the onset of the raining season with longer dry spells. Changes in rainfall are not uniform. For instance, contrary to the observed and projected general decline, (Owusu & Waylen, 2009) find that Kete-Krachi has experienced increase in rainfall between 1951–2000. These controversies are the outcome of different methods, modelling approaches, timescales and local variations.

Table 5: Spatial variation of rainfall in the various agro-climatic zones in Ghana

Zone	**Projected Changes in Mean Annual Rainfall by 2100 (mm)**
Sudan Savannah	-170
Guinea Savannah	-74
Transitional	-78
Deciduous Forest	-99
Rainforest	110.5
Coastal Savannah	No Data

Source: Amlalo & Oppong Boadi (2015)

Similar to observed and projected temperature changes, rainfall decline is greatest in the Sudan Savannah than any other agro-ecological zone. Considering the fact that agriculture is almost exclusively rain-fed and limited diversification of livelihoods options, the decline in rainfall has the potential to offset large-scale multiple shocks to the Ghanaian economy. Agriculture production, hydroelectric power production, and water supply are almost in certain jeopardy if robust adaptive and resilience capacities are not built. The combined ramifications for national security could be catastrophic.

2.10 Climate change, water security and food security vulnerabilities in Ghana

High population growth, low technology, inflation and degrading soils continue to be major hindrances to achieving food security in Ghana. However, the most important factor in the fight to feed Ghana is a seasonal variation of rainfall. The frequency and intensity of climatic extremes such as dry spells and droughts, as well as floods cause substantial losses in yields (Barron et al. 2015; ISDR 2015; Mârza, Angelescu, & Tindeche 2015; Molle & Mollinga 2003) and consequently affect household income and overall national growth. Due to reliance on rain-fed agriculture, food production is vulnerable and very sensitive to climate change and variability. Several climate models have consistently, projected not only higher temperatures in semi-arid regions but declining rainfall amount and duration. The El Niño South Oscillation (ENSO) event is also projected to intensify droughts and floods (IPCC, 2013).. Currently, the El Niño phenomenon is driving drought in Southern Africa, Ethiopia, India, and Thailand. In a globalised world of interconnectedness and interdependence, this has significant ramifications on Ghana which spends over 60% of its rice consumption on importation (FAO 2010). This dependence means that drought in South Asia has significant implications on prices of imported rice in Ghana. Consequently, this undermines both food availability and food access especially to the urban poor who do not produce alternate foods themselves.

2.11 Theories and approaches to water security research

Water (in) security theorisation albeit still at the fledgling stage has evolved through borrowing from theories in food and energy security. This dependence on food and energy security theories is possibly because of the intrinsic relationship between the triad. This thesis borrows Sen's entitlement failure as a guiding theory to understanding water insecurity. Water security theories spanned from those that emphasises physical availability often underlined by geography and locational reasoning to how poverty, societal rules and entitlements constrain access and use of water resources. Growing and deeper understanding of water insecurity has provoked multiple theoretical conceptualisations of the causes, indicators and analytical methods and approaches. Calow, Macdonald, Nicol, Robins, & Kebede (2006) and Garrick & Hall (2014) emphasise physical water availability while others focus on demand-supply deficits (Alcamo et al., 2003; Falkenmark, 1989), how entitlements constrain access to resources creates vulnerability (Sen, 1981, 1987; Yaro, 2004a).

2.12 Emerging approaches in water security discourse

Two competing approaches have emerged to explain the complexity of water security; the reductionist and integrationist. The reductionist approach, favoured by the World Bank is epistemologically positivist using quantification and value-neutral methods to convey depth and extent of water security. The latter recognises diversity in society and acknowledges that water security is shaped by social rules which can be quantified. A more detailed discussion of these two broad categories of approaches in the literature is imperative for a deeper understanding of either side of the fault line.

2.12.1 The reductionist theory (approach)

Falkenmark's (1989) work is the wellspring of the reductionist approach. The World Bank (2004) and Grey & Sadoff (2007) however popularised it. Garrick & Hall (2014) and Sadoff et al. (2015) subsequently built on their arguments around the tenets of this approach. Grounded in classical economics and engineering traditions, the reductionist seeks to represent water security through calculable risk. They further quantitatively link economic growth, particularly in the developing world to hydro-climatic variability. This stream of approach views water security from a demand-supply lens. Water security is basically calculated as the per capita water available for use. It posits that reliable supply is key to water security (Zeitoun et al., 2016). As Zeitoun et al. (2016) summarises:

> The range of applicability of quantitative risk analysis for water security is thus restricted to contexts that are very well studied, with well-rounded (and thus known) conditions. It can

thus take its place as one option within the plurality of approaches required to address water security, in particular with land use planning decisions in the face of droughts and floods" (Zeitoun et al., 2016, p. 148).

The strength of this approach like most positivist approach to research lies in its simplicity, clarity of its messages and generalisation and prescriptive ability. Critical eyes, however, points to its assumptions that ignore diversity and politics in society. Quantification is only valid if only all variables and boundaries are known. Hence the conclusions of the reductionist approach are only valid when comprehensive data is available.

2.12.2 The integrative theory (approach)

A substantial number of water insecure people are not a result of lack of physical availability. Even in countries with high water per capita, many people are still water insecure. The failure of the reductionist approach to sufficiently account for this paradox trumped up support for an integrative approach. The integrative approach involves a comprehensive analysis of diverse tributaries of underlying processes. Unlike the reductionist, integrative emphasises the social domain of water insecurity. Water security is not only filtered through the lens of the demand-supply equation but equitable distribution, access and environmental sustainability throughout the hydrological dry-wet regimes are seen as crucial (Beek & Arriens, 2014; Calow et al., 2006; Macmahon, 2015; Zeitoun et al., 2016). The strength of this approach lies in the fact that it is context specific and local hence it enables policy makers and households to respond better to dynamic hydro-climatological and social circumstances. In the words of Zeitoun et al. (2016):

> the 'integrative' body of water security research grapples with the complexity of water-society challenges by : a) explicitly recognising diversity in society and the environment, while marinating focus on the most marginalised; b) incorporating water resources that are less easily controlled into the analysis ; and c) welcoming innovative and adaptive approaches to move beyond supply-side prescriptions (Zeitoun et al., 2016, p. 149).

Similar to Sen’s path-breaking approach to examining famine in his famous *Poverty and Famines,* the integrative approach envisions hydrosocial spatial interactions from which fountains water insecurity. It takes into cognisance that an understanding of the cause of water insecurity as physical absence alone is incomplete. Even though insecurity may arise from natural causes, water insecurity is actively constructed and historically produced through the interfaces amongst power relations, culture and nature. This proposition recognises that social structure and power intentionally or unintentionally exclude certain groups from access to and use of resources namely water. These socially-constructed and politically-enforced inequalities lead to unequal distribution of opportunities. Society is not homogenous and is riddled with different and varying degrees of resource endowments and entitlements.

Entitlements are described as the actual or potential resources available to individuals or communitybased on their own production, assets or reciprocal arrangements (Adger, 2006). In the words of Sen;

> The entitlement of a person stands for the set of different alternative commodity bundles that the person can acquire through the use of the various legal channels of acquirement open to someone in his position (Sen, 1987, p. 8).

An individual’s entitlements are thus the realised or latent welfare or income sources.

The vulnerability of household or individual livelihood to shocks (example flood) and stresses (such as drought) arises when people command insufficient income, social capital and wealth, and when previously held endowments collapse (Adger, 2006; Chaudhuri, 2003; Coirolo & Rahman, 2014; Cutter et al., 2003).

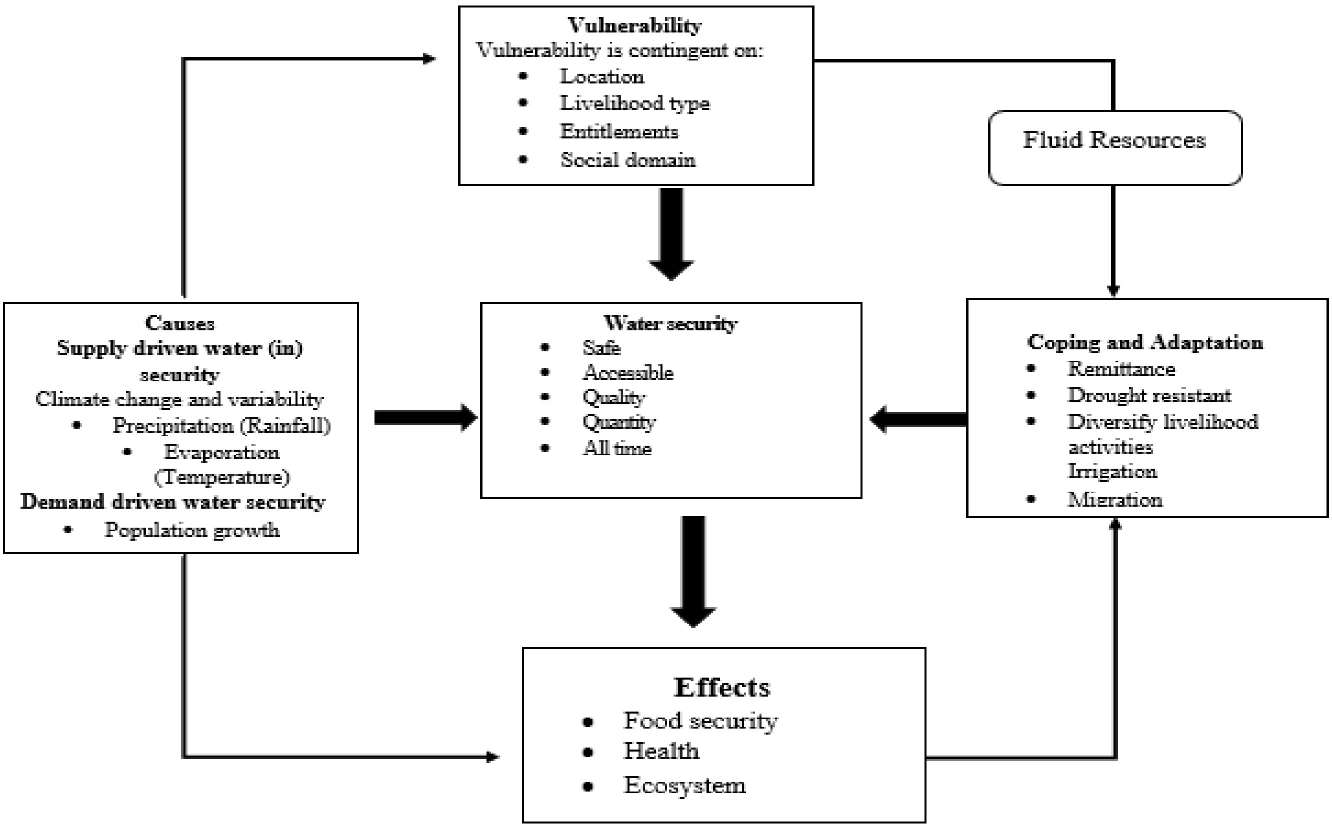
The integrative approach to analysing water insecurity recognises that societal functioning is non-linear and water security has been squarely located in a changing political, technological and biophysical processes and outcomes (Zeitoun et al., 2016). In sum, the integrative approach argues that water is inherently relational and shaped by multiple levels of access and control. The reductionist approach presents an incomplete reality of water insecurity.

2.13 Conceptual framework

This thesis views water insecurity through the integrative approach (Grey & Sadoff, 2007; Zeitoun et al., 2016) to water insecurity analysis. It consents that water insecurity is located within a socially complex and evolving arena in which the role of power relations is intractable. The conceptual framework identifies climatic and non-climatic factors that affect water security and presumed relationships amongst them. As a fundamental element for poverty reduction, economic development, and environmental sustainability, water security has a significant impact on lives and livelihoods. Water security is an outcome of multiple interactions and interplay of physical and social systems. The concept map visually displays the complex interactions. Water security is influenced by both climatic and non-climatic factors. Climatic factors affect the supply side of the water security loop (FAO, 2008; Tandon, 2007). Non-climate factors such as population growth induce increased demand for agriculture and household consumption. A decline in the supply side of the equation sets off stress and scarcity by altering the physical availability and quality of water at a particular location. Climate variability or change affects water availability and quality directly by altering precipitation or evaporation via temperature (Bates et al., 2008b). Water availability for household and agriculture use is then compromised.

However, vulnerability within communities is not homogenous due to different resource endowments and pre-existing inequalities and rules that may exclude or impair participation, access and use of water resources. Hence, vulnerability to the impact of climate-induced water insecurity reflects the structure and processes inherent in society (Boelens, Hoogesteger, Swyngedouw, Vos, & Wester, 2016). Poor households with agriculture as the only source of income will likely have low adaptive capacity to cope with climate variability and change compared to a household with diverse non- agranian income sources. The level of susceptibility of a household is a function of the resources that the household can command (entitlements) for example, the transportation assets it may have to go to the source of water. Even though a household may be far from a water source, it may not be automatically vulnerable. A government worker or a wealthy farmer with a motorbike or donkey may thus be less susceptible compared to a peasant household which may be closer to a water source but does not have sufficient storage facilities. Households with fluid resources and capacity to benefit from the wider economy permit successful adaptation. Fluid resources are resources that can easily be deployed with higher returns. For example remittance, cattle and powerful social connections that be leveraged to ameliorate the impact of water insecurity resulting from climate change.

Figure 3: A conceptual framework of water and livelihoods in rural Garu-Tempane District.



Source: Author's construct

CHAPTER THREE: METHODS AND STUDY AREA

3.1 Introduction

This chapter is in two parts. The first part highlights the location and characteristics of the study area. The second part discusses the research methods and research design.

DESCRIPTION OF THE STUDY AREA

3.2 Location and size

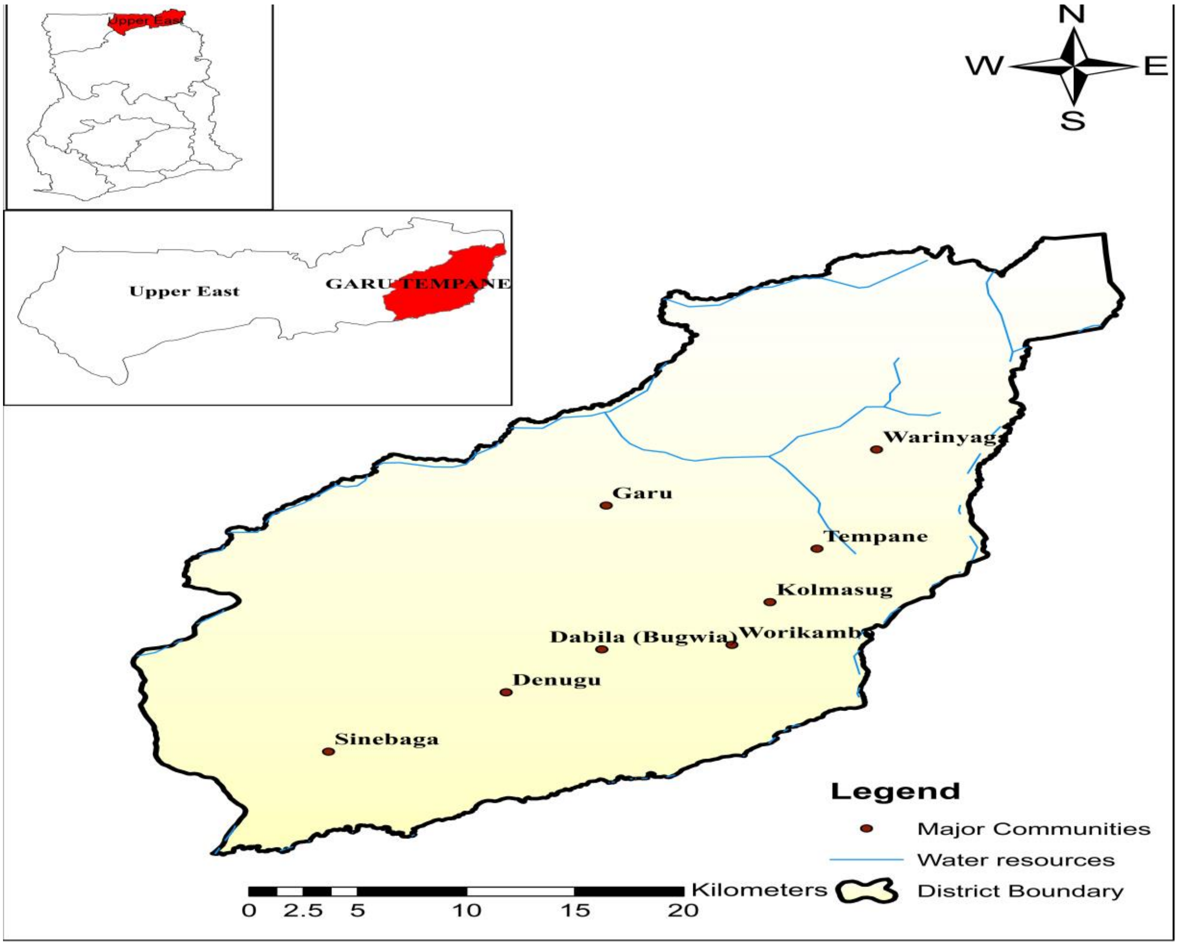
The Garu-Tempane District is located in the South Eastern corner of the Upper East Region of Ghana. It covers an area of 1060.91 km^2 and lies approximately on latitude 11^0 38^1N and11^0N and longitude 0^0 06^1E and 0^0 23^1E (Ghana Statistical Service, 2014).. The district borders five other districts in the region making it the District with most borders in the Upper East region. It shares boundaries with Bawku Municipal to the North and Binduri District to the North West. It is flanked in the northeast by the Pusiga District while the East Mamprusi District is to the South West fringe. Bunkpurugu-Yunyoo District shares its South East border and Bawku West District is to the West. The district shares an international border with the Republic of Togo to the East. According to Ghana Statistical Service (Ghana Statistical Service, 2014), the population of the district is 130,003 consisting 47.7 percent male and 52.3 percent female. The population of the district is primarily rural and scattered in dispersed settlement.

3.3 Relief and drainage

The district forms an extension of the Gambaga scarp and is underlain mainly by Birrimian and granite rock formations separated in parts by thinly to moderately bedded sandstones. The relief of the district easily marks the highest point of the Upper East Region. In areas bordering the White Volta and its tributaries, the relief is generally low and slightly undulating with heights of 120-150 meters above sea level. The rest of the district consists of a series of plateau surfaces. The average height of the plateau is 400 meters above sea level, but isolated peaks rise beyond 430 meters.

The White Volta and River Oti have their tributaries in the district. The major rivers that are in the district are Tamne, Azimbaas, Baaring and Pawnaba-Kiyinchongo. These rivers have strong irregular seasonal flow patterns. They flow from June to December with peaks in August and September. The district usually experience flooding perhaps due to overflows of the Bagri dam in the Burkina Faso. But due to the good drainage system, the water recedes within few hours or days in the case of major flooding. The topography of the district is flat with shallow soils.

Figure 4: District Map of Garu-Tempane



3.4 Geology and soil

The soils within the district are mainly developed from granite rocks which are shallow and low in soil organic matter content. The three (3) main soil types found in the district are red and brown sandy loam and clays, moderately deep pale brown coarse sandy loams with biotic granites and grey sandy loams and clays in valleys. The demoniac of sandy, gravel and clayey soils complicates the hydrological makeup of the area.

3.5 Climate

Garu-Tempane is typifies the Sudan Savanah climatic zone characterised by pronounced dry and wet seasons. The seasons are determined by rhythm of two alternating air masses. The North East Trade Winds is cold, dusty and dry and blows mostly from late November to early March in the north-eastern direction. It is locally known as the harmattan winds. During this period, rainfall is entirely absent (less than 10mm) and humidity is very low rarely exceeding 20 percent during the day but may rise up to 60 percent during the night and early morning. Temperature is usually modest at this time of the year by tropical standards (26^0-28^0 C). Between March and May temperatures could be as high as 38 ^{0}C.The highest mean monthly temperature is 40 ^{0}C, which occurs in April while the lowest temperature of 18 ^{0}C and occurs in December/January. There is abundant sun shine in the area which can support solar energy development. High wind speed can also be harvested using wind mills for irrigation purposes. The period is characterised by such human and animal diseases such as Cerebral Spinal Meningitis (CSM), Anthrax, and Newcastle.

The second air mass, the Tropical Maritime Wind is moisture-laden blows between May and October. This winds are associated with rainfall Total rainfall amounts to an average of 800mm per annum. During this period (May to October) the rainfall is torrential, unpredictable and unreliable. The large quantity of rainwater is normally lost through evapo-transpiration from open surfaces partly due to the bare and dry nature of the ground. This affects availability of water for agriculture and domestic consumption. It is estimated that a volume of between 1.55 to 1.65 cubic metres per square area of the rainfall is lost per annum. Rains during this period of the year support the on-season cultivation of the major food and cash crops in the District.

3.6 Agriculture

Agriculture is the predominant occupation of the people in the area, 82.5 percent of the district's population is engaged in agriculture (Garu-Tempane District Assembly, 2013). The predominant crops are maize, early and late millet, sorghum, rice, soybean, cowpea, groundnuts, sweet potato, "frafra potato", watermelon. Livestock such as pigs, cattle, sheep, and goats are commonly reared. Cattle especially have sentimental relevance. Cattle are seen as a measure of the wealth of households. Again, aside providing meat and milk, cattle specifically bulls are used to draw ploughs. Poultry especially fowl and guinea fowl production is quite significant. In the dry season, crops such as onion, tomatoes, pepper, okra, cabbage and leafy vegetables are produced. The rivers in the district are the major source of water for dry season vegetable production. According to Garu-Tempane District Agricultural Development Unit (GTDADU, 2010), the district has eight (8) dams and fourteen (14) dugouts which serve as a source of water for dry season vegetable production and drinking water for animals. The average household size in the district is seven (7) persons per household. Farmlands are incorporated into the settlement structures, houses are built far apart from one another creating a dispersed scene for compound farming. Donkeys play an important role in the farming system as means of transport. With the shallow soil profile in the district, bullock plow is the main equipment used for land preparation. Other agricultural economic activities in the district include livestock trading, rice and soybean processing, pottery, shea butter extraction, groundnut oil extraction, dawadawa processing and blacksmithing fabrication.

Several extension organizations are operating in the study area. These include the Ministry of Food and Agriculture (MOFA), Presbyterian Agricultural Station (PAS), Community Base Rehabilitation (CBR). The main aim of these organizations is to provide extension services to farmers to enhance production and productivity in order to increase incomes and improve the livelihood of the people. Non-governmental organizations through collaboration with extension organizations in the district provide services to farmers. Such non-governmental organizations include Care International, Technoserve, USAID, International Fertilizer Development Centre (IFDC), and Alliance for Green

Revolution in Africa (AGRA), Association of Church Development Projects (ACDEP) and World Vision International.

3.7 Socioeconomic profile of in Garu-Tempane

Daily life in Garu-Tempane revolves around agriculture characterised by smallholder farming mainly of subsistent orientation except for cotton production. An emerging cash crop is cashew plantation albeit still yet to catch up. Millet, maize, sorghum and cowpea are the main subsistence crops which are often intercropped. The combination of early millet, late millet, and sorghum has demonstrated to be profitable as such agronomic practice enables nitrogen-consuming plants such as millet to benefit from nitrogen-fixing plants such as cowpea.

Farming systems are characterized as extensive, low external input, mixed crop, and livestock rearing largely determined by rainfall features of the area. Rainfall variability is a key constraint to increasing yields. Farming is almost exclusively rain-fed hence it dictates yield variability, and droughts and floods can result in crop failures. Sorghum, locally called guinea corn or "red millet" is widely cultivated as it has adapted to low levels of rainfall compared to maize.

Cropping exhibits an interesting spatial and geomorphic pattern. Drought tolerant crops namely cowpea, sorghum and millet are grown in the uplands while maize and root crops are common in the deeper heavier soils near the bottom of the slopes with rice, watermelon and onions found in the valley bottoms (Callo-Concha et al., 2013; Somah, 2013). This strategy plays a double role, of diversifying livelihoods and adaptation minimizing the risk of complete crop failure in the occurrence of extreme weather conditions.

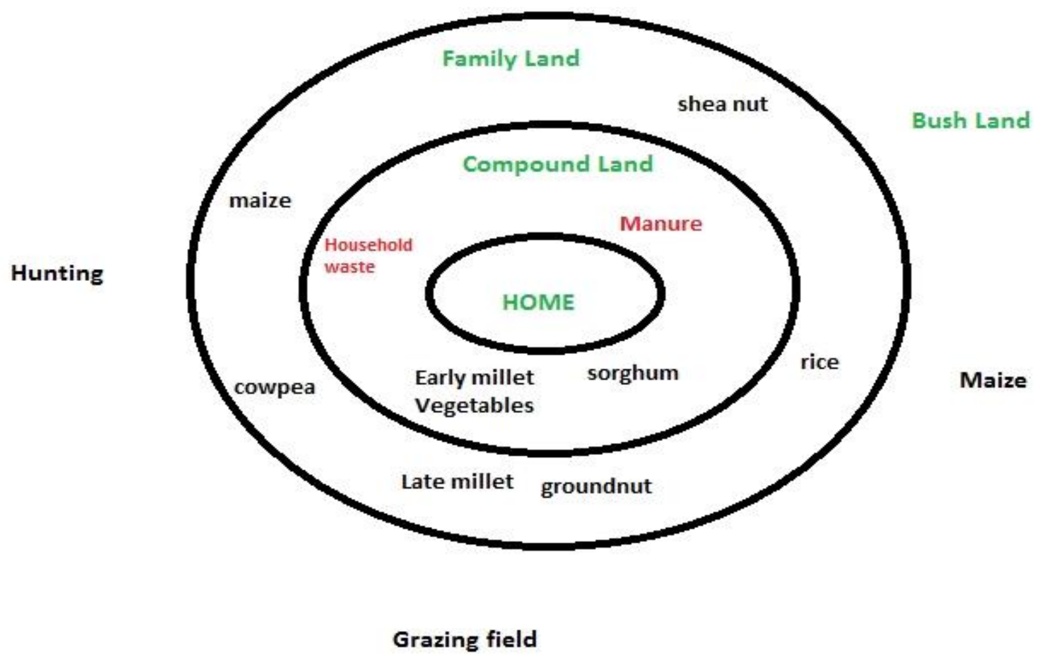
Similarly, the distance between household and fields follows what Callo-Concha et al. (2013) describe as a "concentric ring" pattern. Callo-Concha et al. (2013) identify three agricultural land use categories: compound land, family land, and bush land. The compound land is the land immediately surrounding the house. It is the closest and is the waste field for the household waste.

Livestock enclosures are also built on this land. It therefore naturally receives the largest share of livestock manure. Consequently, it poses rich soil organic matter content hence it is the most intensely cultivated. Early maturing millet, sorghum vegetables are cultivated on this land.

The family land usually may lie just outside the village or *fon*[1]. Ownership and use of this land is by lineage to a particular family or clan. Unlike the compound land, this land rarely receives organic manure hence farming is based on the natural fertility of the soil. Fallowing and intercropping are employed as the application of manure is uncommon. However, due to rapidly declining soil fertility and population pressure, artificial fertilizer are now used.

The outer concentric ring is the "bushland". It is generally large and a common property. Although it was mainly used as a grazing field, population pressure, declining soil fertility and poverty have acted simultaneously to gradually change it to farming zone.

Figure 5: Concentric agricultural land use



Source: Author's construct

[1] *Fon* is the smallest traditional political subdivision of a village in the Garu-Tempane. They are usually governed by a headman who is appointed by the divisional chief

RESEARCH METHODS

3.8 The research process

The research has a dual objective of assessing the impact of climate change/variability on both household and agricultural water security. The household is the preferred unit of analysis since livelihood activities in the study area also revolves around the agricultural use of water. Participants and respondents are both household consumers and agricultural water users. Community level analysis was also conducted as there is a continuum of interactions, activities and processes at macro levels that shape the underlying reality of households and individual farmers.

This study was in two faces. The first face covers the rainy season which spans from June to November 2016 whilst the second face is during the dry season from December 2016 to March of 2017. Such an approach is ideal for this study as water security is characterised by both intra and inter-seasonal variability. The nature, scope, and dynamics of vulnerability adaptation and coping strategies vary in response to the different climatic seasons. Conducting the study in both seasons allows for a holistic characterisation of water security and deepens our understanding of areas that endure the dual dilemma of droughts and floods. Again, it allows for a better and more compelling explanation of the alternating vulnerabilities of households and communities. In sum, it is ideal for mapping of vulnerable areas and households thereby revealing the spatiotemporal dimension of water security.

3.9 Research strategy

The case study research design is ideal for this study since the overall objective of the study is to contribute to our knowledge of individual, group and social behaviours concerning an evolving and contemporary phenomenon. A case study is also suited for this study as it allows the investigators to retain holistic and meaningful characteristics of real-life events such as change processes while enabling activities and processes to be traced over time. In sum, a case study enables the researchers to derive richer, more contextualized, and more authentic interpretation of the phenomenon of interest (Bhattacherjee, 2012).

The research employs a mixed method approach. Mixed methods enable a good explanation of the multifarious socio-biophysical reality (Flowerdew & Martin, 2005; Teye, 2012) while giving the research both solid positivist grounding and revealing the human agency. Questionnaires, survey and in-depth interviews and as well as focus group discussions were the main tools for data collection. Deploying interviews and focus groups discussion is ideal for this research as it generates an in-depth understanding of the realities that may not be adequately covered by the questionnaire. It thus complements the pitfalls of questionnaires. Attributes such as location of communities, main sources of water such as dam, river and borehole were included in the GIS Data base.

3.10 Selection of research site

The study sites were purposively selected taking into consideration the nature of livelihood pursuits, nature of farming, and availability of floodable water body such as a river or lake, availability of a dam and location of farming activities close to a river basin. The dominant source of household water was also considered. Four agro-pastoral rural savannah communities in the Ghana Garu-Tempane district north-eastern Ghana were studied. Worikambo and Kolmasug are to the south-eastern part of the district while Bugwia (Dabila) and Denugu/Danvorga are located to the south of the Distrcit capital, Garu. Bugwia (Dabila) is chosen due to the presence of ephemeral stream which floods the community in the rainy season. Worikambo is particularly suited for this study due to the presence of a dam that continues to shrink in size. Similarly, Denugu/Danvorga was also chosen because of the irrigation dam and a river in the community. However, unlike Worikambo, Denugu/Danvorga has a high population density and characteristics of an emerging urban area. Such a comparative study allows spatial variations to emerge while enabling selective generalization to rise beneath. Unlike earlier study sites, Kolmasug is located on a rocky upland with limited natural sources of water and is largely dependent on rainfed agriculture. This case provides a contrast hence allows a deeper analysis of the nature and dimensions of climate-induced water insecurity and determinants of vulnerability. It also gives an opportunity for an in-depth appreciation of variation in response to households and communities regarding water insecurity.

