Climate Variability and Farm-households in the Sudan Savannah Zone of Ghana

Gerald Atampugre

B.A. (Honours), University of Cape Coast, Ghana

MPhil, University of Cape Coast, Ghana

MSc. (Distinction), Wageningen University and Research, The Netherlands

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Department of Geography, Environment and Population

School of Social Sciences

The University of Adelaide

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Table of Contents

Content **Page**

List of Tables

List of Figures

List of Boxes

Abstract

This thesis contributes to knowledge by providing a better understanding of the social-ecological factors underlying the exposure, vulnerability and adaptation to climate variability and extremes. While there is research on the topic, there is little understanding about how these factors manifest in various livelihood contexts that are simultaneously experiencing increasing severity in climate variability and extreme events, particularly in rural areas that dominated by smallholder farmers. The Sudan Savannah Zone (SSZ) of Ghana, a zone that experiences and has rain-fed agriculture as the predominant livelihood source, presents an excellent lens through which this knowledge contribution can be explored. There is ample evidence suggesting that rural farm-households in the SSZ of the country, will continue to bear the brunt of climate-induced impacts, which may include devastated crop production and a major threat to natural resource-based livelihoods. In the face of these expected impacts, there is the need for in-depth understanding of climate-farm-household relationships in order to facilitate efficient and effective responses.

This mixed method research project involved the geospatial analysis of the distribution of climate risks, indexing of exposure and vulnerability levels and the examination of climate risk coping and adaptation dynamics among smallholder farm-households. These activities were done using secondary spatial data and primary data from focus group discussions and surveys of farm-household heads. In all, 3 districts, 230 farm-household heads (for the survey) and 33 (for FGDs) were involved in the study.

Study results show that although districts were in the same agroecological zone, there were significant spatial variations in terms of the distribution of climate risk. Out of the five biophysical factors used in the geospatial analysis, three factors significantly explained the spatial variance in risk levels (i.e. aridity, vegetation cover, and land use/cover). Similarly, the survey found that despite the high level of respondent awareness and perception of climate risks and livelihood threats, there were significant variations among farm-households depending on the district, the gender of household heads and the number of years engaged in farming. Interestingly, although all farm-households were in the category of moderate and high exposure to climate risks, female-headed households were relatively less exposed compared to male-headed households. However, disaggregation of the composite exposure index showed that under some of the risk factors, female-headed households were relatively more exposed than male-headed households. Results

from the exposure analysis varied according to the specific climate risk factor and by the gender of the household head.

Findings from the vulnerability assessment indicated that female-headed households were comparatively more likely to be highly susceptible to climate risks. The gendered asymmetry in farm-household vulnerability was found to be rooted in the inequalities in livelihood diversification opportunities, finance, human and natural capital base. Moreover, the significant variance across study districts affirms that vulnerability is contextual and heterogeneous in space, even at the local level. Results showed that the underlying determinants of the chosen adaptation strategies included: the gender of the household head; age; education; farming experience; access to credit; livelihood diversification; and land tenure. The findings further showed that barriers to climate adaptation in the study area are mainly related to issues such as: farm-household finance; lack of institutional support; cost of farm inputs, the socio-cultural structure which defines relationships in these communities, and physical infrastructure.

This project finds there is significant relationship between the availability of, and accessibility to, sustainable livelihood assets and the extent to which a farm-household may or may not be exposed, vulnerable, and able to engage in adaptation. The study, therefore, demonstrates that having a comprehensive understanding of social-ecological system dynamics and how they determine climate exposure, vulnerability, and adaptation is fundamental to any planned or autonomous initiative that seeks to build system resilience.

Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Signature Date

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Chapter 1: Background and problem statement

1.1 Introduction

The recent pattern of devastating extreme climate events is conspicuous in every continent (IPCC 2014). Since the 1970s, there have been recurrent floods and droughts in Sub-Sahara Africa (SSA) on several occasions; droughts, heat waves in Australia; and recurrent hurricanes and tsunamis in North America and Asia. These are but a few of the examples of devastating extreme climate events in the last century. Climate change is widely conceived as a reality by both the epistemic community and ordinary citizenry of the Earth. Globally, the substantial spatial and temporal differentiation of climate change impacts have been broadly studied, ranging from significant differences in temperature rise between land and sea, to considerable variations in precipitation in the higher latitudes and decreases in the tropics and subtropics (Thornton et al. 2014; IPCC 2007).

In its fourth Assessment report, the IPCC (2007) warned that warming by 2100 will be worse than previously expected, with a probable temperature rise of 1.8^{o}C to 4^{o}C and a possible rise of up to 6.4^{o}C. As temperatures continue to rise, the impacts, especially in the developing south will be significant (IPCC 2012). Hazards will include, but are not limited to, increased flooding in low lying areas, greater frequency and severity of droughts in semi-arid and sub-humid areas, and excessive heat conditions, all of which have implications for resource-dependent livelihoods (IPCC 2012; Altieri & Koohafkan 2008; Morton 2007). It has also become clearer that even the most rigorous mitigation efforts cannot forestall additional impacts from climate change for decades to come (Thornton et al. 2014; IPCC 2012; McLaughlin 2011; National Research Council {NRC} 2010). As a result, questions of vulnerability, resilience, adaptive capacity and adaptation have come to the forefront of climate change research and action (Thornton et al. 2014; NRC 2010; Adger et al. 2009).

Consequently, there is an increasing need for an improved understanding of climate-related risks and their implications for food security (availability, access, utility) and livelihoods, especially in developing countries (Rowhani et al. 2010; Altieri & Koohafkan 2008; Morton 2007; Lobell & Field 2007). This need is even greater in the context of the over 500 million smallholder farmers globally (85 percent of world’s farms). These smallholders, ironically, also represent half of the global hungry and three-quarters of the hungry in Africa (Harvey et al. 2014). Obviously, these farmers have a huge role to play in whether the world succeeds in meeting the sustainable development goals. They are, however, faced with many risks, ranging from pest and disease outbreaks, extreme events, to market shocks (Morton 2007; O'Brien et al. 2004). These risks, according to Harvey et al. (2014), are expected to be heightened due to changes in the variability of climate and extremes. Although this is widely acknowledged in literature, not much attention has been given to study of the dynamics of climate-related risks at local level smallholder systems. Morton (2007) attributes this to the difficulty in assessing the intrinsic characteristics of these smallholder systems (i.e. location-specificity) and their vulnerability, not only to climate-related risks, but also non-climate stressors.

Smallholder farming in the context of this thesis denotes farming located between subsistence farming and concentration of crop production for the market, with plot size, 3 hectares or less (FAO, 2010; Morton 2004; Barnett et al. 2001). According to Dixon et al. (2004), the importance of this group of farmers is derived from their prevalence, their role in agriculture and economic development, and the concentration of poverty in rural areas where they are mainly found. Smallholder farming is the backbone of agriculture and food security in Africa. In Sub-Sahara Africa (SSA), for instance, two-thirds of the population resides in rural communities, with 75 percent considered smallholder farmers, producing about 80 percent of food produced in the region (Yaro 2015; FAO 2010:2006; Altieri & Koohafkan 2008; Chamberlin 2007). However, climate variability and extremes are altering the milieu for smallholder farming in this part of the world where rainfall is the most important climatic element in smallholder farming systems.

> "A key climate risk in Africa will be reduced crop productivity associated with heat and drought stress, with strong adverse effects on regional, national, and household livelihood and food security." (IPCC 2014a: p.21)

Accordingly, changes in the frequency and severity of drought spells, for example, does not only negatively impact farming activities, but also threatens livelihoods in already vulnerable communities (Schlenker & Loball 2010; Mapfumo et al. 2010). Frequent drought conditions have reduced the GDP growth of many SSA countries and threatened their development gains (Brown et al., 2011; World Bank, 2005). The heavy dependence on rainfall for agriculture has made about 60 percent of SSA vulnerable to frequent and severe droughts, with 30 percent being extremely vulnerable (Brown et al., 2011). Among the hardest hit are the smallholder farmers, whose livelihoods are virtually anchored on rain-fed agriculture (Laube, et al., 2012; FAO, 2007). Most of these farmers operate outside the formal business economy, farming to meet their own needs for food staples and selling small surpluses for extra cash. Over the centuries, smallholders within the SSA drew on indigenous knowledge and historical experiences to manage the effects of variations in climate elements and extremes (Wossen, et al. 2015; Laube, et al., 2012; Altieri & Koohafkan, 2008). Today, recent trends and future projections of climate change mean that these smallholders' dependence on past experiences to predict and adjust their livelihoods to seasonal climate/weather conditions, is increasingly becoming unreliable (Wossen, et al. 2015; Altieri & Koohafkan, 2008). This has been compounded by shortcomings in the governments' capacity to provide short-term relief and initiate or support medium- to long-term adaptation strategies.

It is important to stress that since the dynamics of extreme events will continue to change significantly for decades (IPCC 2014a), humanity must also focus on increasing its ability to adapt to existing and imminent impacts. Consequently, there is a consensus among researchers about the need to understand the context-specific vulnerabilities and the identification of adaptation options that strengthen ongoing sustainable development efforts and enhance adaptive capacities (IPCC, 2014a; Frank & Buckley, 2012; Olsson & Jerneck, 2010; Mastrandrea, et al. 2010; Altieri & Koohafkan, 2008). Thus, while the urgency of mitigation remains, local level vulnerabilities and the opportunities for climate adaptation must be addressed more specifically and vigorously in action and research (Logar & van den Bergh, 2013; Clarke et al., 2012; World Bank & GFDRR, 2010; Jerneck, & Olsson, 2008).

1.2 Problem statement

This thesis contributes to knowledge by providing a better understanding of the social-ecological factors underlying exposure, vulnerability and adaptation to climate variability and extremes. While there is research on the topic, there is little understanding of how these factors manifest in various livelihood contexts that are simultaneously experiencing increasing severity in climate variability and extreme events, particularly in rural areas that dominated by smallholder farmers. The Sudan Savannah Zone (SSZ) of Ghana, a zone that experiences severe seasonal rainfall variability and has rain-fed agriculture as the predominant livelihood source, presents an excellent lens through which this knowledge contribution can be explored. There is ample evidence suggesting that rural farm-households in the SSZ of the country, will continue to bear the brunt of climate-induced impacts, which may include devastated crop production and threaten natural resource-based livelihoods (Altieri & Koohafkan, 2008). In the face of these expected impacts, there is the need for in-depth understanding of the climate-farm-household relationship in order to facilitate efficient and effective responses. This mixed research study involved the geospatial analysis of the distribution of climate risks, indexing of exposure and vulnerability levels and the assessment of climate risk coping and adaptation dynamics among smallholder households:

Problem one: Geospatial distribution of and farm-household exposure to climate risks

It is argued in literature that climate adaptation efforts must be cognizant of spatial distribution of identified risks (e.g. Ericksen et al. 2011; Thornton et al. 2008). As already highlighted, evidence suggests that spatial distribution of climate risk remains poorly understood in the context of Ghana (MEST 2015; GEPA 2012). An academic justification of this objective is to improve existing knowledge on the spatial dynamics of climate risks, particularly in semi-arid regions. Using drought as a proxy, this objective provides data-driven information and an improved understanding of the biophysical indicators underlying the spatial distribution of climate risk in the Sudan Savannah zone, with lessons for areas with similar characteristics. The mapping of the spatial distribution of drought risk had methodological implications for this research since the resultant drought risk map formed the basis for the selection for the study districts and communities for the survey.

Assessing exposure of farm-households to climate variability and extremes is a prerequisite for understanding their vulnerability dynamics and adaptive capacities. However, a review of literature suggests that little primacy has been given to the topic. Moreover, the scanty and scattered studies on the issue have tended to use national level secondary data that may not capture the actual exposure dynamics at the subnational level (Antwi-Agyei et al. 2012). More importantly, no study has yet incorporated local level perspectives in climate exposure analysis. Using the Sudan Savannah Zone (SSZ) in Ghana as a case study, this research explored the awareness of climate risks and perceptions of the associated threats to livelihood assets of farm-households. The study also used these perspectives to construct farm-household climate exposure indices. Based on the argument that climate related risks are spatially disproportionate in terms of impacts, the objective here was to explore the location specificities of exposure. That is, how the characteristics of a geographical location of an individual or a group influence their levels of exposure.

Problem two: Social-ecological factors underlying farm-household climate vulnerability

This research also explores the drivers of vulnerability and highlights why farm-households within the same community or communities within the same agroecological zone experience variations in the level of vulnerability. The accumulative impacts from climate variability and extremes are dramatically altering the natural balance of local ecological systems, with implications for human systems (Chang et al. 2018; Pathak et al. 2018; Liu et al. 2016; Oppenheimer et al 2014). Consequently, vulnerable groups and communities in marginalised environments are facing problems such as food insecurity and loss of livelihood, with potential devastating consequences for human security in general. In Ghana, both policy documents and scholarly literature show that farmers in the country, especially the smallholders in Northern Savannahs will continue to experience higher losses and damages due to droughts and floods in coming decades (Derbile et al. 2016; Acheampong et al. 2014; MESTI 2012). Local level vulnerability assessments become very important for climate adaptation interventions.

Moreover, a review of the literature on vulnerability to climate events in Ghana indicates that the few existing empirical studies on climate vulnerability use national level data and indicators. Though these national level vulnerability analyses provide a strong foundation for more detailed research, their relevance at the local level is limited (Antwi-Agyei et al., 2013). These vulnerability indices are limited in terms of their ability to capture the heterogeneity in the vulnerability of individuals, households, and communities. This has implications for adaptation policy development and targeting because the most vulnerable at the subnational level might not be reached. Thus, using local perceptions and constructions, this thesis provides empirical evidence to demonstrate the relevance of vulnerability characterisation to adaptation targeting at the local level. At the District and community levels, this is particularly crucial for the identification of vulnerable smallholders and communities who should be the prioritised in adaptation policies, strategies, and projects.

Problem three: Climate risk coping and adaptation dynamics

As alluded to earlier, rainfed agricultural sector in Ghana is one of the most exposed and vulnerable to climate change. This is particularly the case in agroecological zones with huge adaptation deficits and limited livelihood alternatives. Notwithstanding this fact, adapting to variability in climate and extreme events is not a new a phenomenon among farmers in these zones.

Consequently, this research aims to identify and evaluate the climate coping and adaptation dynamics among smallholder farm-households in the study area. By examining the availability of, and/or accessibility to, sustainable livelihood assets, it is possible to understand how these assets are applied or accessed to ameliorate the negative impacts from climate-related hazards. This is fundamental to any planned initiative that seeks to assist smallholder farm-households and communities.

The research is designed to answer questions about the underlying factors of farm-household choice of specific adaptation measures. This is an important question in the sense that every choice or preference is informed by a different mix of factors, and aggregating all strategies means that critical information on individual choices may be lost. Much of the existing adaptation literature that focuses on adaptation determinants is limited when it comes to discussing how social-ecological factors influence the dynamics of adaptation choices (Deressa eta al. 2009; Hassan & Nhemachena 2008). Most of these research studies largely analyse whether a farmer will adopt an adaptation measure when faced with climate-related risks (aggregation of adaptation measures). Understanding what influence the strategy preferences of farm-household adaptation will not only aid practitioners and policy makers to reduce maladaptation but could also facilitate the reduction of current and future adaptation deficits.

Issues around barriers that trigger farm-households' adaptation deficits are assessed, as are the opportunities that smallholders could harness or access to improve their adaptation to climate change. In the context of this thesis, Moser & Ekstrom's (2010) interpretation of "barriers" is used. Barriers in their work refers to malleable obstacles that can be overcome with concerted efforts, creative management, change of thinking, prioritisation, and related shifts in resources, land use, institutions, etc. Understanding the nature of the barriers and locating their sources provides a guide for future designed approaches to avoid, eliminate or lessen the effects of such barriers on the adaptation process (Moser & Ekstrom 2010; National Research Council [NRC] 2010; Adger 2007). Moreover, site-specific identification and examination of available windows of opportunities for sustained adaptation is forward-looking and fundamental to well-targeted adaptation programmes, projects and policies.

1.3 Research questions

This thesis was guided by the following specific questions:

- Are there geospatial variations in the distribution of climate risk within the SSZ?
- What are the climate exposure dynamics in the Sudan Savannah agroecological zone (SSZ)?
- What social-ecological factors influence climate-related vulnerability dynamics among farm-households in the SSZ? and
- What are the climate risks coping and adaptation dynamics among smallholders in the SSZ?

1.4 Aims and objectives

This project aimed to assess the social-ecological systemic (SES) factors underlying the exposure, vulnerability and adaptation of smallholder farm-households to climate variability and extremes in the Sudan Savannah Zone of Ghana. The specific objectives of this study were to:

- Analyse the geospatial variations analyse in the distribution of climate risk within the SSZ;
- Assess the exposure dynamics of smallholder households to climate variability and extremes;
- Assess the vulnerability (or otherwise) of smallholder households to climate variability and extremes; and
- Identify and examine the climate risk coping and adaptation dynamics among smallholder households in the study zone

1.5 Public interest statement

Ghana faces numerous risks due to severe variability in climate and extremes (e.g. floods and droughts). This is particularly true for the northern savannah belts, where rain-fed agriculture is the predominant source of livelihood. The Sudan Savannah zone (SSZ) in northern Ghana presents a good case for this research because there is ample evidence indicating that (predominantly) smallholder communities in this zone bear the brunt of climate-induced livelihood impacts, resulting in devastated smallholder crop production and threatened natural resource-based livelihoods (Wossen, et al. 2015; Aniah et al. 2014; Antwi-Agyei, et al., 2014; Wossen & Berger, 2014). The SSZ, an area with a poverty incidence of 44.4 percent, has experienced recurrent food crises over the years, with droughts being a major factor (Aniah et al. 2014; Armah, et al., 2010). Evidence from the SSZ suggests that even minimal rainfall variability leads to a significant reduction in crop yield. The zone, unlike the southern zones with two rainfall seasons, is drought-prone and very vulnerable to the vagaries of climate elements, further limiting livelihood choices. In fact, both Ghana's Ministry of Food and Agriculture [MoFA] (2011) and Ministry of Environment, Science, Technology and Innovation [MESTI] (2015) have, in separate instances, indicated that the Sudan Savannah region has experienced agricultural drought every other one or two farming seasons. Under the climate scenarios for Ghana, crop yields are expected to be very low especially in the case of maize, millet, and sorghum, which incidentally are key staple crops in the zone (MoFA 2011).

Smallholder farmers in these largely poor rural communities have limited access to the assets that could enhance resilience in the face of extreme climate and weather events (Wossen et al. 2015). With limited livelihood choices and climate extremes, one can expect poverty and food insecurity to be exacerbated in coming decades. Moreover, most of the young men and women leave their communities for urban areas where they perceive "greener pastures". This migration trend leaves behind an ageing and generally less dynamic population, further hindering smallholder farming systems (Kwankye 2012; Tanle & Awusabo-Asare 2009).

Acknowledging the above, governments (e.g. Ministry of Food and Agriculture's adaptation policy decentralisation), numerous non-governmental organisations (e.g. Oxfam, ADRA, ActionAid, etc.), and international agencies (e.g. IFAD's Upper East Region Land Conservation and Smallholder Rehabilitation Project [LACOSREP] I and II) have all put in various policy, project and programme initiatives to ameliorate the negative effects of climate change on farmers in this area. However, declines in crop yield, the resultant food insecurity, and general loss of livelihoods are still prominent in the Sudan Savannah zone (See Antwi-Agyei et al. 2018; Wossen et al. 2015; Aniah et al. 2014; Laube et al. 2012). Although there is broad acknowledgement of these shortcomings, particularly in the wider context of Northern Ghana, there are few empirical studies on farm-household exposure to climate-related risks and none on the spatio-temporal distribution of these risks. Moreover, existing literature suggests limited data-driven evidence on local level characterisation of smallholder farm-household vulnerability to climate-related impacts.

Consequently, addressing the above gaps could enhance understanding about the dynamics of the spatial distribution of climate-related risks and enliven knowledge on the nature and drivers of households' vulnerabilities. The outcomes of this study could also provide insightful and practical lessons for adaptation in smallholder farming systems in Ghana and beyond.

1.6 Organisation of thesis

This thesis is organised into nine chapters. Chapter one elaborates the background issues of the topic under investigation, the problem statement, and the specific research questions. This chapter also seeks to contextualise the study from the Ghanaian perspective. Chapter two discusses in detail the theoretical perspectives of the key concepts in this thesis. These guiding concepts include vulnerability, resilience, and adaptation. The aim of this chapter is to identify the synergies and complementarities of these concepts, highlighting how their connectedness enhances their utility in this thesis, and climate change studies in general. Informed by the theoretical review, the conceptual framework adopted for this study is also discussed. Chapter three discusses the contextual issues that this research investigated. The methodology chapter, Chapter four, outlines in detail the systematic steps used for this research. The chapter starts with a description of the study area, followed by a discussion of the methodological orientation, the research design, and the various research methods. Chapter five covers issues surrounding the spatial distribution of drought risk in the Sudan Savannah zone of Ghana. Here, results from the spatial mapping (in GIS) are presented and discussed. Chapter six looks at farmers' awareness of changes in climate and extremes and their threat perceptions. The chapter then uses these results to develop and discuss indices of farm-household exposure levels. Results and discussion on the characterisation of the vulnerabilities of households are captured in chapter seven. In chapter eight, the thesis presents a discussion of how farm-households employ existing livelihood capital to enhance adaptation or provide means of improving resilience. Chapter nine details the conclusions of the research and presents the overarching implications of these for policy and practice.

Chapter 2: Climate vulnerability and adaptation: A theoretical review

2.1 Introduction

This chapter examines the concepts of vulnerability, resilience, adaptive capacity and adaptation within the context of climate change impacts social-ecological systems (SES). Closely related, the concepts of vulnerability, resilience, and adaptation have gained eminence in on-going academic debates on climate change, and sustainable development in general (See Christmann et al. 2014; Adger 2006; Gallopín 2006; Knutson & Ostwald 2006; Brauch 2005). Accordingly, this chapter aims to highlight areas of divergence and convergence between these concepts and how these synergies enhance their application in this study, and climate change studies in general.

2.2 Climate variability and change: framing the problem

Over the past three decades, international organisations like the International Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC), have produced substantial evidence suggesting that unprecedented changes are occurring in the earth's climate system. There is a general consensus on this evidence, given that it is well established that these changes pose considerable risks for both the human and natural subsystems. These risks are associated with the season-to-season, year-to-year and decade-to-decade variability in climatic elements. The variability, consequently, influences the frequency and severity of climate extremes, further widening the range of risks for the earth's systems. Risk refers to the probability of a loss (Muller-Mahn & Everts 2013)). Risk can be assessed by considering both the likelihood that the event occurs and the associated consequences (Crausbay et al. 2018; Jurgilevich et al. 2017; Carao et al. 2016). Climate variability and extremes, in this regard, can be considered risks; partly because they are likely to affect human interests in a negative way, and partly because many of their consequences are uncertain (King et al. 2015). According to King et al. (2015), the greatest risks of climate change may occur through the interaction of the climate with complex human arrangements like food systems, governance systems, and general human and environmental security.

The severity of climate related risks depends largely on the level of exposure and vulnerability to these events (Cardona et al. 2012). According to UNISDR (2016), understanding vulnerability and exposure are fundamental to the understanding of risk. Consequently, exposure and vulnerability dynamics can be said to be major drivers of changes in climate risks, and of impacts when risk actually occurs. The severity of the impacts of disasters depends strongly on the level of exposure and vulnerability in the affected area, and evidence indicates that risk has increased worldwide largely due to increases in the exposure of persons and assets **(**UNISDR 2016; Cardona et al. 2012). Understanding the multi-faceted nature of exposure and vulnerability, therefore, is a prerequisite for determining how weather and climate events contribute to the occurrence of hazards, and for the design and implementation of effective adaptation strategies to associated reduce risks.

In the IPCC (2001), the 'burning embers' diagram captures how the different risks increase with increasing global temperatures. This framework was used to elucidate the emergent risks related to the five 'reasons for concern' as mean temperature rises. These Reasons for Concern (RFC) include: risks to unique and threatened systems; risks from extreme climate events; distribution of impacts (disproportionalities); aggregate impacts (e.g. economic and health risks); risks of large-scale discontinuities (risk of hitting 'tipping' points where change is progressively faster and irreversible). Smith et al. (2009) updated these RFCs based on new knowledge about the susceptibility of the environment to climate change and highlighted new thresholds and irreversibilities in the earth's systems. Adger and Barnett (2009) emphasise four RFCs for adaptation to climate change risks: contractions and uncertainties in the window of opportunity for adaptation; the difference between adaptive capacity and adaptive action; the risk of maladaptation; and misguided measures of loss. Obviously, in the literature, there is a general sense of what the risks are and what could constrain responses. What seems elusive in climate change literature, is how the climate change problem is framed at various spatial scales - and how these framings delineate the associated risks and responses.

The significance of scale in the assessments and/or discussions of climate-related problems is very important because it has the potential to improve understanding of the interaction between society and nature. Over three decades, scholars have argued the importance of scale within the frame of climate change discourse (e.g. Pingale et al. 2015; Adger et al. 2005; Turner et al. 1990; Clark 1985). One of the key arguments has been that the interaction between climate change and social-ecological systems transcends a tremendous range of spatial scales (Pingale et al. 2015; Clark 1985). The implication is that changes in climate and how it impacts society varies in a spatial context. Consequently, any general framing and application of climate-related problems might be misleading, considering that at each spatial scale there are different interpretations of climate change. There is, therefore, a need for assessments to consider the special circumstances of place, without which adaptation initiatives may fail and vulnerabilities escalated. Scale in the context of this review refers to global, regional, national, and local level. At these various levels the interpretation of climate issues varies and thus need to be taken into consideration in any level of assessment (Kok & Veldkamp 2011). Similarly, Cash et al. (2006) suggests that over the years there has been continuous disappointment in policy and assessment due to the failure to properly take into consideration issues of scale and cross-scale dynamics in social-ecological systems. The scale for this project is the local level. This is because research has shown that climate impacts and actual adaptations are encountered at this level and must be recognised as such (Pingale et al. 2015; Yaro 2015).

Relevant to this thesis are three distinct framings of the climate change problem, as distinguished by O'Brien et al. (2007). These are the scientific (Biophysical), human-security (critical), and the human-environment (integrative) framings. These categories of framings, they argue, emerge from discourses on global environmental change (See also Leichenko & O'Brien 2007).

The ensuing discussion is not to show which framing of climate change is superior, but to highlight the increasing importance of 'framing' in the climate change literature. O'Brien (2006) and Forsyth (2004) highlight the implications of (in)appropriately framing the issue (i.e. climate variability and change and its impacts). They argue that how the problem is framed influences the kind of questions that are asked (by scientists, policymakers, and the ordinary citizenry), the research that needs to be prioritised (which aspects of climate change require urgency in terms of research and at what level), and the resultant responses that should be prioritised (climate mitigation or adaptation options).

Scientific framing of the climate problem

The scientific framing of climate change can be considered the antecedent conception of the term. To those who subscribe to this framing, the climate change problem is anthropogenically-induced (GHG emissions) and the primary means of understanding this scientific problem is via climate modelling (Demeritt 2001). Here, the foci of research are the quantifiable impacts of climate change based on simulations from General Circulation Models (GCM) (reflecting more of positivist thinking). Under this approach a vivid distinction is made between Society and Nature, placing greater emphasis on biophysical processes and human-induced impacts (Castree 2001). Critics of this framing, mostly Marxists and stakeholders from developing countries frequently stress the physically reductionist nature of climate models, arguing that they place emphasis only on the physical properties of emissions, ignoring the surrounding social context that produced these gases (Demeritt 2001; Macnaghten & Urry 1998; Shiva 1993; Agarwal & Narain 1991). Demeritt (2001: p 316) argues that "…physical reductionism of climate models serves to conceal, normalise, and thereby reproduce the unequal social relations". Thus, maintaining climate change as an issue of "science" rather than "human-security" implies limited engagement with society in creating the transformation needed for sustainability (O'Brien 2006).

Human security framing of the climate problem

> "Our science is sound; our security is not" (O'Brien 2006: p3)

The human-security framing of climate change emphasises how society shape processes, responses, and outcomes of climate change (O'Brien 2006). The objective of the reconceptualisation of climate change as a human-security phenomenon is not to exclude scientific research, but to reinvigorate the need for greater urgency for climate change responses (O'Brien et al. 2007). O'Brien and Barnett (2013: p.375) define human security as "a context where and when individuals, groups, and communities have the options necessary to end, mitigate, or adapt to risks to their human, socio-economic, and environmental rights, and have the capacity and freedom to exercise these options". Following this definition one can say that the human-security framing places emphasis on the societal context in which impacts of climate variability and change occur. Christmann et al. (2014) in their article on local construction of climate vulnerability and resilience established that climate change is a social construction. Hence, varied capacities in responding to the changing conditions are accentuated by situating climate change in the broader context of human security (O'Brien 2006). By changing conditions, reference is made not only to climate change but also the co-occurring social, economic, technological, political, and institutional dynamics (See Leichenko & O'Brien 2008; O'Brien et al 2007; O'Brien 2006). The human-security framing, thus, reflects more of social constructivist position (social theoretical perspectives), implying a seemingly limited role for positivist science in ensuring sustainable development under climate change.

Human-environment framing of the climate problem

A more recent framing, the human-environment framing, links both scientific and human-security framings by emphasising the social-ecological system (SES) (O'Brien et al 2007). Here, climate change is situated within the context of interrelated human and environmental sub-systems, stressing the inseparability of nature and society. Despite the recent increasing acceptance among scholars, protagonists of this framing acknowledge the difficulties associated with understanding the nature of the interactions within the SES (Ostrom 2007b; O'Brien et al 2007). The difficulty is that problems associated with the dynamics of the interaction within and between the social and ecological sub-system are not attributable to a single cause (Anderies et al 2007). Consequently, as Holling et al. (1998: p352) put it, "…the problems tend to be systems problems, where aspects of behaviour are complex and unpredictable and where causes…are always multiple. They are nonlinear in nature, cross-scale in time and space, and have an evolutionary character". Thus, framing the climate change problem under the human-environment discourse highlights the critical need for interdisciplinary research on the impacts, vulnerability, resilience, and adaptive capacity of social-ecological systems at all levels.

> "…we need a way of thinking and speaking that captures the fact that climate change is not merely one of many environmental problems, but a completely unique collective action problem, and one that is implicated in every aspect of our lives" (Rowson & Cornor 2014: In the Guardian of 24th May 2014)

It is true climate change has become an issue of extraordinary public concern in recent years. However, it is also a fact that the scientific interpretation or framing of the climate change problem has been slow in triggering the needed urgency in terms of responses at national and subnational levels, at least in the developing world. Rowson and Cornor (2014) attribute this gap to the fact that climate change over the years has remained more of a 'scientific fact' than what the sociologists usually refer to as 'social fact'. They posit that although scientific translations of climate change are necessary, such framing does not explicitly capture the relevant ethical, cultural, political, social, and economic issues. The difficult chore of socially framing climate change is, to a larger extent, left to policymakers who are less equipped in this regard. If this holds true, then it will suffice to say that the 'framing' of the climate change problem is fundamental and an essential (but neglected) subject in the context of brokering solutions to climate change risks for the social-ecological system.

2.3 Framing the social-ecological system under climate variability and change

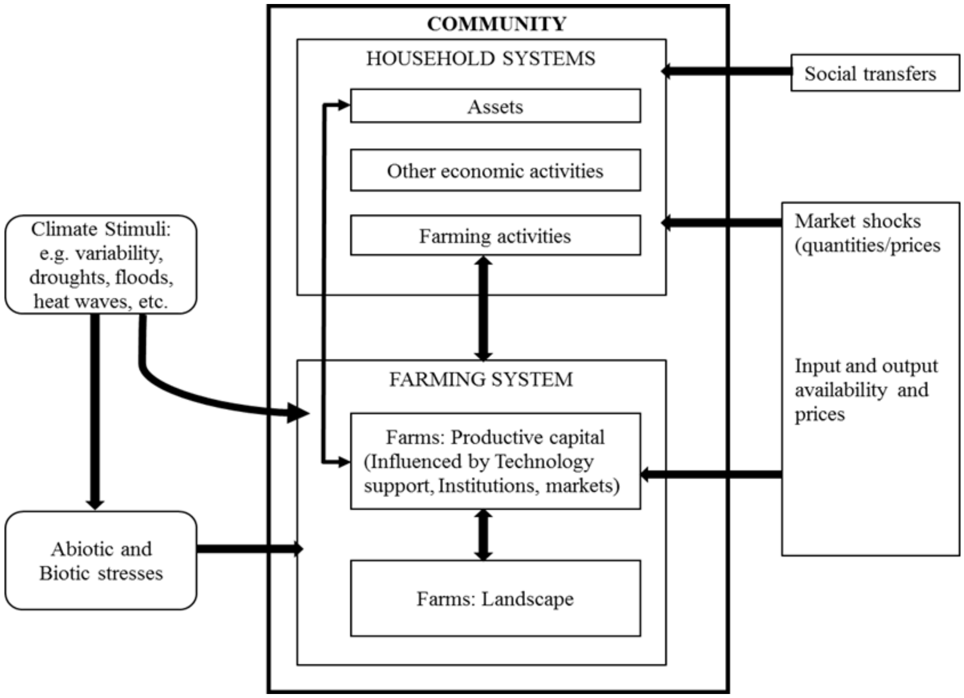
It is widely accepted that climate variability and change is likely to have negative implications for both human and natural systems (IPCC 2014a; Thornton et al. 2014). There is also consensus on the notion that the distinction between human and natural dominated systems is becoming blurred due to the interaction and the feedback loops (Daron et al. 2015; Turner II 2010; Daily et al. 1997). Consequently, despite the significance of disciplinary research, it is increasingly becoming ineffective to study the social and ecological systems separately when addressing issues related to their interactions (See Ostrom 2009; 2007a; Folke 2006; Young et al. 2006; Newell et al. 2005). As a result, there is an emerging accord on the need to conceptualise both the human and natural systems as components of a larger system, the social-ecological system (SES) (Daron et al. 2015; Binder et al. 2013; Ostrom 2009:2007b; Young et al. 2006). This implies drawing on interdisciplinary approaches to study climate impacts on the SES which could produce solutions to both social and ecological problems (Daron et al. 2015). In the frame of this thesis, SES refers to any dynamic and complex bio-geophysical unit and its associated social actors and institutions (Daron et al. 2015; Ostrom 2009). Such a system is characterised by regular interaction at various spatial, temporal and organizational scales, which may or may not be hierarchically related (Ostrom 2009).

With regards to the social system (human system) rules and institutions created and used to govern society's use of natural resources also constitute the knowledge and ethics systems that interpret nature from a human perspective (Adger 2007; Berks & Folke 1998). In this system it is the social and political actors who create the preferred rules, institutions, knowledge and ethics systems. The ecological system (natural or environmental), on the other hand, refers to the biological and biophysical processes and products (Berks & Folke 1998). Society is dependent on nature for a wide range of ecological goods and services (See Millennium Ecosystem Assessment 2005). Humans depend on nature for goods and services such as clean air, fresh water, food, medicine, raw materials, drought and flood mitigation, maintenance of biodiversity, partial stabilisation of climate and so on. However, the very components and processes of nature on which humans depend are threatened by human actions or inactions (anthropogenic climate change, land fragmentation, water resource degradation, deforestation, etc.), which further compromises the adaptation ability of society or increases the frequency of hazard events (like droughts, floods, hurricanes, heat waves, etc.). In effect, continued exploitation and degradation of ecological resources, combined with the associated hazards, further compromises the adaptive capacity of the individual components as well as the entire SES. According to Marina et al. (2011), the SES (also known as human-natural system or human-environment system) is an approach for assessing the interface and interactions between human (social, economic, etc.) and natural (climate, atmospheric, biological, etc.) sub-systems of the earth. Adger (2007) argues that any distinction between human and natural systems is arbitrary since human actions and social structures are integral to nature. That is, social and ecological systems interact reciprocally across diverse levels to form complex networks of interaction entrenched in each other (Pickett et al. 2005; Liu et al. 2007a). This underscores why Turner (2010) posits that conceptualising the SES is fundamental to sustainability.

Farm-household as an illustration of social-ecological system

A farm-household system is a good example of a social-ecological system at the sub-national level (See Figure 2.1). According to Gitz and Meybeck (2012) and Ericksen (2008), farm-household systems are by their nature socio-economic and ecological, with intra and inter-relationships. Gitz and Meybeck (2012), particularly, highlight that each dimension is considered a subsystem with its own organisation, and they tend to interact with each other or even share some common components. Consequently, occurrences (e.g. changes in the severity of droughts and floods, land use change, market failures, etc.) in one subsystem will have implications (e.g. variability in production, decrease in production, land degradation, input and output availability and prices) for the other. Food security (availability, access, utility) in a farm-household system, for example, is an interactive outcome of social welfare (e.g. income, employment, social and political capital, human capital, and infrastructure) and natural capital/environmental security (e.g. ecosystem stocks and flows, ecosystems services, ecosystem integrity, and access to natural capital) (Ericksen 2008). Ericksen (2008) argues that to fully understand the impacts of climate change on food security, it is imperative to consider the entire farm-household system rather than just agricultural production, since the impacts are felt through multiple pathways.

Figure 2. 1: Illustration of the dimensions of a farm-household system



Source: Adapted from Gitz and Meybeck (2012).

Assessing the interactions and feedback between the social and ecological components of a farm-household system is consequential for an improved understanding of the complexity and adaptive attributes and pathways in the entire system (Liu et al. 2007b; Turner II et al. 2003; Walker & Meyers 2004). In Ostrom (2009), the inference is that a core challenge in establishing the vulnerability or resilience of a SES is the identification and analysis of relationships at the varying spatio-temporal scales. Thus, McGinnis and Ostrom (2014) maintain that it is important to fully appreciate the complexity of the nested SES when responding to societal and climatic pressures. They assert that this requires a coherent framework that enables an in-depth understanding of the multiple interacting components (and feedback), and the nonlinearities of the interactions in space and time (also see Birkmann et al. 2013; Ribot 2013; Adger 2000). The emphasis in the literature is that the continuing process of building a common lexis and a comprehensive framework for studying the SES has two key advantages (See McGinnis & Ostrom 2014; Ostrom 2009; Resilience Alliance 2009): 1). it could enhance the accumulation of knowledge from empirical studies and assessments of past responses; and 2). It could aid the organisation of the analytical, diagnostic, and prescriptive capabilities of relevant institutions.

2.4 Vulnerability of the social-ecological system

Vulnerability has generally been strongly influenced by constructivist ideas (Miller et al. 2010), and its origins draw from several traditions in the social and biophysical sciences that have focused on addressing environmental risks, household responses to risk, and welfare outcomes (Paul 2013; Kasperson et al. 2005). Over the years, theoretical traditions in disciplines such as geography, economics, food security, sociology, anthropology, health, environmental science, and hazard studies in the geophysical sciences, have all contributed tremendously in shaping vulnerability research (See Paul 2013; Eakin & Luers 2006). Adger (2006) groups these traditions under: absence of entitlement; natural hazards; pressure and release; and human/political ecology. However, in terms of contribution to vulnerability studies under global environmental change, Miller et al. (2010: p3) posit that "…political ecology has been the most influential in providing a strong critique of the technocratic focus of earlier geophysical approaches to climate change and hazard research". They argue that political ecology and sustainability science provides the most integrative viewpoints on the concept of vulnerability. It is relevant at this point to highlight that although there have been recent conscious efforts to bring the various traditions/disciplines together, disciplinary integration and internal tensions and debates in the vulnerability community remains significantly diverse (Miller et al. 2010; Turner II 2010; McLaughlin & Dietz 2007; Liu et al. 2007; Adger 2006).

2.4.1 Interpretations of vulnerability

> "Vulnerability is a term of such broad use as to be almost useless for careful description at present, except as a rhetorical indicator of areas of great concern" (Timmerman 1981: p17)

Vulnerability as an analytical concept has been widely used in several disciplines, lending itself to tensions and debates over its scientific meaning (Adger 2006; Timmerman 1981). Accordingly, there is little consensus among academics within and between disciplines over the definition of vulnerability (for examples of definitions see Table 2.2) (Hinkel 2011; Adger 2006; Smit & Wandel 2006). However, there appears to be general consensus on the attributes assigned to the vulnerability concept: multi-dimensional; dynamic; scale-dependent; and site-specific (See O,Brien et al., 2007; Villagran de Leon, 2006; Cardona, 2004; Turner et al 2003; van der Leeuw 2001). In this study, the vulnerability definition by Adger (2006) is adopted. He defines vulnerability as the "state of susceptibility to harm from exposure to stresses associated with environmental and social changes and from the absence of capacity to adapt" (Adger 2006: p268;

also see Gallopin 2006; Smit & Wandel 2006). Going by this definition, it is consistent to say that the predisposition to harm constitutes the internal characteristic of the exposed unit. Therefore, vulnerability to environmental change cannot be isolated from the broader political economy of resource use (Adger, 2006: pp270).

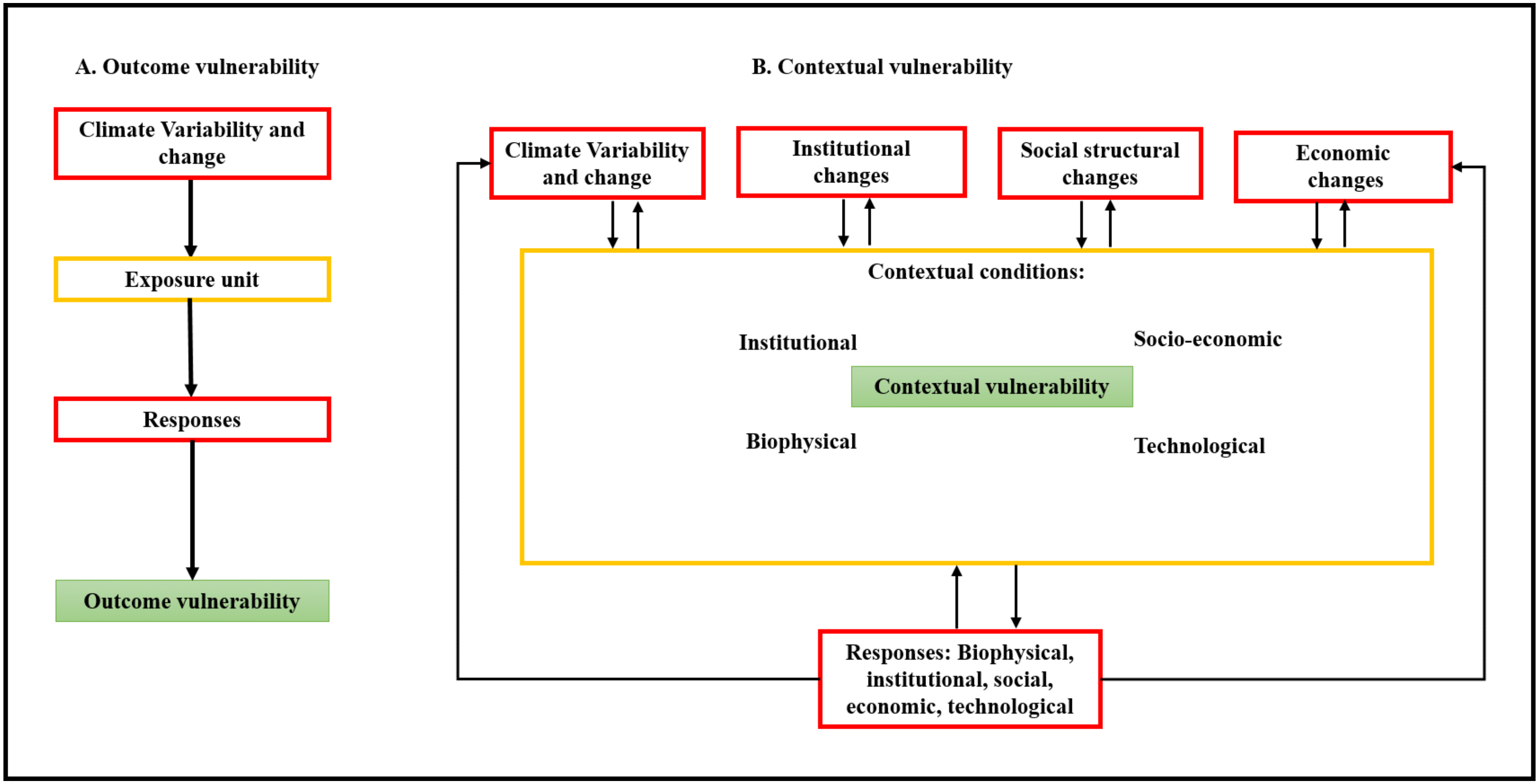
Table 2. 1 Examples of various definitions of vulnerability in climate change lexicon

Author(s)	Definitions
Bohle et al. (1994)	Vulnerability is best defined as an aggregate measure of human welfare that integrates environmental, social, economic, and political exposure to a range of potential harmful perturbation.
Moss et al. (2001)	Vulnerability is the extent to which a particular system or society experiences disruption due to changes in the climate.
Turner et al. (2003)	Vulnerability is the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress/stressor.
Luers (2005)	Vulnerability is simply the susceptibility to harm by climate stress.
Adger (2006)	Vulnerability is the "state of susceptibility to harm from exposure to stresses associate with environmental and social change and from the absence of capacity to adapt.
IPCC (2007)	Vulnerability is the degree to which an environmental or social system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity
Simelton et al. (2009)	Vulnerability of an agricultural system refers to a situation where slight changes in the climate have significant impacts on agricultural yields due to lack of adaptive strategies to buffer yields against the adverse impact of the weather.
Ciurean et al. (2013)	Vulnerability refers to the inability to withstand a hostile environment.

Source: Adapted from Antwi-Agyei et al. (2013) and Paul (2013)

Two general interpretations of vulnerability are distinguished in the climate change literature; outcome vulnerability and contextual vulnerability (O'Brien et al. 2007). This categorization of vulnerability interpretation is in consonance with the end-point verses starting-point approaches to vulnerability analysis (Paul 2013; Fussel & Klien 2006; O'Brien et al. 2004; Kelly & Adger 2000). An illustration of this interpretation of vulnerability can be found in Figure 2.2 (A & B) and Table 2.2.

Figure 2. 2 Illustration of the two interpretations of vulnerability to climate variability and change. A. Outcome vulnerability B. Contextual vulnerability



Source: Adapted from Pearson et al. (2008) and O'Brien et al. (2007)

Table 2. 2 Characteristics of the various interpretations of climate change vulnerability

Characteristics	Outcome interpretation	Contextual interpretation
System of interest	Biophysical, well defined closed-systems	Nature-society, open system
Prioritised meaning of vulnerability	Susceptibility of a system to expected net climate change	Susceptibility of a system to climate variability and change as influenced by multiple factors and processes
Antecedent /Vulnerability approach	Risk-hazard, integrated	Political economy, social vulnerability, livelihood and entitlement
Temporal reference	Vulnerability and adaptation to future climate change impacts	Present vulnerability and adaptation to current climate variability and change
Entry point of analysis	Projections and scenarios of future emission trends and climate risks/hazards	Current climatic, biophysical and contextual conditions driving vulnerability
Framing of climate change	Scientific framing of the climate change problem based on the physical-flow (the state of nature) view	The human security framing based on the notion that nature and society are inseparable aspects of the same context
Vulnerability and adaptive capacity links	Adaptive capacity determines vulnerability	Vulnerability determines adaptive capacity
Theoretical basis	Physical sciences (quantitative, reductionist, positivist)	Social theory, qualitative, constructivist, (sometimes post-positivist perspectives)
Policy context (Results)	Climate change mitigation, compensation, technological and sectoral adaptation	Social and economic adaptation, reducing inequalities, promote sustainable development

Source: Adapted from Okpara et al. (2016), Paul 2013, and Pearson et al. (2008)

Outcome vulnerability interpretation

The outcome interpretation, (also referred to as end-point), prioritises the susceptibility of SES to potential net impacts from a given level of global climate change after feasible (future) adaptation

(Okpara et al. 2016; Fussel 2007; Adger 2000). O'Brien et al. (2007) in a similar direction state that outcome vulnerability represents a linear outcome of future climate change impacts on a particular social or natural exposure unit, balanced by adaptation responses (see Figure 2.2A). According to Adger and Kelly (2000), analysis of outcome vulnerability involves projections of future trends of emissions, development of climate scenarios, biophysical impact evaluation, and identification of response options. In other words, the climate change problem is scientifically framed based on the state of the biophysical system, with projections and scenarios of future trends and risks being the entry point of analysis. In essence anthropogenic climate change is assumed to be the only exogenous stressor of the system.

The theoretical foundations of outcome vulnerability can be traced to the physical sciences. Specifically, it is informed by positivist (reductionist) perspectives, resulting in the static quantification of biophysical vulnerability in relation to susceptibility after potential adaptation to the impacts of projected climate variability and change (see Okpara et al. 2016). Fussel (2007), highlights that this interpretation of vulnerability is consistent with the risk-hazard or integrated vulnerability approaches and is most relevant to mitigation and the compensation policy option. Vulnerability assessments that adopt the outcome interpretation largely focus on mitigation and technological options for adaptation to impacts of climate variability and change (Fellmann 2012; Erikson & Kelly 2007; Fussel 2007; Brooks 2003). For example, research that focuses on the vulnerability of crop yields to projected climate change can be situated under the outcome vulnerability interpretation. Usually prescribed technical solutions will include changes in crop production methods, changes in seed variety, and the adoption soil and water conservation techniques.

Contextual vulnerability interpretation

The contextual vulnerability interpretation (likened to the starting-point view), in contrast, represents the current susceptibility of a system to climate variability and change as influenced by multiple factors and processes (Okpara et al. 2016; O'Brien et al. 2007). This interpretation makes temporal reference to 'present' vulnerability and adaptation to current impacts of climate variability and change. According to O'Brien et al. (2007: p.74), contextual interpretation of vulnerability is "…based on a processual and multidimensional view of climate-society interactions". Climate variability and change co-occur with social, economic, institutional dynamics, all of which together interact with the contextual conditions of the exposed unit (see Figure 2.2 B). That is, the exposure to a climate-related hazard and the potential responses are contingent on the contextual conditions (e.g. institution capacity and flexibility, marginalisation, social capital, level of inequality, technology adoption rate, poverty levels, land use/cover dynamics, access to water). Timmerman (1981: p19) emphasises that vulnerabilities to risks/hazards (e.g. climate variability impacts) are somehow part of the exposure unit's internal weaknesses. The focus of this interpretation is on the coupled human-environment system and the vulnerability of this system can be reduced by modifying the contextual conditions to enable individuals or groups to better adapt to climate change risks.

Theoretically, the contextual vulnerability interpretation lends itself to constructivist (social theory) perspectives and consequently, is consistent with the political economy and social vulnerability approaches. It is most relevant to adaptation through behavioural or policy adjustments and the broader sustainable development.

Outcome and contextual vulnerability: Relevance of the varying interpretation

A major contrast between the outcome and contextual interpretations of vulnerability rests on how they characterise adaptive capacity. Vulnerability assessments under outcome interpretation consider adaptive capacity as a determinant of vulnerability. Contextual vulnerability analysis, on the other hand, holds the contrary view that vulnerability is a determinant of adaptive capacity (Okpara et al. 2016; Paul 2013; O'Brien et al. 2007; Fussel and Klein 2006). The above discussions clearly indicate that the variance in the conceptualisation of vulnerability is due to the different usage of the concept in different contexts, referring to different systems exposed to different hazards or risks (Fellmann 2012; Fussel 2007). While acknowledging that the variations in the definition and interpretation of vulnerability are an outcome of the wider scope of climate change research and the diverse epistemic communities involved (See O'Brien et al. 2007; Adger 2006; Fussel & Klein 2006; Kelly & Adger 2000), not much primacy has been given to the implications of these variations for climate change research and action (O'Brien et al. 2007). Kelly and Adger (2000) highlight that these varying interpretations are surrounded by issues of disciplinary focus, policy relevance, and levels of uncertainty, consequently leading to the creation of different types of knowledge and emphasising different types of policy responses (also see Fussel 2007; O'Brien et al. 2007; O'Brien et al. 2004). Karen O'Brien and her colleagues used two empirical studies in

Mozambique to emphasise this point and showed that "… the deferring definitions and interpretations of vulnerability are a manifestation of different discourses on climate change…, that not only represent different approaches to science, but also different political responses to climate change" (O'Brien et al. 2007: p74). Thus, the interpretation of the vulnerability concept in climate change science is essential for designing and implementing research, presenting the climate change problem to a wider audience, and to the identification of priority responses to climate risks (see O'Brien et al. 2004).

It is important to emphasise that regardless of the interpretation one subscribes to vulnerability, the six fundamental dimensions of a vulnerable situation should apply. Based on the works of Turner II et al. (2003), Brooks (2003), Luers et al. (2003), Fussel (2004), Downing and Patwardhan (2004), and Metzger et al. (2005), Fussel (2007) proposed six key fundamental dimensions to any assessment of a vulnerable situation. These include:

- **The vulnerable system;** e.g. SES, population group, economic sector, geographical region, natural system, farming systems etc.
- **The system's attribute of concern;** e.g. human life, health, income, cultural identity of a community, biodiversity, carbon sequestration potential, timber productivity of a forest ecosystem, crop yield per hectare, etc.
- **Hazard/Risk;** e.g. climate change, climate variability, droughts, floods, heat waves, etc.
- **Temporal reference;** e.g. current vs. future vs. dynamic
- **Sphere;** e.g. internal vs. external vs. cross-scale
- **Knowledge domain;** e.g. socio-economic vs. biophysical vs. integrated

Accordingly, a significant application of vulnerability as an analytical framework, hinges on the 'context' and 'purpose' of the study. In the context of this research, both vulnerability interpretations are considered complementary, with different perspectives and relevance for an in-depth understanding of climate change impacts and responses.

2.4.2 Approaches to vulnerability assessment

> "Analysis of vulnerabilities…may not motivate all decision makers to make those investments, but it can give development professionals, activists, and affected populations fodder to promote or demand the rights and protections that can make everyone better off". Ribot (2009: p1)

Vulnerability, as a concept, is increasingly becoming a powerful analytical tool for assessing susceptibility to harm, powerlessness, and marginalisation (Adger, 2006). Broadly, vulnerability approaches are put under two groups based relating to how each approach has evolved over the years. These groups are the antecedent approaches and the successor approaches (Table 2.3). Under these groups, three vulnerability assessment categories emerge. These are risk-hazard (positivist oriented), entitlement and livelihoods (a seemly social constructivist orientation), and the integrative (Pragmatist perspective) groups methods (Ribot, 2013; O'Brien et al. 2007; Adger, 2006; Fussel & Klien, 2006; Sarewitz et al. 2003).

The risk-hazard approaches (also referred to as impact assessment approaches) tend to evaluate the multiple outcomes of a single climate event (Ribot, 2013; Adger, 2006). Risk-hazard models locate causes of risk (and vulnerability) in the hazard. That is, they tend to trace a linear causal relationship back to the hazard. The central aim of a risk-hazard model is "…predicting the impact of a given climate event and estimating the increment of damage caused by an intensification from "normal" climate conditions to the conditions expected under climate change scenarios" (Ribot, 2013: p 169). However, these approaches are usually criticised for not adequately incorporating social dimensions of climate risks and vulnerabilities (Adger, 2006; Cannon, 2001).