In selecting respondents and participants, farmers and women who headed households were preferred. This is because both climate change and water security are experiential phenomena and the respondents are better placed to practically conceptualize and express how these phenomena affect their lives and livelihoods over time. Women tend to be managers and multi users of water. It also enables the researcher to define the problem more concisely (Kothari, 2004).

3.11 Sources of data

The sources of data for a research undoubtedly have implications on the trustworthiness, validity of findings and conclusion. This investigation used both primary and secondary sources of data.

Primary data sources for this research include observation, interview method, questionnaires and focus group discussions. Bryman (2012) describes primary data as data that the researcher is responsible for collecting and analysis. Although primary data sources are often time-consuming, they provide a rich source of data for understanding and constructing the present circumstance of the climate impact on water security in the study area. Questionnaires were used to generate quantitative data to establish linkages between perceived climate change/variability and water insecurity.

Understanding the impact of climate change/variability on water security at the local level will not be complete without an appreciation of the global context of climate change discourse. Both droughts and floods are not just local phenomena but have regional and global roots. What happens locally to agricultural production, the dependence on rain-fed agriculture and vulnerabilities are all shaped by sub-local and national power relations. It is, therefore, imperative to analyse macro level secondary data in relation to micro level data by establishing the overt and covert linkages and how they circularly shape and reshape each other. Data on rainfall and temperature trends, topographical and soil characteristic were analysed in synchrony with agricultural production over time. In particular, journal articles on climate change and water security, reports of the Intergovernmental panel on climate change, food, and agricultural organisation, district statistics, and other related reports were examined. Sociodemographic statistics from Ghana Statistical Service were also explored. These secondary data sources give a solid contextual geographical, historical and socio-economic material for a compelling analysis (Flowerdew & Martin, 2005).. Aside allowing for case study comparison, secondary data permits for a longitudinal analysis as data is likely to cover a longer period. Hence, it enables for trend analysis.

Secondary data on the nature of changes in climate were also reviewed. In particular, precipitation and temperature characteristics where the study area is located were examined from 1983 to 2013. These macro-level data are essential in quantifying the nature and extent of changes and variability in climate. Kemp-Benedict et al. (2009) contend that rainfall pattern is an effective way of illustrating the variability of climate over time since water available is correlated partly by the natural water availability (the hydrological system) and partly by the available water infrastructure.

3.112 The survey method

Quantitative methods are generally grounded in positivist epistemology and objectivist ontology and entail a deductive approach to knowledge construction towards maximizing objectivity, replicability, and generalizability of findings (Creswell, 2009; Flowerdew & Martin, 2005; Kothari, 2004). Fundamental to this method is the anticipation that a researcher sets besides personal experiences, perceptions, and biases to ensure objectivity in the conduct of the study and the conclusions that are drawn. It mainly uses the survey approach to data collection.

In estimating the extent of the relationship between climate change and water insecurity, it is imperative to quantify. The survey method was used to collect data at the household level through a questionnaire. The household was the primary sampling unit. A structured questionnaire sought to investigate the state of knowledge of farmers on climatic variability and change by using long-term rainfall and temperature variability/changes as indicators. Both probing open and closed-ended questions sought to understand how these changes have impacted on water availability for both household consumption and agricultural use. Various sources of water in both seasons, causes and dynamics of water insecurity, determinants of vulnerability to climate-induced water insecurity, and the variation in households respond to changing water availability for agricultural and household uses, as well as constraints to adaptation, were also evaluated. In addition, relevant background characteristics of respondents such as age, the number of years in the community, sex, marital status, education, household size, income sources and ownership of assets were captured on the questionnaire. Questionnaires were administered to the respondents who are residents of the study area for at least ten years. This group of people have enough experience and can give better information on the climate change and variability for at least the last ten years (Yiran and Kusimi, 2011).

Using quantification in the investigation, establish relationships such as climate and water insecurity is ingrained with some practical advantages. The use of questionnaires allows me to impute causality to the findings as it provides the basis for more precise estimates of the degree of relationship between climate change/variability and water insecurity in the study area (Bryman, 2012).. For example, quantitative data is imperative in correlational and regression analysis. Again, the use of questionnaires according to (Teye, 2012) also ensures reliability and validity of research findings; this makes it ideal for this research. Besides enhancing reliability and validity of findings, the survey as a method is ideal for this study because there is no existing empirical data (Yansaneh, 2005) on the nexus of climate change/variability and water security.

3.12.1 Sample method and size

The 2010 Population and Housing Census District Analytical Report of Garu-Tempane district, estimate the combined total number of households in the four study sites to be 1,147 households. Using (Yamane, 1967) simplified formula to calculate the sample size at 95% confidence level and assuming maximum variability to be .5 (p=5) with a 5% level of precision, the equation is assumed as follows: $n = \frac{N}{I + N(e)^2}$

Equation 1: Yamame simplified formula to calculate the sample size

Where n is the sample size, N is the households in the study communities, and e is the level of precision. When this formula is applied to the population size of 1,260, the results is as follows:

$$n = \frac{N}{I + N(e)^2} = \frac{1147}{1+1147(0.05)^2} = 296.6 \; Households$$

Hence sample household is 297 out of the 1,260 households in the study area. This number is considered a good representative sample. Notwithstanding the above, considerations of sampling size are often profoundly affected by matters of time, cost and practical consideration (Bryman, 2012).. While the actual sample size is important, striking a balance between the ideal and practical is essential to understanding the everyday reality of rural life. The sample size can thus be revised to reflect the cost, time and practical realities on the ground without compromising reliability and validity of findings. Similarly, Kothari (2004) proposes an optimum sample size.. In deciding the sample, Kothari suggests that the researcher must consider confidence level and cost implication. A key quality of a valid research is representativeness, reliability, and flexibility. For the practical and cost purposes, the sample size was run to the nearest whole significant number. Consequently, a sample size of 297 households was used.

To ensure representativeness of sample size in each study site, the proportion of household in each community relative to the combined total was calculated. The number of households sampled in the each was then proportionally sampled relative to the sample size of 296 households. For example, the number of households in Denugu/Danvorga is 515 which is 44% of 1147. Table 1 provides a summary of sample frame and sample size. Household is the basic unit for data collection of this research. Hence, household head is the focal person although, in his or her absence, the next in charge of the household were sampled.

Table 6: Household sampling frame and size in study communities.

Community	Number of households	Percentage of total number of households %	Sample size
Denugu/Danvorga	515	45	134
Bugwia (Dabila)	188	16	48
Worikambo (Guuni/ Boko)	230	20	59
Kolmasug	214	19	56
Total	1147	100	297

Source: Author's construction based on Ghana Statistical Service (2014)

3.13 Qualitative data

While the survey is ideal for quantification and generalization, the use of interviews complements the inherent weakness of quantification. Qualitative interview and focus group discussion is well suited when the goal is to gain an in-depth understanding of a phenomenon (Creswell, 2009).. This goal corresponds with the objective of this study. Again, a qualitative investigation allows perceptions, meaning, and conceptualisations which are often downplayed or least valued when quantitative approaches are used.to be appreciated.

Qualitative research methods focus on discovering and understanding the experiences, perspectives, and thoughts of participants by exploring meaning, purpose, or reality towards understanding the lived worlds of people (Baxter & Jack, 2008; Patton & Cochran, 2002; Whitehead, 2002) through case studies, ethnographic work, and interviews. The method has an interpretivist epistemological underpinning and is rooted in a constructivist ontology emphasising the presence of multiple "truths" that are socially constructed and can be uncovered through an inductive approach. Qualitative methods emphasise the meanings people give to phenomena around them, and thus reveal the thoughts and individual perceptions about structure and processes and how they influence life options and outcomes.

Qualitative compliments the weakness of quantification by addressing why and how society and institutions act and react in a particular form and shape than another. Rather than living in a world in which the causes and outcomes are clear and the definitions of success are unproblematic, we live in a world in which causality is unclear and the evaluation of outcomes are ambiguous. In short, a qualitative approach enables us to understand the participant's construction of everyday reality through their experiences, knowledge, interpretation, and agency and how power relations are socially defined. This is a contrast to the assumed reality inherent in survey approach. Qualitative data emphasise the use of words, quotation and pictures.

3.13.1 Interviews

Interviews are no doubt an effective data collecting instrument that unearths deep structures which may be glossed over by surveys. Unstructured interviews have been found to be useful in understanding water-related poverty (Kemp-Benedict et al., 2009) and climate change/variability (Teye et al. 2015). Unstructured interviews are flexible hence researchers "do not follow a system of pre-determined questions" (Kothari 2004). This flexibility exudes a relaxed environment allowing for a more penetrative probing of issues. A total of 9 participants were interviewed; comprising farmers, women, and children. Women and children are essential in this study as they are primarily responsible for fetching water for household consumption. Again, patriarchal societal structures in the study exacerbate their vulnerability to water-related insecurities and risks. Studying such a group allows for a deeper understanding of vulnerability as they reveal their experiential stories. This is crucial for policy planning and intervention.

Both interviews sought to understand the water security using water poverty indicators. Kemp-Benedict et al. (2009 p.2) argue that "water poverty emerges when water resources constrain or impact upon people's livelihood options and assets". Poverty, therefore, occurs when there is drought, floods, limited access, expense, water quality, or water-borne disease or of various combination of the mentioned.

3.13.2 Focus group discussion

Understanding how different people hold differing views on a single topic in relation to the nexus of climate change/variability and water insecurity is crucial since long-term adaptation policy intervention is the goal of this research. Hence, focus group discussion is indispensable in this research. In all, four focus group discussions were held in Worikambo and Kolmasug. These two communities have distinct and contrasting experiences with floods and droughts. Kolmasug in particular due to its topography and soils is prone to floods yet drought is severe due to poor soils and ephemeral stream. Worikambo on the other hand has a dam but it has been shrinking in size hence putting dry season farming in jeopardy. In each community, two separate female only and male only focus group discussion were held. Patrimonial structures may not freely allow women to actively express themselves in the presence of men. Again, women's uses of water vary from that of men. The focus of the discussion is designed to elicit information livelihoods pattern, views on climate change/variability, observed changes and impact on water security, and how these changes impact on livelihoods. It also sought to understand their perceptions of vulnerability and adaptation.

The use of this technique has some practical advantages. First, the use of this technique enables the study of "ways in which individuals collectively make sense of a phenomenon and construct meanings around it" (Bryman, 2012, p. 504). Such collective construction of reality through face-to-face encounters enables a deeper understanding of how micro-level interactions shape meaning among individuals to define structures in a society. Carter and Fuller (2015) identify this unending cycle of creation and recreation of social reality as symbolic interactionism. Apart from creating a relaxed environment that invites participants to open up, focus group discussions deepen our understanding of how people respond to each other's views and build a group view from a natural perspective. It also complements individual interview by making a clear understanding of social phenomena and processes that are not undertaken by individuals in isolation from each other. Example of sharing of water during dry season farming, dealing with flooding at the community level. Table 2 provides a summary of the qualitative data collection process.

Table 7: Summary of qualitative data collection

Qualitative research tool	Number
In-depth interviews:	
Men	4
Women	4
Focus group discussion:	
Men only	2
Women only	2
Field observation	Researcher
Field notes	Researcher

Source*:* Field data

3.13.3 Field observations

In the complex and dynamic process of data production in research, (Baxter & Jack, 2008) observes that, the researcher is an active participant in the research process. As a result, participant observation remains a useful mode for the researcher to make useful observations about a given research problem whilst he/she relates with the people and surroundings of the research setting. It entails paying very close attention to, and sometimes getting involved with the everyday activities of the researched (Kothari, 2004).. This technique was used to gain first-hand information on the type of crops grown by smallholder farmers and insights into the nature of the farming system in general. The nature of study necessitates also field observation of sources of water, nature of livelihood activities and the physical characteristics of a community and households that make them vulnerable. Compared to other methods of data gathering, field observation is independent of the respondent or participant. Hence, it allows for an unbiased interpretation of reality from the perspective of the researchers. Whereas respondents and participants may hide certain aspects of their lives in their responses, field observation does not rely on respondent's willingness to share. Participant observations also permit me to deliberately immerse myself into the everyday rhythms and routines of farmers and households thus allowing me to understand how they work 'from the inside (Flowerdew & Martin, 2005)(Flowerdew & Martin, 2005).

Observation involved taking extensive notes during interviews and moving around study communities, taking photographs of local water stress issues and sources of water.

Using the observation approach is, therefore, indispensable when the study involves understanding man-physical environment relationship (Flowerdew & Martin, 2005) and geographic inquiry for that matter (Harvey, 2001).

3.14 Data analysis

Quantitative data from the survey was entered into SPSS software for analysis. Within this package, descriptive statistics was used to analyse and describe quantitative data from questionnaires. Frequency tables were used to show the level of popularity of t certain variables such as changes/variability in climate, sources of water in both seasons, type of farming, various uses of water, livelihood ventures, various impact of climate change/variability on water availability, frequency of droughts and floods as well as adaptation and coping strategies. Contingency tables are used to simultaneously analyse two variables and the relationship between the two variables was examined. Cross tabulations were used to display strategies that households adopt against the effectiveness of such strategies in reducing the impact of hazards such as floods and droughts. Similarly, graphs were used to plot the perceived changes against actual climate data from Ghana Meteorological Agency. Correlation and chi square test were used to measure relationships between the variables on the questionnaire.

Qualitative data from interviews and focus group discussions were transcribed and analysed using Nvivo software. Various themes such as the perceptions of climate change, impact on water availability for household and agricultural use, perceived causes of water insecurity, determinants of household vulnerability and adaptation and coping strategies are outlined. Narratives and quotations were used to make emphasis on certain comments and also validate the results of the survey (Kemp-Benedict et al., 2009). Again, life histories were built to enable participants to tell their experiences and meaning of those experiences.

CHAPTER FOUR: THE CHANGES IN CLIMATE AND WATER INSECURITY

4.1 Introduction

This chapter addresses the evidence of changing climate and its relationship with water security in the Sudan Savannah. It presents weather data from the Garu weather station and juxtaposes with responses from the survey. It then validates the results with interviews and focus group discussion transcripts. Long term variations in rainfall and temperature data are used as proxies to establishing evidence of climate change. It further deals with how rising temperatures and declining rainfall and the resultant condition of droughts gives rise to low agricultural production and household water insecurity.

4.2 Nature of changes in the climate of the Sudan Savannah

Climate change and variability experienced grossly by the changes in rainfall trend and temperature regimes. These two elements of climate also directly determine the availability of surface water resources for both household and agricultural use.

4.2.1 Rainfall

Using 1983 as the baseline for comparison, rainfall pattern from the Garu weather station displays an interesting oscillating pattern. The choice of 1983 was informed by two underlying reasons. First, 1983 marked the period of regional meteorological drought that triggered a devastating agricultural drought across the West African region. Hence comparing with post 1983 rainfall pattern is essential to understanding the nature and extent of changes. The second reason is related to establishing climate change and variability within the IPCC frame.

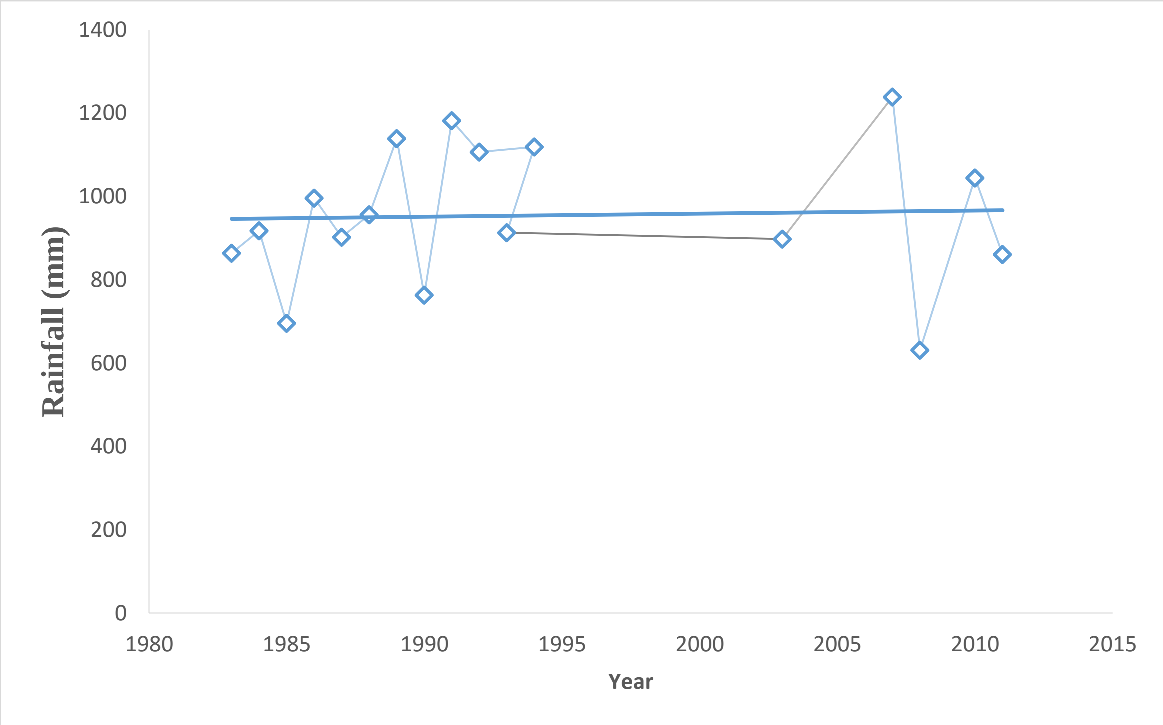


Figure 6: Rainfall in Garu from 1983-2013[2]

Source: Compiled from Ghana Meteorological Agency data sheet

The rainfall data shows an average total annual rainfall of 955mm a year with extremes ranging from 631mm to 1,239mm. A trend analysis shows a slight recovery from the 1983 drought in 1984 and a significant relapse in 1985 rainfall season. This was followed by a string of above 1983 recoveries till 1990 where total annual rainfall was less than 800mm (763.4 mm). The total annual rainfall for 1990 was 54mm more than 1984 while in the 1985 rainfall season experienced 221.8mm drop to 696.2mm. A closer loser look at the 1990 records reveals an interesting detail. The 1990 rainfall season did not only record low annual rainfall but also a significant drop in the number of rainy days (see table 8). While the preceding years (except 1985) had an average of 68 rainy days, 1990 recorded only 46 days of rain. This suggests a meteorological drought and by logical extension water insecurity. In a context where livelihoods depend on agriculture and the natural environment,

[2] There is a ten year gap in rainfall data (1993-2003) because the rain gauge at the Garu weather station was broken and was not replaced until 2003. However, it has been documented (Adger *et al.*, 2003; Yaro, 2013; Teye, Yaro and Bawakyillenuo, 2015) that ordinary people's lived experiences and perceptions compensates for the fussy climate data in the developing world. I would have liked to extend the period of analysis beyond 1983-2013, the lack of accurate rainfall and temperature data made it difficult.

it is not difficult to contemplate agricultural drought and subsequent chain of reactions. As Owusu & Waylen (2009) observe, a significant drop in rainfall in Ghana often reflects in shocks in Gross Domestic Product and general decline in the economy. At a micro community and household level, Hesselberg (2015), Quaye (2008) and Yaro (2004) find that a single bad raining season could plunge just above poor rural households into poverty, seal escape valves for those already in poverty and ultimately retard progress to ending poverty. Post 1990 show a recovery trend with an average of about 280mm more than the 1990 level till it reaches highest record of 1,239mm in the 2007.

The 2007 record rainfall was 284mm above the average of 955mm triggering massive scale flooding thus activating a declaration of state of emergency and appeal for international assistance. The flooding in the Upper East Region, Upper West Region, Northern Region and parts of the Western Region affected 332,600 people and caused the death of 56 people. Some 35,000 houses, 1,500 kilometres of road and thousand hectares of crops have been destroyed (UN Country Team in Ghana, 2007) . . The alternating episodes of droughts and floods and the loss and damages associated therein that makes water security in semi-arid Ghana disconcerting. Floods and droughts do not only occur in alternating years but sometimes within the same year. The double blow of flood and drought in combination with the general economic stagnation (Cooke et al., 2016; Ghana Statistical Service, 2015) in the study area is a potent cocktail that drags household in to poverty. Focus group discussion participants identified alternating floods and droughts as major challenge to the sustainability of livelihoods activities. One discussant's testimony sums up the difficult hydrology in which they find themselves. He recounts:

> *Three years ago there was flood in this community. It washed away our farms, seeds, and destroyed homes. In general, we have experienced more droughts than floods. Every leap year we have better rainfall than the odd years but this year is an exception; it is only this leap year that we have a drought. Every four years we have better rainfall and people have a bumper harvest. We have abundant food in those years, Traders from the south used to come here to buy food but it now vice verse. Indeed times have changed!* Luukud, 27 years, a young farmer Denugu

Table 8: Annual rainfall, divergence from the 1983 rainfall regime, number of rainy days and onset and end of rainy season

Year	Rainfall (mm)	Divergence from 1983 rainfall regime (mm)	Month of onset of rains*	Number of rainy days	End of rainy season
1983	864.1	0	March	62	August
1984	918	53.9	March	66	November
1985	696.2	**-167.9**	March	44	October
1986	995.8	131.7	March	65	November
1987	902.5	38.4	March	67	November
1988	956.1	53.6	March	73	November
1989	1139.3	275.2	March	68	December
1990	763.4	**-100.7**	April	46	November
1991	1181.9	317.8	February	89	October
1992	1106.6	242.5	March	63	November
1993	913.6	49.5	March	68	October
1994	1119	254.9	April	83	November
2003	898	33.9	February	66	October
2007	1239	374.9	April	82	December
2008	631.7	**-232.4**	March	47	October
2010	1044.2	180.1	February	82	November
2011	860.9	**-3.2**	March	62	October

Source: Compiled from Ghana Meteorological Agency data sheet
* The month of first recorded rain in the year

The 2007 extreme was followed by a meteorological drought in 2008 with rainfall plummeting to 631.7mm - 232.4mm. This finding resonates with Brida, Owiyo, & Sokona (2013) in Mozambique that one drought season is succeeded by series of floods and above average precipitation. Unreliable rainfall imposes dire effects on agriculture production and surface water availability for households consequently triggering reactions which may extend into the future. In response to how poor rains manifest in water in security, a headman in Kolmasug narrates;

> *As I said, the rains are just scanty and the few times it rains heavy, it comes with storm. When it rains heavy the ground absorbs the water and you can use the groundwater later. But it barely rains. The few times that it does, the ground dries up in less than three days afterwards. How [then] can the ground absorb enough water for use in the dry season? In times like this, my concern is water for drinking [for household and livestock] not irrigation. Irrigation becomes a luxury.*

The headman’s sentiments clearly underscore the increasing variability of rainfall in the study community. This finding also highlights the intricate link between climate variability, water insecurity and livelihoods choices. In times of scarcity and limited options, households are likely to use water sources that they may not ordinarily use. This could expose households to water-related health risk. From a livelihood perspective, reassigning irrigation water for household water use denies households the opportunity to make engage in dry season gardening which is critical to poverty reduction at the household level. Farmers' experience with climate change and variability is thus not only manifested in poor yields and income but also in household water security. As table 9 shows, rainfall variability and consequent water variability is expressed in the agricultural productivity and translated into low income. This finding further reinforces the link between physical phenomenon such as meteorological drought and its socioecological repercussions. Meteorological droughts are often a precursor for other forms of droughts such as agricultural, hydrological and socioeconomic droughts. The National Oceanic and Atmospheric Administration (NOAA) provides a distinction of the types of droughts. Meteorological drought occurs when precipitation duration and/or intensity is lower-than-normal (NOAA, 2008).. Agricultural drought on the other hand arises when there is scarce soil moisture to meet the crops, livestock and other dry-land agricultural requirements. A hydrological drought refers to deficiencies in the availability of surface and groundwater supplies (NOAA, 2008). Socioeconomic drought sets in when physical water shortages start to impact on health, wellbeing, and quality of life of the people. It also arises when other forms of drought start to affect the supply and demand of the production of goods and services such as water. They occur in a logical sequence with meteorological drought as a precursor to the rest. It can be reasoned that meteorological droughts and near-droughts of 1983, 1985, 1990, 2003, 2008 and 2011 triggered water crisis for both household and agricultural use. To determine whether an agricultural drought occurred, a comparison was made between food production levels and rainfall records. Records from the District Agricultural Office show a dip in food crop production levels in 2011 in response to decline in the rainfall and early cessation of the rainy season (Garu Tempane District Assembly, 2013).

Table 9: Rainfall variability and food production levels in metric tonnes in the Garu-Tempane District

		Crop production in Metric Tonnes			
Year	Total annual rainfall in mm	Maize	Millet	Groundnut	Soya beans
2010	1044.2	2610	6940	4890	1597
2011	860.9	1095	4890	918	1216
Change	-183.3	-1515	-2050	-3972	-381
Percentage change (%)		58	30	26.56	23.9

Source : Compiled from Meteorological data and Garu-Tempane District Assembly, 2013)

Food crop production and by extension agricultural production shows a high correlation with rainfall trend. A small (-3.2mm) decline rainfall in 2011 induced a significant fall in the production of almost all crops (see table 9). For instance, the 2011 drought correlated to a decline in millet (2,050 metric tonnes representing about 30%), maize (1,515 metric tonnes representing 58%) and groundnut (332 metric tonnes translating into nearly 27%). The results reveal causation between rainfall variability and low agro production. The data thus suggest that meteorological drought in the area induces agricultural drought too. When there is crop failure, income failure is an inevitable outcome and with it, food insecurity. With collapsed depleting food stock and limited alternative income options imposed by a wider national and district economic malaise and failure of policy implementation to build irrigation facilities to forestall impact of droughts, household coping strategies could be detrimental. Collapse of household food and muted income in turn compels vulnerable household to adopt coping and survival options.

Boasup's story in Box 1 adequately captures the narrow options that households are stuck with in times of drought. It reveals the complexity of climate-water relations and livelihood outcomes. It also carves a picture of choices that peasant farmers and their households face in limited options. Boasup's story clearly shows how climate change can act in conjunction with pre-existing limited socioeconomic opportunities to produce environmentally-unfriendly coping and adaptation strategies.

Box 1: Links between climate change and water insecurity

Boasup's story: Drying dams crumbling buffers

I am a farmer. In this community, we farm rice, groundnuts, soybeans, okro, maize and millet. We (female farmers) plant okro in the dry season. The men farm onions while we interlace it with *bito*[3]. In the rainy season, we plant maize, millet, vegetables, rice, cowpea, bambara beans, millet, and guinea corn.

Changing climatic pattern: The rainfall pattern has changed. In the past we used to start farming by late March. And it rained regularly in those days throughout the rainy season. But not anymore. Now we start farming in late April and mid- May and unfortunately it rainy season has become shorter. With the late start of the rains, if you don't plant early you will lose your crops. Maize and millet require regular rains to yield better. I planted bambara beans this June but due to poor rains, it has failed completely. There is nothing to harvest. Not even seeds for next season. The rice that we planted wasted in the fields. In the past, we used to have bountiful harvest but not anymore. The rainfall this year and the past four years has been the worse- very irregular and short.

Gender activities: Women farm groundnut and bambara beans here. We, however, have to finish planting our husbands' maize farms before working on our farms- by which time the rains are almost over. Besides, these crops require more water to yield compared to maize or millet. These crops are our (women) main source of independent income. But the poor rains this past half decade is eroding it.

Crumbling buffers: Dry season farming was a buffer against crop failure in the rainy season. We used not to worry so much about crop failures in the past because we could compensate with dry season farming. The river and the swampy lowlands had water. However, for the past three years, the river has dried up completely; it only comes to life in the rainy season. Even with that, it is a pale shadow of itself. Last year, my husband's onion farm was completely wasted because we run out of the water just before it started to flower. This the crucial time when onions need more water.

Negative coping: Poor rains in the rainy season translate to dried rivers in the dry season. It is hard. Men are running to the South [to work as labourers in cocoa plantations and cities in southern Ghana] and leaving us alone with children and our aged in-laws. We are left with no choice but to burn charcoal for survival.

Since the annual values and distribution of rainfall alone are not sufficient to properly show the times when rainfall deficits occur that would affect availability of water to satisfy individual water demands, a further qualitative analysis of monthly rainfall availability is necessary. Figure 9 gives a graphical representation of the distribution of monthly rainfall over the year.

[3] Hibiscus sabdariffa

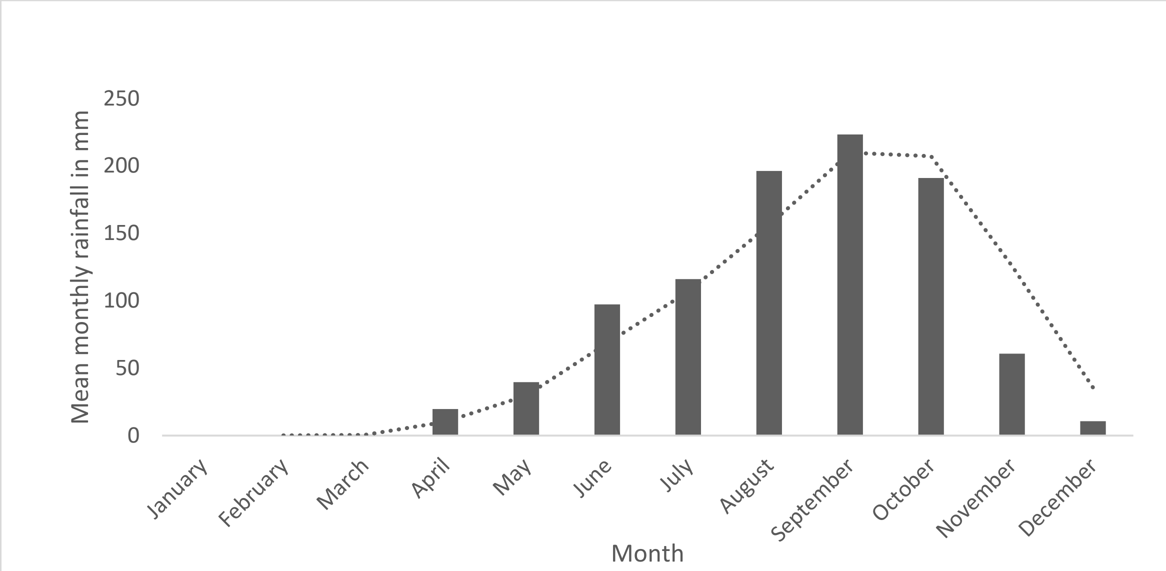


Figure 7: Average monthly distribution of rainfall 1983-2013

Source: Compiled from Ghana Meteorological Agency data sheet

Rainfall is strongly concentrated in certain times of the year with marked dryness pre- and post-concentration period. An annual rhythm is observed with rainfall starting in April and ending ceasing by November as figure 3 shows. From December to April, the station records less than 20mm of rainfall with high temperatures averaging about 38^0C. The period is thus associated with excess evapotranspiration and consequently the study area is exposed to periodic surface water insecurity. In a study of rainfall characteristics in the West African Savannah, Oguntunde (2004) found that about 80% of rainfall is lost to evapotranspiration.. Marked rainfall within year variation could have considerable and sometimes catastrophic effects on water availability and the already precarious food security situation could worsen. Fig. 9 suggests that area experience a prolonged dry season of at least 7 months. Consequently, many of the rivers and stream are ephemeral and subjective to evaporative losses due to the high average temperature of 38^0C. Surface water sources are thus unreliable and insufficient to support agricultural and household activities all-year-round. This puts enormous pressure on groundwater as a key source for sustaining lives and livelihoods. However, recent studies in the Upper East region suggest a declining groundwater level (example Gyau-Boakye & Tumbulto, 2006; Water Research Institute, 2002; Yidana, Banoeng-Yakubo, Aliou, & Akabzaa, 2012).. Two major factors explain the declining groundwater stock. First, the primary rock formation makes groundwater storage capacity limited and recharge more difficult (Obuobie, Diekkrueger, & Reichert, 2016).. The second is related to demographic pressure. As shown in figure 4,about 66 percent (Fig. 4) household got water from a groundwater source (well or borehole). This finding confirms Ghana Statistical Service (2014) survey findings that nearly 72 percent of households in rural parts of the Garu-Tempane district obtain household drinking water from either borehole or well. Figure 10 shows type of sources of water.