The entitlement and livelihoods approaches, on the other hand, distinguish the multiple causes of a single outcome such as loss of livelihood (Ribot, 2013; Fussel & Klien, 2006). These supposedly social constructivist models locate causality in society and as such, trace causes of vulnerability to multiple socio-economic, political, and environmental factors. Ribot (2013) and Adger (2006) emphasise that the entitlement and livelihood approach often posit natural hazards as playing a role, but not as having caused the risk or damage in the face of the event. Here, climate-related hazards and trends are viewed as external, while the risk of hazard and suffering is considered social. As a result, the burden of explanation of vulnerability is placed within the social system (Antwi-Agyei et al., 2013; O'Brien et al., 2007; Gallopin 2006; Smit & Wandel, 2006). Vulnerability in this context portrays a lack of entitlements or livelihood assets needed to sustain an individual or group in the event of a climate-related hazard. One of the criticisms of entitlement and livelihood approaches is they often ignore or reduce the significance of environmental factors (Adger, 2006).

Table 2. 3 Categorisation of vulnerability approaches

Vulnerability approaches	**Objective**	**Source**
Antecedent approaches		
Vulnerability to famine and food insecurity	Developed to explain vulnerability to famine in the absence of shortages of food or production failures. Described vulnerability as a failure of entitlements and shortage of capabilities	Sen (1981); Swift (1989); Watts and Bohle (1993)
Vulnerability to hazards	Identification and prediction of vulnerable groups, critical regions through likelihood and consequence of hazard. Applications in climate change impacts.	Burton, et al., (1978, 1993); Smith (1996); Anderson and Woodrow (1998); Parry and Carter (1994)
Human ecology	Structural analysis of underlying causes of vulnerability to natural hazards.	Hewitt (1983); O'Keefe et al. (1976); Mustafa (1998)
Pressure and Release	Further developed human ecology model to link discrete risks with political economy of resources and normative disaster management and intervention.	Blaikie et al. (1994); Winchester (1992); Pelling (2003); Wisner et al. (2004)
Successor approaches		
Vulnerability to climate change and variability	Explaining present social, physical or ecological system vulnerability to (primarily) future risks, using wide range of methods and research traditions.	Klein and Nicholls (1999); Smit and Pilifosova (2001); Smith, et al. (2001); Ford and Smit (2004); O'Brien et al. (2004)
Sustainable livelihoods and vulnerability to poverty	Explains why populations become or stay poor based on analysis of economic factors and social relations	Morduch (1994); Bebbington (1999); Ellis (2000); Dercon (2004); Ligon and Schechter (2003); Dercon and Krishnan (2000)
Vulnerability of social-ecological systems	Explaining the vulnerability of coupled human environment systems.	Turner et al. (2003a, b); Luers et al. (2003); Luers (2005); O'Brien et al. (2004)

Source: Author's construct, 2017

To understand vulnerability under the SES frame, therefore, a third strand of framework emerged. According to Birkmann et al. (2013), Adger, (2006), and Turner et al. (2003a), new synthesis of systems-oriented research conceptualises vulnerability as an inherent property of the SES. These Integrative approaches tend to combine the two antecedent approaches discussed above. Here, vulnerability is considered a function of both biophysical and anthropogenic factors (Birkmann et al, 2013; Ribot, 2013), and subsequently focuses on the interaction between these two factors. This approach, according to Turner et al (2003a), seeks to analyze the elements of vulnerability, that is, the exposure, sensitivity, and resilience of a bounded system at a particular spatial scale.

In Fussel and Klein (2006), vulnerability within the context of integrative approaches is viewed as having an external dimension, which is represented by the exposure of a system to climate variations, as well as an internal dimension comprising the system's sensitivity and adaptive capacity to these stresses. It is imperative to stress that, the notion of external and internal aspects of vulnerability are entirely dependent on how one draws the boundaries of the system under analysis (Ribot, 2013). To avoid this boundary issue, Turner et al (2003a) and Watts and Bohle (1993) adopted the approach of considering the entire system as one whole. This approach implies that to avoid this problem, one can trace causes of vulnerability out from each unit at risk; in turn this explains why an individual, household, community, is at risk of a particular set of hazards.

Despite the differences in approaches, Cutter et al. (2008:2000), Brooks et al. (2005) and Sarewitz et al. (2003) outline a number of common elements that run through all of them: (1) the examination of vulnerability from a social-ecological perspective; (2) the importance of place-based studies; (3) the conceptualisation of vulnerability as an equity or human rights issue and (4) the use of vulnerability assessments to identify hazard zones, thereby forming the basis for pre-impact and hazard mitigation planning.

2.5 Resilience of the social-ecological system

Miller et al. (2010), Folke (2006), and Gallopin (2006) highlight that the epistemic or disciplinary origins of resilience has mainly been in the natural sciences, with emphasis from the ecological sciences, especially in addressing persistence and changes in ecosystems (also see Turner 2010; Holling 1996; Timmerman 1981). Resilience research has largely been influenced by post/positivist approaches. The concept was originally introduced by the ecologist C. S. Holling in the 1970s to understand multiple interacting populations in a natural system, and how they relate to ecological process and disturbances in time and space (Folke 2006). Holling's work basically focussed on systems functional responses to random events and the ecological stability theory (See the review by Schefer 2009). Holling (1996) posits that an ecosystem under perturbation is capable of either returning to the original state (equilibrium), or moving to an alternative threshold that marks the limit of the system. This is in contrast to how some disciplines narrowly conceptualise resilience as the return rate to equilibrium after disturbance (referred to as engineering resilience by Hollings 1996).

A review by Downes et al. (2013), established some differences in resilience studies between the social sciences and natural sciences. The social scientists mainly focus on responses of individuals to human-induced change and are dominated by one-off surveys. In contrast, the resilience research by the natural scientists largely focus on responses of ecological communities and populations to both ecological and human-induced change, using different approaches to draw inferences about cause-and-effect. Despite contributions from social scientists (e.g. Berkes et al. 2003), substantial diversification of disciplinary contributions and the exploration of integrated approaches for studying resilience of the SES are relatively recent (Miller et al. 2010).

2.5.1 Definitions of resilience

It is widely accepted that though resilience, as an analytical concept, has its roots in the natural sciences, there is an established body of scholarly work on the concept from the social sciences, as well as from the emerging field of interdisciplinary research on "society and ecology" (Downes et al. 2013; Bahadur et al. 2010; Folke 2006). This implies variation in the definition, interpretations, and the praxis of the resilience concept. However, Bahadur et al. (2010) note that these variations in definition and interpretation have been given less scrutiny in terms of how they inform the practical application of the concept. Brand and Jax (2007) suggests a typology of various definitions of resilience under sustainability science (Table 2.4), providing a background to its conceptual development. These varied definitions give an indication of the breadth of the concept and the disciplinary involvement. However, what is common among the various definitions is the concern with responses to unfavourable changes. Galliard (2010) opines that, this concern with responses to undesirable changes forms the basis on which the resilience concept is meaningfully applied to climate change adaptation.

According to Bahadur et al. (2010), any work towards an operational definition of resilience should in essence consider the key characteristics of the system to which the concept is applied. In a similar direction, Carpenter et al. (2001) argue that for any praxis of the concept, it is critical to specify resilience of "what to what". The Resilience Alliance (2006) and Cumming et al. (2005) in their definition stress the maintenance of the identity of the system under internal dynamics and external perturbation. By identity, they make reference to a system's structure and functions. In Adger et al. (2005), resilience is broadened to encapsulate the coupled human-environment system, explicitly capturing the feedback of the interaction between the human and the biophysical subsystems. Based on the above ideas (by Bahadur et al. (2010), Resilience Alliance (2006), Adger et al. (2005), Cumming et al. (2005), and Carpenter et al. (2001)), this research operationalises resilience as the ability of a social-ecological system to preserve or conserve its structure, processes and feedbacks in the face of internal changes (social, economic, environmental, etc.), and external shocks (severe climate variability, droughts, floods, heat waves, etc.) across time.

Table 2. 4 Examples of definitions of resilience from ecological and social sciences

Definition	**Reference**
The ability of the system to maintain its identity in the face of internal changes and external shocks and disturbances	Cumming (2005)
The capacity of a social-ecological system to absorb recurrent disturbances…so as to retain essential structures, processes, and feedback	Adger et al. (2005: p1036)
The capacity of a system, community, or society potentially exposed to hazard to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure this is determined by the degree to which the social system is capable of organizing itself to increase this capacity for learning from past disasters for better future protection and to improve risk reduction measures	UN ISDR (2005)
The capacity of the system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, and feedbacks-and therefore the same identity	Resilience Alliance (2006)

Source: Adapted from Downes et al. (2013)

2.5.2 Interpretations of resilience concept

The numerous disciplinary foci and definitions as identified above come with varied interpretations or conceptualisation of the resilience concept, especially in climate change and disaster management contexts. It is considered, among many things, as a framework; a research approach to social or ecological or social-ecological systems; a descriptive or normative concept; specific or general; and a boundary object linking disciplines and epistemological traditions (Folke et al. 2010; Brand & Jax 2007; Nelson et al. 2007). In an attempt to categorise the various conceptions of resilience, Bahadur et al. (2010) reviewed 16 overlapping interpretations of the concept in social, ecological, and social-ecological systems. The five of these conceptualisations most relevant to this thesis are now discussed.

Resilience: "persistence of the system" interpretation

According to the "persistence of the system" interpretation, resilience is considered a measure of the absorptive power, recuperative power, perseverance, and stability of an ecological system (Schoon 2005). Holling (1973: p14) referred to resilience as "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables". Central to this interpretation is the impact of the relationships of the different elements on systems stability; the randomness or non-linear dynamics of events within the ecological system; and the degree of fluctuation within the system (Bahadur et al. 2010). Here, the randomness of events in the ecological systems is further aggravated by human agency. Holling (1973) emphasises that an equilibrium centered view of an ecological system offers little insight into the transient behaviour of systems that are not near equilibrium. As such, it will be prudent to shift attention from equilibrium states to the conditions of persistence. Characteristically, a resilient ecological system under this interpretation is one that is flexible and dynamic but persists in terms of intra-system relationships over space and time. Policies aimed at building such a resilience employ post-modern approaches (systems thinking/complexity theory) and are adaptive instead of rigid. Under such ecosystem management strategies, resilience is maintained by keeping options open, recognizing that perfect knowledge can never be achieved, that future events can never be perfectly anticipated (Bahadur et al. 2010).

Resilience: social-ecologically oriented interpretation

A more social-ecologically oriented interpretation of resilience is put forward by the Resilience Alliance. It is an institution of scientists and practitioners with a common aim of studying social-ecological systems (Resilience Alliance 2009:2010). They argue that, fundamentally, resilience is a systems property (Resilience Alliance 2010). By resilience, they refer to the "…magnitude of change or disturbance that a system can experience without shifting into an alternate state that has different structural and functional properties and supplies different bundles of the ecosystem services that benefit people" (Resilience Alliance 2010: p5). An example of the shifts between alternate states of a system, could be the conversion from wetland catchment to farmlands or a coastal lagoon to a waste receptacle. These shifts have implications for the supply of ecosystem services; tourism and recreation, fish production, ecosystem health etc. Focal to this conceptualisation is the capacity of the SES 'to stabilize', 'to self-organise', and 'to adapt through learning' when it experiences shock/stress/perturbation. The resilience of the SES is dependent on four key factors (Bahadur et al. 2010):

- The magnitude of the disturbance required to cause a dramatic shift from one systemic state to another (changes in the variables within domains of attraction);
- The policy, regulatory, and governance structures which allow different parts of the system to (re)organise (ability to self-organise);
- The quality and nature of learning processes that exist within the SES; and
- The diversity of elements/groups/communities performing different functions in the SES.

Resilience under this interpretation is underpinned mostly by the idea of multi-stable states of social-ecological systems, implying that there are hosts of possible states around which systems can stabilize after disturbance. The existence of land tenure systems, socio-economic, and institutional arrangements in the SES promotes equity and sustainable land use among resource users (farmers, fishers, etc.), enhancing their ability to determine quality of resource units (soil, water, etc.). Giving some legal and regulatory control to users through these arrangements inherently gives some credence to the importance of local knowledge in resilience building. The quality of the learning process in a system determines its ability to adapt to disturbances. Institutions within a resilient SES should be able to effectively conduct experiments in building resilience, monitor results, update assessments, and modify policy as new knowledge is gained. In line with Holling (1973), the existence of diverse ecological elements or groups of species performing different functions in the SES contributes to enhance resilience, while a homogenous system, on the other hand, has low resilience.

Resilience: As an approach to environmental change adaptation

The conceptualisation by Nelson et al. (2007) depicts resilience as an approach to environmental change adaptation. Here, the resilience concept is assigned a critical role in the assessment of environmental impacts and preventive actions. They consider resilience as "… the amount of change a social-ecological system can undergo and still retain the same function and structure while maintaining options to develop" (Nelson et al. 2007: p396; also see Walker et al. 2002; Carpenter et al. 2001). The proposition under this interpretation is that environmental change should be framed within the context of system resilience, with an emphasis on governance, adaptive capacity, and the robustness of responses. This proposition is founded on Holling's argument that "… the natural state of a system is one of change rather than equilibrium" (Holling 1973: in Nelson et al. 2007: p398). The inference here is that rather than managing or adjusting to maintain stability, it is pragmatic to manage or adjust systems for flexibility since change is inevitable. Nelson et al. (2007) apply this thinking of resilience to adaptation on four fronts:

- **Multiple states (desirable states and thresholds):** Every SES has several states, at least from the ecological point of view. However, the desirability of each of these multiple states is contingent on societal goals and desires. The types of services and the state of a system is the product of individuals' and societies' manipulation of the SES on the basis present knowledge and goals. On this basis a case is made that adaptation must move away from being reactionary to anticipatory in order to alter system dynamics to sustainably deal with shocks. This resilience approach also acknowledges that each of the multiple states of the SES has a threshold. These thresholds represent the boundaries between one system state and the other, which when crossed indicate a transition in to another system state (Nelson et al. 2007). According to Schneider et al. (2007) most of these transitions are triggered by climate change and may represent key vulnerabilities. Bahadur et al. (2010) in their review indicate that thresholds are not fully predictable, as such self-organisation and learning becomes critical for sustainable adaptation. The implication here is that this resilience thinking could be used to gauge the qualitative attributes of adaptation such as the degree to which resource use policies are flexible and decentralized.

- **Adaptive capacity (adaptation processes, element of surprise, and scale):** Here, emphasis is placed on a systems capacity to deal with both positive and negative surprises. In building adaptive capacity, a system should be able to develop its potential to harness opportunities from positive surprise and curtail the impacts of negative ones. Timmerman (1986) opines that a resilient SES has the capacity to nurture epiphanies (positive surprises) and avoid catastrophes (negative surprises). With this point of view, adaptation should be viewed more of a process than a one-time response. This affirms the effectiveness and equitability of anticipatory action compared to reactionary responses. With regards to the scale of adaptive capacity building, the resilience perspective uses systems thinking to inform adaptation, emphasising the importance of working across governance and timescales (Bahadur et al. 2010). Adger et al. (2008) and Janssen et al. (2007) provide good examples of how vulnerabilities are transferred across scales and levels and the implications for sustainability of local adaptive capacity.

- **Trade-offs in resilience and adaptedness:** Standard adaptation aims at building the ability of social-ecological systems to deal effectively with perceived risks. Premised on the management of uncertainties and having the right blend of system attributes in place, adaptation from a resilience perspective, on the other hand, emphasises the management of a systems capacity to survive future change (Nelson et al 2007). These differences, according to Nelson et al. (2007: p407), breeds some level of "…tension between achieving high adaptedness and maintaining sufficient sources of resilience" (also see Walker et al. 2006). The question then is how do we increase efficiency and effectiveness of adaptation responses without compromising the flexibility of these responses? Nelson and Finan (2008) used Brazil's drought risk reduction through humanitarian aid to demonstrate how a SES can be highly adaptive to a range of variability and still be vulnerable to changes with the range. Bahadur et al. (2010: p11) advocates that "…a balance must be negotiated between what is an acceptable level of risk to current system stressors and the breadth of flexibility necessary to respond to future change".

- **Governance and normative issues (adaptive governance and equity):** Vulnerability from a resilience perspective is considered an intrinsic character of the SES. Consequently, any response that reduces vulnerability at a particular point in time or area of the system, increases or creates susceptibility in another time or area. According to Miller et al. (2010), balancing the need for specific and general resilience of a system is essential to adaptation efforts. For instance, a farming system's resilience to droughts is not only defined by its ability to recover and the return time, but also by the system's capacity to deal with other unspecified (novel and unforeseen) impacts triggered by the drought hazard itself, or by the responses to the hazard. Nelson et al. (2007) raises the issue about how governance structures accommodate the diverse potential risks/hazards and the internal factors of the SES. In adapting this perspective to adaptation, they argue that emphasis should be placed on: 1) co-management (combination of lower and higher-level management of the system); 2) considerations for local knowledge; 3) flexibility of governance approaches; and 4) the internal learning process within the SES governance structure. On the issue of equity, Lebel et al. (2006) argue that adaptation actions targeting the reduction of vulnerability and increasing resilience must ask the questions of who decides what should be resilient to what, for whom resilience is managed, and to what purpose? In other words, resilience building through adaptation must resolve/address the issues of distributive and procedural equity (or justice).

Resilience: As an adaptive capacity

The next interpretation of resilience originates from the Rockefeller Foundation, an institution engaged in building/promoting greater resilience and more inclusive economies in an era of changing climate. The foundation conceptualises resilience as "... the capacity of individuals, communities, institutions, businesses and systems to survive, adapt, and thrive in the face of stress and shocks, and even transform when conditions require" (Rockefeller Foundation 2009). The focus of this interpretation of resilience is specifically in response to climate change. This conceptualisation sets out five determinants of system resilience (See Bahadur et al. 2010):

- High diversity in skills sets of individuals, organisations, or systems enhances the degree of flexibility of their responses to climate change.
- A resilient system should have a considerable amount of redundancy in terms of its process, capacity, and response pathways to accommodate partial failure in the system without complete collapse.
- Extensive planning in anticipation of identified climate change impacts is required. However, it is important to acknowledge that accurate future climate change planning has been found not to be very useful, except for the fact that it leads to learning and building skills.
- Diversity of stakeholders (sectors) in the planning and implementation of strategies in response to climate related impacts.
- Diversification of responses and high level of decentralization.

Resilience: Interpreted within the frame of sustainable livelihood capitals

Resilience within the community disaster literature, is conceptualised around the five main capital domains; social, economic, physical, human, and natural capital. Here, the resilience concept is interpreted as "… the capacity or ability of a community to anticipate, prepare for, respond to, and recover quickly from impacts of disaster" (Mayunga 2007: p3). The major forms of capital assets correspond to several characteristics and indicators of a resilient system. For example, strong social networks allow individuals and households to access social resources in their communities in times of disaster, enhancing the ability of those communities to adequately address collective concerns. Again, an individuals or household access to credit is an indicator of level of their preparedness and ability to take protective measures. Access and availability of critical infrastructure (roads, schools, hospitals, water, electricity, telephones, etc.) are critical for the functioning of a community especially during disasters. The conventional logic in this interpretation of resilience is that the more entitlements and endowments a community has, the higher its ability/capacity to reduce and/or recover from disaster impacts and hence the more resilient the community (Mayunga 2007).

Following the above definitions and interpretations, this study considers resilience as the capacity of the system to recover or transform in the long term. This conceptualisation of resilience allows for the use of integrative approaches for social-ecological system analysis, enhancing the understanding on the interaction between social and ecological subsystem from the local context.

2.6 Vulnerability and resilience: convergent or divergent concepts

Vulnerability and resilience concepts have been widely used in scholarly literature and by policy makers, with variations not only in foci but also in meaning (See Miller et al. 2010; Turner II 2010; Folke et al. 2010; Nelson et al. 2007; Adger 2006; Eakin & Luers 2006; Folke 2006; Fussel & Klein 2006; Gallopin 2006; Walker et al. 2004). Although these concepts have evolved distinctively, there have been conscious efforts in recent years to harness their linkages and complementarities for a holistic understanding of SES responses to perturbation (Christmann et al. 2014; Miller et al. 2010; Turner II 2010; Nelson et al. 2007; Liu et al. 2007; Gallopin 2006; Vogel 2006; Turner et al. 2003). Turner II (2010: p) emphasises the importance of both concepts by arguing that "…the strength of vulnerability and resilience as analytical tools…hinges on their linkages in addressing trade-offs between the social and ecological subsystems".

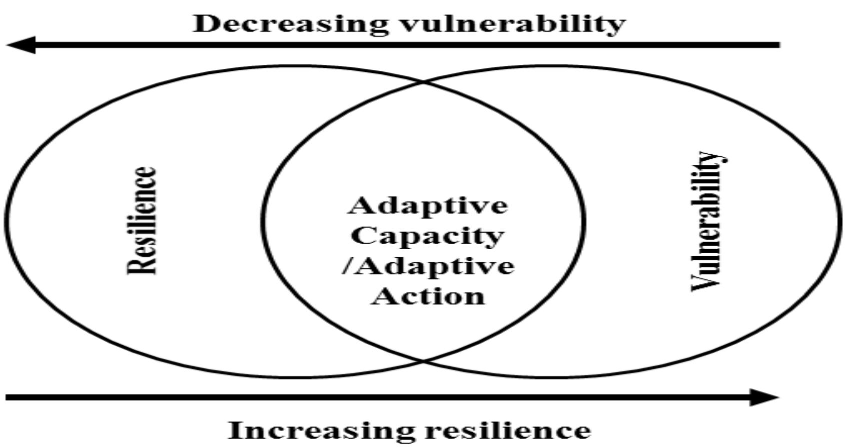
Literally, the only one true opposite of vulnerability is invulnerability. However, it is dangerous to presume a SES as invulnerable because of the "Achilles heel" effect that might occur (See Timmerman 1981). The more invulnerable a system is presumed to be, the greater the damage when system fortifications fail in the face of a hazard. The slightest vulnerability unaccounted for may culminate in a greater damage or a total collapse of the system. To this end, Timmerman (1981) argues that: 1). one can only simply compare the vulnerabilities of different exposure units to a hazard/risk; 2). compare the vulnerability of an exposure unit to different hazards/risks; or 3). use the vulnerability concept concurrently with another concept that contradicts the supposed state of the vulnerable system. The latter, he argues, represents the basis for the divergence between vulnerability and resilience. Gallopin (2006), in establishing this divergence, argues that vulnerability is defined in terms of shifts in a system's functions, processes, and feedback whilst the resilience (apart from these also) refers to radical structural changes in system.

A key factor underlying the different emphases, interpretations, and approaches used by scholars of vulnerability and resilience is their origins in the social and natural sciences respectively (Miller et al. 2010; Turner 2010; Folke 2006). This difference in origin has been a contributing factor to the absence of an easy exchange of ideas and experiences between researchers from the two communities, hindering interdisciplinary collaboration over the years (Miller et al. 2010; Janssen 2007; Janssen et al. 2006).

Studies that have combined vulnerability and resilience frameworks to evaluate SESs under climate variability and change, particularly those applied to behavioural transformation and policy-making are still limited (Miller et al. 2010; Nelson, et al. 2010; Walker, et al. 2009; Nelson, et al. 2007; Adger 2006; Eakin & Luers 2006; Janssen et al. 2006). The most frequently cited reason for this slow integration is that vulnerability is actor-centric and relatively easier to apply to policy, while central to resilience scholars is the interaction, feedback, and processes within the coupled human-environment systems (Turner 2010; Nelson et al. 2007; Gallopin 2006). O'Brien et al. (2004) explains that resilience is relatively difficult to apply to policy because of (political) boundary issues. Carpenter et al. (2001) highlight how challenging it has been in the last 30 years to put resilience into practice. Another frequent critique relates to the fact that resilience literature does not sufficiently deal with the social component of the social-ecological system, while the vulnerability literature insufficiently captures the ecological aspects of the system (Adger 2006)

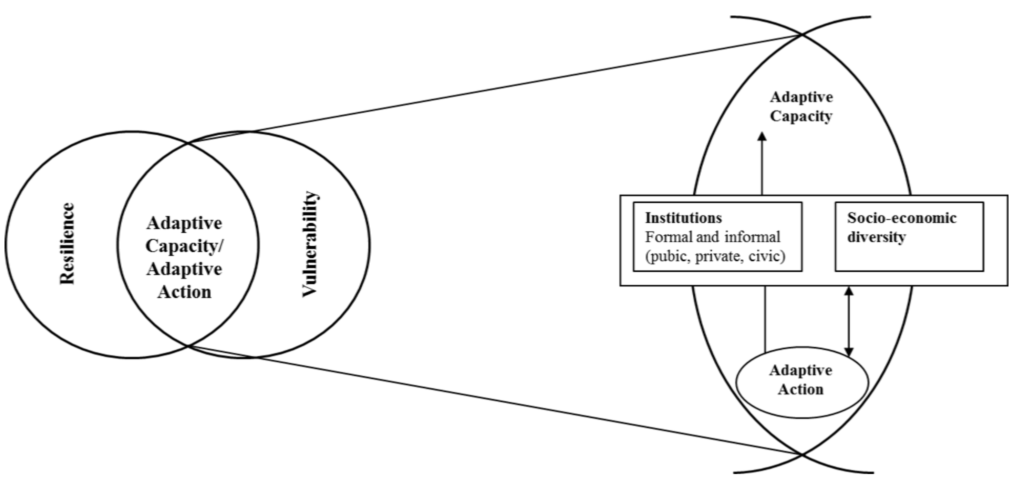
Nursey-Bray et al. (2007: p 21), on the other hand, illustrate the convergence of vulnerability and resilience. In their review on climate change and coastal management, resilience is interpreted as one of the determining factors of vulnerability. Berkes (2007), in a similar direction, argues that resilience could be thought of as a way of reducing vulnerability. Berman et al. (2012), Fellmann (2012), and Engle (2011) also emphasise this convergence by arguing that the basic link between vulnerability and resilience of a SES can be conceptualised through the institutional, political, social, and economic adaptive capacities of the system (Figures 2.3 and 2.4). In other words, a reduction in vulnerability through improved adaptive action and/or adaptive capacity will inherently increase resilience (Paul 2013; Turner et al 2003). Thus, resilience in this context becomes an intrinsic characteristic of an exposed (vulnerable) SES. The extent of convergence of these concepts, therefore, can be established by exploring ecological issues together with institutional and livelihood diversity for adaptation. Drawing from the ideas of Berman et al. (2012), Fellmann (2012), Engle (2011) and O'Keefe et al. (2008), this study considers vulnerability and resilience as a continuum linked by adaptive capacity and adaptive action as outlined in Figure 2.3. This thesis emphasises the exploitation of the synergies between vulnerability and resilience as analytical tools, with a focus on the role of institutions and socio-economic diversity in the transformation of adaptive action to adaptive capacity (Figure 2.4), arguing that it is fundamental to the long-term sustainability of the social-ecological system (Bermanet al. 2012). It is imperative to also highlight that the above discussion in no way suggests that decreasing vulnerability and increasing resilience is always desirable. This research acknowledges the exceptional instances where a system's resilience needs to be reduced (increased vulnerability) to enable transformative alterations of the whole system to a more sustainable state.

Figure 2. 3 Vulnerability-resilience continuum



Source: Adapted from Fellmann (2012).

Figure 2. 4 Influence of institutions and socio-economic diversity on the transformation of adaptive action to adaptive capacity within the vulnerability-resilience continuum



Source: Adapted from Berman et al. (2012).

2.7 Adaptive Capacity of the social-ecological system

This section gives a brief overview of the concept of adaptive capacity. The concept is fundamentally linked to vulnerability, resilience, and adaptation (Adger et al. 2007; Cutter et al. 2008; Engle 2011), which are at the core of this research. The application of adaptive capacity in this research is further emphasised under the conceptual framework presented in chapter 4 of the present thesis.

2.7.1 Definitions of Adaptive capacity

The scholarship on adaptive capacity has gained considerable attention in recent years, particularly in the area of environmental and climate change. Similarly, decision makers and practitioners are increasing exploring the concept as a means of reducing vulnerability, increasing resilience and fostering sustainable adaptation. However, its usage over the years has varied by field/discipline, context and systems (Engle 2011; Adger et al. 2007). Consequently, there are several definitions and/or interpretations of adaptive capacity (Table 2.5) Adaptive capacity in the context of environmental change comprises the availability of requisite pre-conditions and the ability to mobilise these elements for adaptation and learning (Freduah et al. 2018; Brown & Westaway 2011; Engle 2011; Nelson et al. 2007). This conception considers adaptive capacity as a source of resilience (Gallopin 2006; Gunderson 2000).

This view of the adaptive capacity tends to resonate with conceptualisations in climate adaptation literature. In most adaptation literature, adaptive capacity is generally referred to as a set of latent intrinsic social-ecological system properties, or the potential, needed to adapt to climate change and the ability to be actively involved in the process of change (Ensor & Berger 2009; Smit & Wandel 2006; Pelling & High 2005; Adger 2003; Folke et al. 2003). These authors consider adaptive capacity as a system's property. Similar to this view is the IPCC (2014b: p1758) definition, which states that the adaptive capacity refers to the "ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences".

All these interpretations under both global environmental change and climate change usually identify adaptive capacity as a characteristic of human actors and recognise that these actors have the ability to anticipate and plan and take reflexive actions to modulate impacts (Brown & Westaway 2011). Engle (2011) similarly captures this view by arguing that the ultimate potential for the implementation of sustainable climate change adaptation is strongly dependent on the social-ecological system's adaptive capacity. This view is shared by Smit & Wandel (2006) who highlight that adaptations are manifestations of adaptive capacity, and adjustments that deal with problematic exposures and sensitivities reflect adaptive capacity. On the basis of these conceptions and as also shown in the preceding section, adaptive capacity, vulnerability, and resilience are applied in the present research as intertwined concepts (Fidelman et al. 2017; Cutter et al. 2008; Smit & Wandel 2006). It is important to note that adaptive capacity is not equally distributed either by context or by system, as such there is always the need to identify the determinants of what builds adaptive capacity or the barriers to adaptation (Adger et al. 2009). Therefore, one of the objectives of this study is to examine the barriers that hinder sustainable adaptation among smallholder farm-households in the Sudan Savanna Zone.

Table 2. 5 Various definitions of adaptive capacity

Author	**Definition of adaptive capacity**
Walker et al.(10)A	The collective capacity of the human actors in a social-ecological system to manage resilience,
Gallopin (7, p. 300)	The capacity of any human system from the individual to humankind to increase (or at least maintain) the quality of life of its individual members in a given environment or range of environments.
IPCC (2014b: p1758	The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.
Adger 2005: p168	The property of a system to adjust it characteristics or behaviour, in order to expand its coping range under current or future climate conditions.
Chapin et al. (11)	The capacity of actors, both individuals and groups, to respond to, create, and shape variability and change in the state of the system.

Source: Author's construct

2.7.2 Determinants of adaptive capacity

The IPCC in its third assessment report (TAR) of Working Group II indicates that the determinants of adaptive capacity, particularly for human systems in developing countries (e.g. in Africa) include lack of economic resources (poverty) and technology, information and skills, weak institutions, and equity related issues (IPCC 2001). Since then there has been an expansion of these factors by scholars. Adger (2003) argues that most communities, for instance, have limited ability to adapt because of their inability to act collectively and that this inability is underpinned by social capital and trust. Smit and Wandel (2006) expands the list by suggesting determinants such us kinship, social networks, and political support. According to Brown and Westaway (2011), adaptive capacity is influenced by both tangible and intangible livelihood assets. These assets may include financial access, access to natural resource, skills, and opportunities to implement changes in their livelihoods. Fidelman et al. (2017) categorises these determinants as follows:

- Information and technology
- Material resources and infrastructure
- Organisation and social capital
- Political capital
- Wealth and financial capital; and
- Institutions and entitlements

Brown and Westaway (2011) also presents a summary of 6 adaptive determinants capacity:

- Recognition of the need to adapt;
- A belief that adaptation is possible and desirable;
- The willingness to undertake adaptation;
- The availability of resources necessary for implementation of adaptation measures;
- The ability to deploy resources in an appropriate way; and
- External constraints, barriers and enablers of implementation.

It is important to emphasise that all these determinants of are measured at multiple levels, from individual, community, institutional, national, to cross-national (Folke 2006; Smit & Wandel 2006). At each these levels, there are different sets of complex web of interrelated factors that determine adaptive capacity. For instance, adaptive capacity and vulnerability tend to have similar causes and consequences (Vincent 2007). The argument is that, for instance, a household has low adaptive capacity has a probability of having high vulnerability. On the other hand, a household with poor demographic characteristics (e.g. chronically ill members, high dependency ration, and high low education levels) are more likely to have relatively low adaptive capacity. Consequently, it is crucial that determinants of adaptive capacity are examined with context, taking into consideration how these factors manifest at the various levels. For example, at a global level, factors that shape or constrain adaptive capacity (e.g. political, social, and economic processes) emphasise only the possibility for adaptation to occur, i.e. whether or not adaptive capacity will be accessed and used for adaptation depends on a further set of uncertainties (Vincent 2007). In this regard, it is important for any initiative that seeks to build adaptive capacity to define clearly the level and consider in detail, the context.

It is important to emphasise that both the determinants and scales of adaptive capacities are not independent or mutually exclusive. According to Smit and Wandel (2006), some adaptive capacity determinants are mainly local (e.g. a strong kinship network which will absorb stress) while others may reflect the more general socio-economic and political situation (e.g. the availability of state subsidized fertilizer or public irrigation schemes). However, the capacity of a farm-household to adapt to climate risks may depend, to some degree, on the prevailing enabling environment with the community. In the same direction, the adaptive capacity of the community may be reflective of the resources and processes of the broader region (Smit and Pilifosova 2003). It is also key to mention that the determinants of adaptive capacity cannot be isolated, they are they interact at various spatial and temporal scales to generate or enhance adaptive capacity (Smith & Wandel 2006). For example, the absence of a weak kinship network may decrease adaptive capacity by limiting greater access to economic resources, decrease managerial ability, limiting supply of supplementary labour. On the contrary, greater access to economic resources may facilitate the implementation of a new technology and ensure access to training opportunities and may even lead to greater political influence.

2.8 Adaptation to climate variability and change

The definitions and interpretations of adaptation as it relates to climate change and, by extension, global environmental change in general, differ by discipline and practice (Ekstrom et al. 2010). Even though its usage is inexplicit to some extent (Eisenack & Stecker 2012; Ireland 2012; Moser et al. 2010), most of the definitions and interpretations of adaptation in the global environmental change literature have their origins from the work of the IPCC. The IPCC (2008: p 869) defines adaptation as "…adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities"). The IPCC definition is useful to this thesis because it highlights the essential elements and the complexity of climate change adaptation. There are some commonalities between the IPCC definition and those found in Table 2.6 below. All of them allude to system adjustments in response to climate-related stimuli and consider adaptation as building resilience and vulnerability reduction. However, they also establish some variations in the scope, application, and interpretation of the adaptation concept (Smit et al. 2000).

Based on the various definitions, Smit et al. (2000) proposed two interpretations of adaptation. They suggest that adaptation could be interpreted as a predictive process/action depending on how and under what conditions likely adaptation is expected to occur (e.g. Frankhauser 1996). According to them this interpretation is usually invoked when the concept is perceived as part of an impact assessment. On the other hand, adaptation could also be interpreted as a prescriptive policy or response strategy to current climate change-related risks/hazards (e.g. Tol et al. 1997). To them, fundamental to this interpretation is the question of what adaptation options are recommended or appropriate. Answering this question will require critical information on possible adaptation strategies and guiding principles for their evaluation. Both interpretations engender a useful classification criterion for adaptation, anchored on certain key attributes and some central questions in the climate change adaptation debate (Pelling 2011; Bosello et al. 2009).

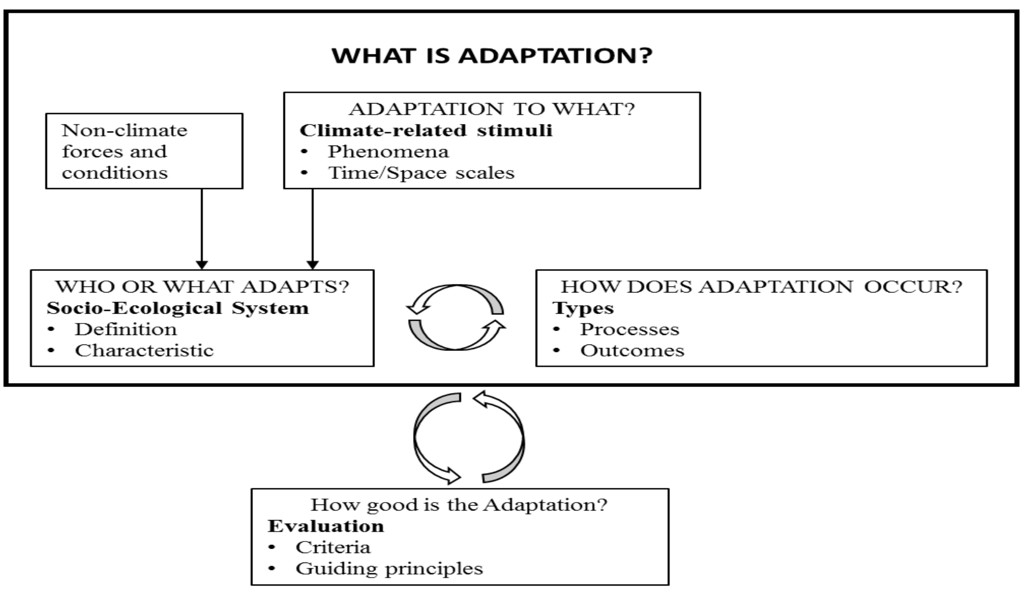
Table 2. 6 Examples of definitions of the adaptation concept

Definitions	Source
Adaptation refers to adjustments by individuals and the collective behaviour of socioeconomic systems	Denevan, (1983); Hardesty, (1983)
Adaptation is the process through which people reduce the adverse effects of climate on their health and well-being and take advantage of the opportunities that their climatic environment provides.	Burton 91992)
Adaptation involves enhancing the availability of social and economic activities and to reduce their vulnerability to climate, including its current variability and extreme events as well as longer term climate change.	Smit (1993)
The term adaptation means any adjustment, whether passive, reactive, or anticipatory, that is proposed as a means for ameliorating the anticipated adverse consequences associated with climate change.	Stakhiv (1993)
Adaptation to climate change includes all adjustments in behaviour or economic structure that reduce the vulnerability of society to changes in climate system	Smith et al. (1996)
Adaptation is adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.	IPCC (1996; 2008)

Source: author's construct, 2017

Depending on the degree of spontaneity (freedom of response) adaptation could be classified as autonomous or planned. Adaptation could also be either anticipatory or reactive depending on the timing of the response. Anticipatory-planned adaptation and capacity building for autonomous adaptation are the two major adaptation classes concurrently and frequently cited by UNFCCC, IPCC, and in most climate change literature (which are also the focus of this thesis) (Eisenack & Stecker 2012; Moser et al. 2010; O'Keefe et al. 2008; O'Brien et al 2006; Smit & Wandel 2006; Smit & Pilifosova 2001). The debate about the appropriateness of an adaptation option is centred on four key questions as outlined in Pelling's (2011: pp. 13-17) book *"Adaptation to Climate Change"*. These questions raise the complex issues that surround certain key (and complex) attributes of a system's responses to climate stimuli (Bosello et al. 2009). What adaptation "is" or "is not" is circumscribed by the questions: What to adapt to? Who or what adapts? How does adaptation occur? Figure 2.5 demonstrates that the uncertainty and complexity of climate change adaptation arises as a result of the difficulty associated with answering these questions (Figure 2.5).

Figure 2. 5 Gross anatomy of adaptation to climate variability and change



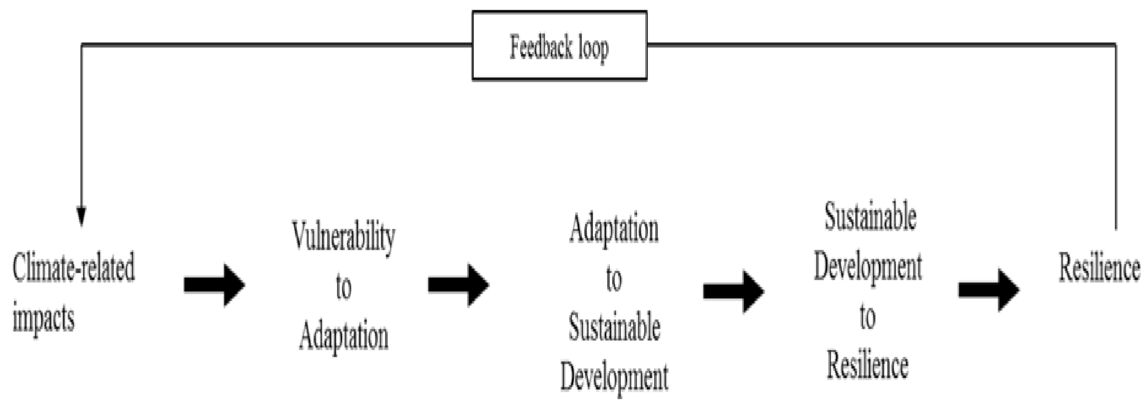
Source: Adopted from Smit et al. (2000)

It is important to reiterate that the intent of this present section is not to cover in detail all the components of the anatomy of 'adaptation'. The main focus here is to expand on O'Keefe et al. (2008) framing of the concept as a 'continuum'. To begin with, this study makes a clear operational distinction between adaptation and adaptive capacity. The later, primarily, refers to a system's ability/capacity (strengths, attributes, and resources) to maintain a particular desirable domain or state under perturbation, whilst the former is conceived as actions (and their outcomes) aimed at making profound adjustments in a SES to moderate harm or exploit beneficial opportunities (Birkmann 2011; Pelling 2010; IPCC 2008). Adaptation in the context of this thesis encompasses both adaptive capacity and adaptive action. This conjecture is based on Pelling's (2011: p 21) argument that "…capacity drives the scope of action, which in turn can either foster or hinder future capacity to act". This assertion is in tangent with Smit et al. (2000) earlier observation of adaptation as a process and a condition (the outcome of the process). How adaptation and adaptive capacity is applied in this thesis is also emphasised here and in chapter 4.

2.8.1 The adaptation continuum

The adaptation continuum was proposed by O'Keefe et al. (2008). The concept refers to the process of climate change adaptation that consider vulnerability to climate impacts as the starting point and resilience building as the destination. Here, the feedback loop (positive or negative) is emphasised. That is, improved resilience, for instance, has a positive feedback on impacts and vulnerability, both of which represent a starting point of climate change adaptation. In between the departure and the destination points are the adaptation and sustainable development interventions. The fundamental assumption under the adaptation continuum concept is that vulnerability, adaptation, resilience, and sustainable development are interrelated and, in reality, are processes that should be considered parts of the three stages of the continuum (See O'Keefe et al. 2008): Figure 2.6 shows the relationships between vulnerability to adaptation, adaptation to sustainable development, and sustainable development to resilience. O'Keefe and his colleagues emphasised that due to the high uncertainty and complexity of "produced unknowns", the most effective climate response strategy is to enhance the capacity of those at the first line of response, the "survivors" or those "left standing" after perturbation. They suggest that people-centred resilience building through adaptation and sustainable development (together) is required for an effective response to the uncertain risks from climate change (also see O'Brien et al. 2008). This framing of climate adaptation expresses the diversification of the social-ecological system as pivotal to resilience building. On this basis, O'Keefe et al. (2008) argued that development interventions (e.g. Poverty Reduction Strategies [PRSPs], social protection policies, etc.) could drive the adaptation process further if they are planned in such a way that resilience issues are central to the development agenda.

Figure 2. 6 The Adaptation Continuum



Source: Adapted from O'Keefe et al. (2008)

Four key elements are required for the transition from vulnerability to adaptation. These are the adaptation scope, scale of adaptation, the integration of obtained adaptation outcomes into political or policy dynamics, and the integration of feedbacks in to the broader context of development. It is widely accepted in climate change literature (both scholarly and policy documents) that impacts (both direct and indirect), will be disproportionately felt by the most vulnerable in society. The unresolved question, however, has to do with adaptation scope and what matters to those who are considered vulnerable. In delineating the adaptation scope, under the adaptation continuum concept, careful consideration should be given to the specific sustainable livelihood assets (human, natural, physical, financial, and social) at risk. This is founded on the fact that vulnerability or otherwise of the SES is anchored on these assets (Holling 2001; DFID 2000). On the issue of scale, it is important to emphasise that spatial context within which adaptation processes occur is mostly cross-scale. This attribute shapes the spatial extent to which adaptation interventions are implemented. According to O'Keefe et al. (2008: p8), unlike impact or vulnerability assessment, "…adaptation requires the application of different set of tools and methodologies that allow for the integration of information and concerns". The integration of adaptation outcomes and feedbacks into policy and the broader development agenda is perhaps the most critical element of the transition from vulnerability to adaptation. The efficacy of this transition must rest on how political and policy dimensions accommodate adaptation outcomes and how well sustainable development plans incorporate/integrate feedbacks (O'Keefe et al. 2008; Smit & Pilifosova 2001).

> "Good (or sustainable) development (policies and practice) can (and often does) lead to building adaptive capacity. Doing adaptation to climate change often also means doing good (or sustainable) development" (Huq & Ayers 2008a: p52).

The adaptive capacity of a system, community, or nation to respond to climate stimuli is dependent on the state of development (Berke 1995; Huq & Ayers 2008a). Ribot et al. (1996) demonstrate that the fundamental constraint on adaptive capacity is underdevelopment. Smit and Pilifosova (2001: p899) explicitly show that the requirements for improved adaptive capacity are similar to those of sustainable development. Citing Ahmad and Ahmed (2000) and Robinson and Herbert (2000), Smit and Pilifosova (2001: pp900-905) argue that enhanced adaptive capacity for climate change can be regarded as a component of the broader sustainable development. Based on these recognitions, it is prudent to stress that there is the need for concerted efforts towards the adaptation-development perspective. O'Keefe et al. (2008: p9) argue that "…focusing on the synergies between adaptation and sustainable development and their potential contribution to effective planning…promotes sustainable conditions and self-reliance...which could substantially reduce the cost of disaster assistance". Much of the difference between adaptation and sustainable development is methodological (Huq & Ayers 2008a). As a result, a fundamental requirement for this transition will be the integration of adaptation and sustainable development approaches. This is a desideratum because the metric of the climate change impact is broadened beyond direct (lives lost, economic damages, loss of ecosystems, etc.) to include the indirect (livelihood security, morbidity, economic growth, etc.) (O'Keefe et al. 2008).

Central to the transition from sustainable development to resilience are improved coping mechanisms, recovery and continuation of development pathways, and validating the evidence of reduced climate impacts and vulnerabilities (positive feedback). The argument here is that to build resilience, both social and ecological diversity needs to be maintained (or enhanced). According to O'Keefe et al. (2008) this diversity maintenance will lead to improved/enhanced livelihood capital and entitlements needed for climate responses. In order to obtain positive feedbacks that reduces climate change impacts and enhances resilience, the adaptation continuum recommends:

- Building livelihood capitals and entitlements through transparent negotiations

- Existence of appropriate information sets
- Knowledge of the range, effect, and cost of adaptation technologies
- Access to adaptation technologies
- Enabling and learning environment

To sustain the shift from sustainable development to resilience building, O'Keefe et al. (2008) and O'Brien (2006) outline the needed changes for the new resilience paradigm for adaptation (Table 2.7).

Table 2. 7 Changes needed for a new resilience paradigm for adaptation

From	**To**
Isolated event	Development process
Risk is not normal	Risk is an everyday event
Centralised response	Participatory adaptive capacity
Low accountability	Transparency and negotiations
Status quo restored	transformation

Source: Adopted from O'Keefe et al. (2008).

In conclusion, the central idea/argument of "The adaptation continuum" is that resilience building for climate change adaptation comprises sustainable development. Normalizing climate risks, vulnerability, adaptation, and resilience building as part of the sustainable development process involves risk avoidance when possible, least cost response strategies, institutional and societal learning, and scrutinizing environmental surprises and thresholds that when breached lead to disastrous changes in the SES (O'Keefe et al. 2008). This contradicts Pelling's (2011) conceptualisation of adaptation as resilience. His argument is that adaptation for resilience does not seek to change or question the status quo or the power asymmetries in society. On the other hand, however, the adaptation continuum could be linked to Pelling's vision of adaptation as a transition and transformation. On this basis, both interpretations of adaptation encapsulate reforms in governance regimes and the predominant political economy of development, through the assertion of rights and distribution of responsibilities. This, as Pelling and O'Keefe et al. concur, will require a critical reflection of current institutions and practices. Within the context of this thesis, capacities (livelihood assets and diversity) and adaptive actions (planned and autonomous responses) are assessed to understand the various components of adaptation continuum in the context of farm-household systems within the Sudan Savannah agroecological zone of Ghana. This is based on the belief that the interrogation of purposeful adaptive actions and outcomes (through actors/institutions) moderate vulnerabilities to impacts of climate variability and extremes is key to enhancing system resilience (and adaptive capacity), as well as the long-term agenda of sustainable development.

2.8 Conclusion

The chapter describes how the concepts of vulnerability, resilience, and adaptation are framed within current theoretical discourses in the context of climate impacts on social-ecological systems (SES). The SES concept acknowledges the interdependency of the human and environmental sub-systems in the determination of the condition, functioning, and response of the broader SES to climate risks. The review highlights that although there is little consensus over the scientific meaning of vulnerability, there seems to be a general agreement on the attributes assigned to it: multi-dimensional; dynamic; scale-dependent; and site-specific. It should also be noted that both vulnerability and resilience constitute different but overlapping research themes that appear to coalesce around the coupled human-environment system (i.e. SES). The review also showed that conceptualising adaptation as a continuum allows for the examination of how climate responses and outcomes may reduce vulnerability (or enhance resilience) to climate-related risks. Understanding the vulnerability of a SES to climate-related risks is a fundamental step in fostering adaptation and long-term resilience among individuals, groups, and communities, especially those in marginalised environments.

Chapter 3: Climate variability and agricultural vulnerability in context

3.1 Introduction

This chapter synthesizes the scholarly literature and policy documents on climate change and variability, and the vulnerability and adaptation of farming systems in Ghana. The chapter starts with a general overview of climate variability and extreme events, and concludes with an overview of the study area. In Africa, and for that matter Ghana, climate variability has increased in severity, particularly over the latest three decades (Ly et al. 2013; World Meteorological Organisation (WMO), 2013). Africa is one of the most vulnerable continents to climate variability, a situation that has the potential of aggravating already precarious environmental conditions. This, in most instances, has been attributed to the interaction of multiple stressors occurring at various levels and the relatively low adaptive capacities in farming communities. In the context of Ghana, governments, Non-governmental organisations, and development partners have emphasised the vulnerability of the country's agriculture, outlining broader underlying factors such as geographic location, socio-economic, political, and institutional capabilities. There has also been a wide consensus on need to reduce the adaptation deficit in the agriculture sector.

3.2 Climate variability and extremes: a general overview

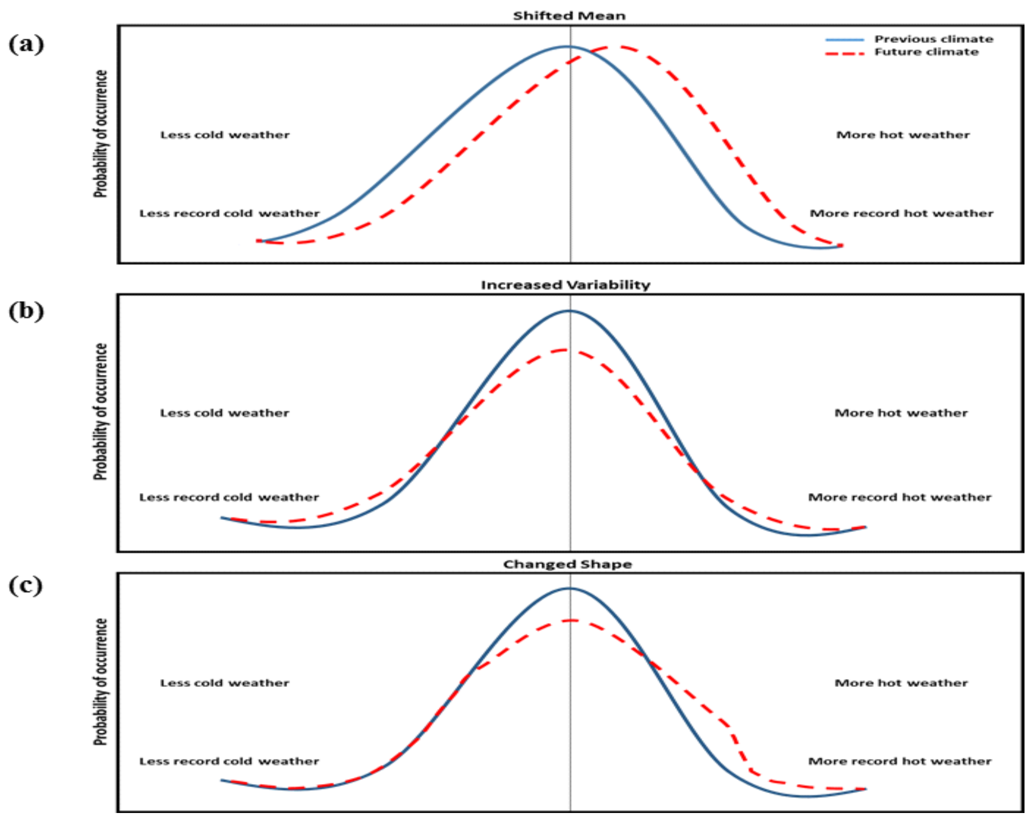
> "Climate variability refers to the decadal or yearly or seasonal fluctuation of climate elements (e.g. rainfall, temperature, humidity, etc.) above or below a long-term average." (IPCC, 2012: p5)

> "Climate Extreme (extreme weather or climate event) is the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable." (IPCC 2012: p5)

It has generally been predicted that with increasing global warming, climate variability will increase, with implications for the frequency and severity of extreme events (Thornton et al. 2014; IPCC 2012; McLaughlin 2011). The IPCC (2012), in particular, clearly indicated that anthropogenic-induced climate change is, predictably, causing changes in climate variability and extremes. Figure 3.1 visualises the different present and future changes in temperature distributions and its effect on climate extremes. Component 'A' shows a change in mean temperature towards a warmer climate, implying that more hot weather (less cold weather) can be expected. Component 'B' illustrates the distribution that preserves the mean temperature value.

However, this temperature distribution involves an increase in the variability of the distribution. That is, the average temperature is the same for now, but there will be more future hot and cold weather. The bottom component (C) highlights a situation where the temperature distribution maintains its mean, but its variance evolves through changes in asymmetry towards the hotter part. This implies near constant cold weather, but with some increases in hot weather. The adverse effects of these changes, as outlined in the IPCC (2012:2014a) report, are likely to include increasing frequency and severity of heat stress, droughts, and floods, which are expected to have greater impacts than changes in just the mean climate variables.