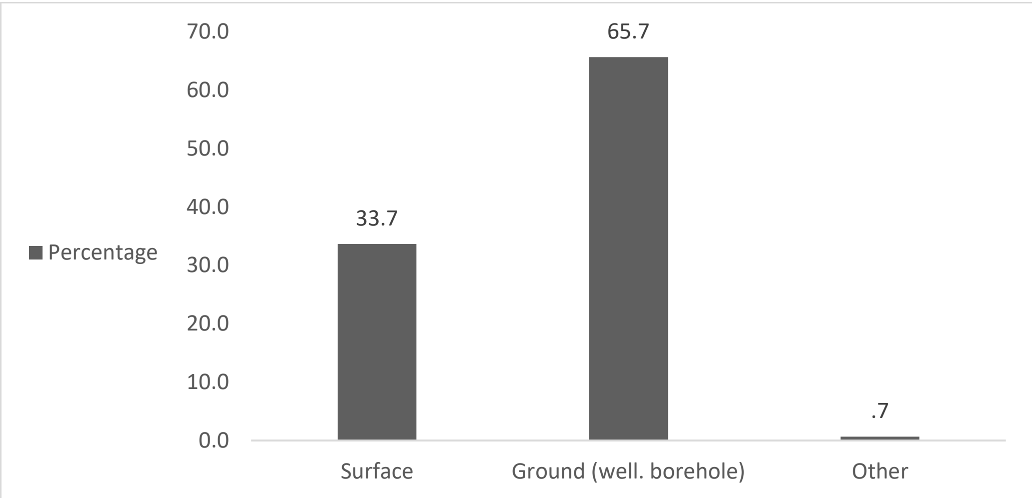


Figure 8: Type of water source

Source: field data

A majority of respondents (61%) also indicated that their main source of water was not available throughout the year with an absolute majority of nearly 96% reporting their main source of water drying up between December and March. Two reasons explain this occurrence. The air mass system imposes a change in the monsoon winds within this period thus offsetting the dry harmattan winds. The dry and fast winds absorb any ambient moisture and thus drying up surface water bodies. The second reason has to do with the temperature characteristics within the period. Daily average temperature within the period is about 39^0C. This increases to about 41^0C by March/April. Such high temperature is laden with high evaporative effect on any exposed surface water. Dried surface water source in turn puts pressure on groundwater sources which are also experience low recharge levels due to the variation in climate.

Wide swings in rainfall variability as is likely influence groundwater recharge. For instance in years of low rainfall, wells may run dry inducing a series collapse in livelihood activities and eventual plunge into poverty. Dried dugouts could compromise dry season farming to supplement food in the rainy season. This may compel a vulnerable household to consume the seeds intended for the following season. This may ultimately compel these individuals in this household into undesirable migration with its attendant challenges.

Rainfall variability in the area shows no clear pattern of change. It oscillates between increasing occurrence of droughts and floods especially since 1985. Climate scenarios fail to agree on the nature of precipitation over the northern Savannah. This ensuing debate is reflected on the results various studies. For instance (Owusu & Waylen, 2009; Tachie-Obeng, Hewitson, Gyasi, Abekoe, & Owusu, 2014) observe an overall increase in rainfall while others (Eguavoen, 2013; EPA, 2000; Oguntunde, 2004) contend there is a decrease and project further decreases. In either scenario, the long-term and immediate ramifications are dire. Increased in flood frequency and intensity could potentially displace households and increase sediment erosion and thus increase siltation in dams. On the other hand, droughts could lead to a more precarious water scarcity. Thus in both scenarios, Garu-Tempane is likely to experience a decline in water security with its lateral implications on food and income security and hence poverty reduction. . The implications on lives and agrarian livelihoods will be tragic. This calls into focus the urgent need for productive management of existing water resources in order to build resilience in the face of climate change.

Besides rainfall, another important element of climate that has profound impact on water security is temperature. Increased rainfall variability increases the risk of crop failure and consequent food insecurity and thus deepens rural vulnerability to poverty.

4.2.2 Temperature

Temperature plays an important role in determining water availability in arid and semi-arid regions. It shapes both supply and demand for water. Temperature affects water supply through its latent power of evaporation especially in the dry season. High temperature affects demand as households and livestock require more water for cooling and digesting dry forage. The analysis in this section is based on annual maximum temperature in the study areea.

Meteorological observation of temperature in Garu from 1983 to 2013 shows an interesting oscillation with ramifications for water availability. For purposes of analysis in this thesis, mean annual maximum temperatures are considered. Using 1983 as the reference line, the data unravels an interesting correlation between drought years and high maximum temperatures. For every drought year, temperature rises slightly higher than the previous year. For instance, the drought years of 1990, 2008 and 2011 all experience slightly higher temperatures than the immediate preceding year.

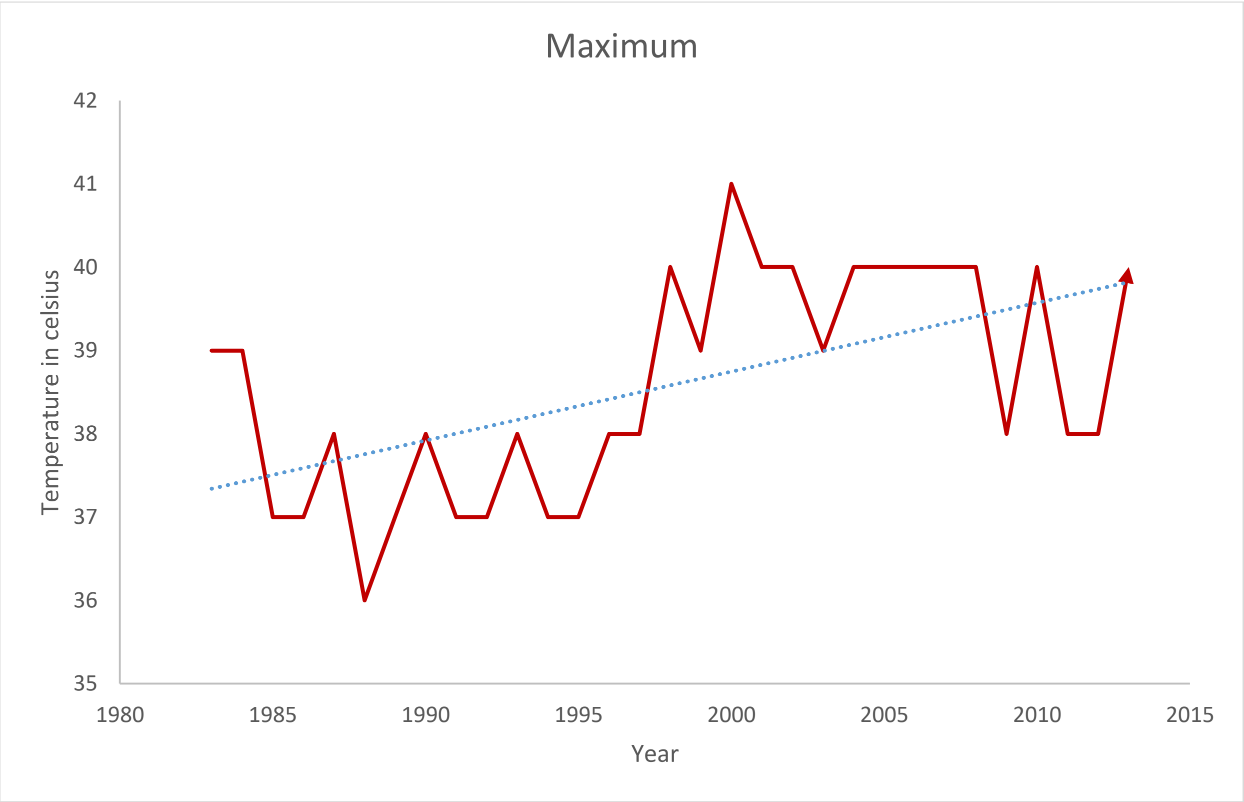


Figure 9: Actual temperature changes in Garu

Generally, temperature post 1983 oscillates in a trough rising slightly in 1990, 1993 before falling till 1995. The year 1997 marks a radical turn. Temperatures for the first time rise beyond the 1983 level and peaks in 2000 at a record of 41^0C as the yearly average maximum temperature. This makes the year 2000, the warmest year in Garu.

The pattern of temperature change between 1983-97 and 1998-2013 as shown in Figure 5 reveals a 2˚C rise in temperature. It appears that the above 1983 levels seems to be the new normal six successive years recording an average of 40^0C. This trend corresponds with observed warming global temperatures (Bates et al., 2008a; IPCC, 2013; Riede et al., 2016). The shift coincides with an escalation in the severity of drought years. Both 1990 and 2008 drought exhibits very high divergence from the 1983 level of rainfall records. Statistically-observed meteorological changes translate into crop failures thus undermining food and income securities. Such high climate variability will adversely affect agricultural production in Garu and severely challenge the livelihood of rural communities, already undermined by a range of economic and development malaise.

Respondents from the survey also reported experiencing high temperatures over the last two decades. Table 10 provides details of response.

Table 10: Observed temperature changes in the last twenty years

Temperature variations/changes		
Perceived long-term changes in the mean temperature over the past 20 years		
Response	Frequency	Percent
Yes	284	95.6
No	13	4.4
Changes in the number of hot days		
Increased	281	94.6
Decreased	14	4.7
Effects of temperature changes on water availability		
Dried up	284	95.6
Decrease	13	4.4
Total	297	100.0

4.3 The state of water insecurity in Garu

The water security signature in the area is characterised by limited surface water availability (Map 1). Groundwater sources mainly boreholes and wells are thus the main reliable sources of water for households and livestock. In all of the study communities, especially in Kolmasug and Bugwia, seasonal shortages of water, and especially of potable water, are chronic (see table 9). The seasonal distribution of precipitation is such that many streams and springs fail in the dry season. Moreover, the yield of most boreholes and shallow dug wells declines sharply during the dry season, and many wells go dry. Consequently, water security calendar appears to be emphatic with access and availability severely constrained. Livelihood activities are carved around water, hence the wellbeing of especially households are squarely determined by the water availability and accessibility for household and agriculture. This assertion is further given credence in the following quote from Danze community opinion leader an in-depth interview in Worikambo;

> *When the water bodies dry up, people have to go far to get water. Drinking water becomes scarce. It affects household water consumption, not a particular household but generally-everyone feels it. When there is no water there is no farming and with no farming, there is no money and poverty will devour us. You can't live a healthy life without water…the water resources in this area are not good on the grounds that we use water from the stream, and well. These dry up in the dry season. It temperatures these days are just too high. We notice it in the number of dead pigs in the dry season. It is only recently that the district assembly sunk a borehole for us which is yet to be fitted with a pump. So people in this area suffer greatly. We had guinea worm cases in the past. The only well here runs out of water in the course of the year, especially in March and April the weather is very hot.* Mr. Danze, 69 years, Worikambo

The seasonality of access and availability of water in the above quotation typifies the situation in the study area. Households leaving farther away would not only have to walk longer distances but spend more time in queues at boreholes. The months March and April also coincidentally the hottest months with high evapotranspiration rate. Evidence from literature suggests high temperatures and evapo-transpiration induce increased demand for water by both humans and livestock, due to the lesser water content of forage, and domestic bathing (Dessalegn et al., 2013). The result also highlights the fact that where there are no groundwater sources, people are compelled to travel longer distance beyond their *fon.* Seasonality of water insecurity emerged clearly as a key dimension of local water insecurity.

Table 11: Water sources and seasonality of use in a year

	Rainy season			Dry season		
Name of Community	Household water source	Livestock water source	Irrigation	Household water source	Livestock water source	Irrigation
Worikambo (Guuni/ Boko)	Boreholes, wells, rain	Dam, swamp, dugouts	N/A	Boreholes, wells	Dam, swamp, dugouts	Dam
Bugwia (Dabila)	Well, borehole, rain	Dugouts, rain	N/A	Well, borehole	Dugouts,	N/A
Denugu/Danvorga	Boreholes, wells, Rain	Dam, swamp, dugouts, Rain	N/A	Boreholes, wells	Dam, swamp, dugouts,	Dam
Kolmasug	Boreholes, wells, rain	River, dugouts	N/A	Boreholes	River, Dugouts	Dugouts

Source: Compiled from focus group discussions in study communities

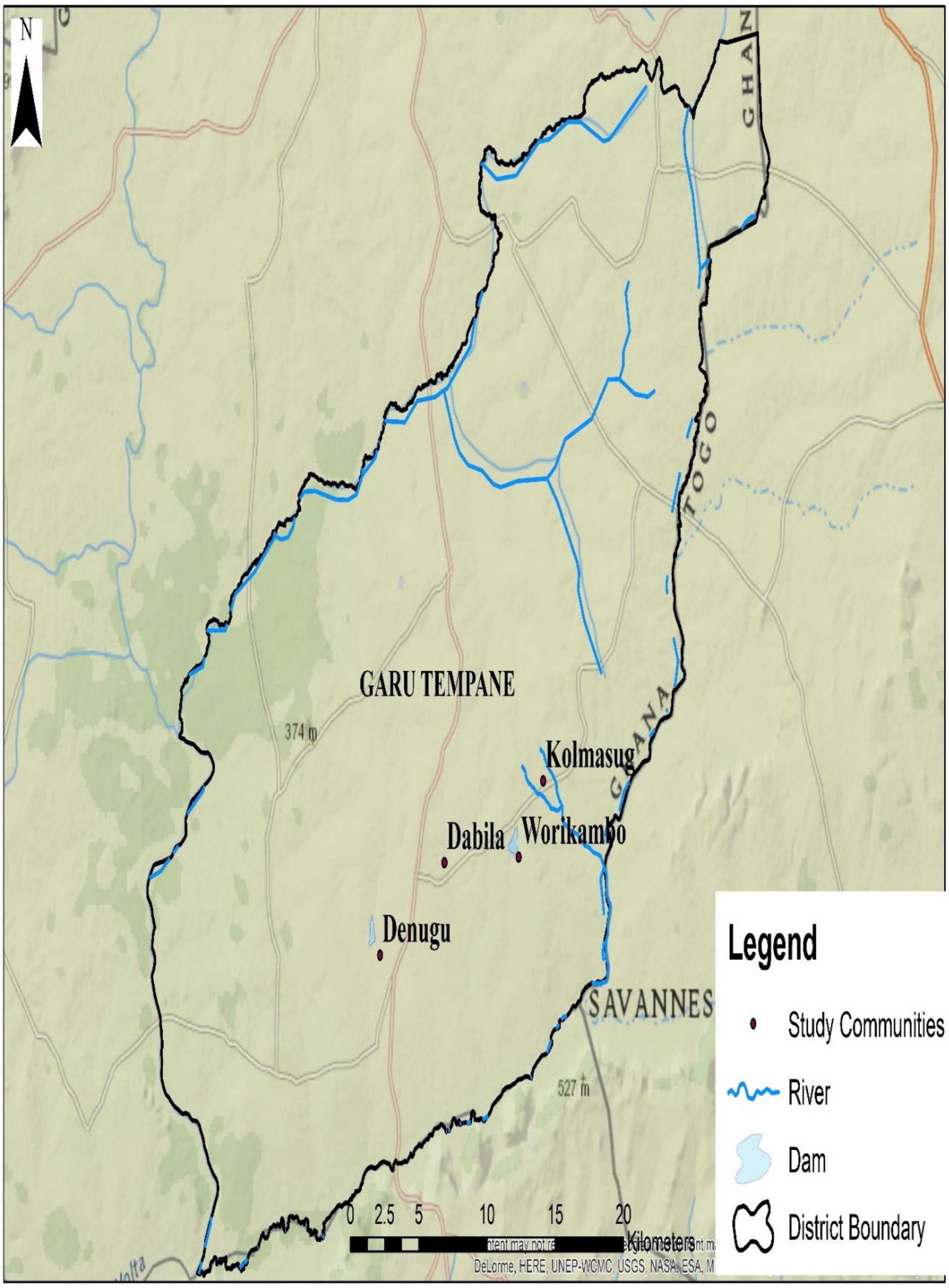
A closer analysis of Mr. Danze's assertion reveals how intricate and complex relationships between water security and livelihoods activities are. It brings to the fore the weaknesses of uni-perception, uni-disciplinary and aggregational approach to water insecurity studies in literature. It positions water not just a commodity but as a natural resource whose value permeates all aspects of rural live and calls to focus the multisectoral linkages and multiple uses of water. Drawing on the broader literature, this finding exposes the weakness of the reductionist approach often favoured by policy makers and highlights the need for a more nuanced approach that incorporates that Boelens, Hoogesteger, Swyngedouw, Vos, & Wester (2016) call the "socionature" of water security. The finding supports Boelens et al.(2016) calls assertion that water security should be analysed against the lived experiences of people. The quotation also highlights the fact that water does not just flow through landscapes but also through lived spaces and livelihood activities and thus shapes livelihood outcomes in ways and manner that the reductionist approach fails to recognise.

The state of water insecurity in non-networked communities such as the study community is largely dependent on the availability of water resources. With barely 6% of the district's rural population having access to piped water connection (Ghana Statistical Service, 2014), the overwhelming majority of households have to leave their homes to fetch water for both drinking and other household use from either surface or groundwater sources. Consequently, household water sources are subject to variations depending on climatic conditions in a particular year as Table 6 shows.

The proceeding discussions elaborate on the determinants of water insecurity taking into cognisance meso-level structures and micro level household characteristic that predisposes people to water insecurity.

Map 1 displays the water resource available in each of the study communities. Denugu and Worikambo have multipurpose dams. However, only the Worikambo Dam has been fitted with concrete irrigation canal.

Map 1: Map of surface water resource in the study communities



Assessing household water insecurity in Garu

Several determinants of water insecurity have been identified in the literature (Grey & Sadoff, 2007; GWP, 2014; Sadoff et al., 2015; Schultz & Uhlenbrook, 2007; UN-Water, 2013). For the purposes of this thesis, a household is water secure when it has reliable access to water in sufficient quantity and of acceptable quality to meet its basic needs at all times including times of climate variability. Three measureable indicators are used to assess household water security; accessibility, reliability and quality. For each indicator, there are sub indicators that are used to assess intra-household security. Figure 13 displays the conceptual map of indicator that was used to assess household water insecurity. Besides these three determinants, spatial disparity in water resource endowment constitutes the primary underlying determinants of insecurity although wealth and social connections mediated the extent of the insecurity.

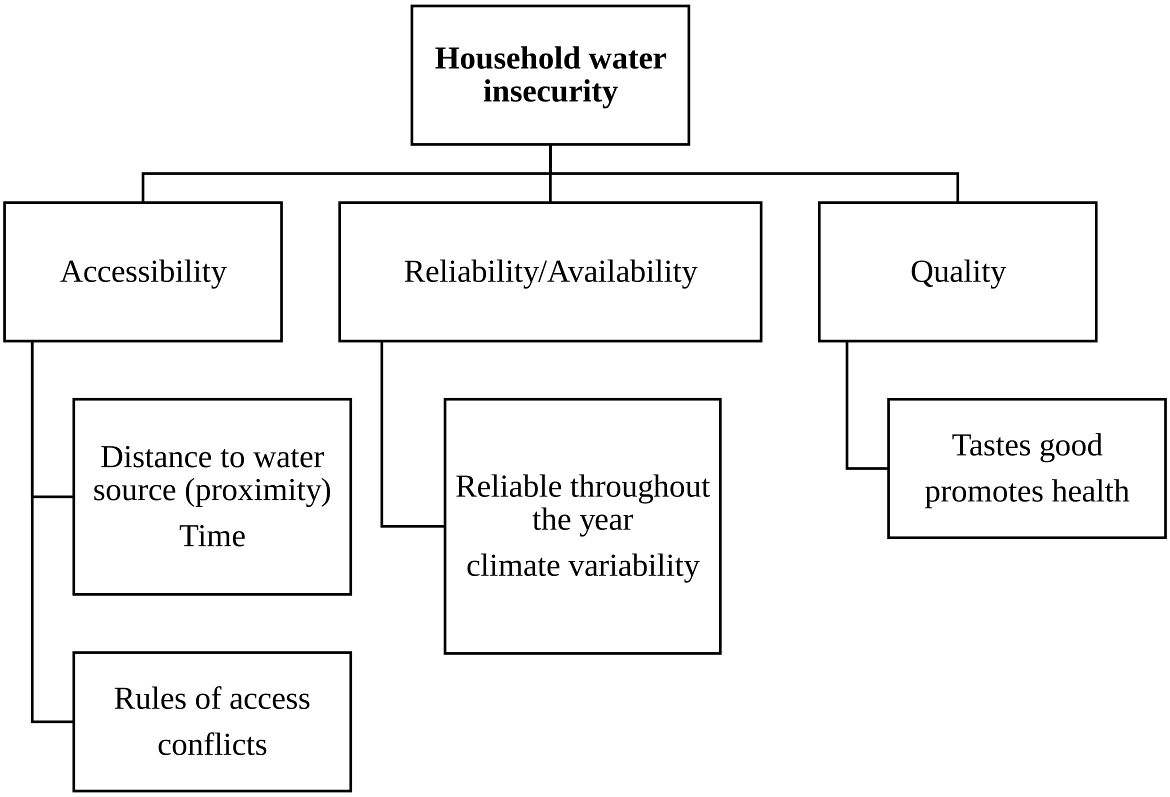


Figure 10: Dimensions of household water security
Source: Author's construct

4.3.1 Accessibility

Accessibility is a key indicator of water security. The time spent and rules governing who have access to water shape accessibility. Water availability does not automatically translate to water accessibility. The ability to acquire water is a function of labour and time. The security of access is hence assured when households are able to command sufficient amounts of these factors to acquire enough water to meet household needs. Nearly 80 percent households reported spending at least thirty minutes to fetch water in the dry season including time spent in queuing. This could entail traveling beyond the immediate *fon* to collect water. According to minimum international humanitarian standards on access to water as advocated by the SPHERE manual (The Sphere Project, 2011) and United Nations (UN-Water, 2013a; UNICEF/WHO, 2011), households are water insecure if they travel beyond 200 meters and queuing time of 30 minutes maximum. It thus suggest that communities hardly meeting the minimum water security in the dry season.

A significant forty three percent spent at least two hours on a roundtrip in the dry season to fetch water. More than twice the number of women (66) spent at least three hours a day compared to men (31). In terms of spatial distribution of time spent on water collection, about 19% more households in Bugwia spent three hours compared to the average household in Worikambo, Denugu and Kolmasug. This is suggestive of a sparse spatial distribution of water points in the Bugwia. Field observations and interviews with women revealed that waiting time at the water point ranges from zero waiting in the afternoon to up to one hour in the morning and late afternoon-evening. Figure 14 shows the time spent on round trip.

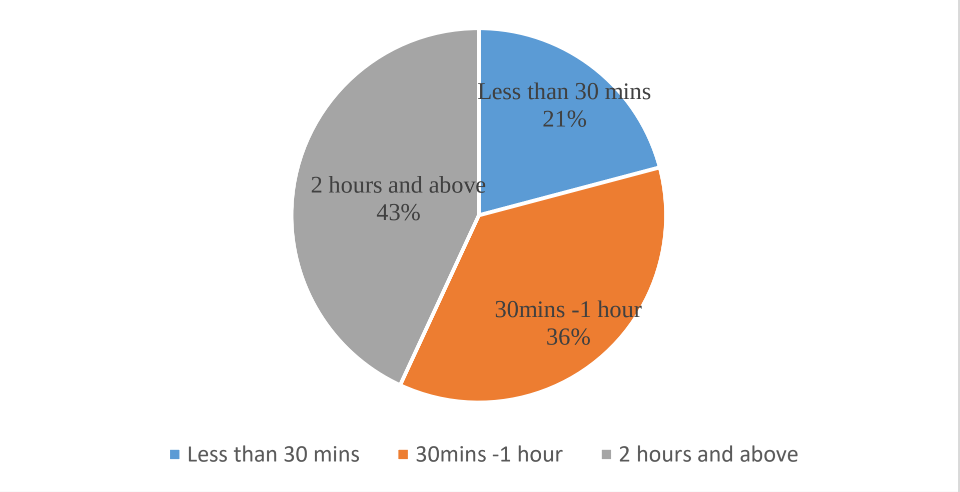


Figure 11: Time spent on a round-trip
Source: Field data

According to the United Nations, a household is considered water insecure if the distance and time spent in waiting at the water source exceeds thirty minutes. Long walking times could limit the volume of water collected by households and consequently impair the use of water for sanitation services and hygiene behaviour including handwashing with potential health hazards. Long distance and time spent will encourage households to store water for long. Longer storage time of drinking water increases the chances of microbial contamination. Longer hours spent in search for water could also limit quality time with family and other sociological needs to the family. Again, time spent on water collections concomitantly reduces available time for income-generating activities which could contribute towards poverty reduction.

Besides time and distance dimension of access, conflicts and rules of access also determine access security. Interviews with women revealed that water points are hotspots for conflicts. Most women recounted getting into arguments and getting angry with someone on many occasions especially between December and April when pressure on boreholes is at its peak.

As one man succinctly puts in a focus group discussion;

> *The river is dried up. Nothing is in there. We often quarrel with our wives because we water our animals from the household water they* (women) *fetch. The troubles that (lack of) water brings to the household are enormous.* Akuka, in a focus group discussion (Kolmasug)

These claims were corroborated by the survey results. Conflicts associated with access to water also emerged as one of main outcomes of water insecurity. About 60% of respondents felt that water has caused conflicts and disagreements.

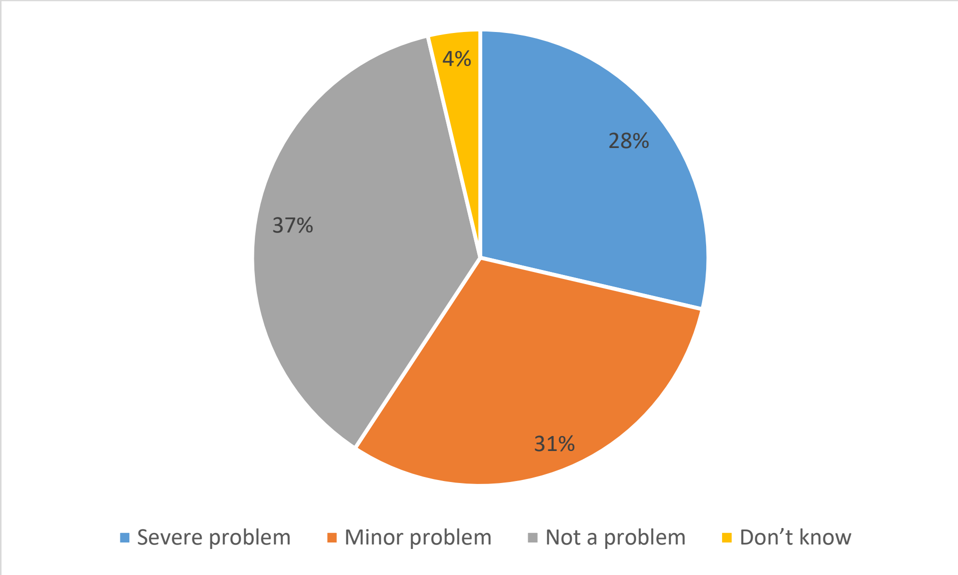


Figure 12: Perceived conflicts associated with water access

Conflicts over water resource could become bedrock for other forms of tensions and thus threaten communal harmony and progress .Access to land at the dam for dry season farming revealed an interesting but unsurprising pattern. Accessibility to land closest to the dam sites in both Denugu and Worikambo was shaped by social links and connections with the village chief and or royal line. The pattern has semblance of the von Thunen's land use model. The land immediately by the dam was exclusively dominated by household with direct links with the ruling clans in both villages with the periphery assigned to other clans. Figure 16 gives a pictorial illustration of this observation.

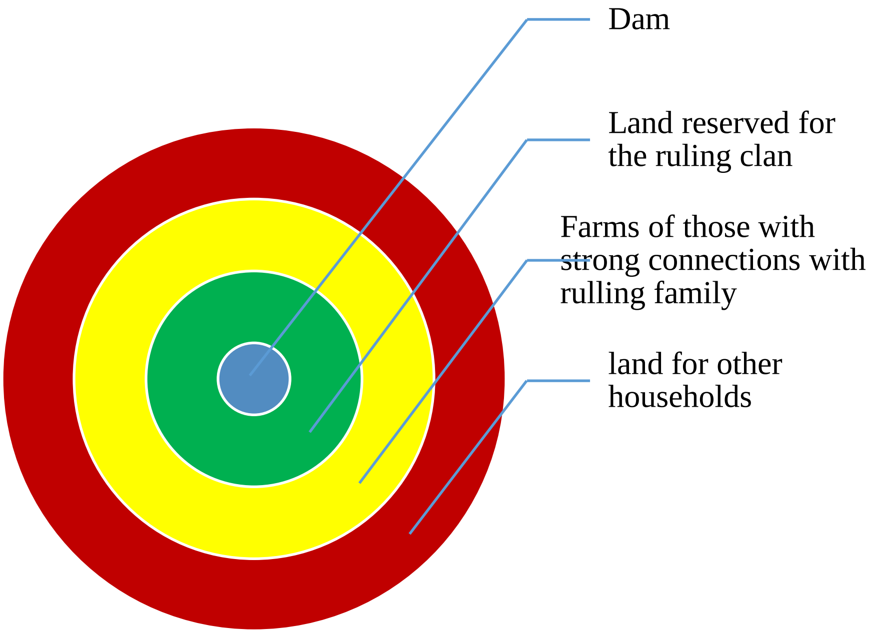
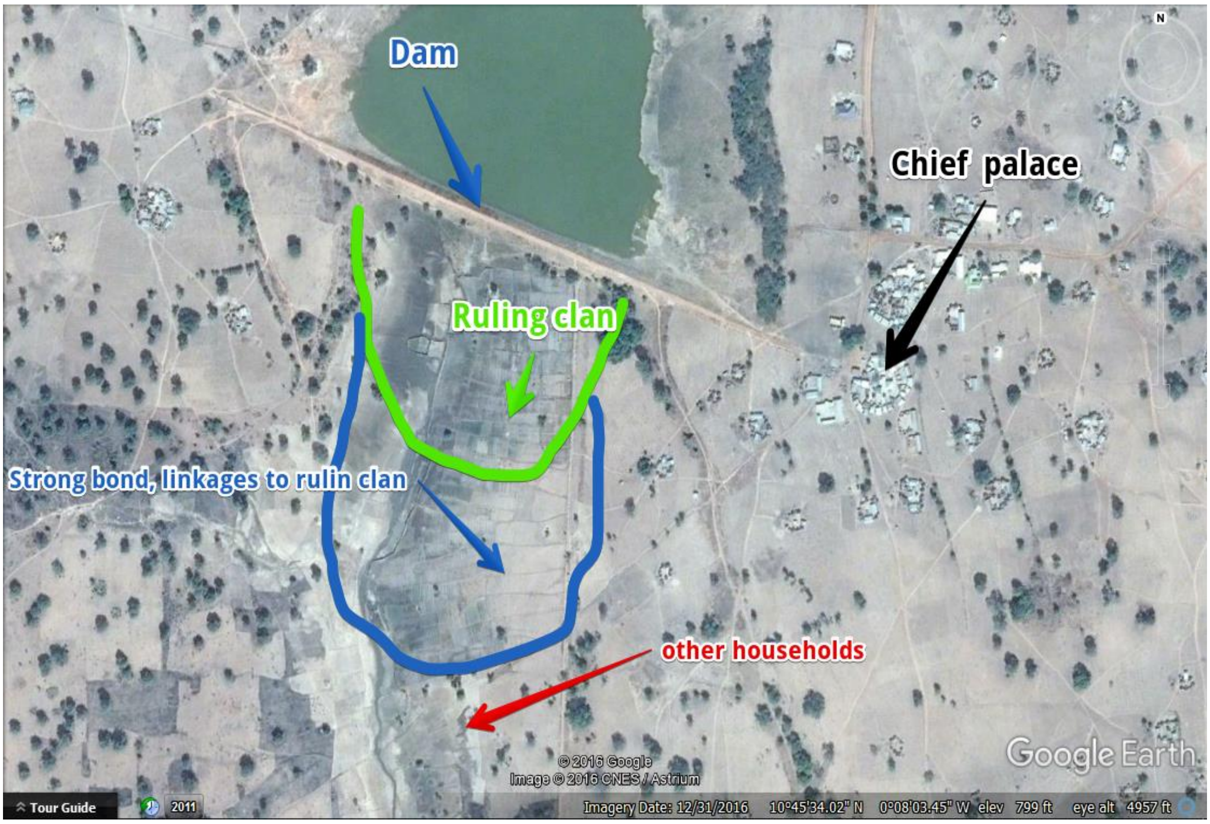


Figure 13: Spatial distribution of access to land at dam sites

Source: Author's construct

Such socially-determined rules of access exclude the poor and most vulnerable in society. It denies vulnerable households of the opportunity to engage in income-generating activities and to climb the ladder out of poverty. Since the dam uses gravity to pump water into the canal, land closest to have access to water even when the dam is at its lowest. Farms closest are thus more likely to get sufficient water before the valve is closed each day. Those at the fringes are thus inadvertently sacrificed. Survey data reveals that about 42 % of households believed that social and economic status played an important role in determining access to water. This finding is indicative of the underlying forces that shape security of access. It moves the securitisation discourse from the physical realm to the sociocultural and political realm.

It highlights the intractable role of existing social mechanism, rules sets, bonds and linkages in determining water security outcomes. As Start & Johnson (2004) observes that a household or individual's command over resource may vary as determined by one's capabilities (social capital) and the 'excludability' of the resource, and willingness to invest in a particular social rule. From a political economy standpoint, individuals with status and wealth tend to have access to irrigable land in Worikambo. Thus, the contextual structural forces of the community promotes resilience accumulation for the top ruling class while eroding and perpetuating vulnerabilities of the lowly and less connected households. Figure 5 is a satellite image of Worikambo displaying the spatial configuration of access to land at the irrigation site.

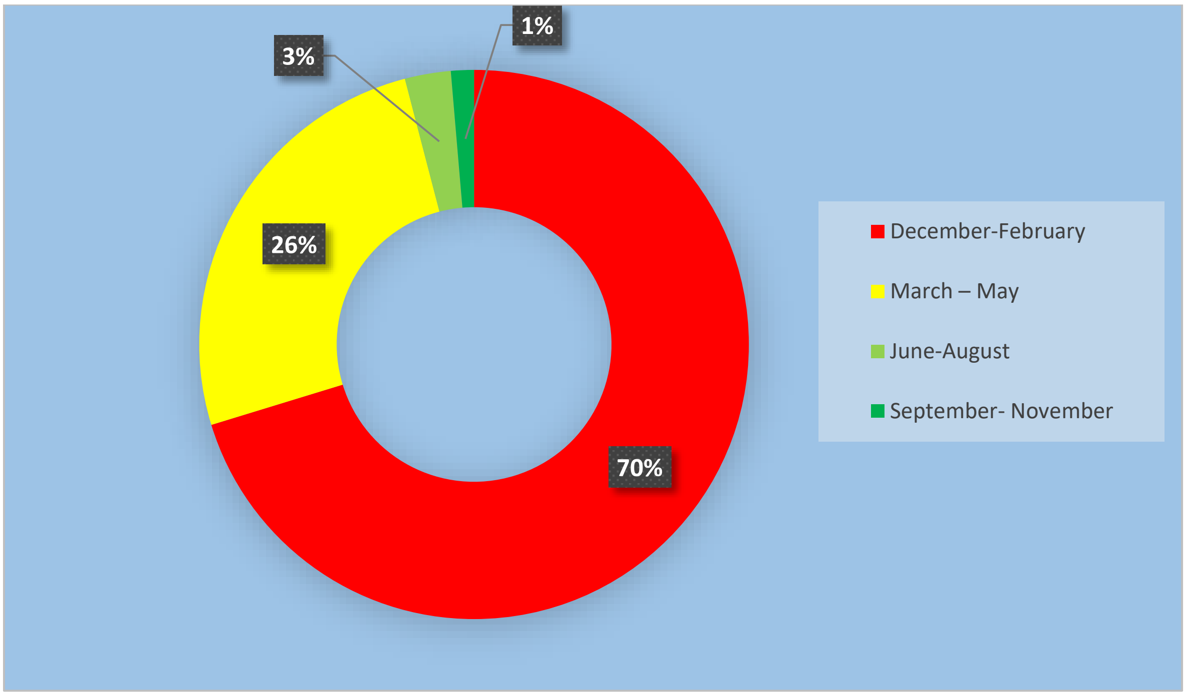


Map 2: Satellite image of the spatial configuration of access to irrigable land

Source: Google Earth

4.3.2 Temporal dimension of water insecurity-reliability

Reliability of water is crucial and directly related to sustainability of water resources. Reliability implies availability of water from a water source throughout the year. A household is therefore water insecure if the source of water is not available throughout the year. An overwhelming majority (95%) of households held that water availability in their community was a function of season. Overall, 40% of respondents held that their main source of water was not available throughout the year.



Red – most insecure months Yellow-relative scarcity Greenish-least scarcity Green- No scarcity

Figure 14: Water security calendar

Source: Field data

Inter and intra annual variability of rainfall compromises water security at certain times of the year. From the figure above, these times coincide with dry season. It is therefore suggestive that water availability for households is seasonally unreliable. Households are thus compelled to spend more time in search for water to the detriment of other productive ventures. The story of Tiesema summarises the multiple dimensions of water insecurity and its latent power to offset other forms of insecurity. It shows the fluid adaptation and coping strategies that households adopt in dealing with the water quandary.

Box 2: Tiesema's multiple dimension of water insecurity

Tiesema lives in a small *fon* in Worikambo called Swavuuse with her five children. Located near the border with the Republic of Togo, her village does not lay any close to a road and is difficult to reach. The district capital is about forty-five minutes' walk plus an hour and a half drive away.

Her typical day starts at 5 am when she prepares breakfast of Tou Zaafi or heats leftovers for the family. In the past, she would have headed out to her husband's garden in the dry season when the river and swamp had water. But for the last three to five years, she engages in charcoal burning in the dry season as a substitute source of family income. She leaves her youngest daughter Comfort with her 70-year old mother-in-law who lives with them since Comfort is too young to make the 17-kilometer journey to the nearest school.

She brews *pito*[4] to supplement the family's earnings from the main farm and charcoal burning activity. However, she has to wait forthnightly for her turn to since other women too brew. She makes shea butter in between the turns but for the past two months, she has neither brewed pito nor made shea butter. The water in the river has run low and the borehole is far (about one hand half hours round trip) and tedious to pump. She fears that the declining trend of the rain may perpetually take away her source of income in 9-month long dry season.

Her husband left for Kumasi (Ghana's second largest city in the south) because he could no longer farm vegetables, water lemon and onions in the dry season as he used to. Tiesema is left alone to fend for the family. The deteriorating health of her 80-year-old father-in-law is draining both her meagre savings and the sporadic remittances she receives from the husband.
She always feel exhausted each night because she has to fetch water for the entire family. Though she has two girls; Lamisi and Comfort, it is only Lamisi who helps in making the thirty-minute round trip to the borehole if the borehole is not congested. But Lamisi is too young to go more than three trips. The boys play football and tend the animals. With no husband and donkey to help, Tiesema fears she may have to endure this stress at the expense of her health.

Her hope is that her children will rise higher on the educational ladder and get a decent jobs so that they will not have to live the way she is living now. "The rains and land cannot be trusted" she cautions. She fears agriculture is a sure bet for poverty. She hopes that a dam is built to store water for her village. A dam means a reliable source of water for farming and brewing pito. It also means her husband would not have to migrate seasonally. Something she longs for.

Drawing from the above life history, household water security is a function of multiple disadvantages. Composition of and intra household gender dynamics is critical in determining access and availability. This suggests that community level water security does not automatically translate to household level security. From Tiesema experience human capital example labour for water collection proves crucial to determining access and consequently the quantity of water available at the household level. Household with a more diversified composition and animal power

[4]Pito is a local traditionally brewed alcoholic beverage in some parts of West Africa including Ghana. It is produced mainly from the grains of guinea corn (*Sorghum vulgare* and *Sorghum bicolor)* and/or millet, see Duodu et al., 2012, p 1

(such as donkeys) for transportation may generally not have access and availability constraints, make fewer trips and save more time for other livelihoods activities.

Climate change is no doubt a major cause of water insecurity in Garu-Tempane as the finding above depicts. However, non-climatic factors such poor institutional capacity, low investments in water infrastructure for treatment, storage and distributions are also recognised in literature as causes of water insecurity.

4.4 Local notions of water security in the context of the literature

The effects of water insecurity at the household level are crucial for socioeconomic development and a healthy population. However, there is often a gap between water researchers and local people view as water (in) security. If effective steps are to be taken to combat water insecurity it is imperative to adopt a much more meaningful for concept of household drinking water (in) security that narrows or eliminates this gap. The Ghana national policy views water security from a perspective similar to the UN water perspective. The UN describes water security as "capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability" (UN-Water, 2013b, p. 13). Hope, et al., (2012) and others underlines this view but proceeds to incorporate "risks" in view of droughts and floods. While these definitions often appeal to policy makers, a local experiential notion of water insecurity takes a different meaning.

One woman describes what it means to be water secure;

> *I am concerned about getting water that is close to me or nearby without walking to another fon. I shouldn't struggle with someone to get water…everyone should have peace of mind so that we live peacefully with the men (our husbands)… once my children do not fall sick I am ok.*

A focus group discussant also observed that;

We often quarrel with our wives because we water our animals from the household water. The troubles that (lack) water brings to the household; lt is enormous.

Another discussant believes;

Water should be neat. Once it is neat, I have no problem.

A third participant gives a scale of priorities when it comes to water security;

As for me, I consider water to drink first. Then farm and give to livestock. For me these three things come to mind. Can you live without water? So drinking water for human beings than anything else.

The finding above reveals the multiple and varied understanding of water security reflecting multiple uses and interests. The above quotations put forward the dimensions of access, quality and quantity which are often captured in prevailing notions water security in the literature. It also brings to the fore a dimension which is often not emphasised in literature. Water security with emotional distress manifested in fear, tensions and uncertainty (Contention and competition with someone either inside the community or outside with respect to access and use of water resource). These notions support the view that policy interventions must consider existing notions of insecurity rather than depend on views that are exogenous to local communities in combating water insecurity.

4.5. Effects of emerging water insecurity on agriculture

Climate change has profound impact in the study area because it is largely dependent on rain-fed agriculture and low incomes coupled with a fragile environmental have constrained adaptive capacity. Observed rising temperature (figure 5) coupled with rising potential evapotranspiration rates and declining rainfalls conspire to increase the severity, frequency and duration of droughts. The FAO (FAO, 2011) proclaims that rise in temperature by 2 ^{0}C induces a 5% decline in cereal production while ground flowering significantly declines when temperature exceeds the 35^{0}C threshold.

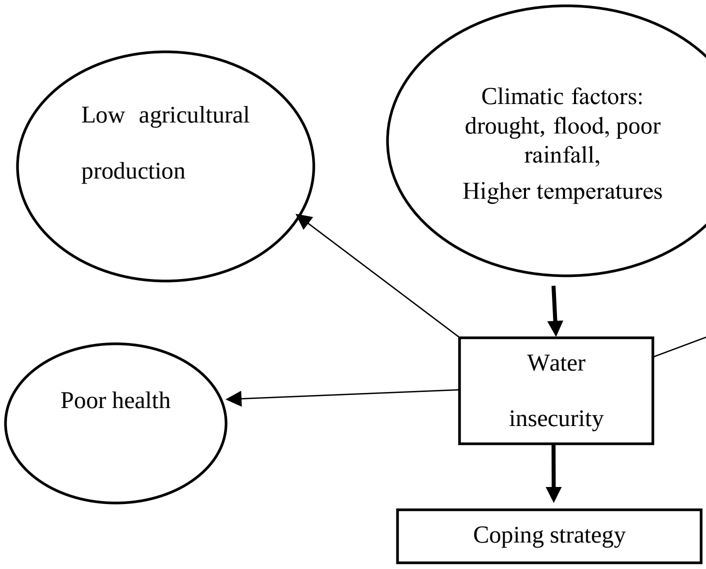
Table 10 outlays farmers' experiences with drought and crop failure in the past thirty years. Respondents in the communities surveyed had an extensive experience with drought and its attendant consequences. A cross-tabulation of community and perception on the frequency of the occurrence of drought reveals that about 70% of farmers had experienced drought in the past thirty years and that the frequency of occurrence has increased. A more nuanced community level analysis reveals that differences in experiences of drought. Nearly three out of four farmers in both Kolmasug and Bugwia perceived drought to be increasing compared to about half of their counterparts in Worikambo. The variations in experiences reflect the community resource endowments and thus the varying adaptive capacity imposed by the differences in entitlements. Worikambo has a dam and farmers are thus able to engage in dry season farming and gardening to cater for drought in the raining season. Dry season gardening could thus be a buffer to poor rains in the main farming season. Kolmasug and Bugwia on the other hand do not have dams except for an ephemeral river that quickly dries with the onset of the rainy season.

Table 11: Drought perceptions and effects on sources of water

Occurrence of droughts over the past 30 years		
Perception	Frequency	Percentage %
Increasing	199	67.9
Decreasing	74	25.3
Remained the same	8	2.7
Don't know	12	4.1
Total	293	100.0
Effects droughts on sources of water		
Crop failure	185	63.1
Drying up of water source	104	35.5
Trees dying	2	.7
Other	2	.7
Total	293	100.0

When farmers were interviewed about the effects of droughts, more than half of the households (63%) listed crop failure as the major outcome. Drought and poor distribution of rainfall and high temperature cause poor yields by reducing the amount of organic matter in the soil, raining out soil nutrients or limiting the accessibility to soil nutrients during critical stages of plant growth. Another 35% of reported their source of water for farming drying up due to droughts. This result reveals how drought-triggered water insecurity could lead to multiple pressures and collapse of livelihood options in rain-fed dependent communities.

Figure 16: A conceptual map of farmer perception of climate variability and water security



Source: Constructed during focus groups in Kolmasug

In general, farmers noticed variability in climate relating to the occurrence of extreme events, such as flood and drought, and the distribution of rainfall, including dry spells and onset of rainfall. Respondents opined that the frequencies of drought and floods have increased over the past 30 years. This is also in line with the global and regional level observations (ISDR, 2008, 2015b; Riede et al., 2016) stating that occurrences of floods and drought have increased substantially in the 2000s compared to the 50 years ago. Moreover, at over 90% of households reported more frequent long breaks (lasting between two to three weeks) in rains during the rainy season breaks and late onset of rainfall. Farmers also observed a shortening of the rainfall growing season.

These perceptions are more or less consistent across all the communities. In Kolmasug, farmers reported changes in all climate variability parameters. Indeed, a vast majority clearly observed an increase in the temperature, onset of rains, amount and duration of rainfall. Similar changes tend to be observed by farmers in Bugwia and Worikambo. However, farmers do not unanimously agree on the climatic variable that strongly affects agricultural production. For example, in Worikambo, the perception of the impact of temperature and rainfall was nearly equally shared while more farmers in Denugu weighed temperature more compared to farmers in the rest of the communities. These diverse perceptions may be explained by the variety of crops (maize, guinea, groundnuts and soybeans) cultivated. For example, while all exposure to climate variability may be uniform in the study communities, some farmers may be more exposed because of the nature of the crops cultivated. Maize and other cereals are more vulnerable to storms compared to groundnuts and soybean. This suggests that other factors beyond climate play a role in influencing experiences with climate variability. This finding corroborates (Teye et al., 2015) in studying local farmers' experiences and perceptions of climate change in the Northern Savannah zone of Ghana. They find that factors such as location and gender are playing a role in influencing perceptions of climate change. They argue for instance that variations in availability of ground water for agricultural activities may explain spatial variations in perceptions about climate change (Teye et al., 2015). In contrast, other studies highlight the coherence between meteorological data and local community perceptions of declining rainfall. Asif (2013) found that Pakistani farmer's perception of a declining trend in rainfall is consistent with observed rainfall data in the Thar region. This finding is further supported by FAO (2011) and Yiran (2016) in Ghana.

From a broader perspective, the impact of climate change in the area includes increased incidence of droughts and heatwaves. This impact devastates crops and farmlands, property, increase incidence of pests and diseases of plants and animals, the disappearance of some water bodies and increasing aridity of the soil as a result of increased evaporation (Yiran, 2014; Oguntunde, 2004; Tachie-Obeng et al., 2014). Variable rainfall and high temperatures have led to low crop yield, low production in livestock and the use of diversified livelihood strategies mainly charcoal production which further causes deforestation and land degradation. With rain-fed agriculture as the most important livelihoods now and into the future in this ecologically sensitive environment, a new approach to livelihood security is urgently required. This calls to focus, new strategies that enables peasant households to adapt successfully.

Famers described the link between water insecurity and agriculture and its implications on their ability to produce. One respondent highlighted how uncertainty surrounding rainfall influences household food and income security;

> *Water is the source of everything. Without (rain) water how can anything be done? We use water for all farm types: rice, maize, groundnut and bambara beans. It is from the rainfall that these crops bear fruits for us to harvest. So if there is less rainfall then we will harvest less and consequently the youth will have no option than to migrate. This year the rain came early and stopped early- it came March and October. It usually stops in November so this year the crops didn't do well. The rain was better last year. Only that we made an error. We didn't start early because we know the farming season starts in April and ends in November. Consequently, when the rains started in March we were still not sure whether to plant or not. So we lost.* Mr Danze, 69- years Worikambo

Such losses do not usually occur due to uncertainty of the onset of rainfall have accumulative effect on subsequent or chronic drought years preventing restocking. Thus further undermining the capacity to households to be food secure in the future. Poor rains and resulting poor pasture conditions were also reported to have affected livestock production and the market value of livestock. This destabilises the use of livestock as insurance in the long run.

Rain failures may be the apparent immediate cause of food and livelihood insecurity, but it is clear that underlying structural mechanisms and processes are critical in determining the extent to which households feel water insecurity. Assets such as livestock, access to irrigable lands and alternative income sources mediate the vulnerability. As argued by Adger (2006), Brooks (2003), Yaro (2004) and many others since then, while natural systems such as climate change may generate hazards and risks, the extent of vulnerability to these hazards and risks is a function of human-driven social, economic and political interactions. Local water insecurity must therefore take into cognisance the wider context of interactions between nature and human systems. An attempt at explaining water insecurity in the context of climate change will thus be an incomplete effort that only results in partial understanding of the reality.

Box 3: Water insecurity and agricultural productivity and consequences of water insecurity

Bondegre, Denugu

Bondegre is 64 years old and lives a in a sub village in Denugu. He is a grandfather with four wives. He has seven sons and twelve daughters who are all married. Two of his sons and their families share a compound with him- it is customary for at least a son to remain in the same compound with his father. The journey to his village is about one drive from the district capital.

His home is largely modern by the village standards with corrugated iron roofing sheets. Two of his sons are teachers and one is a nurse but they all live in Tamale - in a different region. Bongre farms maize at the banks of Morago- a tributary of the White Volta. His farm is very large but Bongre says he has no labour problem because he has three sets of bulls and implements and with his four wives and two daughters-in-law. Five years ago he harvested one hundred and two bags of maize. He was the district best soybean farmer two years ago and is targeting the prize this year too. Thanks to subsidised fertilizers yield of the maize has improved compared to two years ago. Unlike most households in the village, he has a lot of livestock. He however fears that he may lose more cattle this year as the dam was barely half at the end of rainy season. Every year his cattle crosses to the side of the river bank (this river is the borderline between Ghana and Togo) in search of water and fresh grass. He recounts the ordeal he had to go through with the Togolese Gendarmes- a branch of the Togolese Armed Forces responsible for among other things protecting people and property in rural areas. He had to pay in sum five hundred cedis (500) to free ten cattle including five bulls used for ploughing. There are cases where the cattle get lost for good. He blames the unusually short rainy season. The cattle and other livestock will not cross the border when there are sufficient water throughout the nine month dry season.

With a drying dam, dry season farming of watermelon and vegetables will surely take a hit. This means some households are on a head-on collision with poverty. Majority of the youth will have to migrate down south to work as labourers in cocoa farms or head porters in urban centres. He laments about how a neighbour's son returned with practically nothing after over eight months down south. In years when the dam is full no one migrates because dry season is more profitable than migration plus you live in your own home here. "*Migrants live a life of indignity at their destination".*

He fears his wives and children might have to walk a longer distance to fetch water since the well in front his house often run out of water in years of low rainfall. He dreads it because by March when the weather is hottest, not having sufficient water close to home could be a grave punishment for those fetching.

He is worried that his neighbours and other households will come to borrow food and money. This may be a strain on his resources but he has to put up with it because he recognises that without him some household could starve.

Bondegre's account reveals how climate and pre-existing social, economic and the wider political ecology of interactions co-evolve to create local livelihoods insecurities and thus highlights the difficult in singling out climate alone as the driver. His story calls to focus Adger and his colleagues (Adger et al., 2003) claim that peasant livelihoods are defined by multiple strata of capabilities and reserves. The responses of the resource an individual household depend alone are insufficient to determine vulnerability but crucially, the entitlements and ability to call on this resource. Thus social capital plays a very important role in the ability to manoeuvre around the impact of climate change (Yiran, 2016). This is clearly shown in (Yaro, Teye, & Bawakyillenuo, 2015). In a study of how local institutions enable or constrain adaptation in Northern Ghana they posit that a peasant household's ability to survive and respond appropriately to climate change impact is contingent on people and community's strengths and weaknesses as defined by idiosyncratic and wider processes. The above story reveals how climate change may reinforce existing inequalities and tighten the poverty escape valve for the already poor. It further highlights different degrees of shocks and stress. Comparatively, Bondegre may not be concerned about bad weather because he farms on alluvial land close to a river which is a shock buffer compared to someone on marginal lands. He also has large livestock as insurance in times crop failure although they are exposed to water stress and detention by the Togolese Gendarmeries. Losing livestock could be a shock to a household in three ways contextually. First, livestock is a store of wealth and thus an investment cum insurance against future crop uncertainties. Second is loss of labour. Donkeys and bulls are beasts of burden for farming activities in the study area. While bulls are used to plough farms donkeys are mainly for transport. They are also a source of income when hired out. The third shock is cultural related. Livestock are used in cultural and traditional ceremonies such as marriage, festivals and other sacrifices. Losing a livestock in search for water could therefore hurt cultural pride if a household if unable to afford one at time of need. This highlights contextual stress and shocks due to difference in resource endowments and entitlements and draws attention to the social context vulnerability.

4.6 Effects of emerging water insecurity on domestic water availability

Household water security is highly vulnerable to climatic changes in the study area. Except during raining season, all households use water from boreholes and streams with an average of about thirty minute travel time (figure 12). In a focus group discussions participants felt that their main source water was close nearby. However, in times of drought or floods, they are compelled to travel beyond their 'normal' water source. With declining rainfall leading to poor surface water availability and diminished groundwater recharge, traditional water collection points have moved. The survey results (table 9, 10 and 11) show that distance to water sources increases in bad years. Floods and droughts severely affected the households surveyed with 74.3% of households who experience flood saying that their source of household water source had been affected. 65% of affected households claim floods pollute water sources. Consequently, nearly 60% respondents spent more time than usual looking for safer water source during flood. A similar percentage (59.1%) of households admitted they use water sources from polluted sources. Another 34% fear the risk of health burden on their household increases during floods. Less than a percentage (0.7%) experienced water scarcity.

Table 8: Impact of floods on household water insecurity

Response	Frequency	Percentage
Flooding affects sources of drinking water		
Yes	185	74.3
No	64	25.7
Total	249	100
Nature of effects of flooding on source of drinking water		
Polluted	161	65.4
Cut off because access route is flooded	79	32.1
Silted with eroded material	4	1.6
Other	2	.8
Total	246	100

Table 9: Nature of flood impact on household water security and coping strategies

Response	Frequency	Percentage
Nature of flood impact on household water security		
More time is spent looking for water	160	59.3
Increase health burden	93	34.4
Spend more money to buy water	15	5.6
Water becomes scarce	2	.7
Total	270	100
Coping strategies		
Buy water from Tankers	1	.4
Receive water from NADMO /NGOs	29	11.7
Use the polluted water	146	59.1
Move to a nearby community to fetch water	71	28.7
Total	247	100.0

Drought also had similar effects on household water security albeit more (90%) households were of the view that drought had significant impact on household water security compared to floods. Compared to floods (28.7%), droughts compel over ¾ (79.8%) of xx to travel beyond their community to fetch water. When it comes the using polluted water, the reverse holds. Just above 17% of household claim to use water from polluted sources compared to over 65% of households during floods. Table 10 displays perception of drought impact on household water security.

Table 10: Impact of drought on household water insecurity

Response	Frequency	Percentage
Depletion of water source during drought		
Yes	265	90.1
No	29	9.9
Total	294	100
Coping strategies		
We move to the nearby community to get water	233	79.8
Use untreated water	50	17.1
Buy water from tankers	4	1.4
Other	5	1.7
Total	292	100

The findings show that floods are likely to affect water security by altering quality rather than availability through polluting existing surface water source. Droughts on the other hand influence water availability because the surface water dries up. Throughout interviews and focus group discussions, people viewed drought as the major threat to household water insecurity than flood. The combined blow of drought and floods highlights the precarious nature of the water insecurity semi-arid regions. As Grey & Sadoff (2007) summarise the quandary, semi-arid regions are faced with a difficult hydrology that locks them up in trap of poverty and underdevelopment.

4.7 Chapter Conclusions

This chapter examined evidence of climate change and variability and its manifestations in water security.

Majority of the households in the study community have noticed a rise in temperatures and simultaneous decline in rainfall. This perception is consistent with trend analysis of meteorological data though household perception of decline rainfall is not strongly correlated with rainfall data. The declining rainfall regime is also associated with late onset of the rains. Early start of the rainfall season is critically important to food crop production and food security. The seasonal cropping cycle has produced a regular rhythm that farmers are adjusted to accordingly. However, climate change forces a new uncertainty regime that farmers and households have to deal with. Statistically observed meteorological changes translate into crop failures thus undermining food and income securities. Such high climate variability adversely affects agricultural production and household water availability in Garu and severely challenges the livelihood of rural communities, already undermined by a range of economic and development malaise. Rainfall shapes the perceptions of water insecurity. Livelihoods are almost exclusively rain-dependent except in Worikambo and Denugu where small numbers of households are engaged in irrigation. Impact of rainfall variability is thus a major constraint to agricultural and household water use. The effects of the variations are amplified by the lack of a robust and reliable meteorological early warning system. Hence a little delay in in the onset of the rains could translate into crop failure and long distances to fetch water. Are increasing temperatures and perceived declining and irregular patterns of rainfall solely responsible for water insecurity in Garu?

Although climate variability is a major driver of water insecurity in Sudan Savannah, climate alone is insufficient to understand the water insecurity challenge. Contextual factors such as natural physical environment of the study area are a contributory factor. Lakes and natural perennial rivers are limited in comparison with the forest zones of southern Ghana. The exclusive natural storage for rainfall, with the exception the topsoil and sparse vegetation, is the ground. However, even though groundwater resources are very important, considerable variation in rainfall in Garu combined with poor subterranean strata as discussed in chapter three poses an enduring challenge to household and agricultural water security.

Aside the physico-climatic constraint on water security is also embedded in the socio-politico fabric of society. Even though water is a natural and physical resource, its existing structure and processes engrained in society that determines access and use. These structures define who controls access and therefore who becomes water secure or insecure. Chapter five reveals and discusses the multifaceted and pluralistic determinants of water security in detail.

CHAPTER FIVE: VULNERABILITY TO WATER INSECURITY AND HOUSEHOLD RESPONSES

5.1 Introduction

This chapter examines vulnerability and households' response to water insecurity. It first highlights the determinants of household vulnerability to water insecurity which explains why certain households are more vulnerable to water insecurity than others. Both idiosyncratic and structural factors are presented. The second part assesses household responses to climate variability and water insecurity.

5.2 HOUSEHOLD VULNERABILITY TO WATER INSECURITY

5.2.1 What makes a household experience water insecurity?

In general, the study observed that the insecurity of a household arises out of a combination of several of factors. Two household stories (Tiesema's household in Box 2 and Alima's household in Box 4) highlight what makes households experience water insecurity.

5.2.2 Scenario 1

Tiesema is the breadwinner of her household of nine members since her husband migrates to Kumasi seasonally to work in cocoa fields. He barely remits them. She is the only person working with seven other dependents. She brews pito and burns charcoal alongside but has no donkey to fetch water for her. Her daughters are too young to assist in fetching water so after a tedious day burning charcoal she fetches water herself (see box 2 for a detailed description of her household characteristics).