Figure 3. 1: Illustration of the effects of changes in temperature distribution on climate extremes.



Note: (a) Effects of a simple shift of the entire distribution towards a warmer climate. (b) Effects of an increase in temperature variability with no shift in the mean value. (c) Effects of an altered shape of distribution, that is, a change asymmetry towards the hotter part of the distribution.

Source: Adopted from the IPCC (2012).

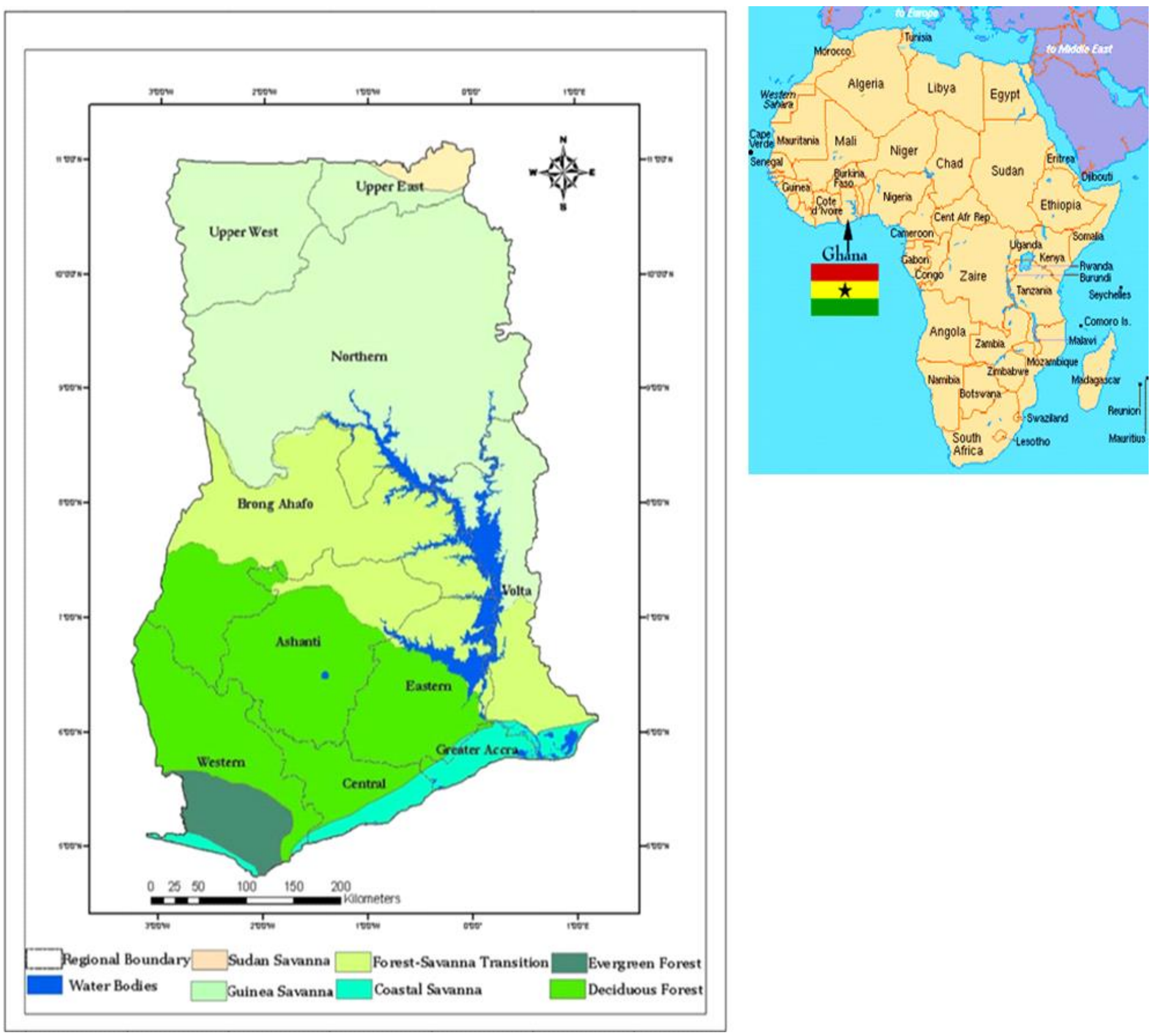
Accordingly, Thornton et al. (2014) and Lobell and Field (2007) argue that the concentration of most climate change impact studies on changes in the mean climate alone could seriously lead to underestimation of the full impacts on social-ecological systems (SES). Using Ethiopia, Niger, and Mozambique as cases, Thornton et al. (2014) are of the view that climate variability has already had considerable impact on biophysical systems and countries whose growth depends on these systems (also see Ray et al. 2015). They also emphasise that although there is considerable uncertainty and low confidence in projections of variability in climate and extreme events, the probable impacts on food systems and development in general cannot be ignored. However, not much primacy has been given to the effects of variability in climate and extremes on food systems compared to food production (Thornton et al. 2014; Codjoe & Owusu 2011; Rowhani et al. 2011). For instance, out of the nearly five hundred pages of the SREX report by the IPCC, only one page discusses the effects of climate variability and extremes on food security and food systems (See IPCC, 2012).

It is important to highlight that climate variability and change cannot be observed in everyday life. These dynamics can however be inferred, according to Christmann et al. (2014: p1), "…from the spatially and temporally narrow clustering of changing weather patterns or extreme events like droughts, floods, and storms". Again, Katz and Brown (1992) have argued that climate extremes underpin concerns about climate variability and change. Thus, it is consistent for this research to use local level observations of changes in weather elements (precipitation and temperature), and extreme events in the last decade, to capture local concerns and anxieties about climate vulnerabilities in the Sudan Savannah agroecological zone of Ghana.

3.3 Climate variability and change: the Ghana context

Ghana is situated in western Sub-Sahara Africa, between latitudes 4.44°N and 11.15°N and longitudes 3.15°W and 1.12°E (Figure 3.2). It shares borders with Cote d'Ivoire to the West, Togo to the East, Burkina Faso to the North and the coast of the Atlantic Ocean to the south. By virtue of Ghana's location in the tropics, the country is vulnerable to climate change risks (MESTI, 2013). In the National Climate Change Adaptation Strategy (NCCAS) and National Climate Change Policy (NCCP), four major climate change related risks are identified: severe variability in rainfall, increasing temperatures, sea level rise, and changes in the frequency and intensity of extreme events (heat waves, droughts, floods, etc.). There have been various studies on climate trends in Ghana (e.g. Ghana Environmental Protection Agency (GEPA) 2015: 2011; Nyantakye-Frimpong & Benzer, 2015; Stanturf et al., 2011; Owusu & Waylen, 2009; Mania, 2004). Although these studies used varied methods, there is a general consensus that climate will be more variable in decades to come, with implications for the frequency and severity of climate and weather extremes.

Figure 3. 2: Map of Ghana showing all agroecological zones.



Note: The brownish yellow portion at the upper right corner represents the Sudan Savannah zone (Study area).

Source: Ministry of Food and Agriculture (2011).

In a World Bank (2010) report entitled *"Ghana: Economics of Adaptation to Climate Change"*, it is indicated that the annual rainfall in the country is highly variable on inter-annual and inter-decadal time scales, implying that long-term trends are difficult to identify. In this report, the precipitation forecast shows a cyclical pattern over the period of 2010 and 2050, with high precipitation levels followed by a severe drought every decade. The World Bank (2010) document also highlights warming over Ghana, with a temperature increase between 2.2^{o}C and 2.4^{o}C by

2050. It is also explicit in the report that the average temperature in Ghana during the same period will range between 34^{o}C and 41^{o}C, with significant temperature variability of between 4.3^{o}C and 5.7^{o}C.

Ghana's second and third communication to the United Nations Framework Convention on Climate Change (UFCCC) in 2011 and 2015, also highlight trends in both observed and projected time series of rainfall and temperature between 1961 and 2000 (base year), and for thirty-year periods (2020, 2050, and 2080). These assessments were presented according to the agroecological zones in Ghana. The annual mean rainfall is likely to reduce between 1.1 percent and 3.1 percent across all the agroecological zones by 2020 (Ghana Environmental Protection Agency [GEPA] 2011). Again, from the observed baseline values, the changes in annual mean rainfall by 2080 is expected to be between 13 percent and 21 percent. In Ghana's third communication to the UNFCCC (See GEPA 2015), rainfall across the country is projected to decrease by 2.9 percent in 2040, followed by a slight increase of 1.1 percent by 2060, and later decrease by 1.7 percent in 2080. According to the GEPA (2015) "…this observation is a reflection of the uncertainty associated with rainfall in Ghana".

Based on historical observations (1961-2000), the GEPA (2011) predicted temperature changes of 0.6^{o}C, 2.0^{o}C, and 3.9^{o}C in 2020, 2050, and 2080 respectively. They found that February to May are likely to still be the hottest months in the year, with temperatures in June to September being the lowest. In Ghana's third communication to the UNFCCC, the projections are less severe. Analysing historical temperature data (1981-2011), the GEPA (2015) observed a 2 percent rate of change in minimum temperature for southern Ghana and 37 percent for northern (Guinea and Sudan Savanah zones). The GEPA (2015) predicts that the mean temperatures are likely to increase by 1.2^{o}C, 1.5^{o}C, and 1.8^{o}C in 2021-2040, 2041-2060, and 2061-2080 respectively. They, however, emphasise that the changes in both rainfall and temperature will be more intense towards the north than the South of Ghana. For instance, the projections indicate that the average temperature for the Sudan Savanna Zone is expected to increase in the range of 2.5^{o}C and 3^{o}C by the year 2080, with projected mean annual rainfall decreasing by 170 mm in the same period. If these trends or projections are anything to go by, then it will suffice to argue that farming systems, particularly those dependent on nature will be severely hampered, with severe implications for human lives.

3.4 Climate risks and farming systems in Ghana

The above projections present greater risks to agriculture and development in general. Frequent flooding, erratic rains, early cessation of rains, reduction in growing seasons, rising temperatures, and long dry spells are but a few of the expected risks to agriculture. According to the factsheet by USAID (2012), droughts are anticipated to become more frequent and intense, implying severe consequences for farm-households. The agricultural sector employs close to 50 percent of the country's employed population. However, the sector's contribution to GDP has been reducing since the 1980s. Growth in the agriculture sector as a percentage of GDP has declined from about 70 percent in the 1980s and 1990s to 19.9 percent in 2014. This suggests that the sector is increasingly being neglected by successive governments and other stakeholders (Wossen et al. 2015; Antwi-Agyei, et al., 2014; Laube, et al., 2011). Ghana's agriculture is overwhelmingly dominated by smallholders (MoFA 2006). About 90 percent of all farms are smallholder, with farmland holdings between 0.5 and 2 hectares in size (Chamberlin, 2007). Even though they are responsible for over 70 percent of food production in Ghana, smallholder farmers are among the most vulnerable to current and future trends of climate extremes (Stanturf et al. 2011).

Increasing variability in climate and the greater incidence of extremes are likely to result in a range of direct and indirect impacts on Ghana's food security and food system. It is predicted that by 2050 the length of growing seasons may decline by about 5 percent or more (USAID 2012; World Bank 2010). This could have devastating consequences for yields of crops such as maize, sorghum, millet, and rice (staple crops). Again, frequent temperature extremes could increase the stress on crops such as maize that are already being grown close to its thermal tolerance limits (USAID 2012). Using the projected climate scenarios and CERES model, the GEPA (2011) projected that the yield of maize would decrease in the Northern Savannah zones and the Transition Zone by 6.9 percent by the year 2020, though millet yield will not be affected due to the fact that it is more drought tolerant. Indirectly, non-climate perturbations like land degradation, desertification, poverty, land tenure, and institutional inadequacies are likely to intensify the direct impacts. According to the FAO (2012) and the World Bank (2010), these impacts are already being felt by smallholder farmers in Ghana, particularly those in the Northern Regions of the country. With higher average temperatures and lower average rainfall, coupled with the high incidence of poverty and poor socio-economic infrastructure, the vulnerability of farmers in these marginalised Regions will be exacerbated.

3.5 Relevant climate adaptation policies, programmes, and projects in Ghana

Since 2005, the Government of Ghana (GoG) and its development partners (both local and international), have recognised the ecological and socio-economic impacts of climate change, and the associated development challenges (Sova et al. 2014). There has been some level of commitment towards mainstreaming climate change adaptation into key development planning processes at the national, regional and local level (Sova et al. 2014; MEST 2010). Tables 3.1 and 3.2 give an overview of the institutions, policies, and programmes relevant to climate change and agriculture in Ghana. Given that climate change adaptation traverses both socio-economic and ecological systems, the tables not only capture initiatives on climate change adaptation in agriculture but also the broader development policies relevant to climate change adaptation and agriculture. Two major issues arise strongly from this review; there is low level decentralization of climate change adaptation strategies for agriculture, and there are inadequacies in the capacity of subnational institutions to implement policies.

Prior to the launching of the Ghana National Climate Change Policy (NCCP) in 2013 and the National Climate Change Adaptation Strategy (NCCAS) in 2012 (See Table 3.2), the country's responses to climate-related hazards/risks in the agriculture sector was basically reactive (ex post). Even though the current adaptation processes exhibit some degree of decentralised planned effort, there is still a significant disconnect between adaptation policy or strategy implementation at the national and subnational levels. With the implementation of the National Decentralization Programme for the agricultural sector in 2015, it is hoped that subnational level institutions will have the autonomy needed to make and implement certain local level adaptation decisions. It is my argument that, to improve the productive and allocative efficiency at subnational levels, there must be a greater transfer of responsibilities and resources from the Central Government (i.e. Ministry of Food and Agriculture (MoFA) to the Metropolitan, Municipal and District Assemblies (MMDAs) and by extension, to the Town Councils and Area Unit committees.

Table 3. 1 Overview of development and agriculture policies and their priorities in relation to climate change

Policy/project	**Institutions**	**Key Climate change Priorities**	**Key Agricultural priorities**
Food and Agriculture Sector Development Policy I (FASDEP (2002)	Ministry of Food and Agriculture	No reference to climate change	• Transformation of the agriculture sector from a resource-based to a technology-based industry (investment in technology) • Improve agricultural marketing (domestic) • Accelerating the provision of irrigation infrastructure • Improving institutional coordination • Reducing post-harvest losses by constructing more storage facilities • Promote the creation of FBOs • Expansion of agricultural financing
Growth and Poverty Reduction Strategy II, 2005 (GPRS II 2005)	National Development Planning Commission	• Enhance awareness on climate change and its impact” • Initiate measures toward minimizing the impact of climate change/variability • Deal with the effect of climate change especially drought and desertification” • Adopt policy framework on climate change and mainstream of the national action programme to combat drought and desertification	• Improve agricultural marketing (domestic) • Increasing access to extension services • Accelerating the provision of irrigation infrastructure • Promote selective crop development • Promote agro-processing
Food and Agriculture Sector Development Policy II (FASDEP II (2007)	Ministry of Food and Agriculture	• Address issues (barriers or opportunities) of productivity in both agriculture and in environmental services, this objective will serve as entry point in addressing the interactions between agriculture and climate change and biodiversity loss.	• Transformation of the agriculture sector from a resource-based to a technology-based industry (investment in technology) • Ensuring food security • Improve agricultural marketing (domestic) • Improving institutional coordination • Investment in agricultural research • Increasing diversification of incomes

Northern Rural Growth Programme (2007)	Ministry of Food and Agriculture (MoFA)	• The diffusion of drought-resistant varieties (Component A), irrigation development and soil and water conservation (Component B) will contribute to mitigating climate change. • Appropriate specifications including enhanced soil binders will be used to withstand extreme weather events due to climate change	• Poverty reduction and food security through: • Commodity chain development • Rural infrastructural development and • Improved access to rural finance
National Decentralization programme for the agricultural sector (2015), National Agricultural Extension Policy (2001).	Ministry of Local Government and Rural Development (MLGRD), Ministry of Food and Agriculture (MoFA)	No reference to climate change	• Decentralization of agricultural extension services • Ensures extension provision to small-scale resource poor farmers with special attention to women, youth, and they physically challenged • Decisions devolved to District Assemblies in consultation with MOFA, farmers, other stakeholders • Involve community in problem identification, planning, implementation, and evaluation of extension
Medium-Term Agriculture Sector Investment Plan (METASIP 2010)	National Development Planning Commission, Ministry of Food and Agriculture (MoFA)	• Assist farmers to adapt to climate change impacts but should also encourage them to undertake mitigation measures. • Enhance the capacities of extension service providers in approaches to climate change adaptation and mitigation	• Transformation of the agriculture sector from a resource-based to a technology-based industry (investment in technology) • Ensuring food security • Improve agricultural marketing (domestic) • Improving institutional coordination • Investment in agricultural research
Medium-Term National Development Policy Framework: Ghana Shared Growth and Development Agenda (GSGDA 2010)	National Development Planning Commission	• Mainstream impact of climate change into sectoral and district plans	• Improving institutional coordination • Improve agricultural marketing (domestic) • Promote selective crop development • Improving agricultural productivity

Source: Author’s own construct, using the review by Sova et al. (2015).

When decisions are devolved to the MMDAs in consultation with farmers and other stakeholders, there is a greater likelihood that the provision of agricultural services and adaptation interventions will reach most of the vulnerable farmers (e.g. smallholder resource-poor farmers, women, elderly, and physically challenged). It is important to reiterate that adequate devolution, deconcentration, and/or delegation of responsibilities for the purposes of agriculture adaptation to climate risks, requires substantial institutional capacity (i.e. human, financial, and infrastructure) at that local level.

Climate change adaptation literature highlights the importance of local level institutions in adaptive responses and in the transformation of adaptive actions to adaptive capacity (See Yaro et al. 2015; Breman 2012; Moser 2009). However, in Sova et al. (2015) the inference is that although personnel within subnational institutions (i.e. MMDAs) in Ghana are aware of most of the policies on climate change, agriculture, and development in general (e.g. the National Decentralization Programme for the agricultural sector), implementation has been a problem over the years. This is attributed to the fact that knowledge and the focus of policies tend to be higher among directors at the national levels and decreases towards the frontline staff at MMDAs.

Table 3. 2 Overview of climate change policies and their priorities in relation to agriculture

Climate change Policies/plans	Institutions	Key climate priorities	Key agricultural priorities
Integrating Climate Change and Disaster Risk Reduction into National Development, Policies and Planning in Ghana, (2010)		• Create and deepen awareness about the critical role of climate change and disasters in national development efforts • Ensure that climate change and disaster issues are fully integrated and sustained in the national planning process • Assist pilot districts to integrate climate change and disaster risk in their District Medium-Term Development Plans • (4) Take up adaptation and mitigation measures	• Awareness creation and capacity building • Improved land use management • Develop drought and flood tolerant varieties, and climate-resilient livestock breeds • Establish national food banks • Develop insurance schemes
National Climate Change Adaptation Strategy (NCCAS), (2012)	MEST, EPA, NCCC	• Improve societal awareness and preparedness for future climate change • Enhance the mainstreaming of climate change into national development to reduce climate change risks • Increase the robustness of infrastructure development and long-term investments • Enhance the adaptability of vulnerable ecological and social systems by increasing the flexibility and resilience of these systems • Foster competitiveness and promote technological innovation	• Awareness creation and capacity building • Promote research in climate-smart agriculture • Develop drought and flood tolerant varieties, and climate-resilient livestock breeds • Invest in post-harvest storage systems • Climate policy integration • Establishing early warning systems • Promote indigenous adaptation • Build and strengthen capacity of extension officers in climate-smart agriculture

National Climate Change Policy (NCCP), (2013)	MEST, EPA, NCCC	• Develop climate-resilient agriculture and food security systems • Build climate-resilient infrastructure • Increase resilience of vulnerable communities to climate-related risks • Increase carbon sinks • Improve management and resilience of terrestrial, aquatic and marine ecosystems • Address impacts of climate change on human health • Minimize impacts of climate change on access to water and sanitation • Address gender issues in climate change • Address climate change and migration • Minimize greenhouse gas emissions	• Awareness creation and capacity building • Agro-forestry • Improved land use management • Promote research in climate-smart agriculture • Build capacity for community level weather data collection, analysis, and dissemination • Promote soil and water conservation in agriculture • Improve efficiency of farming practices through secure tenure • Promote agricultural diversification

Source: Author's own construct, using the review by Sova et al. (2015).

3.6 Overview of the Sudan Savannah agroecological zone

Ghana is divided into three main climatic zones; the Savanah climatic belt (north), the tropical forest climatic belt (south west), and the Accra plains climatic belt. The Savannah and Accra plains climatic belts are characterised by a single rainy season, with the tropical forest climatic zone experiencing double rainy seasons. The country's climate has also been described as warm and comparatively dry along the southeast coast, hot and humid in the southwest, and hot and dry in the north, all with distinct wet and dry seasons. This spatio-temporal variation in climate informed the delineation of Ghana into agroecological zones. Table 3.3 summarizes how the country's 10 administrative regions are distributed among 6 agroecological zones which reflect the dominant climatic conditions and vegetation types.

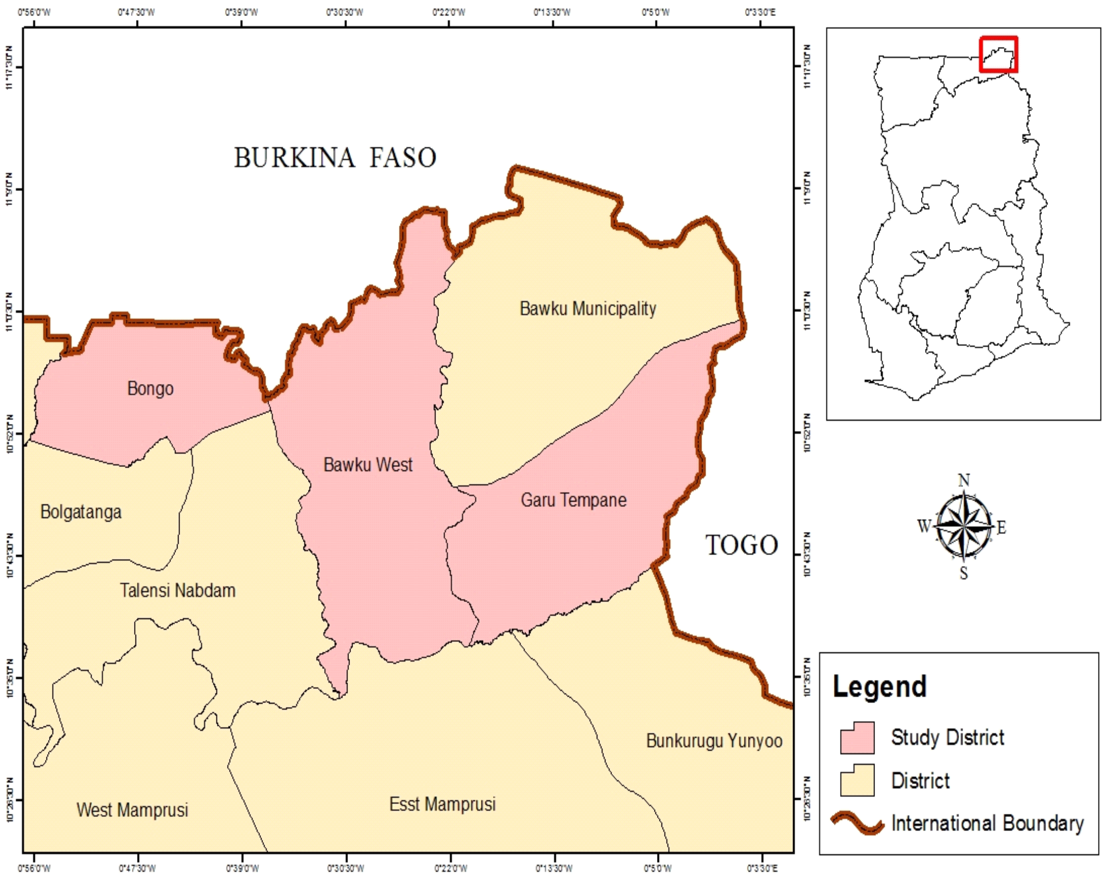
Table 3. 3 Demarcation of Ghana into agroecological zones

Agroecological zones	**Vegetation zones**	**Administrative Regions**
Rain (Evergreen) Forest	High forest zones	Parts of Western, Brong Ahafo, Ashante, Eastern, and Central Regions
Deciduous Forest		
Forest-Savannah Transition	Transitional zone	Parts of Brong Ahafo, Ashante, Eastern, and Volta Regions
Coastal Savanah	*Savannah zones	Parts of Central, Western, Greater Accra, and Volta Regions
Guinea Savannah		Parts of Upper East, the whole of Upper West and Northern Regions
*Sudan Savannah		Part of Upper East Region (UER)

Note: *study area

The Sudan Savannah agroecological zone, the zone of interest, covers more than one third of the Upper East Region (UER), which is located in the in the north-eastern corner of Ghana (See the yellow portion of Figure 3.3). The UER covers a total land area of 8,842 sq.km, with the Sudan Savannah covering almost 35 percent of the area. According to the Ghana Statistical Service (GSS) (2013), the Region has a population of 1,109,338 (4.2 percent of total population of Ghana), with a population density of 118 persons per km^2. It has an estimated 177,631 households, with the average household size being 6.1 in rural communities and 5.2 in urban centres. Most of these households are headed by males (72.3 percent) and are predominantly rural (76.3 percent). The age distribution by sex shows that there are more females (51.6 percent) than males (48.4 percent) in the area. The excess of females has implications for agriculture and food production in the sense that culture gives the males control over access to land in particular, and livelihood assets in general (GSS 2013).

Figure 3. 3 Map of the study Districts



Source: Climate vulnerability assessment, 2017

The main occupations in the Region, in order of magnitude, are agriculture and related jobs (68.7 percent), production and transport equipment work (13.5 percent), petty trading (8.5 percent) service work (3.9 percent), and professional, technical and related work 2.8 percent (GSS, 2013). According to the 2010 population census, 71.8 percent of the adult population (15 years and above) in the Region are employed, with agriculture and related activities employing a greater percentage. Agriculture is the main occupation of the people in this area. Out of the 392,019 adult population employed in agriculture and related activities (per the 2010 population census), 87.1 percent are located in rural communities. Again, the census data also shows that 83.7 percent of households in the Region are engaged in agricultural activities, with 86 percent of these households located in rural areas. This high concentration of agricultural households in the rural communities confirms the assertion that agriculture in this part of Ghana is, essentially, a rural industry (GSS 2013). These mainly smallholder households engage in four major farming activities; crop farming, tree growing, livestock rearing, and fish farming.

Agriculture among rural communities is predominantly smallholder, with 70 percent farming 2 hectares or less of farmland (Chamberlin 2007). These farmers find themselves in a very difficult natural environment where poverty remains significantly widespread (poverty incidence of 44.4 percent above the national average of 24.2 percent), and more persistent than in the southern zones of Ghana. The social-ecological conditions that play in concert to hamper smallholder livelihoods in this area include the climate and weather variability, natural disasters (droughts and floods), ecological degradation, inadequate irrigation facilities, land tenure system, policy neglect, political marginalisation, and poor infrastructure (Yaro et al. 2015). Consequently, the future predictions for the Sudan Savannah Zone indicates that the zone will continue to bear the brunt of climate related impacts for several decades to come (Oguntunde 2006; Minia 2004). According to Minia (2004), the projected annual rainfall total for northern Ghana will decrease by 9 to 27 percent by the year 2100, which could further complicate the already unreliable livelihoods in these marginalised smallholder communities.