5.2.3 Scenario 2

Alima became the breadwinner of her household after her husband was diagnosed with arthrosis. She lives with him and her grandson. She brews pito, makes dawadawa and weaves baskets. She is also a traditional birth attendant. All her children live in Kumasi[5]. They remit her to take care of her

[5] Ghana's second biggest city

husband. She also has a donkey with a cart that she uses to fetch water from the dam for brewing pito. She however wished she had an irrigable land by the dam (refer to Box 4 for detailed description of Alima's household).

From the scenarios above, the following are key determinants of household vulnerability. First, transport assets are key in determining household water security. Longer times and distances to water sources lead to less water collected even if more is required. Table 9 further illuminates this assertion.

Table 11: Determinants of amount of water use and decision to use a water source

Determinants of amount of water used		
Determinant	**Frequency**	**Percentage**
Distance	182	61.3
Quality	111	37.4
Cost of water in cash	4	1.3
Total	297	100

Compared to Alima, Tiesema is likely to fetch less water because she carries it herself. It has been widely documented in literature that households with means of transport are water secure because they are able to travel longer distances and fetch larger quantities from good quality sources. Households with no transport assets such as Tiesema are likely to override improved sources for proximity and convenience. This underscores the importance of time and efforts in household water security.

A second determinant of household vulnerability that emerges from the above scenarios is remittance and migration. Households with remittance tend to accumulate asset base that enables them to generate further income and thus disperse the impact of water insecurity on crops into other non-farm ventures. The third determinant that arose from above narratives is income diversification. Households with multiple livelihoods that are climate dependent such as traditional birth attendants cope better than those whose carved livelihood from only agriculture and water-related activities.

The following quote from an interview further illuminates the importance of income and wealth as factors that determine the vulnerability of a household to water insecurity:

> *Wealth is the main determinant of resilience. When I say wealth, I mean livestock (animals such poultry, donkeys, and cattle) which others haven't got. About a 2/3 of the people haven't got wealth to cushion them in times of drought. So in times of drought, they starve. The capable households are able to endure. The 2/3 households which are incapable have to get a member to migrate down south and remit them to survive.* (Cletus, 58 years, farmer Worikambo)

Within the household, women and children are most vulnerable. Under normal circumstances, water collection is associated with women although men sometimes get involved if the distance increases in the dry season. In all the study communities women bear the brunt of the labour demand for water collection. A 55- year old man succinctly illustrates the gender aspect of water insecurity when he said;

> *In fact generally, women suffer more than men on the grounds that they care for the family. A man may leave the house for a week without coming home. Women cannot do that. If she to leave, she does so with the kids. So she has to deal with her water needs and also satisfy the kids' water needs too. Therefore the women suffer most.*

The above quote supports the view that vulnerability to water insecurity reflects the existing structural inequalities in society (Agrawal, 2008; Boelens et al., 2016;Yaro, Teye, & Bawakyillenuo, 2014) . It also exposes the weaknesses of reductionist approach water security which emphasises aggregation over individual and meso-level over micro level security. The qualitative approach adequately presents determinants of inter and intra household water insecurity which is not sufficiently captured in quantification. The finding thus diffuses the tacit assumption of quantification approach; homogeneity in a heterogeneously complex real world. The above findings consolidate the view that it is necessary to apply partly different strategies and policies to combat water insecurity taking into cognisance contextual issues.

5.3 Broader determinants of household water insecurity

Households may experience different levels of water insecurity even though all climate-induced water insecurity is a natural hazard that may be homogenous across the community. The individual characteristics of a household could make more vulnerability than surrounding household. The story of Tiesema in Box 1 is a portrait of how social conditions make households vulnerable to water insecurity. Tiesema's household insecurity shows that a household's vulnerability is not only determined by its idiosyncratic characteristics. Broader structural forces set the arena within people's vulnerability are contextualised. She has a large household with a high dependency ratio. This is further exacerbated by customs that segregate gender roles. Her male children prefer tending the livestock than fetching water leaving her almost exclusively responsible for household water security.

Box 4: Boasup's story: idiosyncratic and structural determinants of vulnerability

Boasup's household

Different vulnerabilities: When your husband demands for water to bath it is your (women) head that will carry it from wherever you may find it. He doesn't care where you get it from. When he asks for food; it is water that you use to prepare. In the past when the only borehole breaks down, we have to trek to the river bed and dig for water. The men do not care where and how far you go for water. They don't help us. Some husbands even hurl insults at you for returning late. Today, our worst nightmare is the borehole breaking down.

The water table at the river bed has fallen further. We have to dig deeper to get water each time the borehole breaks down. By February, it is worse. Men fetch water for the livestock. But now that they travel down south, it is the women who fetch for both the household and the livestock.

Widows with little children are most affected. However, water scarcity affects pito brewers most. The nearest water source is over two miles away. When the borehole breaks down, we stop brewing except women who own donkeys and donkey carts. Or those who can afford to rent a kart. We have many use of water. There's nothing that you can without it. We use water for dawadawa processing. In the past when the river was flowing in the dry season, we used to process the dawadawa seeds by the river side. Dawadawa supplements our income from farming activities. It is no longer the case. We now process dawadawa in the rainy because it is too hectic for fetch water from the borehole to wash dawadawa seeds. Shea butter processing is relatively easier in comparison to dawadawa processing so we use borehole water in processing. So if you run short of dawadawa in the dry season, you have to wait till the rainy season. Dawadawa making now stops with the rains.

Options for adaptation: A dugout or a reservoir would be helpful. A dam will enable us to do more dry season farming. Our husbands will farm onions instead of running down south leaving us to fend for our children school fees. Women will also plant vegetables to generate incomes instead of burning charcoal.

The story of Boasup in box 4 provides a summary of lived experiences that is routine to the many other households in the study area. It shows how multiple factors intersect to give rise to vulnerability. It also highlights intra-household vulnerability. Her story shows how male privilege and disguised misogyny makes women more vulnerable at the household level compared to men. It also thrust to the fore nature of livelihoods and amplifies gendered nature of vulnerability. Households whose income is carved directly around water are more at risk. In her case, alternative income activities such as dawadawa production, brewing pito and making shea butter are constrained by lack of water. These activities are a major source of income for women in the study area. This throws light on the gendered and differentiated vulnerability to water insecurity that this thesis unravels. Boasup draws attentions to the fact that experiences with insecurity is embedded and filtered through existing inequalities and privileges.

It emerged that transport assets, particular livelihood needs, household composition, and intra-household relations all come into play in deciding which sources to use, and how much water to use for which purposes. For instance, households with donkeys and bicycles are less likely to reduce water consumption in the dry season compared to households which are not endowed with means of transport. Women bear the brunt of the labour demand for water collection and may extend their working hours well into the night when water collection times are long and coincide with peak demands for agricultural labour. This suggests that in times of water scarcity women tend to be more vulnerable than men. This is a reflection of the patriarchal nature of the study communities. Patriarchy imposes male privilege at the expense of female labour and sacrifice. In a focus group discussion in Kolmasug, one woman sums up the everyday struggles of women in the community when the wells run dry:

> *In times of water scarcity everyone is affected but women bear the brunt. We are responsible for fetching water in this community for household consumption. We are also responsible for cooking hence naturally we fetch water for the household unless you have a daughter. Furthermore, our independent source of income which is pottery, pito brewing, dawadawa*

and shea butter processing is also compromised when there is water scarcity. These activities require water so when there is no water poverty eats us. Water is a saviour.

Proximity to water does not automatically translate into access and use. The story of Alima in Box 5 captures this claim. Despite being close to the dam canal, she and husband are yet to get plot of land near it for dry season farming.

Box 5: So close yet so far away - the problem of access

Alima, Worikambo

Alima is about 58 years old. She lives with her husband Anaba who is at least 60 in a *fon* (a small division) at Worikambo. Her three children; Asibi, Awin and Nyaaba all left for greener pastures in Kumasi. Alima and her husband are thus alone with their 9 year old grandson, Ayeebo.
Alima is a robust and hardworking woman. She does many jobs which includes brewing pito once a week as well as preparation of dawadawa for sale in between. Aside weaving cane baskets and mats, she is also a traditional midwife. But with the new CHIPS[6] compound, she has no guarantee of stable income from her midwifery activity.

With the exception of the declining traditional midwifery job, all her other incomes sources are dependent on water or rainfall. The straws for weaving are only available at the beginning the rainy season each year. Dawadawa processing is tedious and requires more water. She is therefore compelled to carry the soaked and fermented seeds to the dam which is about 1 km away.

Anaba though active, is a pale shadow of himself. He has been diagnosed with arthrosis- a degenerative disease of the joints- probably from his former job as a mason. He helps with menial tasks at home although he does not have an independent source of income anymore. He depends on the irregular remittance from his Children in Kumasi although Alima admits it is insufficient. They are however okay since they have a donkey cart that Ayeebo uses to fetch water from the dam in two day intervals before its time for brew pito. Life would have been better if they had access to land close to the dam to do dry season farming.

Alima relates that she has tried on several occasions to obtain land there but she is yet to breakthrough. “We are migrants. We are not a priority when it comes to land by the canal. Since we are strangers, the chief has not honoured our request”.

Even though Alima’s household is very close to the dam, they do not have access to land to farm in the dry season. Thus in years of poor rains in the main farming season, they do not have the opportunity to recover with dry season farming buffer. Her story highlights the social context vulnerability.

Alima’s story highlights the importance of local institutions and how social structure may constrain access to resources and consequently successful adaptation. The finding validates (Agrawal, 2008) claim that climate adaptation is inherently local and thus local institutions such as chieftaincy mediates access and use of resources. These local institutions are important in understanding the

[6] Community Health Improvement Services (CHIPS)

portrait of vulnerability and the adaptive options that different social groups choose. Yaro, Teye, & Bawakyillenuo (2015) similarly recognise the importance of local institutions in shaping vulnerability and adaptive options. Amina's ability to cope with seasonal variability of rain by using dry season irrigation is thus limited by social exclusion.

Map 3: A map of social context of vulnerability in Garu-Tampane

The satellite image (map 3) gives a visualisation to Alima's story. It contextualises how ownership and association with power systematically excludes people despite their physical proximity to water resources and irrigated lands. Even though Alima's house is close to the Chief's palace as shown in the satellite image above, that does not guarantee access. Conventional spatial configuration literature has examined connection between place and access to resources. For instance the distance-decay theory (Fortheringham, 1981), world systems theory (Friedmann & Wallerstein, 1996) gravity model (Redding & Venables, 2004) and structural theories broadly argue that people closer to a nodal power tend to benefit from their proximity. At the core of these theories is the assumption that distance is a deterrent to interaction. According to these theories, spatial hierarchy is determinant of access and degree of control. In sum the closer an individual is to a nodal power, the more likely they will benefit from resource allocation. Contrary to these theories, this finding reveals that proximity does not automatically or necessarily translates to access. Social differentiation rather than spatial (locational) differentiation was critical in denying Alima access to irrigated land. Rather than distance (spatial or locational) differentiation determining access outcomes, Alima's fate was decided by local polity.

The foregoing discussion reveals complex relationships of vulnerability, power, and access to water in particular and natural resources in general.

In the context of literature, the results highlight the limitations of the underlying assumption of Falkenmark (1989) **"***Falkenmark Water Stress Indicator*" which inadvertently equate water availability to water security. Undue emphasis on aggregate water availability, diverts attention from the more fundamental issue of how particular individuals and groups of people gain access to and use of water resources. In the context of Alima's case, bonds and linkages to power are enabling or constraining factors for access to irrigation as Figure 4 reveals. Agrawal (2008) however warns of the limiting nature of bonds and linkages as they have the tendency of restricting close groups from participating. Again, vulnerability reflects the existing contours of inequalities dictated by local institutions. The finding also confirms Yaro et al. (2015) assertion that individual household vulnerability filters through the fabric of broader society laid by local institutions. Household vulnerability outcomes are thus shaped by the contours of power relations.

5.4 Meso level determinants of vulnerability

Spatial visualisation of vulnerability is crucial in monitoring and informing decision making. The integration of these produced a compelling portrait of vulnerability. Such a spatial differentiation of vulnerability according to Hartshorne (Hartshorne, 1959) is the call of the geographer. Table 13 shows a cross tabulation and availability of water source throughout the year.

Table 12: Water sources, cross tabulation study community and perennial availability of water

Type of source of water	Frequency	Percent	
Surface	100	33.7	
Ground (well, borehole)	195	65.7	
Other (pipe, rain)	2	0.7	
Total	297	100	
A cross tabulation study community and perennial availability of water			
Name of study area	Availability of water source throughout the year		Total
	Yes	No	
Worikambo (Guuni/Boko)	42	17	59
Kolmasug	18	37	55
Denugu/Danvorga	57	76	133
Bugwia (Dabila)	19	29	48
Total	136	159	295

Nearly three out of four households in Kolmasug had to find a farther alternative source of water in the course of the year due to water source drying up. Similar portion of households in Bugwia also had to do same.

In a focus group discussion with women in Kolmasug, one woman intimated:

> *Access to water is a significant challenge in this community. There is no surface water from which our animals drink. They roam long distances before they get water. We depend on two boreholes one of which has very low yield. This community was named after the river but there is no water flowing there. It is now a dry river bed. It has been so for about ten years. There are also wells but they are seasonal.* (A woman in her forties)

This observation was corroborated by a man in a separate focus group discussion in the same community.

> *We get water from mainly boreholes and wells both for household and animal consumption. But these sources have low yields by February. In such times we go to Worikambo (6km away). Animals either move to the dam in worikambo or the "Muare" (a tributary of the White Volta which serves as the borderline with the Republic of Togo). Muare*[7] *is further afield. It is really far from here consequently our cattle either get lost or cattle rustlers steal them.*

[7] It is a tributary of the White Volta that borderline dividing Ghana and Togo in the Garu-Tempane District.

To understand the macro level vulnerability of both Kolmasug and Bugwia, an examination of resource base and their physical characteristic are imperative. Kolmasug is located on a rugged yet gentle slope that become gentler as it unfolds towards Worikambo to the southwest. The landscape is under lain by clay with stony to rocky surface especially to the north and northeast. The clay serves a good source of raw material for the dwindling pottery craft industry in the community. It has a dry river valley that cuts through the northwest to southeast and comes to life in the rainy season. It is this dry river valley that gives the community the name *Kolmasug* which translates literally as "*Cold River*". The clayey underlay blocks percolation-the life blood for groundwater recharge. Wells and boreholes thus have low yields to the declining recharge. The vulnerability of this community is thus linked to its location.

Like Kolmasug, Bugwia is also held hostage by geography. Bugwia is located on a sandy landscape with rocky outcrops doting. It is generally low with imperceptible slope toward the South. Unlike Kolmasug, it has no surface water (neither river nor dam) and is thus dependent on rain and groundwater. However, the impervious rocky underlay poses a significant challenge to drilling for water. The few wells and boreholes available barely survive the dry season because they are shallow. Worikambo and Denugu are relatively less vulnerable in that they are in low-lying location with relative pervious underlay which allows for recharge of the groundwater. A chi square test at 95% confidence level shows that there is a significant relationship between location and vulnerability to water insecurity (Pearson Chi-Square = 20.285   P- value = 0.000). See table

Table 13: Chi-Square Tests of relationship between location and vulnerability

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	20.285a	3	.000
Likelihood Ratio	20.664	3	.000
Linear-by-Linear Association	9.027	1	.003
N of Valid Cases	295		
a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 22.13.			

Inasmuch as spatial display of vulnerability is relevant, it masks household level vulnerability. Vulnerability to water insecurity is felt at the household level hence spatial vulnerability is not helpful for a deeper understanding of nature and causes of vulnerability. Other factors such as wealth and asset base, social connection and livelihood ventures have a compelling impact on determining vulnerability. Again, vulnerability varies among and within a group in line with the structure of society. This brings to the fore social domains of vulnerability.

Two broad determinants of water insecurity emerge from Tiesema's story. The first broad category is the household size and characteristics. The poorer and larger the household, the more susceptible they are to water insecurity. Although the large number may provide labour for fetching water, such compensation is eroded by the number of users of water. The second broad determinant is nature of source of income. Households who earn their income from water related activities such farming, pito brewing and pottery are most susceptible to insecurity. Having diversified income sources that are independent of water such as government work and remittances is critical to resilience. In interviews all households viewed formal education or skills training as critical long-term strategies for successful adaptation to the changing water availability.

5.5 HOUSEHOLD RESPONSES: ADAPTATION STRATEGIES TO WATER INSECURITY

The different households who faced different vulnerabilities responded differently according to their experiences with water insecurity and climate change and variability.

In the following section I will discuss the various strategies that households use in dealing with water insecurity resulting from climate change and variability. Reliance on rainfall as the sole source water for agriculture and household water predisposes rural households to a season variation. Transitioning livelihoods between these two repetitive extremes dictates that household engage in activities that reduce exposure, shocks and stress to water insecurity. The adaptation strategies that households used in dealing water insecurity as a result of climate change and variability can be broadly categorised into two; precautionary and *ex post.*

Precautionary strategies (*ex ante*) constitute livelihood decisions prior to the onset of the season including choice of drought-tolerant crops, investing in water storage and diversification of crop. *Ex post* adaptation options constitute risk management alternatives that minimises the impact of water insecurity resulting from climate shocks and stresses. These include non-farm and off-farm labour and migration.

The following quote highlights the importance of seasonal migration as an adaptation strategy for farmers:

> *In past when there was water, we farmed onions and watermelon which gave us supplementary income in the dry season. But now that there is water scarcity, most of us migrate to Kumasi to work as labourers. Those who don't migrate will have to endure poverty in the rainy season because they would consumed all their farm produce. So when there is no water we become miserable. Times have really changed. When I was young, it was only those considered lazy and irresponsible who run [seasonally migrated] to Kumasi but now we all run to Kumasi and leave our wives till the raining season starts.* James, 35 year-old dry season gardener, Kolmasug

It is clear from the above quotation that farmers' decision to migrate is often under subtle compulsion. They only migrate when the available in-situ options for adaptation is limited or when the perceived profit from migration is more compelling. This lends credence to the claim that migrations resulting from environment quality decline are often forced.

Table 14: Household coping and adaptation strategies

Ex ante coping strategies		
Activity/Option	Frequency	Percentage
Switching to irrigation	34	13.4
Planting drought resistant crops	184	72.4
Switch from farming to other Non-rain dependent activities	36	14.2
Total	254	100.0
Ex post coping strategies		
Remittances from relatives	154	52.4
Migration	112	38.1
Other (trading and off farm labour)	28	9.5
Total	294	100.0
Adaptive responses to dry spells		
Delay in planting	102	34.8
Planting short maturing crops	165	56.3
Planting drought tolerant crops	26	8.9
Total	293	100.0

From the results above (Table 14) the key coping strategies used by household to deal with climate variability and water insecurity in the study area are predominantly *ex ante*. These coping strategies include irrigation, planting drought-resistant crops, delaying planting and using early-maturing varieties. Depending on remittance or migrating are the most important *ex post* options that households adopted.

This finding is consistent with Kabat, Schulze, Hellmuth, & Veraart, (2002) and Taddele et al. (2016) claim that farmers due to a multiplicity of factors are likely to seek ways of improving their farm yields than to turn to non-farm activities. New skills and knowledge set for non-farm activities could be a barrier. Again wealth base is key in determining adaptive and coping options.

The preference of *precautionary* over *ex post* coping strategies could also be explained by aversion towards migration. There is a history of failed returned migrants who are worse off than pre-migration. *They live a life of indignity in their destinations* as Bondegre lamented in Box 2. It is thus comprehensible that many respondents adopted irrigation over migration.

Irrigation provides an alternative food and income that enables farmers to endure crop failure during the main raining season. The following quotation reflects the perceived profitability in irrigation to migration:

> *Dry season farming is far profitable and more dignifying compared to migrating to Kumasi to work as a laborer. In one of the years that there was water in the river, we had over hundred bags of onions. We bought motorcycles and roofed part of our house with corrugated iron sheets at a time when motorcycles were rare in this community. I was the first farmer to buy a motorbike with proceeds from dry season farming. It was only government workers who could afford motorbike in those days. It is better to get money sitting at one place [working on your own] than roaming. We wouldn't have had to migrate seasonally if there is water for dry season farming.* Issifu, 27, Denugu

The above quotation highlights the role of water as an indispensable input in agriculture. Having access to irrigable land is an asset that builds adaptive capacity households enabling them to acquire more assets against contingencies.

Reliance on in-situ precautionary options for adaptation such as irrigation validates Adger et al. (2003) hypothesis that household will only choose the migration option if the expected returns outweigh overall cost. Bawakyillenuo, Yaro, & Teye (2014) in exploring the autonomous adaptation strategies to climate change and climate variability in the rural northern savannah zone of Ghana observe that farmers intensified irrigation as a measure against declining and erratic rainfall. Similarly, researchers have found that households and farmers prefer to innovate and live in their current location rather than migrate. For instance Rivera (2011) in Peru and Coulibaly et al. (2015) in Malawi all conclude in-situ adaptation are preferred to migratory adaptation. This could partly be due to the cultural and sentimental values attached to their current location. Uncertainties and possible conflict over resources in destination regions could also be a barrier to choosing the migration option.

5.5.1 Wealth and adaptation options

Adaptation options to water insecurity resulting from climate change is not homogenous in Garu. Different households used different options to reflect their different resource endowments and pre-existing inequalities. Poor households with agriculture as the only source of income tended to have low adaptive capacity to cope with climate variability and change compared to a household with diverse non- agranian income sources. The level of susceptibility of a household is a function of the resources that the household can command (entitlements) for example, the transportation assets it may have to go to the source of water. Even though a household may be far from a water source, it may not be automatically vulnerable. A government worker or a wealthy farmer with a motorbike or donkey could deploy these resources to access water compared to a peasant household which may be closer to a water source but does not have sufficient storage facilities. Such households have to make several trips and spend more time to fetch less water. The story of Tiesema and Alima in boxes 1 and 2 highlights how wealth base enhances or limit coping and adaptation options. Wealth enhances water security in several ways. Wealthier households tend to own a means of transport such as donkeys or bicycles, making water collection easier in times of drought. It also enables them to benefit from hiring and thus empowering them to accumulate more resource to invest in irrigation and storage capacity. Larger storage capacity means less frequent trips and consequently more time to engage in alternative income-generating sources.

Conversely, households with limited wealth are compelled to adopt negative coping and adaptation options. Negative coping denotes options out of compulsion which makes the household even more vulnerable in the long-term as the case of Tiesema burning charcoal for survival highlights. Duraiappah (1998) finds a link between poverty and environmental degradation and the poverty trap.

The importance in wealth in coping and adaptation is summed up in the following quotation from an opinion leader in Worikambo:

> *Wealth is the main determinant of vulnerability and resilience. When I say wealth, I mean livestock (animals such as poultry, donkeys, and cattle). Not every household have valuable livestock... About a 2/3 of the people haven't got wealth to cushion them in times of drought. So in times of drought, they starve. The capable household is able to endure. The 2/3 households which are incapable have to get a member to migrate down south and remit them to survive.*

5.5.2 'The water also belongs to us': emerging contestations resulting from adaptation to water insecurity

Natural resources such as water is central to rural livelihoods transformation. It is this intrinsic value that also brews contestations and conflicts amongst the "have" and "have no" access. In such contestations, power relations, linkages, right claims and local institutions shapes the outcome. As demonstrated and discussed in this research (Box: 1, 2, 3, 4, 5), powerful individuals and institutional coalitions often determined access albeit there may exist an open and universal usufruct rights to irrigated lands by the dams. In the case of Alima, although the dam is a public property sanctioned by the State, it is local arrangements and rules that determine access. Having legitimate claims to a property sanctioned by the state does not automatically translate to benefiting from same. Sikor & Lund (2009) emphasise that property [enforceable claim(s) to some use or benefit of something] is distinct from access which entails the ability to benefit from and use the property in question. So people may have property rights to a resource but are unable to derive any material or nonmaterial benefit from the resource. In effect, they lack the "real" (Cousins, 1997) or "effective" (Verdery, 2003) rights to water promised by law but deprived by practice..

Climate change directly affects water availability. Rising temperature and uncertain rainfall simultaneously coinciding with high population growth and general environmental deteriorating means those contestations for water resource use and access are likely to increase. Such contestation for water could result in negative outcomes if it leads to consolidation and erosion or positive if reconfiguration and compromises are the outcomes. In the context of the study characterized by normative and legal pluralism, climate change could lead to intensified assertion of power and control over water resources such as dams and irrigated lands. Intensified competition and control of water resources could lead to the emergence of new alliances and institutions that may rival existing institutions. For instance, the case of Bondegre (Box 2) has emerged as a challenger from outside the traditional polity. By asserting his position as assemblyman at the local government level, is renegotiating with elite and therefore demanding a say in allocation of irrigation land. Such contention rouses questions of who has authority over resources. It politicises water and challenges the imbalanced distribution of decision-making power at the local level water governance. Power relations are actively constructed and reconstructed by emerging actors who use the pluralistic governance structure to compel chiefs to share authority with previously-vulnerable groups. Thus, intensified contestation has provided opportunity to have a fairer and more democratic construction of local water governance. It is thus leading to inclusion of otherwise excluded people in the decision making process.

The foregoing discussion reveals complex relationships of vulnerability, power and access to water in particular and natural resources in general.

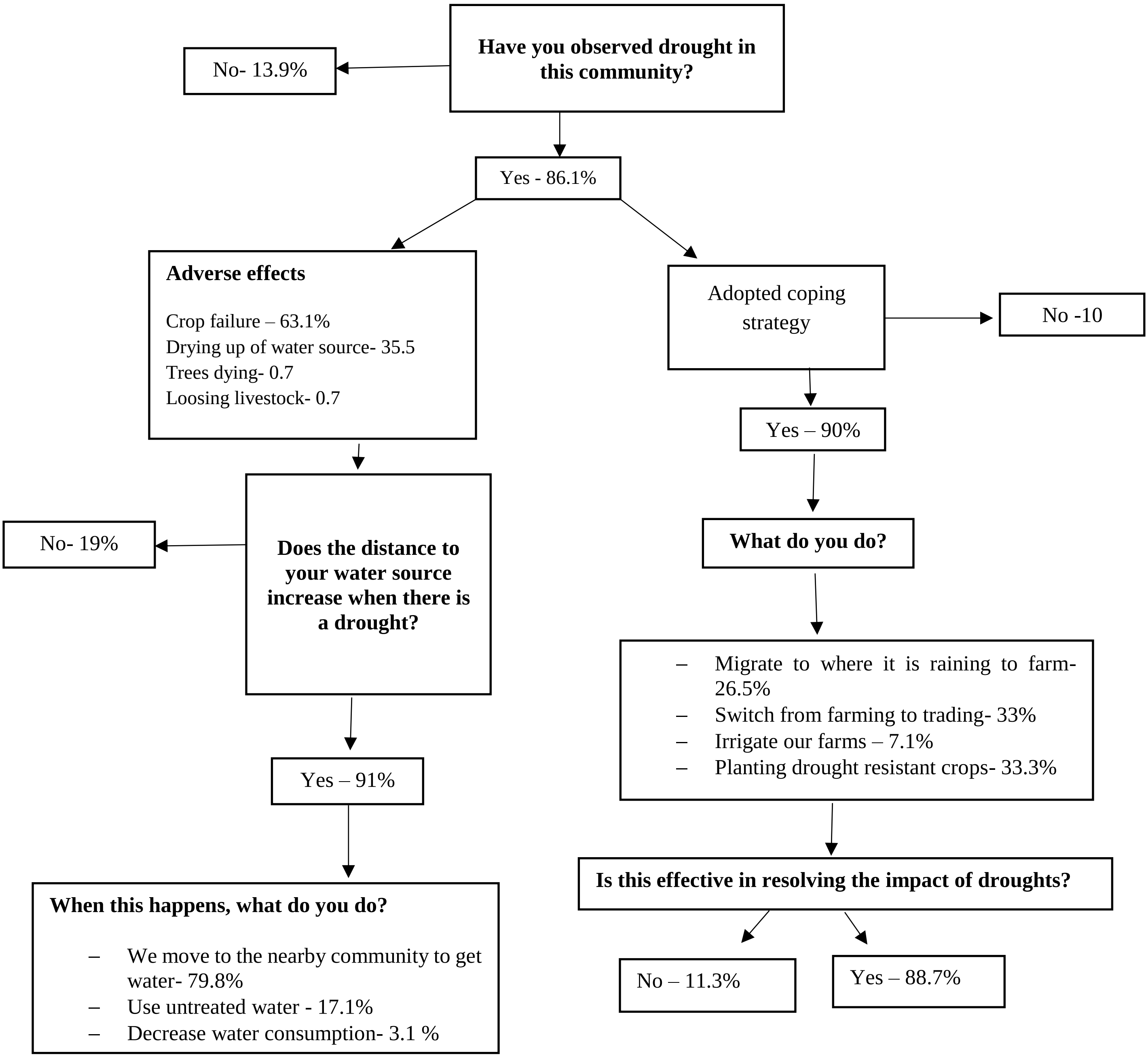
5.6 Chapter Conclusions

This chapter investigated the circumstances that predispose households and communities to vulnerability and the diverse and evolving responses that households adopt in dealing with water insecurity resulting from climate change. Literature on water security often disaggregates vulnerability to agricultural and household water security. This study on the contrary discovers that vulnerability to household and agricultural water insecurity is in continuum. Rural household experience two at the same time.

Household vulnerability to water insecurity resulting from climate variability and change is very high in the study area. Three factors determined vulnerability to water insecurity; the first is the physical characteristics of a community involving the nature and configuration of land; the second being the idiosyncratic household characteristics. The third factor is power relations and local institutions. Household vulnerability is related to economic, political and social structures and processes, at both macro and micro levels which continually construct and reconstruct vulnerability outcomes. Seldom do these factors act alone. These forces often act in combination at different levels to determine vulnerability outcomes.

Livelihood adaptations in response to climate-induced water insecurity are two in forms; diversification and migration. Generally, households engaged in cultivation of multiple crops adapted to low availability and short maturity periods as a means of boosting resilience. Others engage in multiple income activities including non-farm in addition agricultural-related activities as buffer. Yet a second set of households shifted entirely from agricultural activities to trading. Two types of diversification strategies emerge; occupational duplicity where the household or individual still stays within the same occupation but does different activities or jobs. In the second of diversification strategy, the household or individual totally shifts from the farm to non-farm. The diversification involves a sectoral change."

Figure 17: Summary of effects of drought and water insecurity and adaptation strategies



CHAPTER SIX: CONCLUSIONAND RECOMMENDATIONS

This study examined the impact of climate-induced water insecurity on household and agricultural water use in the Sudan savannah. To understand the complex relationship between climate changes, water security, and livelihoods the research sought to answer the following questions: How do hydrological factors affect production in water-sensitive sectors? How has climate change/variability affected water availability for household and agricultural use? What characteristics make a household and community more or less susceptible to water insecurity? And what are the socio-economic implications of such changes in water availability on food security?

6.1 Climate Change/Variability and Water Insecurity

In answering these questions the study focused on four objectives. First, it assessed the nature of changes in the Sudan savannah as the background within which water insecurity plays out. Rainfall and temperature were the two main climatic elements that were assessed. The findings show that a majority of the households in the study community have noticed a rise in temperatures and simultaneous decline in rainfall. This perception is consistent with trend analysis of meteorological data though household perception of decline rainfall is not strongly correlated with rainfall data. The study observes a 2^{0}C rise in temperature between 1983-97 and 1998-2013. Trend analysis shows that post 1996 temperatures are significantly higher. The shift coincides with the severity of drought years. Temperature is thus critical in determining water insecurity though a mediating factor is runoff which is often not considered in literature (Heo et al., 2015; Misra, 2014)

Both 1990 and 2008 drought exhibits very high divergence from the 1983 level of rainfall records. While the 1990 recorded just over 100mm less rainfall, that of 2008 was 232mm below 1983 levels. Statistically observed meteorological changes translate into crop failures thus undermining food and income securities. Such high climate variability adversely affects agricultural production and household water availability in Garu and severely challenges the livelihood of rural communities, already undermined by a range of socio-economic challenges. Rainfall shapes the perceptions of water insecurity. Livelihoods are almost exclusively rain-dependent except in Worikambo and Denugu where small numbers of households are engaged in irrigation. Impact of rainfall variability is thus a major constraint to agricultural and household water use.

From a broader perspective, the impact of climate change in the area includes increased incidence of droughts, floods and rainstorms. Variable rainfall and high temperatures has led to low crop yield, low production in livestock and the use of diversified livelihood strategies such as hunting and charcoal production which further cause deforestation and land degradation. With rain-fed agriculture as the important most livelihoods now and into the future in this an ecologically sensitive environment, a new approach to livelihood security is urgently required. This calls to focus, new strategies that enable peasant households to adapt successfully.

6.2 Determinants of water insecurity

The second objective sought to understand the dynamics and lived experience of people of climate-induced water (in) security. Three dimensions of water insecurity emerged strongly namely: accessibility, reliability and quality. Accessibility dimension of water insecurity in this thesis bordered on time spent and rules governing who has access to water shapes accessibility. Nearly 80 percent households reported spending at least thirty minutes to fetch water in the dry season including time spent in queuing. This could entail traveling beyond the immediate *fon* to collect water. According to minimum international humanitarian standards on access to water as advocated by the SPHERE manual (The Sphere Project, 2011) and United Nations (UN-Water, 2013a; UNICEF/WHO, 2011), households are water insecure if they travel beyond 200 meters and queuing time of 30 minutes maximum. It thus suggest that communities hardly meeting the minimum water security in the dry season.

. Long walking times and time spent in securing water could limit the volume of water collected by households and consequently restrain the use of water for sanitation services and hygiene behaviours including handwashing with potential health hazards. Also, access to irrigated land was a function of bonds and linkages with local power structures. Powerful individuals and institutional coalitions often determined access albeit there may exist an open and universal usufruct rights to irrigated lands around the dams. Additionally, transport assets, livelihood needs, household composition, and intra-household relations all come into play in deciding which sources to use, and how much water to use for which purposes. Reliability implies availability of water from a water source throughout the year. A household is therefore water insecure if the source of water is not available throughout the year. An overwhelming majority (95%) of households held that water availability in their community was a function of season. The quality dimension that emerged highlights the perception of household's suitability of a source of water. Women bear the brunt of the labour demand for water collection and may extend their working hours well into the night when water collection times are long and coincide with peak demands for agricultural labour. Inter and intra annual variability of rainfall compromises water security at certain times of the year.

6.3 Vulnerability to water insecurity

Vulnerability of a household to water insecurity was contingent on two factors; physical location and endowments. Physical location characteristics such as topography and nature of soil were important determinants. For instance, Kolmasug emerged most vulnerable due to its location. The landscape is under laid by clay with stony to rocky surface. This makes it prone to floods and at the same time constrains groundwater recharge. Varying household resource endowments is also an important determinant of vulnerability. Proximity to water does not automatically translate into access and use. Vulnerability is thus a reflection of the existing contours of power. This finding resonates with Adger et al. (2003), Agrawal (2008) and Yaro et al. (2014) findings that vulnerability is often enveloped in the existing inequality landscape although the physical locational characteristics cannot be swept aside.

6.4 Adaptation to water insecurity

Household choices are enveloped in the institutions and fluid resources available to them. Wealth emerged as key determinant adaptation. Wealth enhances water security in several ways. Wealthier households tend to own a means of transport such as donkeys or bicycles, making water collection easier in times of drought. It also enables them to benefit from hiring and thus empowering them to accumulate more resource to invest in irrigation and storage capacity. Larger storage capacity means less frequent trips and consequently more time to engage in alternative income generating sources. Conversely, households with limited wealth (endowments) are compelled to adopt negative coping and adaptation options. Negative coping denotes options out of compulsion which makes the household even more vulnerable in the long-term as the case of Tiesema burning charcoal for survival highlights. The key coping strategies used by household to deal with climate variability and water insecurity in the study area are predominantly *ex ante*. These coping strategies include irrigation, planting drought-resistant crops, delaying planting and using early-maturing varieties. Depending on remittance or migrating are the most important *ex post* options that household adopted.

Overall, analysis has shown that the total annual rainfall is characterized by tremendous temporal variability, with irregular surges and breaks. The district experienced hydrological droughts in 1985, 1990 and 2008. Each of these years was preceded and succeeded by a massive upsurge in rainfall. In the last decade, only two years (2007 and 2010) experienced above average precipitation. The table 8 shows the long-term drift in the onset of the planting rains. A key finding from this data is that key drought years were associated with rainfall staring in March and ending in October. Farmers observed a shift onset planting rains. Planting rains are consecutive rains at the beginning of the farming season with dry days not exceeding one week. These rains are critical to germination and survival of crops hence within this period guarantees optimum survival and long-term yield of crops. As farmers explained, sowing before or after this period often results in poor yields. Uncertainty about when the true rainfall season begins due to pseudo-onsets has affected crop yields. Farmers opined that the production of crops was serious affected by extreme events such as dry spells and rainstorms. Table 9 shows how hydrological variability translates into variability in food production levels in metric tonnes at the district level.

Three factors determined vulnerability to water insecurity; the first is the physical characteristics of a community involving the nature and configuration of land; the second being the idiosyncratic household characteristics. The third factor is power relations and local institutions. Household vulnerability is related to economic, political and social structures and processes, at both macro and micro levels which continually construct and reconstruct vulnerability outcomes. Seldom do these factors act alone. These forces often act in combination at different levels to determine vulnerability outcomes.

6.2 General Conclusion

Rural livelihoods in semi-arid regions are at a crossroad. Poor household's livelihood options are pressured at both ends by two powerful forces. On one hand is the climatico-environmental change to which they have little control over. On the other are socio-economic and demographic changes that increase competition for declining resource availability and quality. Climate is an important element in the water security equation as is affects the biophysical setting upon which rural livelihoods is carved. The climate of an area governs the weather; the accumulated effect of weather determines the distribution of surface water. The pattern and rhythm of life are determined by distribution of water sources.

The above finding is parallel to findings by FAO (2011), Misra (2014a) and Sadoff & Muller (2009) who have demonstrated that water security is intractably intertwined with the climatic conditions. From a broader perspective, the climate regime directly determines rainfall, temperature and evaporation which are key in determining surface water availability.

The thesis highlights three shades of water insecurity resulting from climate variability: change within the year (intra- annual variability. That is the seasonality of water availability), year-to-year (inter annual), and the uncertainty with respect to unpredictable timing and intensity of extremes. Rural household's lived experiences are often stressed by a combination of the above dimensions which translates into eroded livelihood options, poor health and ultimately poverty. A repeated cycle limits the options for livelihoods and accelerates the collapse to deeper forms poverty especially in semi-arid savannah where almost livelihood activities are carved around water.

The water resources and their ability to support livelihood activities of peasant households in Garu-Tempane is at a critical point. Although the literature (example Armah et al., 2010; Kiem & Austin, 2013) has blamed the rising population and environmental degradation, this study has clearly shown that change/variability is putting significant pressure on the water resources of the district. Both livelihoods activities and household water security are at a tipping point. The amplifying challenge is the low autonomous and institutional adaptive capacity due to the perversity of poverty and underdevelopment in the district and Northern Ghana in general.

The thesis confirms that drought risk is higher for poorer households. It also shows that vulnerability of a household is contingent on two factors; location and endowments. Household responses of water insecurity are enveloped in the institutions which define the resources available to them. Wealth enhances water security in several ways. Wealthier households tend to own a means of transport such as donkeys or bicycles, making water collection easier in times of drought. It also enables them to benefit from hiring and thus empowering them to accumulate more resource to invest in irrigation and storage capacity. The above findings suggest that although households are exposed concurrently to climate change and water insecurity, it is overarching political economy structures and pre-existing inequalities that shape the ability to cope with these changes. This resonates with large body of literature on political ecology that argue that power dynamics and culture shape access to resources and ability to cope in the face of environmental change (Ellis, 2006; Naylor et al., 2007; Start & Johnson, 2004).

The key adaptation strategies used by household to deal with climate variability and water insecurity in the study area are predominantly *ex ante*. These coping strategies include irrigation, planting drought-resistant crops, delaying planting and using early maturing varieties. Depending on remittances or migrating are the most important *ex post* options that household adopted. Water management is critically important to the success of food production in the future. This calls for robust investment in resilient water storage systems and use of underground water.

Theoretically, this thesis has contributed to the ensuing debates about the nature and dimensions of water security. It highlights anthropocentric conceptualisation of water security that takes into cognisance location, time and multiple uses of water. By highlighting the multiplex dimensions of water security, it shows various interrelationships often neglected in literature. Water insecurity is a lived experience that cannot be adequately explained using aggregation based on supply-side and availability indicators only. The study results support the social amplification theory of vulnerability (Kasperson et al., 1988). It shows how existing social structures and power relations undermine or enables adaptation and amplifies vulnerability to climate-induced water insecurity. It shows how local institutions and practices interact with natural hazards such as climate change to heighten or attenuate vulnerability.

In sum, the forgoing findings suggest that an overemphasis on climate change alone as a driver of water insecurity may lead to unidirectional policy interventions to the detriment of other non-climatic drivers of water insecurity. Non-climatic factors provide the arena within which water insecurity resulting from climate change plays out as demonstrated in this thesis. This does not imply that climate change-induced water insecurity should be downplayed. Rather this study suggest that in addressing climate change issues, broader and underlying structures of inequality that gives rise to differentiate vulnerability should be taken into consideration. Climate change should be approached as one of the many challenges that poor smallholder farmers and households face in semi-arid Ghana. It should be treated in tandem with other wider and micro political economy of challenges as empirically demonstrated in this thesis and other studies (Brida et al., 2013; Kima, Okhimamhe, Kiema, Zampaligre, & Sule, 2015; Ndaruzaniye, 2011; Joseph Awetori Yaro et al., 2015).

6.3 Recommendations

Given the growing collective realisation of declining water availability in the Sudan savannah, it is imperative to act now and decisively to curb water insecurity. The local government should work together with traditional authorities on conservation campaigns. It also requires investing in efficient irrigation that enables farmers to get more crop per drop through precision agriculture.

In the short-term groundwater holds key. High collection times and availability pressures could be reduced by increasing borehole density in the short-term. The district assembly has shown commitment toward provision of borehole points. It is imperative that this focus is sustained and incorporates growing population into future water provision plans. Groundwater remains crucial to household water security nonetheless, caution must be taken not to overexploit it. Again, borehole development should take into consideration the seasonality of the water table.

Related to the above point is fixing broken dams; existing water infrastructure has proven too inadequate, old and inefficient at generating and storing sufficient water for household and agricultural purposes. For instance, since its construction in the 1980s, the Worikambo dam has never been desilted. Desilting dams and equipping them with more efficient pumps is essential. This improves the storage capacity of dams and at the same water is more productively used. The current gravity driven dams allow for leakages and seepages. Fixing broken and silted dams alone will not ensure efficiency. Irrigation techniques must also be modified. The current canal flooding approach encourages more wastage of water. Using sprinklers will not only conserve water but avoid leakages that are inherent in the canal flooding approach. This is critical for sustainable agricultural water security.

Revamping livestock in the Sudan savannah is only possible if measures are adapted to water availability through the year. One effective way is through increased storage capacity of dams. This calls to focus a robust investment in dams and check dams. Resilient water storage enables communities to prepare for drought by capturing and storing water in wet years in order to maintain a reliable system during the dry years. Availability of water all-year-round will thus engender livestock production and restore the Sudan savannah as the livestock range for Ghana. Aside from being buffers during droughts, dams have the added advantage of recharging aquifers. Dams also serve as a basin from which new economic activities with wider linkages to poverty reduction develop.

Given the high temperatures and consequent evaporation rate in the Sudan savannah, it is more prudent to invest in underground storage than surface reservoir. Underground water storage minimizes evaporation while refilling aquifers. This can be done by maximising flush floods through constructing check dams using local material and labour. Such check dams will reduce flood risk (a form of water insecurity) and the same time serve as a smart long-term strategy for replenishing depleting aquifers. In times of drought, the water can then be pumped back for use.

Mindful of the role existing structures of inequality perpetuate unequal access to irrigated land, it is imperative that reforms are initiated to protect the poor. This reform could be in a form of byelaws that grant special access to vulnerable households. Such a reform requires the district assembly work directly with traditional authorities in the study communities.

The Ghana National Water Policy provides the framework action for water governance and management in Ghana. While it provides a comprehensive background, it fails to address the local actors and emerging conflicts there. It shows that best approach to water management from a top-down bureaucratic approach. Findings on the contestations and emerging power actors must be taken seriously. Mindful of the already fragile community relations among competing tribes in the Sudan savannah further conflicts arising from desire to control water resources are likely. There is, therefore, the need to review the Ghana National Water Policy to incorporate the multiple vulnerabilities. It is only through that the poor and vulnerable can be adequately protected and given a fair chance in competition for land. Security of tenure is essential if continued access to water is to be enhanced especially for the poor

Further research is needed that explores how contestations and power constellations shape adaptation to water insecurity in the Sudan savannah.

References

Addo, L. Y. (2010). *Institutional Analysis of Urban Water Supply in Ghana: The case of Accra Metropolitan Assembly*. University of Aalborg.

Adger, N. (2006). Vulnerability. *Global Environmental Change*, *16*(3), 268–281. https://doi.org/10.1016/j.gloenvcha.2006.02.006

Adger, W. N., Brooks, N., Bentham, G., & Agnew, M. (2004). New indicators of vulnerability and adaptive capacity. *Change*, *5*(January), 128. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.112.2300&rep=rep1&type=pdf

Agrawal, A. (2008). The role of local institutions in adaptation to climate change, 734–764. Retrieved from http://www.snre.umich.edu/~ifri/Publications/W08I3 Arun Agrawal.pdf

Ainuson, K. G. (2010). Urban Water Politics and Water Security in Disadvantaged Urban Communities in Ghana. *African Studies Quarterly*, *11*(4).

Alcamo, J., Döll, P., Henrichs, T., Kaspar, F., Rösch, T., Siebert, S., … Wikipedia. (2003). Development and testing of the WaterGAP 2 global model of water use and availability. *Hydrological Sciences*, *48*(3), 317–337. https://doi.org/10.1029/2001 WR000355; Döll, P., Kaspar, F., Alcamo, J., Computation of global water availability and water use at the scale of large drainage basins (1999) Math. Geol., 4, pp. 115-122; Döll, P., Kaspar, F., Lehner, B., A global hydrological m(TRUNCADO)

Amlalo, D., & Oppong Boadi, K. (2015). *Ghana ' s Third National Communication Report to the UNFCCC*.

Archer, E. R. M., Oettlé, N. M., & Louw, R. (2008). "Farming on the edge" in arid western South Africa: climate change and agriculture in marginal environments Author(s. *Tadross Source: Geography*, *93*(2), 98–107. Retrieved from http://www.jstor.org

Armah, F. a., Yawson, D. O., Yengoh, G. T., Odoi, J. O., & Afrifa, E. K. a. (2010). Impact of Floods on Livelihoods and Vulnerability of Natural Resource Dependent Communities in Northern Ghana. *Water*, *2*(2), 120–139. https://doi.org/10.3390/w2020120

Asante, F. A., & Amuakwa-Mensah, F. (2014). Climate Change and Variability in Ghana: Stocktaking. *Climate*, *3*, 78–99. https://doi.org/10.3390/cli3010078

Asif, M. (2013). Climatic Change , Irrigation Water Crisis and Food Security in Pakistan Climatic Change , Irrigation Water Crisis and Food Security in Pakistan Climatic Change , Irrigation Water Crisis and Food Security in Pakistan Muhammad Asif Supervisor : Roger Herber.

Awotwi, A., Yeboah, F., & Kumi, M. (2015). Assessing the impact of land cover changes on water balance components of White Volta Basin in West Africa, *29*(2014), 259–267. https://doi.org/10.1111/wej.12100

Badolo, F., & Somlanare, K. R. (2013). Rainfall Shocks, Food Prices Vulnerability and Food Security: Evidence for Sub- Saharan African Countries Badolo Felix 1 Kinda Somlanare Romuald 2, 1–20.

Barron, J., Kemp-Benedict, E., Morris, J., de Bruin, A., Wang, G., & Fencl, A. (2015). Mapping the potential success of agricultural water management interventions for smallholders: Where are the best opportunities? *Water Resources and Rural Development*. https://doi.org/10.1016/j.wrr.2015.06.001

Bates, B. C., Kundzewicz, Z. W., Wu, S., & Palutikof, J. P. (2008a). *2008: Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat*. *Climate change and water*. Geneva. https://doi.org/10.1016/j.jmb.2010.08.039

Bates, B. C., Kundzewicz, Z. W., Wu, S., & Palutikof, J. P. (2008b). *Climate Change and Water Governance* (No. 210). Geneva. https://doi.org/10.1007/978-94-007-5796-7

Bawakyillenuo, S., Yaro, J. A., & Teye, J. (2014). Exploring the autonomous adaptation strategies to climate change and climate variability in selected villages in the rural northern savannah zone of Ghana. *Local Environment*, (October), 1–22. https://doi.org/10.1080/13549839.2014.965671

Baxter, P., & Jack, S. (2008). Qualitative Case Study Methodology : Study Design and Implementation for Novice Researchers, *13*(4), 544–559.

Beck, T., Harris, L., & Luker, E. (2016). Institutional and policy mapping of the water sector in Ghana. University of British Columbia.

Beek, E. Van, & Arriens, W. L. (2014). *Water Security: Putting the Concept into Practice*.

Berazneva, J., & Lee, D. R. (2013). Explaining the African food riots of 2007-2008: An empirical analysis. *Food Policy*, *39*, 28–39. https://doi.org/10.1016/j.foodpol.2012.12.007

Bhattacherjee, A. (2012). *Social Science Research: Principles, Methods, and Practices*.

Bigas, H. (Ed.). (2012). *The Global Water Crisis: Addressing an Urgent Security Issue: Papers for the InterAction Council, 2011-2012*. *Papers for interaction Council*. Canada: UNU-INWEH. https://doi.org/10.13140/2.1.2593.8721

Blanc, E. (2012). The Impact of Climate Change on Crop Yields in Sub-Saharan Africa. *American Journal of Climate Change*, *1*(1), 1–13. https://doi.org/10.4236/ajcc.2012.11001

Boelens, R., Hoogesteger, J., Swyngedouw, E., Vos, J., & Wester, P. (2016). Hydro-social Territories: a political ecology perspective. *Water International*, *41*(1), 1–14. https://doi.org/10.1080/02508060.2016.1134898

Bongaarts, J., & Casterline, J. (2013). Fertility Transition: Is sub-Saharan Africa Different? *Population and Development Review*, *38*(SUPPL.1), 153–168. https://doi.org/10.1111/j.1728-4457.2013.00557.x

Bonsu, Y., & Asare, O. (2004). *Household Water Security and Water Demand in the Volta Basin of Ghana Yaw Bonsu Osei Asare PhD Thesis*.

Brida, A.-B., Owiyo, T., & Sokona, Y. (2013). Loss and damage from the double blow of flood and drought in Mozambique. *International Journal of Global Warming*, *5*(4), 514–531. https://doi.org/Doi 10.1504/Ijgw.2013.057291

Brooks, N. (2003). *Vulnerability ,risk and adaptation : A conceptual framework* (Vol. 38). Retrieved from papers2://publication/uuid/D2016620-F4DE-4C0A-BE4B-78E8F2701438

Brown, O. L. I., & Hammill, A. (2014). Climate Change as the "New" Security Threat: Implications for Africa, *83*(6), 1141–1154.

Bryman, A. (2012). *Social Science Methods* (4th ed.). New York: Oxford University Press. https://doi.org/10 9 8 7 6 5 4 3 2 1

Callo-Concha, D., Gaiser, T., Webber, H., Tischbein, B., Müller, M., & Ewert, F. (2013). Farming in the West African Sudan Savanna: Insights in the context of climate change. *African Journal of Agricultural Research*, *8*(38), 4693–4705. https://doi.org/10.5897/AJAR2013.7153

Calow, R., Macdonald, A., Nicol, A., Robins, N., & Kebede, S. (2006). Drought , water security and rural livelihoods Drought , water security and rural livelihoods. *North Star*.

Carter, M. J., & Fuller, C. (2015). Symbolic interactionism. *Sociopedia.isa*, (1), 1–17. https://doi.org/10.1177/205684601561

Chambers, R. (1989). Vulnerability: How the Poor Cope. *IDS Bulletin*, *20*(2), 1–7. https://doi.org/10.1111/j.1759-5436.1989.mp20002001.x

Chaudhuri, S. (2003). Assessing vulnerability to poverty : concepts , empirical methods and illustrative examples. *... of Economics, Columbia University, New York*. Retrieved from http://info.worldbank.org/etools/docs/library/97185/keny_0304/ke_0304/vulnerability-assessment.pdf

Cisneros, J., Oki, T., Arnell, N. W., Benito, G., Cogley, J. ., Döll, P., … Mwakalila, S. S. (2014). Freshwater resources. In and L. L. W. Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White[Field, C.B., V.R. Barros, D.J. Dokken, K (Ed.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://doi.org/10.2134/jeq2008.0015br

Coirolo, C., & Rahman, A. (2014). Power and differential climate change vulnerability among extremely poor people in Northwest Bangladesh: lessons for mainstreaming. *Climate and Development*, *5529*(July). https://doi.org/10.1080/17565529.2014.934774

Cook, C., & Bakker, K. (2012). Water security : Debating an emerging paradigm. *Global Environmental Change*, *22*(1), 94–102. https://doi.org/10.1016/j.gloenvcha.2011.10.011

Cooke, E., Hague, S., & McKay, A. (2016). *The Ghana Poverty and Inequality Report: Using the 6th Ghana Living Standards Survey 2016*.

Coulibaly, J. Y., Gbetibouo, G. A., Kundhlande, G., Sileshi, G. W., & Beedy, T. L. (2015). Responding to crop failure: Understanding farmers' coping strategies in Southern Malawi. *Sustainability (Switzerland)*, *7*(2), 1620–1636. https://doi.org/10.3390/su7021620

Cousins, B. (1997). How Do Rights Become Real? Formal and Informal Institutions in South Africa's Land Reform. *IDS Bulletin*, *28*(4), 59–68. https://doi.org/10.1111/j.1759-5436.1997.mp28004007.x

Creswell, J. (2009). Research Design: Qualitative, Quantitative and Mixed Methods Approaches.

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly*, *84*(2), 242–261. https://doi.org/10.1111/1540-6237.8402002

Danermark, B., Ekström, M., Jakobsen, L., & Kar. (2002). *Explaining Society: Critical realism in the social sicences*.

De Bruin, A., Pateman, R., Barron, J., Balima, M., Ouedraogo, I., Da Dapola, E., … Kileshye Onema, J.-M. (2015). Setting up agricultural water management interventions – learning from successful case studies in the Volta and Limpopo river basins. *Water Resources and Rural Development*, *6*, 12–23. https://doi.org/10.1016/j.wrr.2015.09.001

Dessalegn, M., Nigussie, L., Michago, W., Tucker, J., Nicol, A., & Calow, R. (2013). Voices from the source, (January), 48. Retrieved from https://www.odi.org/publications/7258-water-security-ethiopia

Douxchamps, S., Ayantunde, A., Panyan, E. K., Ouattara, K., Kaboré, A., Karbo, N., & Sawadogo, B. (2014). Agricultural water management and livelihoods in the crop–livestock systems of the Volta Basin. *Water Resources and Rural Development*, *6*, 92–104. https://doi.org/10.1016/j.wrr.2014.10.001

Duodu, G. O., Amartey, E. O., Asumadu-Sakyi, a. B., Adjei, C. a., Quashie, F. K., Nsiah-Akoto, I., & Ayanu, G. (2012). Mineral Profile of Pito from Accra, Tamale, Bolgatanga and Wa in Ghana. *Food and Public Health*, *2*(1), 1–5. https://doi.org/10.5923/j.fph.20120201.01

Duraiappah, A. K. (1998). Poverty and environmental degradation: A review and analysis of the Nexus. *World Development*, *26*(12), 2169–2179. https://doi.org/10.1016/S0305-750X(98)00100-4

Eguavoen, I. (2013). Climate change and trajectories of blame in Northern Ghana. *ANTHROPOLOGICAL NOTEBOOKS*, *19*(1), 5–24.

Ellis, F. (2006). Agrarian change and rising vulnerability in rural sub-Saharan Africa. *New Political Economy*, *11*(3), 387–397. https://doi.org/10.1080/13563460600841025

EPA. (2000). *Climate change vulnerability and adaptation assessment of the agricultural sector of Ghana*. Accra.

European Environmental Agency. (2016). Water stress. Retrieved December 28, 2016, from http://www.eea.europa.eu/themes/water/wise-help-centre/glossary-definitions/water-stress

Evans, A. E. V, Giordano, M., & Clayton, T. (2012). *Investing in Agricultural Water Management to Benefit Smallholder Farmers in Ghana*. *IWMI Working Papers*. https://doi.org/10.5337/2012.211

Falkenmark, M. (1989). The Massive Water Scarcity Now Threatening Africa-Why Isn â€™ t It Bein Add ressed ? *Royal Swedish Academy of Sciences*, *18*(2), 112–118.

FAO. (2008). Climate change and food security: A framework document. *Food and Agriculture Organization of the United Nations*, 93. Retrieved from http://rstb.royalsocietypublishing.org/content/360/1463/2139.short

FAO. (2011). *Climate change, water and food security*. Rome.

Fischer, G., Shahl, M., Tubiellol, F. N., & Van Velhuizen, H. (1990). Socio-economic and climate change impacts on agriculture: an integrated assessment. *Biological Sciences Phil. Trans. R. Soc. B*, *360*(360), 2067–2083. https://doi.org/10.1098/rstb.2005.1744

Fischhendler, I. (2015). The securitization of water discourse: theoretical foundations, research gaps and objectives of the special issue. *International Environmental Agreements: Politics, Law and Economics*, *15*(3), 245–255. https://doi.org/10.1007/s10784-015-9277-6

Flowerdew, R., & Martin, D. (2005). *Methods in human geography: a guide for students doing a research project*. Retrieved from http://books.google.com/books?id=rRvtmefLjDYC&pgis=1

Fortheringham, S. (1981). Spatial Structure and Distance-Decay Parameters. *Annals of the Association of American Geographers*, *71*(3), 425–436. Retrieved from http://www.jstor.org/stable/2562901

Friedmann, H., & Wallerstein, I. (1996). *The Modern World-System: Capitalist Agriculture and the Origins of the European World-Economy in the Sixteenth Century, Vol. 1*. *Contemporary Sociology* (Vol. 25). New York: Academic Press. https://doi.org/10.2307/2077441

Fuseini, I., & Kemp, J. (2015). A review of spatial planning in Ghana's socio-economic development trajectory: A sustainable development perspective. *Land Use Policy*, *47*(MAY), 309–320. https://doi.org/10.1016/j.landusepol.2015.04.020

Gallopín, G. C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change*, *16*(3), 293–303. https://doi.org/10.1016/j.gloenvcha.2006.02.004

Garrick, D., & Hall, J. W. (2014). Water security and society: Risks, metrics, and Pathways. *Annual Review of Environment and Resources*, *39*, 611–639. https://doi.org/10.1146/annurev-environ-013012-093817

Garu Tempane District Assembly. (2013). The Composite Budget of the Garu-Tempane District Assembly for the 2013 Fiscal Year. Governmenet of Ghana.

Ghana Statistica Service. (2012). *2010 Population and housing census: Final results*. *Ghana statistical service, final results*.

Ghana Statistical Service. (2014). *2010 Population and household census district analytical report: Garu tempane district*.

Ghana Statistical Service. (2015). *Ghana Poverty Map Report*.

Glazebrook, T. (2011). Women and Climate Change: A Case-Study from Northeast Ghana. *Hypatia*, *26*(4).

Global Water Partnership. (2012). Increasing Water Security —A Development Imperactive, 16.

GLSS. (2014). *Poverty profile in ghana 2005-2013*. *Statewide Agricultural Land Use Baseline 2015* (Vol. 1). Accra. https://doi.org/10.1017/CBO9781107415324.004

Gregory, P. J., Ingram, J. S. I., & Brklacich, M. (2005). Climate Change and Food Security. *Philosophical Transactions: Biological Sciences*, *360*(1463), 2139–2148. https://doi.org/10.2307/30041400

Grey, D., & Sadoff, C. W. (2007). Sink or Swim? Water security for growth and development. *Water Policy*, *9*(6), 545–571. https://doi.org/10.2166/wp.2007.021

Grönwall, J. (2016). Self-supply and accountability: to govern or not to govern groundwater for the (peri-) urban poor in Accra, Ghana. *Environmental Earth Sciences*, *75*(16). https://doi.org/10.1007/s12665-016-5978-6

GWP. (2013). *Water and food security–Experiences in India and China*. *Technical Focus Paper* (Vol. 3). Retrieved from http://www.indiaenvironmentportal.org.in/files/file/Water and food security.pdf

GWP. (2014). Assessing water security with appropriate indicators. *Global Water Partnership*. Retrieved from http://www.gwp.org/Global/ToolBox/Publications/P763_GWP_Proceedings_Paper.pdf

Gyau-Boakye, P., & Tumbulto, J. W. (2006). Comparison of rainfall and runoff in the humid south-western and the semiarid northern savannah zone in Ghana. *African Journal of Science and Technology, Science and Engineering Series*, *7*(1), 64–72.

Harrington, C., & Harrington, C. (2013). Fluid Identities : Toward a Critical Security of Water by, (November).

Hartshorne, R. (1959). *Perspective on the Nature of Geography*. Chicago: Rand McNally & Company.

Harvey, D. (2001). Spaces of Capital:towards a critical geography, 1–428.

Heo, J., Yu, J., Giardino, J. R., Cho, H., Heo, J., Yu, J., … Cho, H. (2015). Water Resources Response to Climate and Land-Cover Changes in a Semi-Arid Watershed, New Mexico, USA. *Terr. Atmos. Ocean. Sci. Terr. Atmos. Ocean. Sci*, *26331924*(10), 463–474. https://doi.org/10.3319/TAO.2015.03.24.01

Hesselberg, J. (2015). Becoming poor in Ghana. *Ghana Journal of Geography Vol.*, *7*(1), 97–108.