Soils in this area are mainly developed from granite rocks and are shallow in depth and low in fertility, with low organic matter content (on higher grounds). The valley areas have soils ranging from sandy loams to salty clays. In these valleys, soils have relatively higher natural fertility but are more difficult to till, and are prone to seasonal waterlogging and floods. The Sudan Savannah is drained by the White Volta, Red Volta and Sissili Rivers. The vegetation of the area is savannah woodland, characterised by scattered drought-resistant trees and grass. During the long dry season, the vegetation gets burnt by bushfires or charred by the sun. Anthropogenic disturbance within this agroecology is very significant, resulting in the semi-arid conditions experienced by inhabitants. The zone is characterised by a single rainy (wet) season, which is from May/June to September/October. It has a mean annual rainfall within the range of 700 mm and 800 mm. In terms of duration and spatial distribution, the rainfall can be described as erratic. November to March is the long dry season, during which the area experiences the hot, dry, and dusty hamattan winds (like the dusty desert winds). During this period temperatures can be as low as $14^{o}C$ at night and as high as 45°C during the day. Droughts in the uplands, flooding in the valley areas, and severe erosion on slopes are the most predominant environmental challenges in the Sudan Savannah.

3.6.1 Overview of study districts

This subsection provides an overview the study districts selected for this research. Much of the Sudan Savannah (Two-thirds) is covered by four districts, Bawku Municipal, Bawku West, Garu-Tempane, and Bongo districts. Initially the study intended to cover all four districts. However, because of the security situation around the Bawku municipal during the data collection period, the district was not ultimately included in the list of study districts. The study districts were Bongo, Bawku west and Garu-Tempane districts. It important to note that much of the descriptives/statistics in this section were sourced from the Ghana 2010 population and housing census district analytical reports for Bongo, Bawku West, and Garu-Tempane (Ghana Statistical Service [GSS] 2014), and the official Ghana districts webpage (see http://www.ghanadistricts.com/), which are all available for public use.

Bongo district

The Bongo district is found between longitudes 0.45° W and latitude 10.50° N to 11.09 and has an area of 459.5 square kilometres. It one of the nine districts in the Upper East Region of Ghana and shares boundaries with Burkina Faso to the North and East, Kassena-Nankana West and East districts to the West and Bolgatanga district to the South. The Bongo district has a population of 84,545, representing an increase of 8.6 percent of its population from the 2000 census (77,885). The district is predominantly rural, with about 94 percent (79,376) of its population residing in rural settlements. It is characterised by large household size, high population density, and high fertility rate (GSS, 2014), with a relatively young population (two out every five is below 15 years). With these demographic characteristics, it is not surprising that the district is experiencing socio-economic disadvantages related to the over exploitation of natural resources. The population census analytical report argues that for a population that is predominantly engaged in agriculture, increases in population density cannot be ignored (GSS 2014). Another worrying demographic characteristic of the district is that about 52 percent of the population above 11 years of age cannot read and write in any language. This has consequences for climate change communication efforts in these communities. Unemployment is also relatively high in Bongo. The unemployment rate in the district is 26 percent which is more than twice the national average of 10.4 percent, and it is the second to Bawku west within the Sudan Savannah Zone.

Agriculture is the dominant occupation in the district and apart from the district capital, Bongo, all other communities are made up of small farm settlements scattered around all over the district. About 96 percent of households in the district engage in agriculture. 97.3 percent of the total number of rural households engage in agriculture, with 76 percent for urban dwellers. According to GSS (2014), the majority of rural farm-households are headed by people aged above 60 years, while in the urban areas these households are mostly headed by persons younger than 49 years of age. The principal crops grown in the district include millet, sorghum, rice, maize, groundnuts, cowpea, soya bean and fruits and vegetables such as water melon, tomato, onion, and pepper. The major environment related issues that hinder their agriculture activities include land degradation/soil erosion, desertification/deforestation, and declining soil fertility. Apart from inappropriate farming practices, land degradation and desertification has been attributed to high population density, over stocking and overgrazing, bush burning and wood harvesting, which has implications for weather variability in the broader zone.

The climate in the district is similar to most parts of the Sudan Zone. The Mean monthly temperature is about 21^{o}C, with very high temperatures of up to 40^{o}C, which occur just before the onset of the single rainy season in April/May. Low temperatures of 12^{o}C can be experienced in December when dry dusty winds from the Sahara (*Hamathan* winds) destroy the vegetation. The district has an average of 60 rain-days with rainfall ranging between 600mm and 800mm. The district lies within the Sudan Savannah Zone with one rainy season. The amount of rainfall in the district is offset by the intense drought that precedes the rain and by the very high rate of evaporation that is estimated to be 168cm per annum (GSS 2014). The district experiences recurrent floods and droughts and coupled with problems associated with over exploitation of natural resources, agriculture in the district is increasingly becoming unsustainable.

Bawku West district

The Bawku west district, just like Bongo, also falls within the Sudan Savanah Zone in the Upper East of Ghana. The district lies roughly between latitudes 10^0 30'N and 11^0 10'N, and between longitudes 0^0 20'E and 0^0 35'E. The District shares boundaries with Burkina Faso in the North, Bawku Municipality to the East, Talensi/Nabdam District to the West and East Mamprusi District to the South. The District covers an area of approximately 1,070 square kilometres, which constitutes about 12 percent of the total land area of the Upper East Region. The district experiences a unimodal rainfall system which lasts 3 to 5 months and a long dry period of 7 to 9 months per year. According to GSS (2014), the average annual rainfall, temperature and relative humidity are 956mm, 34oC and 56 percent respectively, with potential evapotranspiration of more than 2882mm.There is therefore excessive evapotranspiration over rainfall (GSS 2014).

The demographic characteristics, like in most parts of the Sudan Savannah Zone, are large average household sizes (6.1 relative to 4.4 for entire country), high illiteracy rates, and high birth and fertility rates, high unemployment among youths between the ages of 15 and 29. The total population of the district is 94,034, out of which 85,406 are rural and 8,628 are urban dwellers. The Bawku West has an economically active population of 40,770. Out of this population, 81 percent are actively involved in farm production agricultural and agricultural related activities (agro-processing – pito brewing, shea butter extraction, groundnut oil extraction, malt production, rice processing, *dawadawa* processing). Agriculture plays an important role in the socio-economic development of the Bawku West district. The demand for labour is at its peak in the rainy season for most of the farming activities. The youth are the major source of the causal labour that can be tapped for both agriculture and non-agriculture jobs. The total cultivable area is 58,406 ha and uncultivable area of 33,687. The principal crops grown in the area are sweet potatoes, sorghum, millet, maize, rice, tomatoes, onions, okra, pepper, watermelon, Bambara nuts, cowpea, soya bean, and groundnuts. Apart from crop production, livestock and poultry rearing is the second most important agricultural activity undertaken by farm-households in the district. The production is largely at subsistence level. The livestock reared include, sheep, cattle, pigs, donkeys and goats, while the poultry are fowls, guinea fowls, turkeys and ducks.

The vegetation in the Bawku West is the Sudan Savannah consisting of short drought and fire-resistant deciduous trees interspersed with open savanna grassland. Grass is very sparse and in most areas the land is bare and severely degraded. Most of the soils are consequently of low fertility. The soil nutrients phosphorus and nitrogen are often lacking. Any efforts towards increasing the amount of organic matter in soils is constrained by regular burning of crop residues and/or competitive use of these residues for fuel, animal feed or building purposes. The low vegetative cover during the dry season also renders most of the soils vulnerable to erosion during the rainy season. This, in turn, aggravates the already low fertility problem. The increased crop yields and food security is therefore closely linked with careful management of the soils, with the objective of preventing and controlling erosion, increasing their organic matter content (compost, crop residues, farmyard manure, etc.) and replacing the lost plant nutrients. The natural environment is highly degraded by inappropriate farming practice, fuel wood harvesting, overgrazing, and bush fire. The gold deposits in Zebilla and Sapelliga have increased illegal mining among the youth. This is evident in Widna –Teshie, where illegal surface mining and stone quarrying are prevalent activities resulting in serious land degradation and water pollution.

Garu-Tempane district

The final study area was the Garu-Tempane district, also located in the Sudan Savannah zone within the Upper East Region. This district is located in the north-eastern part of the region, between Latitude 10^0 10'N and Longitude 0^0 10'W. It is bordered to the east by the Republic of Togo, to the north by Burkina Faso, to the west by Bawku municipal, and to the south by East Mamprusi district assembly. The district has an area of 1,230 sq. km and a population density of 99 persons per sq. km. The district is 95 percent rural, with an estimated total population of the district at 130,003.

The 2010 population census for Ghana indicated that the majority of the population were aged between <19 and 59, which has implications for the productive capacity of the district. The labour force is, however, compensated by the large number of hardworking women (GSS 2014). The population is largely rural; about 95 percent of the district is rural, with only about 5 percent being urban. The district has a high fertility rate (4), with an average household size of 6.5, which has implications for the household labour force. Although these large households could mean availability of family labour force, it has some socio-economic implications in terms of feeding, healthcare, education, and clothing. According to the GSS (2014), the child dependency ratio is 101 percent in rural Garu-Tempane (with a total dependency ratio of 119 percent). Farming is the predominant occupation of the people in the district, employing about 85 percent of the labour force. Farmers in the district engage in cultivation of cereals, legumes, vegetables as well as tree crops. Livestock and poultry rearing are an important economic activity for the people of district, with most engaging in mixed farming where majority of farmers cultivating crops also keep some livestock and poultry.

The natural environment is made up of economic trees, grasses and water bodies which are scattered all over the district. Economic trees are constantly being cut for various purposes, a situation that has led to the creation of a district taskforce to monitor and combat the indiscriminate cutting of trees. Other environmental-related problems are illegal gold mining, rampant bush fires and soil erosion. Some parts of the environment, especially along the White Volta basin, are generally prone to flooding during the raining season, while the highlands are prone to recurrent droughts (Yiran et al. 2016). In Yiran et al. (2016), between 1988 and 2012, Garu experienced 13 droughts and that dry spells occurred at least every year. All these factors, coupled with population pressure, increased urbanisation, and climatic change, have played a role in the current state of agriculture in particular, and the livelihoods of communities in the districts.

3.7 Conclusion

Contemporary research on climate variability and change reinvigorates the increasing consensus that the World's social-ecological system (SES) will face major threats in the coming century (IPCC 2014a; McLaughlin, 2011). These threats, it is argued, will severely and disproportionately affect livelihoods that are basically anchored on climate-sensitive resources. This chapter has placed the project in context by discussing climate trends and implications for the vulnerability and adaptation of farming systems in Ghana. In the next decade the country's precipitation and temperature will be severely variable, and that predictions may not be highly reliable. If this holds true, then there will be an increase in the frequency and severity of extreme events like droughts and floods. The consequences of these predictions for the already sensitive agriculture sector, particularly smallholder farming systems, will be grave. There is general agreement among stakeholders on the enhancement of adaptation among these group of farmers, especially in relation to targeting the most vulnerable in marginalised regions. This project used the Sudan

Savannah Zone as a case study to assess the climate vulnerability and adaptation among farm-households. The review showed that the zone has a difficult and persistent social-ecological condition (e.g. poverty, policy neglect or political marginalisation, environmental degradation, high aridity, etc.), despite the numerous efforts by both government and non-governmental institutions over the last decade.

Chapter 4: Research methodology

4.1 Introduction

This chapter presents the methodological orientation and the various research strategies used for the study. The chapter begins with a discussion of the guiding conceptual framework, and then proceeds to discuss how the study triangulated research methods from qualitative and quantitative (mixed methods) approaches at each stage of the research design, to enhance the validity of the research. It then concludes with a socio-demographic description of the respondents in the survey which formed part of the primary data collection.

4.2 Conceptual Framework

This research combined ideas from a set of conceptual frameworks to develop a local level integrative vulnerability framework that facilitated the achievement of the research objectives. Assessing vulnerability by integrating both risk-hazard and the entitlement and livelihood approaches, allows for a multi-factor analysis of vulnerability and adaptation. Figure 4.1 is the researcher's own construction, based on ideas from the MOVE framework (See Birkmann et al. 2013) and the multi-scale vulnerability framework (See Turner et al. 2003). The MOVE and multiscale frameworks provide a clear definition of indicators and their interrelationships (especially, relative to the IPCC framework on vulnerability). Particularly, the choice of both frameworks is based on the fact that they exemplify a vulnerability context that incorporate a mix of interrelated social-ecological factors. These factors include: the characteristics of the climate hazard; components exposed to the climate risk, sensitivity of livelihood asserts; adaptive capacity of exposed components; and climate adaptation. By operationalizing vulnerability of farm-households from a social-ecological system's perspective, this model provides the opportunity to analyse 'vulnerability' in relation to 'resilience' and 'adaptation'. The selection of indicators and variables in this study was largely based on relevance to local context and a thorough review of literature that used similar indicators and variables (e.g. Derbile et al. 2016; Acheampong et al. 2014; Birckmann et al 2013; Shah et al. 2013; Antwi-Agyei et al. 2013; Hahn et al. 2009; Deressa et al. 2008; Smit & Wandel, 2006; Brooks et al., 2005; Turner et al. 2003; Yohe & Tol, 2002).

The local level livelihood vulnerability framework allows for the use of sustainable livelihood assets to develop vulnerability indices. The sustainable livelihoods approach (SLA) was used in this thesis to frame the identification of indicators and variables that determine household livelihood exposure, vulnerability and adaptation to climate change (See Antwi-Agyei et al. 2013; Scoones, 1998). According to Hahn et al. (2009), the use of SLA for climate vulnerability assessment allows for the easy use of household level data to inform strategic community level planning. The SLA provides valuable insights into how people achieve their livelihoods outcomes by combining a range of capital assets to pursue different livelihoods activities (Bauman & Sinha, 2001). Consequently, an assessment of livelihood capitals offers the opportunity to identify the various factors underlying a household's vulnerability and the capacities that might be used to reduce rural communities' vulnerability climate change (Ziervogel &Calder, 2003). How the constructed local level vulnerability framework is applied in this study is discussed in subsequent subsections.

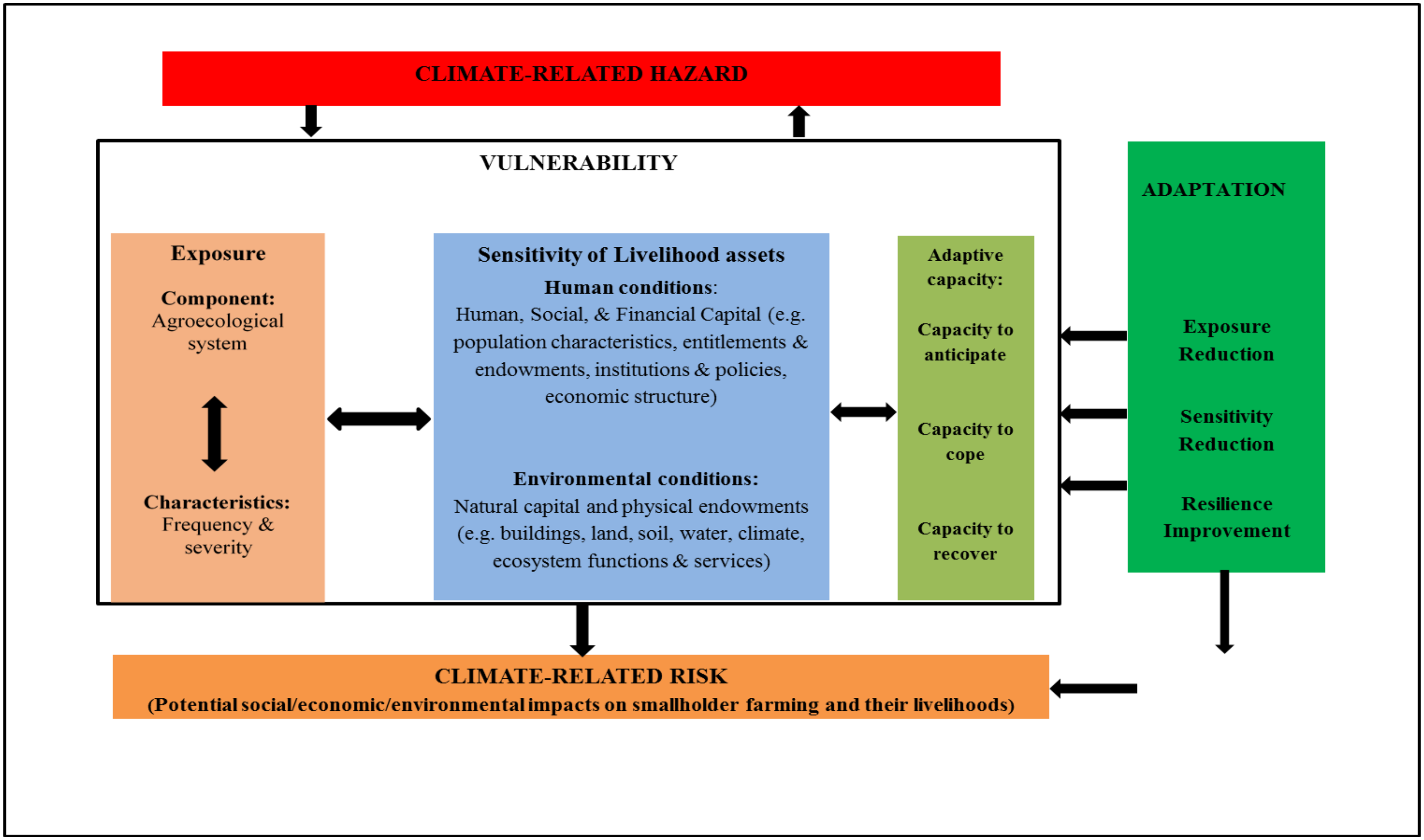
4.2.1 Exposure

Exposure, as defined by Birkmann et al., "…is the extent to which a unit of assessment falls within the geographical range of a hazard event" (Birkmann et al. 2013: p. 200). Exposure conceptualised in this manner comprises the spatial and temporal patterns of the interaction between the characteristics of the hazard (of interest to this study are frequency and severity), and the exposed components (See Birkmann et al. 2013; Cardona et al. 2012; Turner et al. 2003a & b). Figure 4.1 shows the exposed component considered as the combined farm-household system, with the understanding that exposure may also be dependent on intervening socio-economic and institutional structures (Sen, 1983). Consequently, in the context of this study, exposure is examined from two perspectives: biophysical risks and household exposure to climate variability and extremes. Using geospatial analysis, this study mapped the study zone's biophysical risks to drought, highlighting areas of low to high risk of exposure. The study also developed and discussed household exposure indices. It is important to emphasise that exposure to drought is a necessary but not sufficient determinant of drought susceptibility. That is, it is possible to be exposed but not vulnerable. However, to be sensitive, and for that matter vulnerable to drought, one must first be exposed. From the perspective of farm-households, this research also develops exposure indices for respondents.

4.2.2 Sensitivity

'Sensitivity' varies across authors and contexts. The IPCC (2001) defines sensitivity as the degree to which a system is affected adversely or beneficially by climate related stimuli. Birkmann et al. (2013) and Turner et al. (2003a & b) consider sensitivity to exposure as the predisposition of a social-ecological system at risk of a hazard. Considering these two definitions in the frame of this research, sensitivity of the study zone is defined by the human-environmental conditions. Implying that this research assumes that entitlements and livelihood assets (human, social, financial, physical, and natural capital), either influence the adaptive responses of communities and households when climate related hazards are experienced, or are adjusted (or created) because of the exposure to the hazard. In this view, sensitivity is an inherent property of the Sudan Savannah agroecological system, existing prior to the hazard. Sensitivity is used here to highlight the degree of susceptibility of capital assets to climate hazards (Figure 4.1).

Figure 4. 1 Locale level vulnerability framework



Source: Author's own construct (2017), informed by Birkmann et al. (2013) and Turner et al. (2003

4.2.3 Adaptive capacity

Smit and Wandel (2006) argue that adaptive capacity is closely related to other commonly used concepts like adaptability, coping ability, management capacity, and resilience (also refer to Jones 2011 and Fussel & Klien 2006 for similar arguments). Adaptive capacity in the context of this study is conceptualised as the ability of an individual, household, community, or other social groups to maintain a particular desirable domain or state under climate stimuli, guaranteeing survival and sustainability through learning. According to Adger (2003) the forces that influence the ability of the social-ecological system to adapt to hazards represents the determinants of adaptive capacity. The adaptive capacity required to cope with drought is thought to depend on five livelihood assets: financial, human, natural, physical and social capital assets (Gbetibouo et al. 2010).

In line with this, farmers' and communities' adaptive capacities are dependent on indicators of their ability to anticipate, cope, and recover from exposure and sensitivity to climate related hazards. These indicators include, but are not limited to, local knowledge (especially from past experiences), kinship networks, access to technology and information resources, ownership of land, adequate food and income sources, family and community support in times of crisis, political influences, and good leadership and management (See Wisner et al. 2004; Smit & Pilifosova 2001; Kelly & Adger 2000). These indicators are interrelated. For instance, a strong kinship network may increase adaptive capacity by allowing greater access to economic resources. Again, good leadership has the potential to open access to technology and information resources.

It is also important to acknowledge that adaptive capacity is context-specific and varies by country, community, social groups, and individuals, as well as over time. The scale or level of adaptive capacity are not independent (Smit & Wandel 2006). That is, the capacity of a farm-household to cope with climate risks depends on, to some degree, the accessibility to requisite capitals, the enabling environment of the community, and the adaptive capacity of the community is reflective of the resources and processes of the country (Yohe & Tol 2002). The assessment of adaptive capacity in this study consider the interdependence of country context, the district, through to the farm-household. However, this research does not lose sight of the fact that household level analyses have shown that the conditions that interact to shape exposures, sensitivities, and adaptive capacities are locally specific (Smit & Wandel 2006). In this study, the assessment of adaptive capacity is captured within the frame of adaptation and conceives adaptation as constituting both adaptive action and adaptive capacity. This was informed by the argument that the transformation of adaptive action translates into enhanced adaptive capacity and vice versa (Freduah et al. 2018: p62; Breman et al. 2012; Pelling 2011).

4.2.4 Adaptation

The aim of the adaptation component in the above framework (Figure 4.1) is to explore the adaptation strategies adopted by farm-households. Specifically, the research identifies these strategies (both off- and on-farm), determinants of such choices, and the drivers that constrain adaptive action and its translation into adaptive capacity. That is, the study seeks to investigate the capacities and processes that may, or may not, accommodate adaptive responses or provide the means of improving adaptive capacities. Here, the research sought specific information on exposure reduction, sensitivity reduction, and resilience improvement from the survey respondents and FGD participants, through their experiences and knowledge. Thus, the focus was the conditions that are relevant to the communities rather than those presumed by the researcher. The motivation, here, is to identify what can be done practically, in what way, and by whom, in order to reduce exposure and sensitivity, and improve resilience.

4.3 Methodological orientation

> "Blurred genres…" (Geertz, 1980: p165).
>
> "…inquiry methodology can no longer be treated as a set of universally applicable rules or abstractions" Lincoln and Guba (2000: p164).

In the last two to three decades or so the issue of hegemony among social science research paradigms has become increasingly blurred and less relevant (just as Geertz prophesied in the 1980s). The various research paradigms are beginning to "interbreed" in the sense that methodologies that were previously thought of as incompatible under one theoretical rubric, may now appear as informing one another under a different theoretical rulebook (See Lincoln & Guba 2000: p164; Tashakkori & Teddlie 1998: pp24-25). The chosen research methodology emerges from the nature of a particular discipline (study) and a particular theoretical/philosophical perspective (Lincoln & Guba, 2000). Thus, underneath the choices about research methodology in the social sciences are the epistemological and ontological positions (Mkansi & Acheampong 2012). A social scientist's choice of ontological leaning is influenced by his or her epistemological stands. Ultimately, his or her methodological preferences hinge on epistemological orientation.

This study uses pragmatism as its paradigmatic orientation and is therefore adopted a mixed methods research approach (See Tashakkori & Teddlie 1998) and quantitative and qualitative methods. The justification for the adoption of this approach can be traced to the multi-dimensionality of the issues under investigation (climate variability and extremes, exposure, vulnerability and adaptation). To comprehensively and contextually investigate these issues, a mixed methods approach presents an opportunity to combine both objective and subjective viewpoints. That is, it conceives knowledge as both constructed and also based on the reality, while choosing explanations that best produce desired outcomes (the use of multiple realities) (Tashakkori & Teddlie 1998: pp 24-28). According to Tashakkori & Teddlie (1998), it is more reasonable to think of objectivity and subjectivity as a continuum rather than two opposing poles. This is because over the course of research, a researcher may be both objective and subjective in his or her epistemological orientation. This research, therefore, assumes that knowledge is derived from interaction among groups of individuals and the artifacts in their environment, both of which create a reality (See Schuh & Barab 2008 In Spector et al. 2008). Triangulating methods from these two approaches allows for the deepening of understanding of the proposed research questions through the cross-validation of data and results (Bryman & Bell 2007).

4.4 Research design

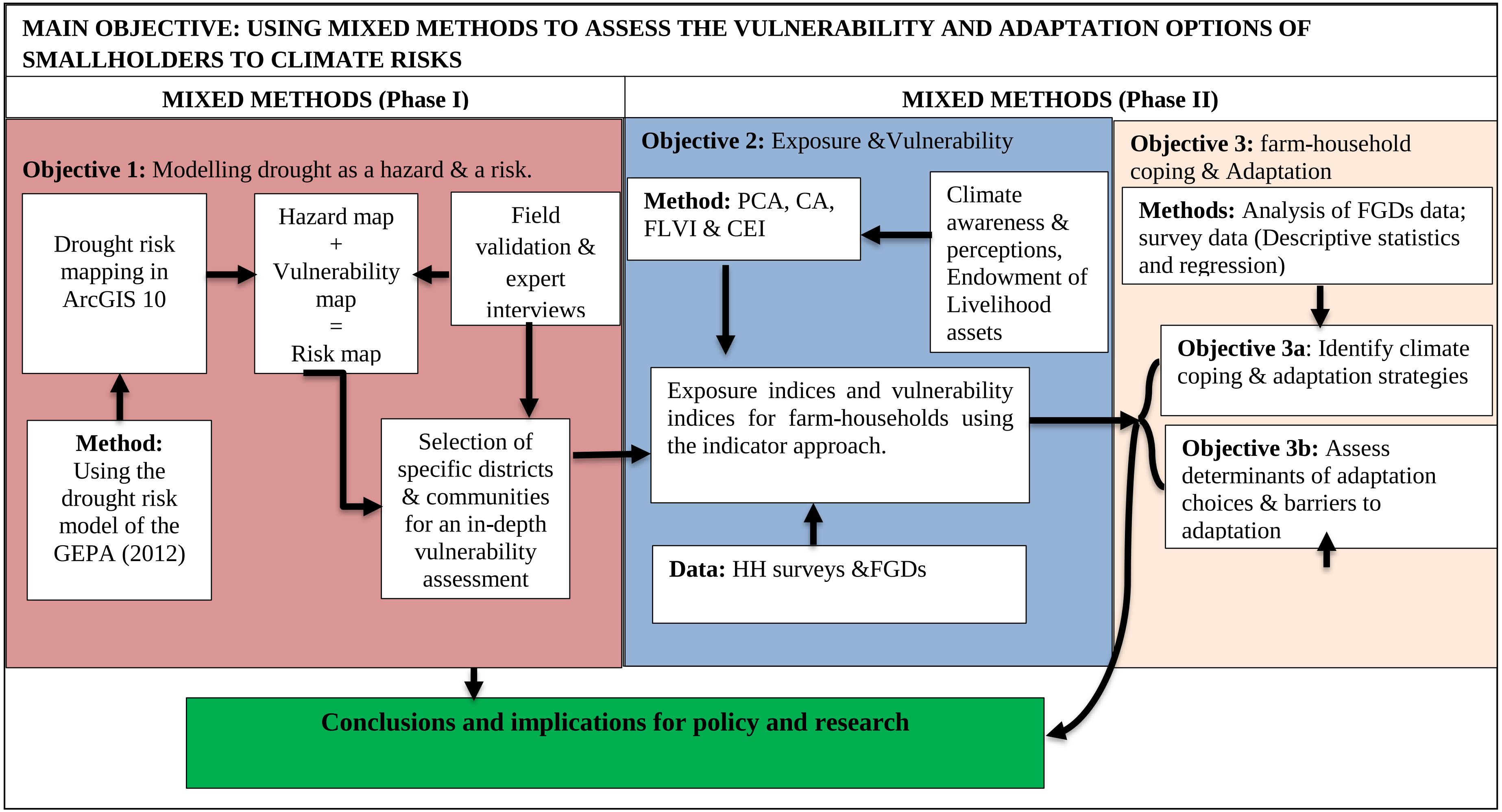
Once the research ethics clearance was obtained from the University of Adelaide, a six month long fieldwork was carried out in Ghana, specifically in the Sudan Savannah Zone (SSZ), between November 2016 and May 2017. The fieldwork started with a visit to the host institution i.e. the Department of Geography and Regional Planning in the University of Cape Coast, Cape Coast. Here, the researcher was given a working space at Department's GIS laboratory and a computer with access to their spatial database. It should be noted that it was from this database that the researcher sourced the spatial data for the first phase of the fieldwork (i.e. the spatial analysis). The researcher spent close to two months in this institution before moving into the study area in January for the primary data collection.