Hope, R., Foster, T., & Thomson, P. (2012). Reducing risks to rural water security in Africa. *Royal Swedish Academy of Sciences*, *41*(7), 773–776. https://doi.org/10.1007/s13280-012-0337-7

Hope, R., Hansen, K., Mutembwa, M., & Schlessingen, S. (2012). Water Security , Risk and Society, *June 2012*(Synthesis Report), 1–15.

Intelligence Community Assessment. (2012). *Global Water Security*. Washington.

IPCC. (2008). *Climate change and water*. *IPCC Technical Paper* (Vol. 6). https://doi.org/10.1016/j.jmb.2010.08.039

IPCC. (2013). Summary for Policymakers. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 33. https://doi.org/10.1017/CBO9781107415324

ISDR. (2008). Climate Change and Disaster Risk Reduction, 1–12. Retrieved from http://unfccc.int/essential_background/convention/background/

ISDR. (2015a). *Making Development Development Sustainable : The Future of Disaster Risk*

Management. (C. J. Anderson & A. Vienna, Eds.). Tokyo: United Nations.

ISDR. (2015b). *Sendai Framework for Disaster Risk Reduction 2015-2030*.

Kabat, P., R.E. Schulze, Hellmuth, M. E., & Veraart, J. A. (2002). Coping with Impacts of Climate Variability and Climate Change in Water Management: A Scoping Paper. *International Secretariat of the Dialogue on Water and Climate*, (November), 2–27.

Kankam-Yeboah, K., Obuobie, E., Amisigo, B., Kankam-yeboah, K., Obuobie, E., Amisigo, B., & Opoku-ankomah, Y. (2013). Impact of climate change on streamflow in selected river basins in Ghana Impact of climate change on streamflow in selected river basins in Ghana, *6667*(January). https://doi.org/10.1080/02626667.2013.782101

Kasperson, R. E., Renn, O., Slovic, P., Brown, H. S., Emel, J., Goble, R., … Ratick, S. (1988). The Social Amplification of Risk A Conceptual Framework, *8*(2).

Kemp-Benedict, E., Bharwani, S., De La Rosa, E., Krittasudthacheewa, C., & Matin, N. (2009). Assessing Water-related Poverty Using the Sustainable Livelihoods Framework. *Environment*, 1–32.

Kiem, A. S., & Austin, E. K. (2013). Drought and the future of rural communities: Opportunities and challenges for climate change adaptation in regional Victoria, Australia. *Global Environmental Change*, *23*(5), 1307–1316. https://doi.org/10.1016/j.gloenvcha.2013.06.003

Kima, S. A., Okhimamhe, A. A., Kiema, A., Zampaligre, N., & Sule, I. (2015). Adapting to the impacts of climate change in the sub-humid zone of Burkina Faso, West Africa: Perceptions of agro-pastoralists. *Pastoralism*, *5*(1), 16. https://doi.org/10.1186/s13570-015-0034-9

Kothari, C. R. (2004). *Research Methodology: Methods & Techniques*. *New Age International (P) Ltd*.

Liehr, S., Drees, L., & Hummel, D. (2016). Migration as Societal Response to Climate Change and Land Degradation in Mali and Senegal. In J. A. Yaro & J. Hesselberg (Eds.), *Adaptation to Climate Change and Variability in Rural West Africa* (pp. 147–170). Springer International Publishing Switzerland. https://doi.org/10.1007/978-3-319-31499-0

Loftus, A. (2015). Water (in)security: Securing the right to water. *Geographical Journal*, *181*(4). https://doi.org/10.1111/geoj.12079

MacCarthy, D. S., Adiku, S. G. K., & Yangyuorul, M. (2013). Assessing the Potential Impact of Climate Change on Maize Production in Two Farming Zones of Ghana Using the CERES-Maize Model. *Ghana Policy Journal*, *5*, 27–39.

Macmahon, A. (2015). Water Security , Gender and Climate Change in Bangladesh.

Martin, J. (n.d.). Climate changes, water security and possible remedies for the Middle East; World Water Assessment Programme side publications series: scientific paper; 2009.

Mârza, B., Angelescu, C., & Tindeche, C. (2015). Agricultural Insurances and Food Security. The New Climate Change Challenges. *Procedia Economics and Finance*, *27*(15), 594–599.

https://doi.org/10.1016/S2212-5671(15)01038-2

Mason, N., & Calow, R. (2012). Water security: from abstract concept to meaningful metrics: An initial overview of options. *Working Paper 357*.

Mawunya, F. D., & Adiku, S. G. . (2013). Implications of Climate Change for Agricultural Productivity in Ghana: An Agrometeorological Perspective. *Ghana Policy Journal*, *5*, 7–26.

Misra, A. K. (2014). Climate change and challenges of water and food security. *International Journal of Sustainable Built Environment*, *3*(1), 153–165. https://doi.org/10.1016/j.ijsbe.2014.04.006

MOFA. (2013). Facts and figures (2012), (2012).

Molle, F., & Mollinga, P. (2003). Water poverty indicators: Conceptual problems and policy issues. *Water Policy*, *5*(5–6), 529–544.

Mosha, a. C. (2011). Climate change and poverty in Africa: An overview. *Regional Development Dialogue*, *32*(1), 1–30. https://doi.org/10.1080/13504500903354424

Müller-Kuckelberg, K. (2012). Climate Change and its Impact on the Livelihood of Farmers and Agricultural Workers in Ghana, (July), 1–47.

Naidoo, S. (2001). A theoretical conceptualization of Human Security. *Peace, Human Security and Conflict Prevention in ...*, 1–9. Retrieved from http://www.issafrica.org/Pubs/Books/Unesco/Naidoo.pdf

Naylor, R. L., Liska, A. J., Burke, M. B., Falcon, W. P., Gaskell, J. C., Rozelle, S. D., & Cassman, K. G. (2007). The Ripple Effect: Biofuels, Food Security, and the Environment. *Environment: Science and Policy for Sustainable Development*, *49*(9), 30–43. https://doi.org/10.3200/ENVT.49.9.30-43

Ndaruzaniye, V. (2011). Water Security in Ethiopia : Risks and Vulnerabilities ' Assessment. *Global Water Institute*, (2).

Nelson, G. C., Rosegrant, M. W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R., … Zhu, T. (2010). *Food security, farming, and Climate Change to 2050: scenarios, results, policy options*. *Research reports IFPRI*. https://doi.org/10.2499/9780896291867

NOAA. (2008). Drought (A Public Fact Sheet). *National Oceanic and Atmospheric Administration (NOAA)*. National Oceanic and Atmospheric Administration (NOAA). Retrieved from http://www.nws.noaa.gov/os/brochures/climate/DroughtPublic2.pdf

Obuobie, E., Diekkrueger, B., & Reichert, B. (2016). Use of chloride mass balance method for estimating the groundwater recharge in northeastern Ghana Use of chloride mass balance method for estimating the groundwater recharge in, *5124*(January). https://doi.org/10.1080/15715124.2010.505895

OECD/FAO. (2016). *OECD-FAO Agriculture outlook 2016-2025*. Paris: OECD Publishing. https://doi.org/dx.doi.org/10.1787/agr_outlook-2016-en

Oguntunde, P. G. (2004). *Evapotranspiration and complimentarity relations in the water balance of the Volta Basin : field measurements and GIS-based regional estimates*. Retrieved from http://edepot.wur.nl/187640

Ojo, O., Gbuyiro, S. O., & Okoloye, C. U. (2004). Implications of climatic variability and climate change for water resources availability and management in West Africa. *Source: GeoJournal GeoJournal*, *61*(1), 111–119. Retrieved from http://www.jstor.org

Osumanu, K., Abdul-Rahim, L., & Songsore, J. (2010). *Urban water and sanitation in Ghana: How local action is making a difference*. *Water and Sanitation*. Retrieved from http://pubs.iied.org/pdfs/10586IIED.pdf

Owusu, K., & Waylen, P. (2009). Trends in spatio-temporal variability in annual rainfall in Ghana (1951-2000). *Weather*, *64*(5), 115–120. https://doi.org/10.1002/wea.255

Patton, M. Q., & Cochran, M. (2002). A Guide to Using Qualitative Research Methodology.

Pérez Blanco, C. D., & Gómez, C. M. (2014). Insuring water: a practical risk management option in water-scarce and drought-prone regions? *Water Policy*, *16*(2), 244. https://doi.org/10.2166/wp.2013.131

Penrose, J.-P., 2012. Delivering Water Security—The Challenges and Opportunities for DFID, Presentation Given for Oxford Water Security Network. Department for International Development, Oxford.

Poussin, J.-C., Renaudin, L., Adogoba, D., Sanon, A., Tazen, F., Dogbe, W., … Cecchi, P. (2015). Performance of small reservoir irrigated schemes in the Upper Volta basin: Case studies in Burkina Faso and Ghana. *Water Resources and Rural Development*, *6*, 50–65. https://doi.org/10.1016/j.wrr.2015.05.001

Quaye, W. (2008). Food security situation in northern Ghana, coping strategies and related constraints. *African Journal of Agricultural Research*, *3*(5), 334–342. Retrieved from http://www.academicjournals.org/AJAR

Redding, S., & Venables, A. J. (2004). Economic geography and international inequality. *Journal of International Economics*, *62*(1), 53–82. https://doi.org/10.1016/j.jinteco.2003.07.001

Reid, H., Sahlen, L., Stage, J., & MacGregor, J. (2007). The Economic Impact of climate change in Namibia. *Environmental Economics Programme Discussion Paper 07-02*, (November), 1–54.

Riede, J. O., Posada, R., Fink, A. H., & Kaspar, F. (2016). What's on the 5th IPCC Report for West Africa? In *Adaptation to Climate Change and Variability in Rural West Africa*. New York: Springer International.

Rivera, A. L. C. (2011). *Water, agriculture and climate chnage: A global computable general equilibrium analysis*. Universität Hamburg.

Rousset, N., & Brown, P. (2007). The Impact of Climate Change, Water Security and the Implications for Agriculture: The Case of Northern China. *China Perspectives*, *69*(1), 30–38. Retrieved from http://www.jstor.org

Sadoff, B. C., & Muller, M. (2009). *Water Management , Water Security and Climate Change Adaptation : Early Impacts and Essential Responses*. Global Water Partnership.

Sadoff, C. W., Hall, J. W., Grey, D., Aerts, J. C. J. H., Ait-Kadi, M., Brown, C., … Wiberg, D. (2015). *Securing Water, Sustaining Growth: Report of the GWP/OECD Task Force on Water Security and Sustainable Growth*.

Schultz, B., & Uhlenbrook, S. (2007). *"Water Security": What Does It Mean, What May It Imply?* Retrieved from http://isites.harvard.edu/fs/docs/icb.topic1239113.files/WaterSecurityWhatDoesitMean.pdf

Sen, A. (1981). Ingredients of famine analysis: Availability and Entitlements. *The Quarterly Journal of Economics*, *96*(3), 433–464.

Sen, A. (1987). *Hunger and entitlements*. *Wider*.

Shepherd, A., Mitchell, T., Lewis, K., Lenhardt, A., Jones, L., Scott, L., & Muir-Wood, R. (2013). *The geography of poverty, disasters and climate extremes in 2030*. Retrieved from http://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/8633.pdf

Sikor, T., & Lund, C. (2009). Access and property: A question of power and authority. *Development and Change*, *40*(1), 1–22. https://doi.org/10.1111/j.1467-7660.2009.01503.x

Smakhtin, V. (2015). Managing water variability , from floods to droughts, 3.

Soeters, S., Yaro, J. A., & Hesselberg. (2016). *Adaptation to Climate Change and Variability in Rural West Africa*. (J. A. Yaro & J. Hesselberg, Eds.), *Adaptation to Climate Change and Variability in Rural West Africa*. Springer International. https://doi.org/10.1007/978-3-319-31499-0

Solh, M., & Saxena, M. C. (Eds.). (2011). Food secuirty and climate chnage in dry areas. In *International Conference, 1-4 February 2010*. Aleppo.

Somah, T. P. (2013). Climatic Change Impacts on Subsistence Agriculture in the Sudano- Sahel Zone of Cameroon - Constraints and Opportunities for Adaptation.

Start, D., & Johnson, C. (2004). *Livelihood Options ? The Political Economy of Access , Opportunity and Diversification*. *Working Paper 233*. https://doi.org/10.1136/bjo.2008.145912

Strzepek, K., & Boehlert, B. (2010). Competition for water for the food system. *Source: Philosophical Transactions: Biological Sciences Phil. Trans. R. Soc. B*, *365*(365), 2927–2940. https://doi.org/10.1098/rstb.2010.0152

Tachie-Obeng, E., Hewitson, B., Gyasi, E. A., Abekoe, M. K., & Owusu, G. (2014). Downscaled climate change projections for Wa District in the Savanna zone of Ghana. *Journal of Disaster Research*, *9*(4), 422–431.

Taddele, Y., Karlberg, L., Daggupati, P., Srinivasan, R., Wiberg, D., & Rockström, J. (2016). Science of the Total Environment Assessing the implications of water harvesting intensi fi cation on upstream – downstream ecosystem services : A case study in the Lake Tana basin. *Science of the Total Environment*, *542*, 22–35. https://doi.org/10.1016/j.scitotenv.2015.10.065

Tandon, N. (2007). Biopolitics, climate change and water security: impact, vulnerability and adaptation issues for women. *Agenda: Empowering Women for Gender Equity*, *21*(73), 4–17. https://doi.org/10.1080/10130950.2007.9676064

Teye, J. K. (2012). Dynamism of Positionalities Associated With Mixed Methods Research in Developing Countries : Evidence From Ghana. https://doi.org/10.1177/1558689812453332

Teye, J. K., Yaro, J. A., & Bawakyillenuo, S. (2015). Local farmers ' experiences and perceptions of climate change in the Northern Savannah zone of Ghana. https://doi.org/10.1108/IJCCSM-05-2014-0066

The Hague Ministerial Declaration. (2000). Ministerial Declaration of The Hague on Water Security in the 21st Century. *World Water*. Hague.

The Sphere Project. (2011). *The Sphere Handbook. Humanitarian charter and minimum humanitarian standards in humanitarian response*. Rugby, UK: Practical Action Publishing.

The World Water Council. (2016). *Water and Climate: Blue Book*. Ministry of Energy. Mining Water and the Environment, Kingdom of Morroco.

Thompson, H. E., Berrang-Ford, L., & Ford, J. D. (2010). Climate change and food security in Sub-Saharan Africa: A systematic literature review. *Sustainability*, *2*(8), 2719–2733. https://doi.org/10.3390/su2082719

UN-Water. (2013a). *UN-Water Annual report 2013*.

UN-Water. (2013b). Water Security. Retrieved from http://www.unwater.org/fileadmin/user_upload/unwater_new/docs/water_security_poster_Oct2013.pdf

UN Country Team in Ghana. (2007). *Ghana: Situation report on floods, Nov 2007*. Retrieved from http://reliefweb.int/report/ghana/ghana-situation-report-floods-11-oct-01-nov-2007

UNFCCC. (2007). Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries. *United Nations Framework Convention on Climate Change*, 68. Retrieved from http://unfccc.int/resource/docs/publications/impacts.pdf

UNFCCC. (2011). *Water and climate change impacts and adaptation strategies*.

UNFCCC. (2015). ADOPTION OF THE PARIS AGREEMENT. In *ADOPTION OF THE PARIS AGREEMENT*.

UNHABITAT. (2010). *The State of African Cities 2010: Governance, Inequality and Urban Land Markets*. Nairobi: UN-HABITAT. https://doi.org/10.1163/156853010X510807

UNICEF/WHO. (2011). Drinking Water Equity, Safety and Sustainability. *JMP Thematic Report on Drinking Water*, 62. https://doi.org/SBN 978 92 806 4613 9

Verdery, K. (2003). *The Vanishing Hectare: Property and Value in Postsocialist Transylvania*. New York: Cornell University Press.

W. Neil Adger, S. H. K. B. D. C. M. H., Adger, W., Huq, S., Brown, K., Adger, N., Huq, S., … Hulme, M. (2003). Adaptation to climate change in the developing world. *Progress and Development Studies*, *3*(3), 179–195. https://doi.org/10.1191/1464993403ps060oa

Water Research Institute. (2002, June). How many boreholes are enough? *Info Water Quarterly Newsletter, CSIR Water Research Institute*.

White, C. (2012). "Understanding water scarcity : Definitions and measurements", GWF Discussion Paper 1217, Global Water Forum, Canberra, Australia, 9–11. Retrieved from http://www.globalwaterforum.org/2012/05/07/understanding-water-scarcity-definitions-and-measurements/

Whitehead, A. (2002). Tracking Livelihood Change: Theoretical, Methodological and Empirical Perspectives from North-East Ghana* Theorising Livelihoods and Developing a Methodology. *Journal of Southern African Studies*, *28*(3). https://doi.org/10.1080/030570702200000652

Wiltshire, A. J., Kay, G., Gornall, J. L., & Betts, R. A. (2013). The impact of climate, CO2 and population on regional food and water resources in the 2050s. *Sustainability (Switzerland)*, *5*(5), 2129–2151. https://doi.org/10.3390/su5052129

WMO. (2016). Provisional WMO Statement on the Status of the Global Climate in 2016. Retrieved December 28, 2016, from https://public.wmo.int/en/media/press-release/provisional-wmo-statement-status-of-global-climate-2016

World Bank. (2004). *Towards a Water-Secure Kenya: Water Resources Sector Memorandum*. Nairobi. Retrieved from http://documents.worldbank.org/curated/en/789291468753297032/Kenya-Towards-a-Water-Secure-Kenya-water-resources-sector-memorandum

World Economic Forum. (2011). Water Security: The Water-Food-Energy-Climate Nexus. *World Economic Forum Water Initiative*. https://doi.org/10.5822/978-1-61091-026-2

Wossen, T., & Berger, T. (2015). Climate variability, food security and poverty: Agent-based assessment of policy options for farm households in Northern Ghana. *Environmental Science and Policy*, *47*, 95–107. https://doi.org/10.1016/j.envsci.2014.11.009

WWAP (World Water Assessment Programme). (2012). *World Water Development Report Volume 4: Managing Water under Uncertainty and Risk. Water demand: What drives consumption?* (Vol. 1). https://doi.org/10.1608/FRJ-3.1.2

Xiao-jun, W., Jian-yun, Z., Shahid, S., Xing-hui, X., Rui-min, H., & Man-ting, S. (2014). Catastrophe theory to assess water security and adaptation strategy in the context of environmental change. *Mitigation and Adaptation Strategies for Global Change*, *19*(4), 463–477. https://doi.org/10.1007/s11027-012-9443-x

Yamane, T. (1967). *Statistics, An Introductory Analysis* (Second). New York: Harper and Row.

Yansaneh, I. (2005). Household Sample Surveys in Developing and Transition Countries. In *Studies in Methods* (Vol. F, p. 617). New York: United Nations. Retrieved from http://unstats.un.org/unsd/hhsurveys/

Yaro, J. A. (2004). Theorizing food insecurity: building a livelihood vulnerability framework for researching food insecurity. *Norsk Geografisk Tidsskrift - Norwegian Journal of Geography*, *58*(1), 23–37. https://doi.org/10.1080/00291950410004375

Yaro, J. A. (2013). Building Resilience and reducing Vulnerability to Climate Change : Implications for Food Security in Ghana.

Yaro, J. A. (2013). The perception of and adaptation to climate variability/change in Ghana by small-scale and commercial farmers, *13*(6), 1259–1272. https://doi.org/10.1007/s10113-013-0443-5

Yaro, J. A., & Hesselberg, J. (2010). THE CONTOURS OF POVERTY IN NORTHERN GHANA : POLICY IMPLICATIONS FOR COMBATING FOOD INSECURITY, *1*, 81–112.

Yaro, J. A., Teye, J., & Bawakyillenuo, S. (2014). Local institutions and adaptive capacity to climate change / variability in the northern savannah of Ghana, (September), 37–41. https://doi.org/10.1080/17565529.2014.951018

Yaro, J. A., Teye, J., & Bawakyillenuo, S. (2015). Local institutions and adaptive capacity to climate change/variability in the northern savannah of Ghana. *Climate and Development*, *7*(3), 235–245. https://doi.org/10.1080/17565529.2014.951018

Yidana, S. M., Banoeng-Yakubo, B., Aliou, A.-S., & Akabzaa, T. M. (2012). Groundwater quality in some Voltaian and Birimian aquifers in northern Ghana—application of mulitvariate statistical methods and geographic information systems. *Hydrological Sciences Journal*, *57*(6), 1168–1183. https://doi.org/10.1080/02626667.2012.693612

Yiran, A. G. B. (2014). *Hazards and Vulnerability mapping for adaptation to climate change risks in savannah ecosystem : a case study of the Upper East region, Ghana*. University of Ghana.

Yiran, G. A. B., Kusimi, J. M., & Kufogbe, S. K. (2012). A synthesis of remote sensing and local knowledge approaches in land degradation assessment in the Bawku East District, Ghana. *International Journal of Applied Earth Observation and Geoinformation*, *14*(1), 204–213. https://doi.org/10.1016/j.jag.2011.09.016

Yiran, J. M.Kusimi,(2011). Application Of Local Knowledge In Land Degradation Assessment In The Bawku East Municipality. *Ghana Journal Of Geography Vol.3.* , Page 88-125.

Yiran, G. B. A. (2016). Mapping social captial for adaptaion to climatic variability in a Savannah ecosystem of Ghana. In J. A. Yaro & J. Hesselberg (Eds.), *Adaptation to Climate Change and Variability in Rural West Africa* (pp. 215–237). Springer International. https://doi.org/10.1007/978-3-319-31499-0

Yussif, S. (2012). Assessment of Water Sources in Terms of Availability, Use and Sufficiency in the Northern Region of Ghana. http://hdl.handle.net/123456789/5893, 146.

Zeitoun, M., Lankford, B., Krueger, T., Forsyth, T., Carter, R., Hoekstra, A. Y., … Matthews, N. (2016). Reductionist and integrative research approaches to complex water security policy challenges. *Global Environmental Change*, *39*, 143–154. https://doi.org/10.1016/j.gloenvcha.2016.04.010

Zimmer, D., & Renault, D. (2003). Virtual water in food production and global trade: Review of methodological issues and preliminary results. *... on Virtual Water Trade, Value of Water ...*, (1), 1–19. Retrieved from http://www.worldwatercouncil.org/fileadmin/wwc/Programs/Virtual_Water/VirtualWater_article_DZDR.pdf

Zimmerman, F. J. (2000). Barriers to Participation of the Poor in South Africa Õ s Land Redistribution, *28*(8).

Appendix 1: Questionnaire for household heads

I am an MPhil student at the University of Ghana, Legon and I am conducting my research on the topic "Climate change/variability and water security in the Sudan savannah zone of Ghana". Please, you have been identified as a knowledgeable informant on this topic and hence I will be very grateful if could complete this questionnaire. This study is purely an academic exercise as such all information provided will be treated as strictly confidential and for academic purpose only. Responses will be used anonymously and cannot be traced to the persons who provide them. Thank you in advance for your time and contribution to this research.

Name study area:

a. Worikambo (Guuni/ Boko) b. Kolmasug c. Denugu/Danvorga d. Bugri-Bulpielsie

Gender: a. Male [ ] b. Female Questionnaire number

……………..

Household information

1. Marital status a. Single b. Married c. divorced

2. Household size ……………….
3. Occupation of household head or spouse
   a. Farming b. government work c. trading d. other…………….
4. What is the most important source of household income
   a. Farming b. Trading c. remittance d. other……………….
5. Do you have any other source of income? a. Yes b. No
6. Please specify……………………………………………………………………………..

Village water sources and water availability

7. Type of source:
   a. Surface (e.g. stream; river) b. ground (e.g. spring, well, borehole) c. other…...
8. Is this water sources available throughout the year?
   a. Yes b. No
9. If seasonal, which period (months) is this source not available?
   a. December-February [ ] b. march – May [ ] c. June-august [ ] d. September-November [ ]

10. Do you like the taste/quality of this source of water
    a. Yes [ ]   b. No [ ]
11. Why comments……………………………………………………………………..

Water access

12. How far in distance is your community/household from water source
    a. less than 50 m [ ] 50 - 100 m [ ] 100 -200 m [ ] over 200m [ ]
13. How is the water source owned and managed?
    a. Open access [ ]   b. common property [ ]   c. private [ ]

14. How do you transport water to your household?
    a. Head/hand [ ] b. donkey cart [ ] c. bicycle [ ] d. pipe [ ]

15. How long in terms of time do you use to collect water in one round trip ………………..
    a. Less than 30 mins [ ] b. 30mins -1 hour [ ] c. 2 hours and above
16. How many hours do you spend in a day fetching water
    a. Less than [ ] b. 1 hour [ ] c. 2 hours [ ] d. 3 hours [ ] e. 4 and above [ ]
17. On the average how many buckets (34 cm size/ "Kufuor gallons") of water do you need for your household per day? 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 [ ] 6 and above [ ]
18. Is this enough to meet your needs?
    a. Yes [ ] b. No [ ]

19. What will you say about the following issues of water in your area?

    Tick (✓) as appropriate in the columns under ***Severe problem, Minor problem, Not a problem*** **and** ***don't know,*** in the table below.

Water issue	Severe problem	Minor problem	Not a problem	Don't know
There is unhealthy competition for water				
Too much time is wasted in search of water				
Children are either late or absent from school				
there are conflicts associated with access to water in this community				
Access to water is dependent on one's social and economic status.				
Risk of drinking water from untreated sources				
Water availability in this community is dependent on the season				
Droughts and floods are common				

Water use

20. List sources and the different uses in the table below

Source of water	Household uses	Agricultural

21. Do you use water for income generation and production?
    a. Yes b. No
22. If yes, how do you use water for income generation and production?
    a. Irrigation b. pottery c. brewing d. other……………..
23. What proportion of your household income depends on productive water usage?
    a. A quarter b. Half c. a third d. All

24. What determines the amount of water you use
    a. Distance b. time spent to fetch water c. cost of water in cash

25. Which of the following most influences your decision to use a water source in your household
    a. Time b. distance c. quality
26. Have you or a family member fall sick from drinking/using water from the current source
    a. Yes Bono

KNOWLEDGE ON CLIMATIC VARIABILITY/CHANGE AND WATER SECURITY

Temperature

27. Have you noticed any long-term changes in the mean temperature over the past 20 years?

    Yes No

28. How has the number of hot days changed

    a. Increased b. decreased c. no changes

29. How have these changes affected water availability…………………………………………………………………………………………

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

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

………………………

Rainfall

30. Have you noticed any long-term changes in the mean rainfall over the past 20 years?

    a. Yes b. No

31. Are the changes in terms of distribution or amount

    a. Distribution b. amount c. both

32. How are these changes manifested

a. Late start of rainfall season

b. Short rainfall season

c. More floods

33. What climatic variable strongly affects you agricultural production

    a. Temperature b. rainfall c. Storm d. Other please specify…………………………………

34. In the past 20yrs, either from your own observation or your parent's account, what time was the rainy season starting?

    a. March [ ] b. April [ ] c. May [ ] d. June [ ]

35. . What time are the rains starting now? a. March [ ] b. April [ ] c. May [ ] d. June [ ]

36. In the past, either from your own observation or your parent's account, what time were the rains ending? a. August [ ] b. September [ ] c. October [ ] d. November [ ] e. Other …………

37. What time are they ending now? a. August [ ] b. September [ ] c. October [ ] d. November e. Other …..

38. When the rain starts, does it rain regularly throughout the season?
    a. Rains regularly [ ] b. There are some breaks [ ] b. Can't tell [ ]

39. If there are breaks, can you tell how long some of the breaks last?
    A. Two weeks [ ] b. 3 weeks [ ] c. 1month [ ]

40. Which crops are most affected by variable water availability:

Floods

41. How often do floods occur in your community? A. Several times in a year b. Once in every yr. c. Once in every 2yrs c. Once in every 5yrs d. Other (specify) …………

42. Did the last worst floods destroy property in your community? a. Yes [ ]b. No [ ]

43. If yes, which properties were affected by the floods?
a. Houses [ ] b. Farms [ ] c. Source of drinking water [ ] f. Other …………………………….

44. Over the past 30 yrs., do you think that the quantity/amount of the property affected is increasing?
a. Yes [ ] b. No [ ]

45. Why the number of properties is affected increasing?
a. More waters come now than before [ ] b. More people are settling in flooded areas [ ]
c. Because of late farming [ ] d. Other…… …………

46. So what have you done or are you doing now to avoid such an event?
a. Relocated [ ] b. Doing nothing [ ] c. Putting up flood resistant Buildings [ ] c. Planting early in flood prone areas d. Other …………………..
47. Does the flood affect your source of drinking water? a. Yes [ ] b. No [ ]

48. How is your source of drinking water affected? a. Polluted [ ] b. Cut off because access route is flooded [ ] c. Silted with eroded material [ ] d. Other ………………………

49. How does this situation affect your life?
a. More time is spent looking for water [ ] b. Increase health burden [ ] b. Spend more money to buy water [ ] c. Water becomes scarce d. Other …………………………………

50. How do you cope with this problem?
a. Buy water from Tankers [ ] b. Receive water from NADMO /NGOs c. Use the polluted water [ ] c. Move to a nearby community to fetch water [ ] d. Other …………………..

51. In your opinion, what do you think is causing the floods to come frequently?
a. More rain falling within a short period of time [ ] b. Increased amount of rainfall [ ]
c. Increased runoff [ ] d. Expansion of human activities into flooded areas [ ] e. Other......................

52. In your opinion, what do you think can be done to reduce/prevent flood impacts?
53. a. Relocate houses in valleys [ ] b. Stop farming in valleys [ ] c. Plant early maturing crops in flood zones [ ] d. Construct drains [ ]

Drought

54. Have you observed drought in this community? a. Yes [ ] b. No [ ]

55. If yes, how often does drought occur here?
a. Very often [ ] b. Often [ ] c. Not often [ ] d. don’t know [ ]

56. What effect does the drought have on you?
a. Crop failure [ ] b. Drying up of water source c. Trees dying [ ] c. Other …………………………

57. How do you cope with these situations?
a. Remittances from relatives [ ] b. migration [ ] c. Other………………

58. Will you say that the occurrence of drought is increasing or decreasing over the past 30 years?
a. Increasing [ ] b. Decreasing [ ] c. Remained the same [ ] d. don’t know [ ]

59. What do you do when there is a drought?

a. Migrate to where it is raining to farm [ ] b. Switch from farming to trading [ ] c. Irrigate our farms
d. Planting drought resistant crops [ ] e. Other …………………………

60. Does your source of water get depleted when there is drought? a. Yes [ ] b. No [ ]

61. When this happens, what do you do?
a. We move to the nearby community to get water [ ] b. Use untreated water [ ] c. Buy water from tankers [ ] d. Other ……………………………..