This study consisted of two distinct phases and each phase constitutes a triangulation of quantitative and qualitative methods, as outlined in Figure 4.2. Qualitative methods are flexible and allow for a deeper understanding of complex phenomena like climate related vulnerabilities and adaptation (Winchester 2005; In: Antwi-Agyei et al. 2012). This advantage is attributable to the fact that participants' own conceptions form the bases of qualitative data.

This provides an understanding and description of people's experiences of the phenomena (See the emic and etic viewpoints by Pike (1967)) within the local context. However, when an insider's viewpoint underlies results, generalisation becomes difficult. Quantitative methods on the other hand, may allow for generalisation of results and predictions (Antwi-Agyei et al. 2013) though it does not afford the researcher the flexibility of incorporating local populations' socio-cultural conceptions of the phenomena. The shortcoming of both approaches forms the basis for triangulation.

One of the aims of the two-phase design in this case is that the results of the first phase (more of exploratory) justifies the selection of study Districts and communities for the second phase (Greene 2007). This phase involved mapping the spatial distribution of drought risk using secondary spatial data and exploratory field interviews with experts at the District level to validate the risk probability map (i.e. the drought risk distribution map). These expert views also facilitated the selection of study Districts and communities for the second phase, to ensure adequate representativeness. The second phase of the study (exploratory and explanatory) adopts selected quantitative and qualitative methods to investigate the characteristics of smallholder farmers and communities that have proven either vulnerable or resilient to climate risks in the chosen districts in the Sudan Savannah agroecological zone. This phase also examined the determinants and barriers to adaptation.

Figure 4. 2 Research Design: Linking objectives and methods in a two phase study



Source: Author's own construct (2017)

4.5 Research methods

4.5.1 Data sources

There are several typologies of data. However, for the purposes of this research, consideration is given to the primary and secondary data dichotomy. The distinction between primary and secondary data depends on the relationship between the researcher(s) who collected the data set and the person(s) analyzing it (Boslaugh 2007). This is because a data set can be primary in one analysis and secondary in another. In the context of this study, secondary data refers to data previously collected by other individuals or organisations for different purposes. As such, data may occur as raw or processed data. Two types of secondary datasets are used in this study, quantitative spatial datasets as shown in Table 4.2. The use of spatial data was important for the mapping of the spatial distribution of drought risk in the study zone.

Table 4. 1 Secondary data used in this study

Data	Source	Purpose
Vegetation (NDVI); Soil	& Department of Geography and Regional Planning, Google Earth.	Drought Risk mapping
Temperature; rainfall;	Ghana Environmental Protection Agency (GEPA)	Drought Risk mapping
Landsat TM & ETM of the study area	Ghana Survey Department	Drought Risk mapping

Source: Climate vulnerability assessment, 2017

Primary data refers to data collected by the researcher for the specific objective of this thesis. Data collected during fieldwork constituted the primary data collected for the purposes of assessing climate risks, vulnerabilities/resilience and adaptation. For comparative purposes, cross-sectional data was collected over a period of six (6) months. Data sets included local awareness and perceptions of climate risks, perceived extent of exposure, perceived extent of vulnerability, drivers of vulnerability, and coping and adaptation strategies.

4.5.2 Data collection and instruments

Two main methods of data collection were adopted for this proposed study; interviewer-administered surveys and focus group discussions (FGDs). The survey and the FGDs were conducted in the local language, with research assistants acting as interpreters and sometimes as moderators. To ensure validity, the study used academic qualification as criteria for selection of research assistants (Tertiary qualification). Selected research assistants had training sessions to clarify concepts and issues in respect to data collection instruments.

Adopting the interviewer-administered survey technique, the researcher solicited data on household climate-related experiences and livelihood activities, assets, and capacities as captured in the Sustainable livelihood Framework (See DFID 1999). Questions on these assets in the survey questionnaire were asked and recorded by the researcher and the research assistants for several reasons. The study zone had high illiteracy rates, as a result it was assumed the research may encounter respondents who could not read and/or write. Thus, to achieve the ideal response rate of 80 to 85 percent (See Babbie 2001), and also to avoid misinterpretation of some questions, there was a need for the researcher and assistants to administer the questionnaire themselves. Moreover, using this method of data collection generally reduces the number of "don't knows" and "no answers" (Babbie 2001). Surveys were conducted in respondents' homes. This allowed the researcher to make informed preliminary observations about their socio-economic conditions, and also to take the opportunity to appraise the knowledge levels of respondents with regards to climate risks, vulnerability/resilience, and adaptation. This was very useful because it also aided the selection of FGD participants. During the survey, individuals who demonstrated appreciable knowledge of the issues were selected for the FGDs.

FGD is a qualitative data collection technique that relies on the systematic questioning of a group of individuals simultaneously in a formal or informal setting (Denzin & Lincoln, 2000). The purpose of FGDs in this study was to stimulate discussions and brainstorming of climate related experiences shared by participants. The FGDs sourced in-depth data on issues such as (though not limited to) the general developmental problems in the community, local understanding of climate variability and extremes, identification of adaptation practices and how they are applied, cropping patterns, poverty, and livelihood strategies. Using a focus group discussion guide, the researcher and sometimes the research assistants did the moderation of the inquiry and the interaction among the respondents in a formal manner. The FGDs were held in the local languages, so where the researcher didn't understand the language, trained research assistant(s) were used as moderators and for the transcription. The advantage of using FGD rests on the fact that it has high face validity and affords the researcher the opportunity to capture real-life data in a social setting (Babbie 2001).

Target population and unit of analysis

The target population for this research was smallholder farmers in the Sudan Savannah agroecological zone of Ghana. The selection of smallholders was not only because they are among the most vulnerable to climate impacts, but also because their vulnerability had rippling implications for other individuals or groups in society who depend on them, particularly for food and/or livelihood in general.

The unit of analysis refers to the person, group, or object from which data/information is sort. The concept, unit of analysis, is an important component in social science research because it shapes the type of data needed and from whom/what to collect it. According to Downing et al. (2000) people are the central concern of a vulnerability assessment. However, this central concern must be placed within the context of socio-economic institutions and activities, and bio-physical resources. Following this argument, this research captured three units of analysis which are linked to the objectives outlined in Chapter 1. This study looked at people (smallholder household heads (HHs) who are 18 years and above within the context of the place (climate-related risks in the Sudan Savannah agroecological system), and the availability of and/accessibility to sustainable livelihood assets.

By household, this study referred to an individual or group of individuals who live together, eat from the same pot, have at least one income generating activity together (e.g. farmland), and acknowledge the authority of a woman or man as the household head (HH). A HH, consequently, is a female or male member of the household who is recognised by the other members as being socially and economically responsible for the household unit. All relationships are, thus defined with reference to the household head. It is essential to highlight that members of the household may not necessarily be related by blood or marriage. This is because non-relatives like domestic worker (household caregiver) may form part of the household. On the other hand, not all related persons living in the same house or compound are necessarily members of the same household. For example, two brothers who live in the same house with their wives and children may or may not form separate households depending on their catering arrangements.

Sample size and sampling procedure

After the first phase which divided the entire zone into low, medium, and high drought risk sub-zones, the risk map, combined with field validation and expert interviews, enabled selection of three districts, each from a sub-zone for the second phase of the fieldwork. Experts from these districts were then consulted which gave rise to the selection of three representative communities, one from each district. The sample size for phase two of the fieldwork was two hundred and seventy. This figure constitutes two hundred and thirty randomly selected household heads for the interviewer-administered survey and forty purposively selected household heads for the Focus Group Discussions (FGDs).

The estimation of 230 household heads for the survey was guided by the need for precision (See Fowler 2009: pp38-47) given time and financially constraining circumstances. Using the table on confidence ranges for variability attributable to sampling (See Fowler 2009: p.41), this research estimated two hundred and thirty respondents at 95 percent confidence level. Proportionally, this number was distributed among the three communities based on the total number of households in each of the 3 selected communities. A sampling frame for each selected community was generated using data from the sixth round of the Ghana Living Standards Survey and the various District Agricultural Development Units (DADU). Based on the sampling frame, respondents were selected using simple random sampling, which avoided bias in sample selection and increased representativeness.

For the qualitative aspect of the primary investigation, forty purposively selected household heads were selected for the FGDs. Purposive sampling makes it possible to get participants who are willing and knowledgeable about the issues under investigation. The study held two FGDs in each of the three communities, one for males and the other for females. Conveniently, each FGD was composed of between five to ten respondents, which is within the ideal range of five to twelve in social research.

4.5.3 Data analysis

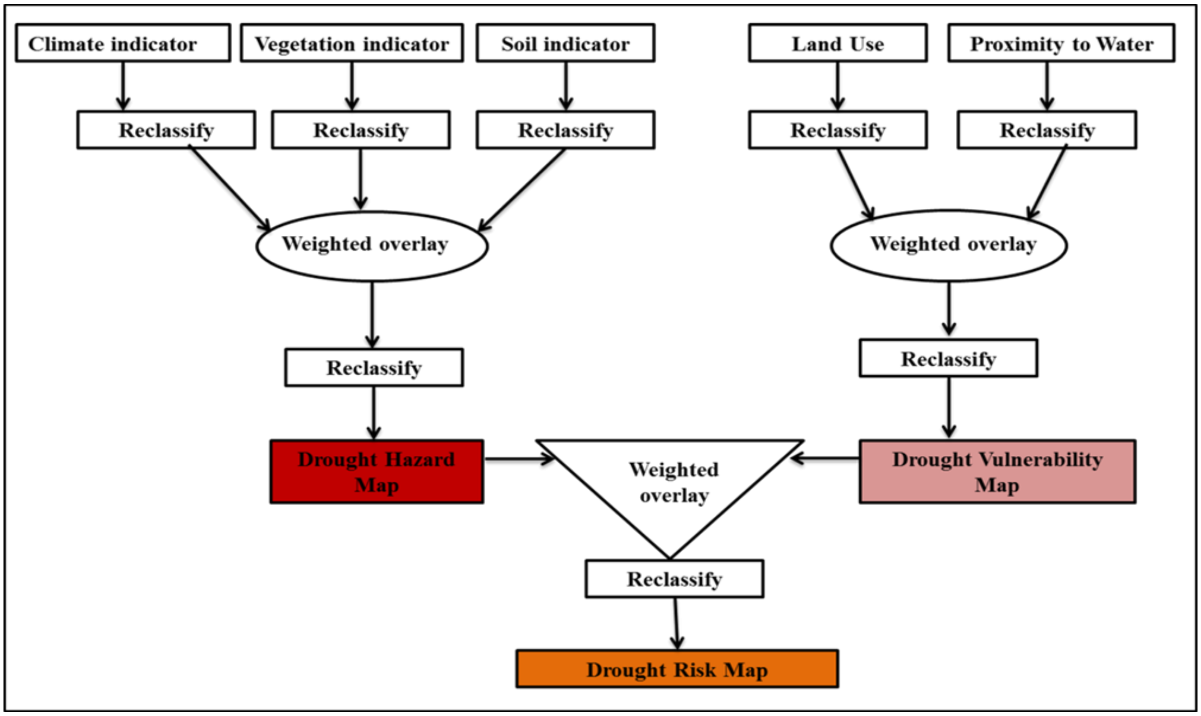
As discussed above, the research adopts a mixture of quantitative and qualitative data collection methods, hence the corresponding quantitative and qualitative techniques to analyze each of the data datasets were applied. In the context of this study, qualitative data analysis refers to the nonnumerical assessment of data from FGDs, while quantitative analysis refers to the spatial and statistical analysis of quantitative data from secondary sources and surveys. The techniques for data analysis included spatial analysis of drought risk in ArGIS version 10.1 and Erdas 2013, descriptive statistics in IBM SPSS version 22, climate exposure indexing and livelihood vulnerability indexing using an indicator approach. Farm-household vulnerability was also assessed using principal component analysis (PCA), and cluster analysis (CA). For the adaptation assessment, descriptive statistics and binary logistic regression were used. Qualitative data were analyzed using content analysis.

Spatial distribution of climate (drought) risk analysis

In this thesis, drought risk, is conceptualised as a product of a zone's exposure and vulnerability to a drought hazard. The process of mapping the distribution of drought risk was guided by the Ghana Environmental Protection Agency [GEPA] (2012) drought risk assessment model as shown in Figure 4.3. This model was adopted because it had been tested and validated within the local context by the GEPA in 2012. The model was built on four main procedures; definition of goal or theme of investigation, identification of criteria, standardisation and weighting, all of which were undertaken spatially within a geographic information systems (GIS) platform. Inputs from knowledgeable stakeholders (e.g. experts from GEPA, National Disaster Management organisation [NADMO] & Stakeholder groups) were also used in the selection and prioritisation of the criteria applied to build the drought risk assessment model.

Probability maps were generated from various biophysical indicators. A combination of indicators such as climate, vegetation, soil, land use, and distance to water were used to develop a drought hazard map, drought vulnerability map, and subsequently, the drought risk map Figure 4.3). The study used different datasets from various sources as shown in Table 4.2. Secondary data such as rainfall, temperature, satellite images, as well as ancillary and derived datasets from the processing of the data layers were used.

Figure 4.3 Drought risk model



Source: Adopted from GEPA (2012).

Table 4.2 Data used for the study

Data	Source
Rainfall and Temperature	Ghana Meteorological Service
Shapefiles for Soil and water bodies	Department of Geography & Regional Planning, University of Cape Coast
LULC and NDVI	Landsat OLI/TIRS Satellite Image from United States Geological Survey(USGS)

Source: Author's construct, 2016

Three indicators were used in mapping drought hazard namely climate, vegetation and soil. The climate indicator was derived from the combined computation of spatial data on annual average precipitation and temperature. These two variables were interpolated into a surface grid based on the Inverse Distance Weighting (IDW) interpolation of the mean annual recorded data for the weather stations in the Upper East Region of Ghana. The reason for the use of temperature and precipitation records in this assessment was that they are often longer and probably have a better chance of revealing detectable changes than alternative climate variables such as cloud cover, wind, and humidity (Toros et al. (2008: p1047). The De Martonne Aridity Index (I_{DM}), which provides a measure of the degree of dryness in an area, was used to derive the climate indicator layer as an input in the risk model. Using the I_{DM}, the study was able to estimate current climatic circumstance in the SSZ. The De Martonne climatic classification is captured in Table 4.3, with the I_{DM} derived using the following equation below:

$$DI = P/ (T + 10)$$

where P is the annual precipitation (mm) and T is the annual mean temperature (^oC).

Table 4.3 De Martonne index for climatic classification

Climate type	**Aridity Index I_{DM}**
Extremely Humid	>55
Very humid	$35 \leq I_{DM} \leq 55$
Humid	$28 \leq I_{DM} < 35$
Semi-humid	$24 \leq I_{DM} < 28$
Mediterranean	$20 \leq I_{DM} < 24$
Semi-arid	$10 \leq I_{DM} < 20$
Arid	< 10

Source: Adopted from Nistor (2016)

The basic data for the estimation of the vegetation indicator was the average Normalised Difference Vegetation Index (NDVI) of the area. The NDVI was generated from the Landsat 8 satellite image of the study area. As earlier studies show, surface reflectance data serves as the prerequisite for the generation of the vegetation indices (Anderson et al. 2011). In this study, the Landsat image that had undergone atmospheric correction was used to convert digital number values into surface reflectance for vegetation indices calculation, using the atmospheric correction module for retrieving spectral reflectance in the ENVI 5.0. The analysis made use of the Red, NIR, referred to the surface reflectance values of Band 4 and Band 5 in the Landsat-8 OLI sensor. NDVI was a good indicator of drought in the sense that it numerically measures photosynthetic activity in an area (Wellens 1997). Theoretically, NDVI values range from +1 to -1, although practically it is possible to have extreme cases of positives and negatives. Very low values (≤ 0.1) usually correspond to built-up, barren lands, and rocks (low vegetation cover), whilst moderate values (0.2 to 0.5) usually represent shrubs, grasslands, and scattered trees (moderate vegetation cover). High values (0.6 to 1) mostly indicate dense forests (vegetation with higher chlorophyll levels).

The categorisation of soil in the SSZ was based on the Food and Agriculture Organisation (FAO) soil classification scheme. The shape files of soil categories obtained from the Department of Geography and Regional Planning at the University of Cape Coast, were processed and then clipped using the boundary polygon of the Sudan savannah. Five main soil types were identified in the study area namely lixisols, leptosols, fluvisols, luvisols and greysols. These were then overlaid to get a composite soil indicator map. Each of the three composite maps (climatic indicator, vegetation indicator, and a soil indicator) were reclassified and a weighted overlay operation was carried out using the weighted overlay tool in ArcGIS 10.3. After the overlay, the output was reclassified to produce a drought hazard map.

To map ecological drought vulnerability, proximity to water and land use/cover indicators were used. The land use/cover (LULC) input was derived from processing the Landsat 8 satellite image of the Sudan Savannah zone of Ghana. This was done using the land use classification algorithm (both unsupervised and supervised) in Erdas 2013. The distance to water was derived from the drainage map with distance calculations undertaken in ArcGIS 10.3. Both land use and distance to water indicators were reclassified and then a weighted overlay performed. After the overlay, the results were reclassified to produce the drought vulnerability map as an input for producing the drought risk map. The drought hazard map and vulnerability map were also weighted, overlaid, and reclassified to produce the output drought risk map.

Climate exposure analysis

Assessing exposure dynamics is a fundamental prerequisite for understanding vulnerability to climate variability and extremes (Monterroso & Conde 2015). According to O'Brien et al. (2004) the exposure of a unit of analysis to its climate stress levels. With this in mind, this thesis measured the climate-related stress levels of farm-households. Using tenets from the works of Monterroso and Conde (2015) and Garlati (2013), climate exposure indices were established. This study integrated selected risk factors and dimensions into a single index to show the degree to which a farm-household may be exposed to climate variability and extremes. This was done using purely primary data solicited from farm-households. Four dimensions (involving 12 risk factors) were adopted in the development of the exposure indices (Table 4.4).

Table 4.4 Dimensions and risk factors used for exposure index

Dimension	Risk factor	Description/variable	Unit
Extreme Events (EE)	Droughts	Number of times household experienced severe droughts in the last 10 years	Average
	Floods	Number of times household experienced severe floods in the last 10 years	Average
	Unseasonal and erratic rainstorms	Number of times household experienced unseasonal and erratic rainstorms in the last 10 years	Average
	Heat waves (severe hotter conditions)	Number of times household experienced heatwaves in the last 10 years	Average
Variability in climate in last 10 years (CC)	rainfall variability	Households aware of severe rainfall variability in last 10 years	Percent
	temperature variability in	Households aware of severe temperature variability in last 10 years	Percent
Direct climate impacts (DCI)	Threats to crop production	Households experienced this threat in the last 10 years or anticipate it in future	Percent
	Threats to land and water resources	Households experienced this threat in the last 10 years or anticipate it in future	Percent
	Threats to household physical assets	Households experienced this threat in the last 10 years or anticipate it in future	Percent
Indirect climate impacts (ICI)	Threats to human and lifestock health	Households experienced this threat in the last 10 years or anticipate it in future	Percent
	threat to social assets	Households experienced this threat in the last 10 years or anticipate it in future	Percent
	threat to food sufficiency	Households who are unable to produce 75 percent of their food	Percent

Source: Climate vulnerability assessment, 2017

The choice of dimensions and risk factors was informed by the theoretical premise that the association between behavioural change in response to a hazard and threat perceptions associated with that hazard, is mediated by awareness of the existence of the hazard and the characteristics of the hazard (See Arbuckle et al. 2013; Nigg & Mileti 2002). Again, the justification for the choice of dimensions (and risk factors) can be traced to Renn and Klinke (2013). They argue that "… risks are ranked and prioritised on the basis of a combination of the occurrence probability of the risk and the impact if it does occur" (Renn & Klinke 2013: p2044). The risk occurrence in this instance refers to the frequency of the recurring period.

In this study the exposure of the social-ecological system was assessed from four perspectives: perceptions on the frequency of extreme events; awareness of changes in the variability of climate elements; perceptions of direct climate impacts; and perceptions on indirect climate impacts (Table 4.5). The variables were first normalised so that values would lie between 0 and 1. The normalisation was necessary since variables varied in units. This was than to ensure that values were free of units of measurement. For illustrative purposes, Table 4.6 presents normalisation of data from respondents in Bawku West. Prior to the normalisation it was important to understand the functional relationship between variables and dimensions. For instance, if exposure increased with an increase in the value of a variable, then it could be that there was a positive relationship between climate exposure and that particular indicator. After the standardisation, variables were weighted equally (using the number of variables under dimension) and aggregation was done to obtain a value for each dimension. A limitation for using equal weighting and averaging as an aggregation method, was the assumption that all dimensions have an equal probability of occurring.

Table 4. 5 Illustration of the normalization of variables using data from Bawku West

Dimension	Risk factor	units	Observed value	min	max
Extreme Events (EE)	Droughts	Average	5.06	0	10
	Floods	Average	3.37	0	10
	Unseasonal and erratic rainstorms	Average	6.18	0	10
	Heat waves (severe hotter conditions)	Average	4.76	0	10
Variability in climate in last 10 years (CC)	Rainfall variability	Percent	70.50	0	100
	Temperature variability	Percent	80.40	0	100
Direct climate impacts (DCI)	Threats to crop production	Percent	96.00	0	100
	Threats to land and water resources	percent	83.00	0	100
	Threats to household physical assets	percent	71.00	0	100
Indirect climate impacts (ICI)	Threats to human and livestock health	percent	81.00	0	100
	threat to social assets	percent	42.00	0	100
	threat to food sufficiency	percent	61.00	0	100

Source: Climate vulnerability assessment, 2017

The main difference between the exposure index approach used in this study and that of Monterroso and Conde (2015), is that this thesis uses primary data (from household heads perspective). Monterroso and Conde used secondary data for several municipalities in Mexico to develop a composite index for each. Another divergent instance is that apart from frequency of extreme events, they included future climate scenarios, whilst avoiding the impacts of the risk factors. Their focus was mainly on the characteristics of the risk factors in space and time. This thesis, however, did not take into consideration future climate scenarios but included, climate impacts/threats in the index. Similarly, when comparing the approach of this study with that of Garlati (2013), a distinction could also be made. As with Monterroso and Conde, Garlati also used secondary data but his concentration was only on impacts of climate change, while avoiding the changing character of the climate hazards. This thesis, relative to the two studies, combined both hazard characteristics and their impacts to develop the exposure indices. Combining both the characteristics of hazards with the losses and damages experienced or anticipated by respondents, gives a more comprehensive index. Comprehensive exposure indices are most crucial at the local level where preparedness plans and adaptation activities are practiced (Carrao et al. 2016).

It is worth emphasising at this point that the evaluation of exposure through the use of indicators may be applied at any level (Monterroso & Conde 2015). The seeming disadvantages of the use of indices are their inability to capture the social complexity of the unit of analysis. This theoretical index approach is also limited in terms of the biases associated with indicator selection and the difficulty in validating results due to the lack of information (Luers et al. 2003). On the other hand, the approach has been regarded by Monterroso and Conde (2015) as valuable, in the sense that it has the capacity to aid the monitoring of hazard tendencies in particular locations.

Livelihood vulnerability analysis

The third objective of this research is to assess the characteristics of vulnerable/resilient smallholder farm-households. This objective is explored from two perspectives:

- First, using principal component analysis (PCA) and cluster analysis (CA), the project categorised farm-households into vulnerability clusters. This was done using data on the availability and accessibility to sustainable livelihood assets.
- The second part of the objective developed and applied a farm-household Livelihood Vulnerability Index (LVI). Using the composite indices of identified major indicators of vulnerability, this research captured the differential vulnerabilities among communities and gender categories.

Principal component analysis and cluster analysis for vulnerability analysis

Principal Component Analysis (PCA) is most appropriate when you want to account for patterns of variation in a single set of variables of mixed scaling levels. Basically, PCA and CA are both used to reduce a dataset into its core components, while accounting for as much of the variation as possible. This becomes necessary for visualization, especially when high dimensionality within a dataset masks a lot of basic insights into data. The PCA was important for the quantitative identification of vulnerability indicators and indicator variance before the CA (Sietz et al. 2012). The PCA yielded six principal components (PCs), with saved component scores standardised to ensure that measurement units were the same. The Eigen value rule was then used to determine the number of components to be retained. Subsequently, PCs with Eigen values less than 1 were excluded. The retained PCs were named making inference to the variables that constituted the component. These were: agriculture and non-agriculture livelihood activities (PC1); Food and health (PC2); perceived soil fertility and access to irrigation (PC3); literacy, access to climate information and farmer experience (PC4); socio-demographics (PC5); and household finance (PC6). The Kaiser-Meyer-Olkin (KMO) was used to test for sampling adequacy, while Bartlett's test was used to test for component variance.

Cluster analysis was then performed on the standardised PC scores to generate the vulnerability clusters. CA was used in this analysis because the research had no a priori hypothesis, but still needed to analyse the data in a way that would produce meaningful results. CA tends to maximize variations between clusters, while minimizing the variation within clusters (Janssen et al. 2012). By so doing, it delineates groups of individuals or objects that are similar, but different to individuals in other groups. The study adopted the K-mean method for the clustering. This was informed by the fact that the researcher knew the number of clusters needed, considering that the sample size was moderate (Everitt et al. 2001). With the K-mean method of clustering there is no hierarchy, it is used to partition classes within the data set. However, the cluster analysis does not automatically generate the clusters (Sietz et al. 2011). Consequently, a qualitative interpretation of clusters was carried out and this was possible because of the limited number of principal components.

Indicator approach to livelihood vulnerability assessment

Informed by the capital assets interpretation of vulnerability and resilience, this study adopted the indicator approach (See Orencio & Fujii 2013; Shah et al. 2013; Hahn et al. 2013) to analyse the level of susceptibility of livelihood activities, assets, and capacities of smallholder households to climate risks. The indicator approach combines inductive and deductive techniques to develop a composite livelihood vulnerability index (LVI). The indicator method is based on the theoretical selection of some indicators that apply to the study context and then statistically combined these indicators to establish levels of vulnerability (Deressa et al. 2008). The ability of the LVI to draw out subtle yet critical differences in specific vulnerabilities (e.g. related to water, food etc.) is valuable in tailoring policies that can meet the needs of resource-dependent communities in the developing world (Hahn et al. 2009). According to Hahn et al. (2009), the structured approach of LVI provides a realistic framework for the developing country context in general.