62. Does the distance to your water source increase when there is a drought? a. Yes [ ] b. No [ ]

63. What effect does drought have on your animals/poultry?
a. Death [ ] b. Wasting [ ] c. Diseases [ ] d. Other …….

64. When there is drought how many animals do you lose?
a. Less the 5 [ ] b. 5-10 [ ] c. 11-20 [ ] d. Other ……………….

65. What are you doing personally or as a community to forestall the effects?
a. Switching to irrigation [ ] b. Planting drought resistant crops [ ] c. Switch from farming to other non-rain dependent activities [ ] d. Other …………………………………

66. Can you list your livelihood activities and score them from 1 to 10, (where 1 is lowest and 10 is the highest) how they are affected by drought (highest score is given to the most affected)?

67. Activity — score

Activity	score
…………………………………	……………………….
…………………………………	……………………….
…………………………………	………………………
……………………………….	……………………….
………………………………..	………………………

Adaptation

68. Do you practice dry season gardening or farming? a. Yes [ ] b. No
69. If yes, where do you get water to water your crops/animals?
a. Dam [ ] b. Pond/dugout [ ] c. Borehole [ ] d. Well [ ] e. Other ……………………………..

70. Are you doing this as a measure against drought or dry spell? a. Yes [ ] b. No [ ]

71. If yes, is this effective in resolving the impacts of droughts? a. Yes [ ] b. No [ ]

72. How do you respond to the dry spells? a. Delay in planting [ ] b. Planting short maturing crops [ ]
c. Planting drought tolerant crops [ ] d. Other ……………………
73. Have you changed crops as a result of the water situation a. Yes [ ] b. No [ ]

Appendix 2: Individual interview guide

General information about climate change/variability and water security people

1. What water resources are available
2. What are the ways in which you make use of them
3. Are these water resources available all year round?
    - What determines their variability?
    - How does it affects what you do and the outcomes you experience?
4. Are water sources now closer than before or further
5. Have you noticed any changes in the climate over the past years? (Probe on the nature of changes observed)
6. How do you notice or see these changes?
7. What are the factors causing variations in climate from your own observations?
8. Do you think climate variability has increased over the past 10 years?
9. Can you tell me some of the problems caused by this variation in climate?
10. How do these changes and variations affect:
    - Water availability for household
    - Distance to fetch water household water security
    - Quality (perceived safety) of water you fetch for household use
    - agricultural water use
11. How are households impacted by these changes
12. Which factors make a household vulnerable to these changes? For instance: Income, Occupation, Location, Household size
13. What households are most affected by these changes- why and how? (water variability)
14. From your own observations, what are the non-climatic factors that cause water insecurity?
15. How have these changes influenced water availability?
16. How do these changes enables or inhibit household water use
17. How do these changes enables or inhibit agriculture use
18. In your opinion has the frequency of floods increased?
19. What have you seen or observed that informed your answer
20. In your opinion has the frequency of droughts increased?
21. What have you seen or observed that informed your answer
22. What do these changes mean for your livelihoods activities over the years?
23. What have you or are you currently doing to reduce the impacts of these changes

Appendix 3: Focused Group Guide (FGD)

General information about climate variability (past and present), climate variability and water security.

1. Can you give a brief history of this community
2. What occupation do most people in this community engage in?
3. What agricultural activity is this community best known for; crop or livestock?
4. Can you tell me which crops are grown in this community?
5. Which of this in terms of ranking is best grown in this community?
6. What other economic activities are directly reliant water in this community?
7. Who engages in them?
8. Can you tell me the sources of water for household use in this community?
9. Which source(s) is/are most used?
10. Which source(s) is most preferred?
11. Do these sources change over the course of the year? Why and which ones?
12. Can you tell me the source of water for you agricultural use?
13. How do you normally obtain water for your household in this community?
14. Who in the household fetches water for household use?
15. Can someone tell me where you get water for dry season crops?
16. If you do not farm during the dry season, what are the factors that prevent you from doing so?
17. Can you describe the water situation in this community?
18. How do you understand climate variability?
19. For the past years till now, have you observed any changes and variations in rainfall?
20. How has it been varying from the past? (10-15 years ago).
21. What are the most important occurrences that have taken place as a result of this change?
22. How often do floods hazards occur in the area?
23. When was the last drought and how often does it occur?
24. Do you think there is a relationship climate change and the occurrence of these hazards?
25. How are they impacting the villages living around? Explain.
26. Can you describe how these changes affect water availability, quality, and accessibility?
27. Which specific crops are most affected water scarcity?
28. From daily observations, which climatic factors mostly affect the water?

29. Which categories of people are the most affected or vulnerable to this impact of climate variability? Explain why.
30. How do people manage in times of water scarcity?
31. In your own opinion, what measures do you suggest to be put in place to cope with the impacts of climate variability influencing water security?

Thank you for your time and response!

Appendix 4: Sample daily rainfall(mm) data for Garu obtained from Ghana Meteorological Agency

1983	01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1983	02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				0.0
1983	03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35.5	35.5
1983	04	0.0	22.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.5	0.0	0.0	0.0	0.0		30.3
1983	05	2.0	0.0	0.0	0.0	0.0	0.0	3.9	5.8	2.1	0.0	0.0	0.0	45.7	0.0	0.0	0.0	0.0	8.5	0.0	1.9	0.0	0.0	5.4	0.0	0.0	23.4	0.1	0.0	0.0	12.9	5.7	117.4
1983	06	0.0	11.9	0.0	0.0	18.9	0.0	0.0	3.6	0.0	3.8	0.0	0.0	0.0	0.0	1.4	20.1	0.0	5.8	0.2	0.0	0.0	2.8	0.0	20.9	0.0	0.0	0.0	0.0	0.0	0.0		89.4
1983	07	0.0	0.0	0.2	20.7	18.3	0.0	14.2	10.5	7.3	0.0	23.2	0.0	22.0	0.0	0.0	34.9	0.0	0.2	0.0	0.0	0.0	0.0	20.8	0.0	0.0	0.0	0.0	0.0	0.0	29.5	0.0	201.8
1983	08	0.0	0.0	3.0	0.0	25.1	0.0	32.4	8.6	0.0	0.0	11.6	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.8	13.2	0.0	0.0	0.0	44.5	8.7	49.1	0.0	5.8	3.0	0.0	223.2
1983	09	48.7	0.0	0.0	0.0	0.5	0.0	6.8	0.0	0.3	11.9	0.0	21.4	0.0	3.3	8.0	18.8	0.0	7.3	0.0	0.0	18.1	0.0	0.0	0.0	0.0	21.2	0.0	0.0	0.2	0.0		166.5
1983	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1983	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
1983	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1984	01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1984	02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0
1984	03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.6	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	44.0
1984	04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0	3.6	0.0	0.0	0.0	2.0	0.0	18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	79.8	0.0	0.0	0.0	0.0		106.3
1984	05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	2.5	0.0	0.0	30.4	0.0	1.3	0.0	0.0	0.0	0.0	1.1	9.2	1.4	0.0	0.0	11.4	25.4	0.0	9.6	0.0	0.0	9.1	0.0	102.3
1984	06	0.0	0.0	0.0	0.0	29.3	3.9	0.0	0.0	0.0	0.0	1.4	1.5	12.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.2	0.0	0.0	0.0	25.1		75.5
1984	07	0.0	5.2	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	18.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.3	0.0	0.0	0.0	0.0	22.4	0.0	0.0	0.0	74.2
1984	08	22.3	0.0	5.2	0.0	33.7	0.0	0.0	0.0	0.0	0.0	12.5	0.0	0.0	0.0	0.0	10.6	13.0	0.0	18.1	0.0	11.2	0.0	0.0	8.1	0.0	0.0	17.8	0.0	4.7	0.0	49.0	206.2
1984	09	0.0	0.0	4.3	0.0	0.0	17.1	0.0	0.0	0.0	8.8	83.2	0.0	9.9	9.9	0.0	0.0	18.4	4.6	0.0	10.9	2.2	0.0	0.0	8.6	0.0	4.8	13.4	1.4	0.0	9.7		207.2
1984	10		0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.0	0.0	24.9	0.0	0.0	1.4	0.0	8.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	61.4
1984	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	40.5	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		40.9
1984	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1985	01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1985	02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				0.0
1985	03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.6	0.0	0.0	28.6
1985	04	0.0	0.0	0.0	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.6	0.0	0.0	0.0	0.0		24.7
1985	05	0.0	0.0	0.0	0.0	0.0	0.0	0.1	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.7	0.0	18.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0	69.1
1985	06	0.0	0.0	0.0	0.0	0.0	0.0	14.4	0.0	0.0	16.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.6	4.2	0.0	0.0	0.1	0.0	0.0	15.3	13.5	1.5	0.0	0.0	13.6		90.0
1985	07	0.0	24.6	31.6	0.0	0.0	14.9	0.0	4.5	0.0	2.4	0.0	0.0	23.8	0.0	0.0	11.8	0.6	13.0	0.0	0.0	0.0	0.0	9.6	0.0	0.1	9.6	0.0	6.6	1.2	0.0	0.0	154.3

1985	**08**	19.7	16.1	0.0	31.1	1.9	0.0	5.5	0.0	19.6	0.1	0.0	0.0	16.3	18.4	4.7	2.1	8.4	0.0	0.0	0.0	0.0	0.0	0.6	0.3	16.2	0.0	0.0	0.0	2.1	0.3	1.9	165.3
1985	**09**	25.6	1.7	0.0	0.0	1.3	23.4	0.0	0.0	6.3	5.6	38.5	0.0	0.0	0.0	0.0	7.5	3.5	1.5	0.0	0.0	1.7	0.0	0.0	13.0	0.0	18.8	4.1	0.0	0.0	0.0		152.5
1985	**10**	0.0	11.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.7
1985	**11**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
1985	**12**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1986	**01**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1986	**02**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				0.0
1986	**03**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.5
1986	**04**	35.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.9	0.0	0.0	0.0	0.0	9.6	0.0	0.0	0.0	0.0		55.6
1986	**05**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7	0.0	0.9	8.0	0.0	0.1	0.0	0.0	0.8	0.0	0.0	14.1	0.0	0.0	6.9	0.0	0.0	0.0	0.0	38.5
1986	**06**	0.0	0.0	0.0	11.5	0.0	0.0	0.0	0.0	29.5	0.0	0.0	2.5	23.4	0.0	0.0	0.0	0.0	0.0	0.0	26.7	0.0	0.0	0.0	33.9	0.0	0.0	0.0	0.0	0.0	44.2		171.7
1986	**07**	0.0	0.0	9.1	0.0	0.1	0.0	0.0	11.2	0.0	0.0	2.6	0.0	0.0	22.1	0.0	4.4	0.0	0.0	0.0	41.0	19.2	0.0	1.2	0.0	0.0	0.0	11.7	0.0	0.0	0.0	53.4	176.0
1986	**08**	1.4	0.0	0.7	0.0	0.0	0.0	8.7	0.0	0.0	16.9	0.0	0.0	0.0	23.6	0.0	0.2	0.0	17.0	0.0	0.0	0.0	18.9	44.7	0.0	0.0	0.0	35.2	0.0	0.0	19.1	0.1	186.5
1986	**09**	87.6	0.0	0.0	47.1	0.0	0.0	12.5	0.2	0.0	0.0	0.0	3.8	5.7	0.0	0.0	0.0	0.0	0.0	21.2	0.1	28.7	2.1	4.8	23.2	0.0	0.2	0.0	0.0	6.7	0.0		243.9
1986	**10**	0.0	0.0	0.0	0.0	15.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	54.4	0.0	42.9	114.5
1986	**11**	5.1	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		8.6
1986	**12**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1987	**01**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1987	**03**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.2
1987	**05**	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0	3.0	0.0	0.0	8.0	2.9	0.0	0.0	12.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.5	0.0	0.0	51.1
1987	**06**	1.0	0.0	6.1	1.0	1.0	36.4	4.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.4	13.5	0.0	34.5	0.0	0.0		120.1
1987	**07**	0.0	3.8	0.3	3.7	0.0	0.0	1.7	9.8	0.0	0.0	1.4	0.0	0.0	21.1	0.0	0.0	21.1	1.3	0.7	30.5	0.0	0.0	0.0	3.4	0.0	21.2	15.6	9.0	0.0	25.0	0.0	169.6
1987	**08**	0.0	16.6	0.0	17.4	0.0	33.5	4.3	8.0	0.0	1.4	29.1	1.0	2.9	44.5	6.6	0.0	0.0	0.0	0.0	16.9	0.0	1.5	0.0	13.6	0.0	0.0	14.1	0.0	0.0	44.5	27.7	283.6
1987	**09**	0.0	14.0	0.0	10.2	0.0	0.0	0.0	0.0	13.6	0.0	0.0	0.0	0.0	84.6	26.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.8	29.8	2.3	0.5	0.0	3.8		202.0
1987	**10**	0.0	0.0	39.6	0.0	0.0	4.6	0.0	5.0	0.0	0.0	0.0	0.0	5.2	0.0	9.5	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	69.9
1987	**12**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1988	**01**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1988	**02**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			0.0
1988	**03**	0.0	6.3	0.0	0.0	0.0	36.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.4	0.0	0.0	0.0	0.0	0.0	50.1
1988	**04**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.6	0.0	0.0	0.0	0.0	0.0	14.9	0.0	0.0	0.0	0.0	0.0	22.0	0.0	0.0	0.0	0.0	0.0		45.5
1988	**05**	0.0	0.0	0.2	0.0	0.4	0.0	12.1	0.0	0.0	0.0	29.8	0.0	0.0	0.0	0.0	0.0	0.0	6.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.8	0.0	9.2	0.0	27.5	96.6
1988	**06**	0.0	0.0	0.0	32.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	23.4	0.0	14.0	0.0	0.0	7.7	0.0	0.0	0.0	0.7	31.1	0.0		112.5

1988	**07**	0.0	0.6	0.0	0.0	0.0	1.1	3.5	9.0	0.4	0.2	0.0	11.4	0.0	0.0	0.0	0.0	16.4	1.3	0.0	0.0	0.0	0.0	45.7	5.4	0.0	0.0	9.2	0.0	0.0	6.1	8.8	119.1
1988	**08**	0.0	0.0	0.0	0.0	1.5	0.0	0.0	19.6	0.0	78.4	14.7	0.0	0.0	0.2	8.7	2.5	0.5	13.7	0.0	0.0	18.7	7.8	0.9	0.0	8.0	0.0	12.3	31.0	0.0	12.8	1.8	233.1
1988	**09**	0.0	0.0	20.0	25.4	0.9	3.8	36.3	4.1	23.4	72.5	14.2	8.4	4.3	0.0	0.0	19.8	0.0	0.0	0.0	0.1	0.0	19.4	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0		253.8
1988	**10**	0.0	1.8	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.8
1988	**11**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	25.3	0.0	0.0		25.6
1988	**12**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1989	**01**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1989	**02**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				0.0
1989	**03**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	3.2	0.0	0.0	0.0	0.0	4.3	15.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.4
1989	**04**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
1989	**05**	0.0	0.8	0.0	0.0	0.0	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.1	28.6	23.7	0.0	0.0	6.9	0.0	0.0	0.0	0.0	0.0	4.8	0.0	0.0	0.0	104.2
1989	**06**	0.0	0.0	6.9	0.0	0.0	0.0	20.9	0.0	0.0	0.0	0.0	8.9	0.0	29.8	0.0	0.0	0.0	16.4	0.0	0.0	0.0	0.0	16.5	0.0	0.0	0.0	34.8	0.0	4.3	5.5		144.0
1989	**07**	7.9	0.0	0.0	12.5	0.7	0.4	0.0	9.1	0.0	24.8	0.0	0.0	8.9	0.1	0.0	0.0	1.4	0.0	0.0	0.0	22.4	6.5	0.0	0.0	0.0	1.3	0.1	6.1	3.9	60.7	53.7	220.5
1989	**08**	3.4	0.0	0.0	0.5	0.0	0.0	11.8	0.4	37.4	2.0	0.1	6.6	104.2	2.7	3.3	0.0	1.1	29.3	2.3	0.6	0.0	0.0	1.9	51.5	0.6	21.2	0.0	3.3	0.0	0.0	16.1	300.3
1989	**09**	57.2	0.0	32.7	1.0	0.0	32.9	0.2	0.0	0.0	14.9	0.0	31.7	15.1	6.1	0.0	0.0	0.0	0.0	0.0	26.5	0.0	3.7	0.0	0.0	0.0	25.8	0.0	0.0	26.0	0.0		273.8
1989	**10**	0.0	12.2	0.0	0.0	32.1	0.0	0.0	5.0	8.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	58.5
1989	**11**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
1989	**12**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.6	0.0	0.0	14.6
1990	**01**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1990	**02**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				0.0
1990	**03**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1990	**04**	0.0	0.0	0.0	0.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	0.0		29.4
1990	**05**	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.5	0.0	0.0	0.0	21.9	29.6	0.0	0.0	0.2	0.0	36.7	6.3	132.4
1990	**06**	0.0	4.5	0.0	0.0	16.8	0.0	19.3	0.0	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.0	0.0	0.0	16.5	0.0	0.0	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		61.5
1990	**07**	0.0	0.0	0.0	0.0	9.3	0.0	7.4	0.0	64.2	1.7	0.0	3.8	10.8	2.8	48.6	6.7	11.2	0.0	1.7	1.6	10.7	0.0	3.4	3.7	0.0	0.0	30.7	0.0	0.0	0.5	9.1	227.9
1990	**08**	14.3	0.0	0.0	12.7	6.2	0.0	0.0	8.0	1.1	2.9	0.0	0.0	33.7	0.0	16.2	0.0	0.0	0.0	0.8	0.0	0.0	0.0	1.2	0.1	0.0	0.0	1.5	27.4	73.7	0.2	0.0	200.0

Appendix 5: Sample daily Maximum Temperatures (in Celsius) data for Garu obtained from Ghana Meteorological Agency

1983	1	36.608	36.321	37.489	35.497	32.346	34.004	34.352	35.024	36.379	36.732	36.947	35.993	38.381	41.038	41.07	40.986	38.737	38.471	38.029	38.071	38.907	41.365	38.445	37.011	35.499	35.414	36.649	36.585	37.317	37.927	37.495
1983	2	36.284	34.887	33.396	29.992	29.316	30.563	32.376	33.496	34.679	34.939	33.519	33.037	34.3	34.916	35.697	36.207	37.288	36.541	37.756	36.454	37.956	34.976	33.17	33.456	32.31	30.876	31.264	31.275	31.953		
1983	3	33.777	35.153	37.702	42.035	40.966	39.391	39.583	44.544	42.074	45.548	41.225	41.308	38.739	38.746	42.122	40.263	40.184	40.258	39.781	40.375	40.109	40.154	39.676	42.965	42.368	40.949	38.524	40.584	39.508	45.319	39.575
1983	4	38.109	41.695	39.746	40.111	41.273	40.234	40.349	40.76	39.335	39.129	46.138	44.412	40.135	41.869	41.544	41.772	46.948	42.18	41.881	40.888	41.635	47.978	45.178	43.107	43.721	37.739	40.962	40.823	42.366	43.301	
1983	5	36.157	40.566	44.097	43.907	46.418	44.955	46.018	44.221	46.532	37.847	46.081	41.673	43.047	46.862	46.793	47.462	44.233	44.968	48.625	46.282	49.634	46.996	42.508	40.757	47.699	47.023	48.33	46.711	48.632	49.599	47.906
1983	6	46.137	47.596	48.54	43.82	41.918	46.406	46.16	45.833	47.506	41.001	41.724	40.288	37.938	37.821 25.225	41.388	46.15	37.751	37.55	40.682	39.162	44.373	41.205	39.596	38.69	42.258	42.564	41.708	40.24	39.721	42.47	
1983	7	40.515	43.298	41.103	45.154	44.679	43.647	46.872	37.927	38.771	35.312	39.128	44.588	40.422	33.449	31.375	36.217	41.19	31.049	33.7	29.741	35.45	36.042	32.184	36.061	38.398	40.244	34.891	32.463	37.168	38.563	36.436
1983	8	34.915	32.244	30.48	31.798	37.399	33.278	35.764	39.808	34.528	29.962	35.837	35.627	37.376	38.253	35.144	33.546	37.23	42.831	38.506	37.654	32.484	32.416	35.689	35.326	33.26	32.494	33.114	28.039	23.307	34.347	39.963
1983	9	30.382	31.319	32.337	29.4	32.367	28.349	31.574	35.208	31.29	24.678	32.398	35.659	36.564	35.31	35.177	34.945	32.915	28.722	34.74	31.049	34.453	38.316	35.922	33.934	33.861	27.89	34.801	35.197	34.345	39.768	
1983	10	37.279	37.043	39.875	39.119	30.124	33.852	38.376	35.037	27.639	32.047	34.424	32.173	31.215	23.362	28.499	25.317	34.345	36.255	36.458	36.479	35.564	36.248	37.523	36.001	34.065	36.455	37.714	41.375	41.976	39.829	37.274
1983	11	40.07	37.804	36.882	41.012	39.455	38.567	40.431	42.083	41.742	42.884	41.086	38.667	40.435 20.870	40.369 17.743	39.551 17.671	40.951 14.397	41.357 18.333	42.631 16.876	39.892 18.807	39.426 23.420	39.056 24.708	37.902 18.472	39.927 14.418	43.208 15.713	39.092 18.967	41.834 16.313	40.423 14.311	39.459 20.461	38.850 16.493	40.338	
1983	12	38.845 14.169	42.990 16.634	37.306 20.415	43.418 22.206	44.052 16.969	41.696 15.643	41.447 13.930	42.174 18.300	40.126 14.352	39.177 15.392	41.701 13.588	40.707 15.677	38.698 15.115	43.765 11.063	43.907 14.784	39.411 15.156	43.794 13.680	38.491 15.167	40.149 12.763	38.845 14.378	38.013 16.503	39.114 15.238	38.655 14.871	38.707 15.518	38.302 17.207	36.117 16.415	37.066 16.576	38.103 12.358	41.403 11.507	41.411	
1984	1	38.730 17.358	38.949 17.114	38.231 16.436	37.824 17.505	37.755 14.995	42.496 11.520	37.847 13.263	38.381 15.870	38.446 14.739	38.913 18.045	38.498 15.617	41.771 17.170	42.630 17.183	38.542 18.128	37.432 17.101	38.500 13.880	39.478 16.244	37.511 18.453	34.497 16.992	35.369 15.528	34.905 14.196	35.965 16.010	37.475 17.159	40.199 15.546	39.395 15.983	38.134 16.350	37.770 16.268	37.045 16.822			
1984	2	37.203 18.504	37.841 18.862	39.721 17.702	41.265 16.582	37.394 16.769	35.252 16.287	41.252 14.630	39.192 15.386	38.579 18.812	37.855 15.568	37.310 11.989	37.723 19.891	37.033 20.812	36.491 16.920	39.234 17.534	40.659 16.492	39.906 15.279	38.875 16.955	37.965 17.842	38.253 17.942	37.146 19.346	38.101 17.395	38.015 16.395	39.216 15.328	38.915 16.271	39.504 16.468	39.485 16.288	43.283 15.385			
1984	3	37.730 14.264	36.505 18.839	38.181 17.237	37.038 16.771	35.499 18.185	33.497 17.109	33.704 14.311	34.666 15.094	35.044 16.297	37.507 16.363	38.513 16.951	40.298 17.823	42.444 16.848	39.034 17.514	40.519 17.382	40.744 13.840	41.067 19.431	40.207 17.465	39.534 20.189	41.004 19.441	41.377 18.608	40.654 16.842	40.904 18.102	40.256 13.840	40.805 13.131	41.559 16.813	45.893 15.579	43.475 15.579	41.789 15.438	41.351 16.745	44.324
1984	4	46.304	47.442	47.247	47.437	48.523	47.465	38.538	37.799	36.43	41.827	39.553	41.994	42.897	43.503	42.472	44.657	41.944	47.279	48.071	42.229	40.885	40.026	39.585	40.368	42.762	41.511	41.147	42.454	42.254	41.564	
1984	5	43.484	47.362	43.848	41.917	42.74	42.118	41.775	41.704	39.853	40.083	43.197	45.748	43.675	44.147	47.313	45.401	48.258	44.222	44.56	42.241	42.857	43.54	39.586	39.968	40.025	40.971	40.858	43.898	37.665	40.353	37.57

1984	6	42.014	40.894	42.996	46.399	42.609	47.51	41.962	45.787	45.567	43.818	44.333	42.595	42.323	41.503	39.353	37.021	43.902	42.237	40.77	41.588	38.942	43.66	41.925	43.68	39.12	39.62	42.472	42.735	40.942	37.142	
1984	7	34.754	40.489	45.055	42.078	39.501	36.827	37.791	42.075	39.969	41.736	44.952	40.275	26.704	38.143	41.677	38.993	36.325	33.797	39.295	35.59	36.994	38.597	35.806	36.505	39.893	41.672	38.014	37.372	39.393	39.01	36.42
1984	8	37.482	41.643	37.208	39.08	34.468	38.138	37.807	38.855	34.802	34.414	36.262	36.575	37.211	31.98	32.628	34.975	35.965	34.173	33.416	31.61	32.724	34.458	35.261	25.848	27.666	29.662	34.103	34.385	29.991	28.889	34.278
1984	9	25.784	32.951	32.579	34.242	33.066	30.041	35.812	33.015	37.08	31.887	34.543	37.653	36.411	40.512	39.132	34.675	34.699	36.204	35.284	28.041	35.814	37.026	37.195	38.286	35.964	36.543	35.93	41.531	36.504	36.191	
1984	10	33.826	33.795	42.027	34.527	29.856	28.050 21.193	35.812	35.577	36.308	31.869	31.745	33.684	35.139	39.359	36.774	39.617	34.097	34.418	39.93	40.284	38.691	33.87	39.693	41.014	37.826	41.433	34.352	29.049	30.899	36.919	33.11
1984	11	38.706	33.607	31.21	40.748	41.446	41.434	41.129	37.748	38.011	38.072	37.854	37.358	38.283	41.077	40.788	37.958	33.136	40.134	38.727	42.864	41.56	41.075	43.548	45.003	40.061	39.799	44.668	44.864	41.959	39.959	
1984	12	41.004	44.866	41.171	42.076	40.522	43.897	42.649	42.497	43.23	40.75	42.221	44.859	42.086	42.198	40.008	40.158	44.512	39.889	40.71	42.159	38.507	38.277	37.653	38.418	37.633	38.694	41.667	42.315	40.216	42.926	38.719
1985	1	38.297	38.346	38.164	37.984	39.123	38.456	38.511	37.003	37.943	36.737	34.45	35.367	36.947	36.304	36.66	37.69	38.058	37.949	40.648	37.508	40.451	39.058	40.948	41.789	40.436	38.432	37.629	38.733	37.579	35.743	34.881
1985	2	39.202	38.251	39.363	37.207	38.188	43.975	44.258	40.119	39.944	39.721	37.681	37.385	38.547	38.507	36.246	35.294	35.857	38.063	38.225	41.11	39.739	42.046	40.141	43.432	42.05	40.251	40.14	40.35			
1985	3	39.499	38.043	36.951	36.909	36.66	35.846	36.718	37.835	36.537	37.44	36.419	37.643	39.779	39.619	38.973	38.004	37.588	37.262	37.831	41.39	41.924	44.664	45.025	44.384	43.792	41.011	41.527	40.491	38.383	39.068	38.914
1985	4	42.99	42.833	41.633	41.907	45.77	42.025	41.972	43.218	38.655	42.393	48.202	46.115	47.172	41.383	44.414	46.815	43.963	39.351	48.148	44.171	44.137	46.64	42.347	47.282	44.968	42.26	40.639	37.959	42.419	38.913	
1985	5	36.114	46.172	46.658	39.069	38.476	40.838	42.576	43.269	40.514	41.345	41.394	41.878	40.518	37.117	36.179	42.398	42.047	46.893	46.909	47.285	46.028	46.771	48.282	48.436	44.18	45.22	47.626	45.753	43.049	41.397	41.719
1985	6	46.529	45.228	42.97	48.753	41.944	42.821	41.749	41.152	38.661	42.565	38.341	44.502	47.588	40.243	45.106	43.846	41.361	39.396	37.165	37.777	47.426	40.621	38.641	43.649	44.199	40.749	40.113	39.065	37.591	39.823	
1985	7	40.952	39.149	39.35	40.056	42.62	41.004	45.989	43.566	41.359	39.201	37.716	38.494	37.237	38.972	31.162	35.12	35.825	28.272	30.442	35.216	34.991	35.186	38.968	36.89	36.491	36.315	30.779	33.916	33.397	36.578	26.815
1985	8	32.77	34.981	36.082	36.503	34.282	35.838	35.682	33.748	35.087	33.63	31.02	29.836	29.717	32.19	30.82	31.253	31.059	22.737	24.731	30.118	30.227	30.084	29.67	31.299	27.568	31.894	35.627	25.818	28.119	25.492	29.454
1985	9	25.623	32.106	25.865	28.749	34.117	29.702	31.66	29.663	32.388	27.771	25.694	32.897	27.322	24.222	28.558	26.92	27.493	34.649	33.549	32.39	35.474	32.449	33.941	31.257	28.716	33.491	34.387	32.809	30.642	28.264	
1985	10	32.883	30.256	30.18	27.481	30.062	28.64	28.217	31.878	33.497	33.201	29.25	28.631	28.058	30.159	31.869	32.912	27.033	30.699	35.228	31.517	30.799	34.839	34.151	34.161	33.126	29.623	28.761	34.512	33.91	36.139	35.324
1985	11	32.896	33.8	37.284	35.099	35.692	38.192	36.182	34.666	36.73	38.507	35.571	37.776	37.032	36.266	35.698	39.369	38.382	40.85	36.442	37.157	38.291	40.437	39.412	40.326	38.873	41.207	42.242	39.013	34.361	41.259	
1985	12	37.924	39.202	37.775	38.607	37.819	39.579	41.775	41.925	39.298	41.909	39.902	37.278	37.609	37.943	39.052	39.837	39.422	41.171	42.521	40.413	41.224	42.639	43.15	41.389	42.383	39.469	38.703	38.382	38.667	38.702	41.579

Appendix 6: Annual average temperature (in Celsius) for Garu obtained from Ghana Meteorological Agency

Year	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Maximum	39	39	37	37	38	36	37	38	37	37	38	37	37	38	38	40	39	41	40	40	39	40	40	40	40	40	38	40	38	38	40
Minimum	21	22	21	21	22	22	21	22	22	21	22	22	22	22	22	22	22	22	21	22	22	22	22	22	22	21	22	22	22	22	22

Appendix 4: List of plates

Plate 1: **Dugout in the raining season in Kolmasug**

Plate 2: Dugout in the dry season in Kolmasug

Plate 3: Livestock drinking from a dam

Plate 4: A boy holding his fish catch from the dam

Plate 5: woman preparing pito, a local drink

Plate 6: woman preparing shea butter

Plate 7: a dry water point

Plate 8: livestock wait to drink water while women fetch water

Plate 9: Gender and multitasking in dry season gardening

Plate 10: aerial view of onion farms in Worikambo

Plate 11: Dry water hole

Plate 12: A boy pulling water on a wheelbarrow