To construct the LVI, the thesis followed the steps as prescribed in Shah et al. (20130):

- Identification and selection of major components and sub-components (variables) for the LVI (guided by Orencio & Fujii 2013).
- Standardization of values for variables
- Quantification of LVI for the various sub-components
- Weighting and aggregating of the various LVI in to a composite farm-household livelihood vulnerability index (FLVI).

Qualitative content analysis

Mixed methods research in the last two decades has evolved as an alternative methodology in the social and behavioural sciences (Creswell & Plano Clark, 2010; Teddlie & Tashakkori, 2009). This method puts together different analytical steps with their different logics, mainly following a pragmatic theory of science (Elo & Kyngas 2007). According to Elo and Kyngas (2007), qualitative content analysis is a mixed methods approach that assigns categories to text through qualitative steps, working through many text passages. Content analysis is considered a systematic approach for analysing and making inferences from text and other qualitative forms of data. It is a research method for making replicable and valid inferences from data to their context, with the purpose of providing knowledge, new insights, a representation of facts and a practical guide to action (Krippendorff 1980). However, the method is criticised for being a simplistic technique that does not lend itself to detailed statistical analysis, while others like Morgan (1993) argue that it was not sufficiently qualitative in nature. Despite the various criticisms, content analysis as a method has gained roots in social science research. The reason for its increasing relevance, as argued in literature, is that it is a content-sensitive method and flexible in terms of research design (Harwood & Garry 2003; Krippendorff 1980). The thesis uses content analysis for the analysis of focus group discussion (FGD) transcripts. Vaismoradi et al. (2013: pp 399) and Mayring (2014) highlight that CA is both inductive and deductive, which has predominantly been applied to recordings from FGDs and in-depth interviews.

Mayring (2014) has put together seven (7) transcription protocols but considering the amount of information this research sought to preserve and acknowledging time constraints with regards to data analysis, the study used two of these protocols. These are the protocol with the comment column, and the smooth verbatim transcript protocols. The protocol with the comment column allows the researcher, who may also be the transcriber, to use a special column for all special observations besides the audio recording. These observations were aggregated with the text during transcription. The smooth verbatim transcript protocol was used for the transcription of the audio recordings. Here, the transcription was done word for word, but all decorating words like, *right*, *you know, yeah,* were left out. In doing this, a coherent text, simple to understand, but representing the original wording and grammatical structure was produced.

4.5.4 Ethical considerations

Academic surveys in Ghana, especially social research with adult participants, do not require formal approval. However, to facilitate the identification and survey relevant participants for this research, the University of Cape Coast agreed to be the on-site contact institution. To undertake data collection in the selected communities, the laid down customary community entry protocols were followed. The first point of call was the District Coordination Councils. Here, the researcher formally introduces himself, the research assistants and the research project to the District Chief Executives/District Coordinating Directors. Members of the District Assembly who represent the communities of interest were then notified of the survey and the need for their support. Meetings were held with the concerned Assembly members to discuss and select the actual community entry protocols to follow. This is important because usually different communities have different entry protocols so it is important to know the relevant one to use. Once community entry issues were clarified and executed, actual surveys commenced.

Participants were contacted with the help of the Assembly members of the various communities. Copies of letters of introduction were given to the Assembly members. After providing this assistance with selection of participants, copies of the participant information sheets were also given to each participant. This sheet details the project aims, the researchers involved, participants' rights and the voluntary nature of the exercise. A consent form was also read to respondents to solicit their consent. If a respondent agreed to participate, she/he was required to sign. Respondents were also made aware of the complaint sheet, just in case any of them had reservations about the research process.

4.6 Farm-household characteristics of sampled respondents

As argued in the above introduction, in assessing the extent of exposure of a population to hazard, the socio-economic context is as relevant as the hazard characteristics since both interact to define exposure dynamics. This section presents an overview of the socio-economic context of farm-households who participated in this study. Here, emphasis is placed on the socio-demographic characteristics, production, consumption, and the livelihood diversity of respondents.

4.6.1 Socio-demographics of respondents

Table 4.6 provides an overview of the socio-demographic characteristics of farm-household survey respondent household heads. More than half of the study households (52.6 percent) had household sizes between 1 and 5, with a substantial number of the households having more than 6 persons (37.8 percent), compared to national average of 4.4 (Ghana Statistical Service [GSS] 2013). Some 69.1 percent of respondent household heads were aged above 40 years, with an average age of 48 years. Table 4.6 shows the relatively lower proportion aged less than 40 years (30.9 percent) and this may be attributed, largely, to the exodus of younger persons from the north to the southern parts of Ghana (particularly Sunyani, Techiman Kumasi, and Accra) where they perceive “greener pastures” exist (Ghana Statistical Services [GSS] 2013; Kwakye 2012; Tanle & Awusabo-Asare 2009). This translates in to a generally high age-dependency ratio among households in all the study districts. Garu Tempane was found to have the highest age-dependency ratio (105.2), followed by Bawku West (92.9) and Bongo (78.5) in that order, as shown in Table 4.6.

Table 4. 6 Socio-demographic characteristics of respondents

Socio-demographics	District	Bawku west (n=82)	Bongo (n=71)	Garu Tempane (n=77)	Total (n=230)
		Percentages			
Household size					
1-5		48.8	67.6	45.5	52.6
6-10		37.8	29.6	41.5	37.8
>11		13.4	2.8	13.0	9.6
Age of household head					
≤30		12.2	11.3	18.2	13.9
31-40		19.5	09.9	20.7	17.0
41-50		24.4	39.4	22.1	28.3
51-60		24.4	19.7	13.0	19.1
≥61		19.5	19.7	26.0	21.7
Dependency ratio		92.9	78.5	105.2	92.5
Sex of household head					
Male		61.0	52.1	71.4	61.7
Female		39.0	47.9	28.6	38.3
Marital Status					
Never Married		19.5	21.1	23.4	21.3
Married		70.7	66.2	63.6	67.0
Divorced/widowed		09.8	12.7	13.0	11.7
Education of household head					
No Formal Education		91.5	75.3	84.5	83.9
Formal Education		8.5	24.7	15.5	16.1
House Ownership Type					
Owned		56.1	29.6	49.4	45.7
Family Owned		32.9	53.5	36.4	40.4
Rented		11.0	16.9	14.2	13.9
Condition of house structure					
Good		7.4	4.2	5.2	5.7
Average		46.3	43.7	45.5	45.2
Poor/needs repair or reconstruction		46.3	52.1	49.4	49.1

Source: Climate variability and vulnerability survey, 2017

The relationship of most household members to the head in the study area was largely affinal and biological. In as much as the nuclear family household appears to be the most common household structure, the extended family household structure is still very significant in rural localities in Northern Ghana. This study found that 61.7 percent of farm-household heads were males, with females accounting for 38.3 percent of the respondents. Garu-Tempane had the highest proportion of male heads (71.4 percent), while Bongo had the least with 52.1 percent. The dominance of male headed households is an obvious finding considering that, culturally, inheritance or lineage in the study zone is patrilineal. Thus, it is not very common to have female household heads, especially in rural areas where “culture” is relatively intact. In all the national censuses males have consistently dominated household headship especially in rural Ghana (GSS 2010).

From Table 4.6, 67 percent of the 230 household heads were married, while the remaining 33 percent were either divorced/widowed or never married. The proportion of married male household heads is almost twice that of their female counterparts. In relation to the gender and marital status of household heads, 52.3 percent of female household heads were either divorced/widowed or never married. The remaining 47.7 percent of the female household heads who were married became heads of the households by virtue of their husbands’ incapacitation (through illness, accident, etc.) or were too old to cater/provide for the households. However, the majority of male respondents were either married (66.2 percent) or never married (25.4 percent). According to GSS 2013, a plausible reason for the lower percentage of male divorced/widowed heads of household is that they are more likely to re-marry in the event of a divorce or death of wife than was the case for female heads. Generally, education levels of respondents were found to be low in all study districts, for both male and female respondents. From Table 4.6, only 16.1 percent of respondents had any sort of formal education with the majority of these respondents being male (67.6 percent). This is consistent with the 2010 national census which found that there are more females (38.4 percent) who never attended school than males (26.2 percent).

Table 4.6 also shows that the majority of respondents lived in houses they owned (45.7 percent), while a smaller percentage rented (13.9 percent) and the remainder (40.4 percent) lived in houses owned by their extended family. This is common in rural northern Ghana where extended families mostly live together in houses partitioned for several households. Again, it must be noted that out of the 103 respondents who owned their houses, males dominated (76.7 percent), while the majority of their female counterparts lived in extended family-owned houses (65.9 percent). This further highlights the issue of culture, extended household structure, and the fact that inheritance or property ownership is skewed by gender in northern Ghana. Respondents were asked about the structural condition of the houses in which they lived and only 5.7 percent said their houses were in good condition. The majority of household heads (49.1 percent), however, claimed that their houses were in bad shape and, therefore, required repair work or complete reconstruction. The majority of female heads of households (60.2 percent) said they lived in poor structures, while for the male heads, 48.6 percent claimed that the condition of their houses were moderately in good condition. Worth noting is the fact that all those who said their houses were in good condition were males.

4.6.2 Farm-household production and consumption characteristics

This section highlights farm-households' food production and sufficiency in the study areas. Table 4.7 shows that out of the 230 farm-household heads, 75.2 percent owned the main land on which they undertook farming activities, while 24.8 percent farmed on lands owned by the entire extended family. Looking at farmland ownership by district, a similar trend could be seen across areas. It is also worth noting that 80.3 percent of those who owned their farmlands were males, while the majority of the females (62.5 percent) undertook farming activities on lands owned by extended family (Table 4.7).

Table 4.7 shows that when farmers were asked about their perceived farmland fertility, 84.8 percent of them perceived their farmlands to be of low soil fertility while none claimed high soil fertility. A similar trend can be seen when the fertility variable is split by district. Some 71.7 percent of farmers produced 2 or 3 varieties/types of crops, and only a few engaged in the production of a single crop. A cross-tabulation of this variable with district and gender shows a similar trend. Across all districts and between male and female household heads, the majority produced 2 or 3 types of crops.

Table 4. 7 Characteristics of respondents' food production and consumption

Variables	District	Bawku West (n=82)	bongo (n=71)	Garu Tempane (n=77)	Total (n=230)
		Percentages			
Perceived farmland fertility					
Low		90.2	77.5	85.7	84.8
Moderate		9.8	22.5	14.3	15.2
High		00.0	00.0	00.0	00.0
Number of crops grown					
1		2.4	9.9	14.3	8.3
2		35.4	25.4	41.6	34.3
3		43.9	35.2	32.5	37.4
≥4		18.3	29.6	11.3	20.0
Percent of food produced/household					
≤ 20		32.9	25.4	36.4	31.7
21-40		26.8	38.0	9.1	24.3
41-60		23.3	15.5	19.5	19.6
61-80		8.5	21.1	9.1	12.6
≥81		8.5	00.0	26.0	11.8
Length of food insufficiency (months)					
1-3		37.7	30.8	36.8	35.8
4-6		60.7	53.8	56.6	57.4
≥7		1.6	15.4	6.6	6.8

Source: Climate variability and vulnerability survey, 2017

Table 4.7 shows that farm-households who produced less that 20 percent of their food needs constituted the majority (31.7 percent), while only 11.8 percent produced more than 80 percent. However, it is important to notice that a considerable number of households in Garu-Tempane (GT) (26.0 percent) produced more than 80 percent of their food needs, even though the major category was those who produced less than 20 percent (36.4 percent). In Bongo (BO), the majority of households (74.6 percent) produced between 21 to 80 percent of food consumed by the household, while 25.4 percent produced less than 20 percent, with no households producing more than 80 percent. For Bawku West (BW), most of the households (51.1 percent) claimed they could produce between 21 to 60 percent of the food they consumed, while a significant proportion of them (32.9 percent), said they were only able to produce up to 20 percent of their food intake. Taking into consideration gender, 72.8 percent of female headed households produced between 21 to 80 percent of their food needs against 46.5 percent for male headed households. Again, compared to the 14.8 percent for female heads, as much as 42.3 percent of male respondents claimed they were only able to produce up to 20 percent of the food requirement of their households.

There were 76.5 percent of the respondents who claimed that they were not food self-sufficient. The majority of households who said they are not food self-sufficient were in Garu Tempane (43.2 percent) and Bawku West (34.7 percent). Asked about how long their food insufficiency usually lasts, the majority (57.4 percent) of them said that in between 4 to 6 months in a year their households were unable to meet their food requirements (in terms of quantity) due to running out of stock they had produced in the previous season. Only a few respondents (6.8 percent) said their food scarcity lasted 7 months and beyond. This trend is the same across all districts and for both sexes, the majority stated that their food insufficiency lasted between 4 to 6 months in the year.

4.7 Conclusion

This chapter presented the details of the conceptual framework and the methodology guiding this thesis. It provides the conceptual basis of the thesis as well as a justification of the research design. The study used both primary (survey and focus group discussions [FGDs]), and secondary data (GIS data). This chapter also outlines the data collection methods in respect to the survey and FGDs. The analysis methods included: spatial analysis in GIS platform, exposure and vulnerability indexing, descriptive and regression analysis of coping and adaptation strategies. The qualitative data was analysed using content analysis. The results from work done with the above methodological steps informs the final discussion on spatial distribution of drought risk, characteristics and drivers of vulnerability, and farm-household coping and adaptation responses to climate variability in the Sudan Savannah Zone of Ghana.

Chapter 5: Spatial distribution of climate risk in Sudan Savannah Zone

5.1 Introduction

This chapter reports on the results of the spatial mapping, which answers the first objective of this thesis. Drought in Sudan Savannah Zone was used as a proxy to assess the spatial distribution of climate risk, highlighting the possible implications for food security and agriculture-related livelihoods. Drought risk was spatially mapped in ArcGIS 10.5 using data on indicators such as precipitation, temperature, vegetation, soil, land use/cover, and proximity to water bodies. The chapter begins with a brief description of the relevance of climate risk mapping and proceeds to discuss the results from the spatial analysis which include spatial distribution of drought hazard, biophysical vulnerability, and drought risk in the study area. The chapter then discusses the implications of these results and ends with a concluding section. See box 5.1 for highlight of key findings.

Box 5.1 Highlight of key findings on spatial distribution of climate risks

- The geospatial analysis showed that about 70 percent of the total area of Sudan Savannah Zone has moderate to high probability of experiencing drought every farming seasons.
- It also found that relative to Bongo and Bawku West, Garu-Tempane and Bawku Municipal had higher drought risk probabilities, implying that, all factors held constant, most smallholder farm-households in these two districts are likely to experience relatively higher losses and damages in terms of crop failure, increased food insecurity, and the general loss of livelihood due to drought.
- Although districts were located in the same agroecological zone, there were significant spatial variations in terms of the distribution of climate risk. Out of the five biophysical factors used in the geospatial analysis, aridity, vegetation cover, and land use/cover significantly explained the spatial variance in risk levels.

Source: Climate variability and vulnerability survey, 2017.

5.2 Climate risk mapping in agroecological systems

Climate variability and change is increasingly becoming a significant challenge to development in general, and particularly the most persistent risk to agriculture (Egeru 2016). According to the African Development Forum (2010), in developing countries the agriculture sector absorbs 22 percent of economic impacts of natural hazards. This suggests that a major underlying factor for the worsening impacts of climate change on agriculture is the limited capacity to undertake risk assessments, especially at the local level where impacts are felt first-hand. In the frame of this research, climate risk in an agroecological system refers to the likelihood of a hydro-meteorological hazard affecting food security and the livelihood of crop farmers, livestock herders, and fishers (Selvaraju 2012). The choice of an appropriate combination of responses to these risks by stakeholders (i.e. farmers, extension officers, policy makers, etc.) is partly contingent on their knowledge of various risk characteristics (Egeru 2016). Over the years, and based on indigenous knowledge, farmers understood the risks and uncertainties of seasonal climatic conditions and adjusted their farming practices accordingly (IFAD, 2012). However, recent trends in the frequency and severity of climate extremes (storm, floods, and droughts), coupled with the spread of agriculture into peripheral environments, require improved climate risk assessments (CRA) to aid agriculture-related decision-support systems (Egeru 2016; Selvaraju 2012).

Globally, climate risk assessments (CRA) have become a key ingredient for strategic planning of short-term coping and long-term adaptation to the impacts of climate variability and extremes (Jurgilevich et al. 2017; Travis & Bates 2014; Dilley 2006).

Climate risk assessments represent the entry point of climate risk management (CRM). Climate risk assessments refer to the appropriate climate information distribution through an efficient delivery system that can alert food officials to assure food and water security long before the hazards happen (Egeru 2016; Selvaraju 2012). Selvaraju (2012) particularly emphasises the immediate relevance and benefits of CRM to smallholder farmers in developing countries. According to the African Development Forum (2010), the integration of CRA and CRM presents a real opportunity for decision makers who seek to understand the dynamics of climate change adaptation and how to prioritise approaches for sustainable agriculture.

This chapter is written on the foundation that the inherent understanding and knowledge of decision makers on possible climate-related hazards and their interaction with a unit of analysis at the local level (e.g. farm-households) facilitates not only early planning to cope, but also provides the justification for the implementation such plans (Jurgilevich et al. 2017). The relevance of spatially mapping risk hinges on the fact that evidence of risk levels and its distribution is key for both promoting and enabling a paradigm shift from emergency to risk management. Such evidence of how risk is constituted at the local level presents stakeholders with a leverage to ensure food and livelihood security long before an actual hazard episode occurs. A priori, practitioners and policy makers can prioritise risk exposed areas, make informed risk plans and preparations, and advance informed and targeted adaptation.

5.3 Drought hazard in the Sudan Savannah Zone

According to the De Martonne scale (See Chapter 4, section 4.5.5), the entire Sudan Savannah zone falls under semi-arid (Figure 5.1A). This finding is consistent with that of Frimpong et al. (2014) and Issahaku et al. (2016), who found that in decadal times, the zone was experiencing decreasing rainfall and increasing temperature, implying increasing evapotranspiration and recurring drought events. It is important, however, to emphasise that though the whole zone is regarded semi-arid, this thesis found that some areas were relatively drier than other parts. For instance, in Figure 5.1A, the area marked brown, mostly in Bawku Municipality and northern part of Garu-Tempane (with I_{DM} of 12.3 to 12.6) were relatively drier than the part marked blue (with I_{DM} of 13.0 to 13.2), around Bongo and some parts of Bawku West Districts. It will suffice to suggest that the generally high aridity levels in the study zone could be attributed to historic increases in temperature and a reduction in precipitation. Thus, aridity assessment becomes an important indicator for any climate-agriculture related responses. The result from this thesis on the aridity index analysis suggests that the Sudan Savannah has a warmer climate and significant dryness, hence high evapotranspiration of soil and vegetation moisture. This has the potential of increasing the deficit in plant-water requirement (Tabari et al. 2014).

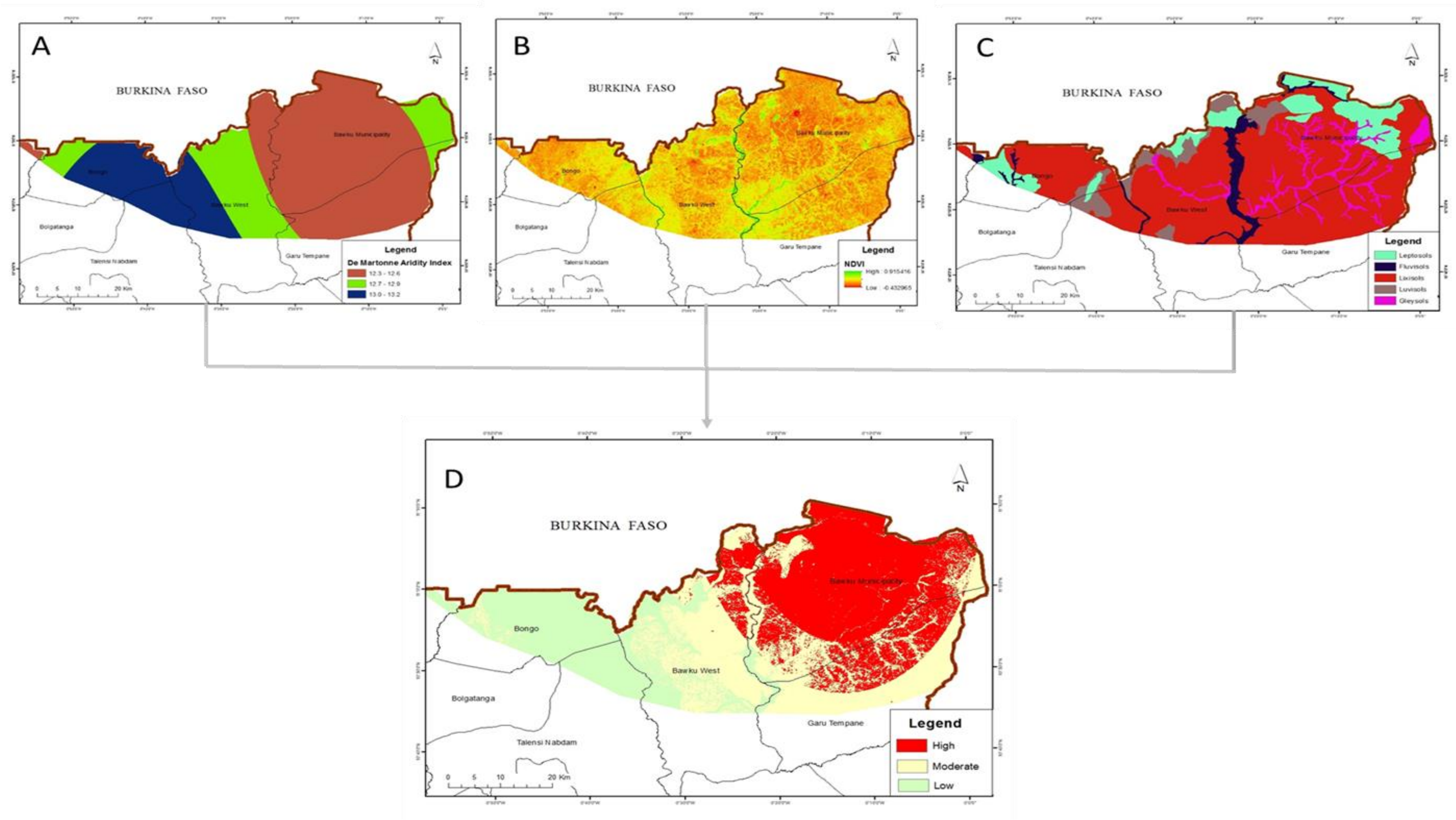
The findings from the vegetation indicator analysis (NDVI) are consistent with the outcome of the I_{DM}, which highlights the relationship between climate and vegetation. The I_{DM} established that there is low moisture availability in the study zone which has serious implications for vegetation, precisely, crop productivity. The resultant NDVI map from this thesis showed that a majority (three quarters) of the study area is covered by low to moderate photosynthetically-active vegetation. From Figure 5.1B, it is obvious that much of the area has NDVI values between -0.4 and 0.5, indicating a very low to moderate healthy vegetation cover. Few areas (mostly around water bodies) fall within areas of vegetation with high chlorophyll levels (healthy and dense vegetation). The NDVI map also indicates that areas of low healthy vegetation cover are concentrated in Garu-Tempane and Bawku Municipality (to the east), with moderate vegetation cover concentrated in the middle (around Bawku West towards Bongo). The NDVI result indicates there is a high plant-water deficit in the Sudan Savannah zone. The combined effect of unreliable precipitation, high evapotranspiration and soils with low water-holding capacity leads to a plant-water deficit at any stage of plant (crop) growth. For instance, frequent plant-soil moisture deficit during early crop growth results in seedling mortality, retarded growth and reduced yields (Muchow & Bellamy 1991).

In Figure 5.1C, lixisols are the predominant soil type within the study area, and it covered about 69 percent of the total land area. Lixisols according to the World Reference Base for Soil Resources (2015) are mostly found in warm tropical climates with pronounced dry seasons and inadequate moisture content. The implication is that, with limited soil moisture and less rain due to climate variability and extremes (e.g. droughts), farm-households in most parts of the study area could experience high probability of a reduction in crop yields. The drought hazard map (Figure 5.1D) shows the spatial distribution of the hazard in the SSZ. The high drought prone areas occupied approximately 39 percent of the zone. They are concentrated in the north-eastern section of the study area, particularly in the Bawku Municipality and some parts of Garu-Tempane District. The indication here is that farm households could expect recurrent drought episodes. The moderate to low drought hazard areas spread mostly across the middle sectors towards the western tip of the study area, and then permeate the north and north-western corridors mainly covering Bawku West and Bongo. This could be attributed to the area's limited aridity, relatively better vegetation index, and soils with relatively better water holding capacity.

The drought hazard map shows that much of the area had either moderate or high probability of experiencing drought incidence. This finding is consistent with the historical account of drought from the focus group discussions (FGD). Most of the participants claimed that there has been an increase in drought frequency in the last three decades and that they are compromised and unable to predict and respond appropriately to drought episodes. One FGD participant shared his experience:

> *My son let me tell you something I am over 60 years and I have been farming for over 30 years now. I can tell you the pattern of drought and rainfall has changed over the years. Apart from the 1981 to 1983 drought, I can tell you that recent droughts affects us very seriously, especially our crop yields. Now my sons have to take our cows very far in search for water because the stream nearby has dried up. (Male participant Garu-Tempane, FGD, April 2, 2017)*

Figure 5. 1 Drought hazard areas in the Sudan Savannah Zone (D). A=climate indicator, B=vegetation indicator, and C=soil indicator



Source: Geospatial analysis of climate risks, 2017.

5.4 Biophysical drought vulnerability

For the purposes of this study, five types of land use/cover were identified during the mapping (Figure 5.2A). These were water, built-up/bare-land, grasslands/farmland, open forest, and closed forest. In consonance with the NDVI results (See Figure 5.2B above), the land use indicator assessment showed that close to two-thirds of the zone is built-up, bare land, and grasslands/farms. Out of a total area of 2,464 sq km, these types of land use/cover together constituted 63 percent of the zone. The remaining 37 percent is covered by water, closed forest, and open forest. However, the predominant land use/cover (LULC) was found to be built-up/bare land (783 sq km), followed by grasslands/farmland (762 sq km). The least land use/cover type was water, covering an area of only 29 sq km. It could also be seen from Figure 5.2A that majority of the built-up/bare lands and grassland/farmland are found mostly in Bawku Municipality and Garu-Tempane (to the east). Open and closed forests were found to be concentrated mostly around Bongo and Bawku West (middle to west).

The results revealed that the major land use land cover (LULC) were built-up/bare-land and grasslands (which included farmlands), an indicator of extensive land utilization by inhabitants of the zone. Male FGD participants from Garu-Tempane alluded to the fact that relative to recent times, their communities had more vegetation cover some two to three decades ago, attributing the situation to human activities (See Box 1). Thus, any drought vulnerability reduction effort within the zone might have to consider both the drought hazard characteristics (e.g. severity) and the agroecological system factors (e.g. LULC) that define vulnerability and risk. Male FGD participants from the Garu-Tempane alluded to the fact that relative to recent times, their communities had more vegetation cover some two to three decades ago, attributing the situation to human activities (See Box 5.2). Thus, this analysis shows that any drought reduction effort within the Sudan Savannah should consider both the drought hazard characteristics (e.g. frequency, severity) and the human factors (e.g. LULC) that define vulnerability. The findings by Kleemann et al. (2017) supports this conclusion. In their assessment of the zone, they found that the changing LULC in the area is attributable to increasing infrastructural development (especially within buffer zones of water bodies), improper farming practices and bushfires. Land use land cover (LULC) is the end product of complex human-environment interactions, implying that the (im)proper management of these interactions has implications for the drought vulnerability of any agroecological system.

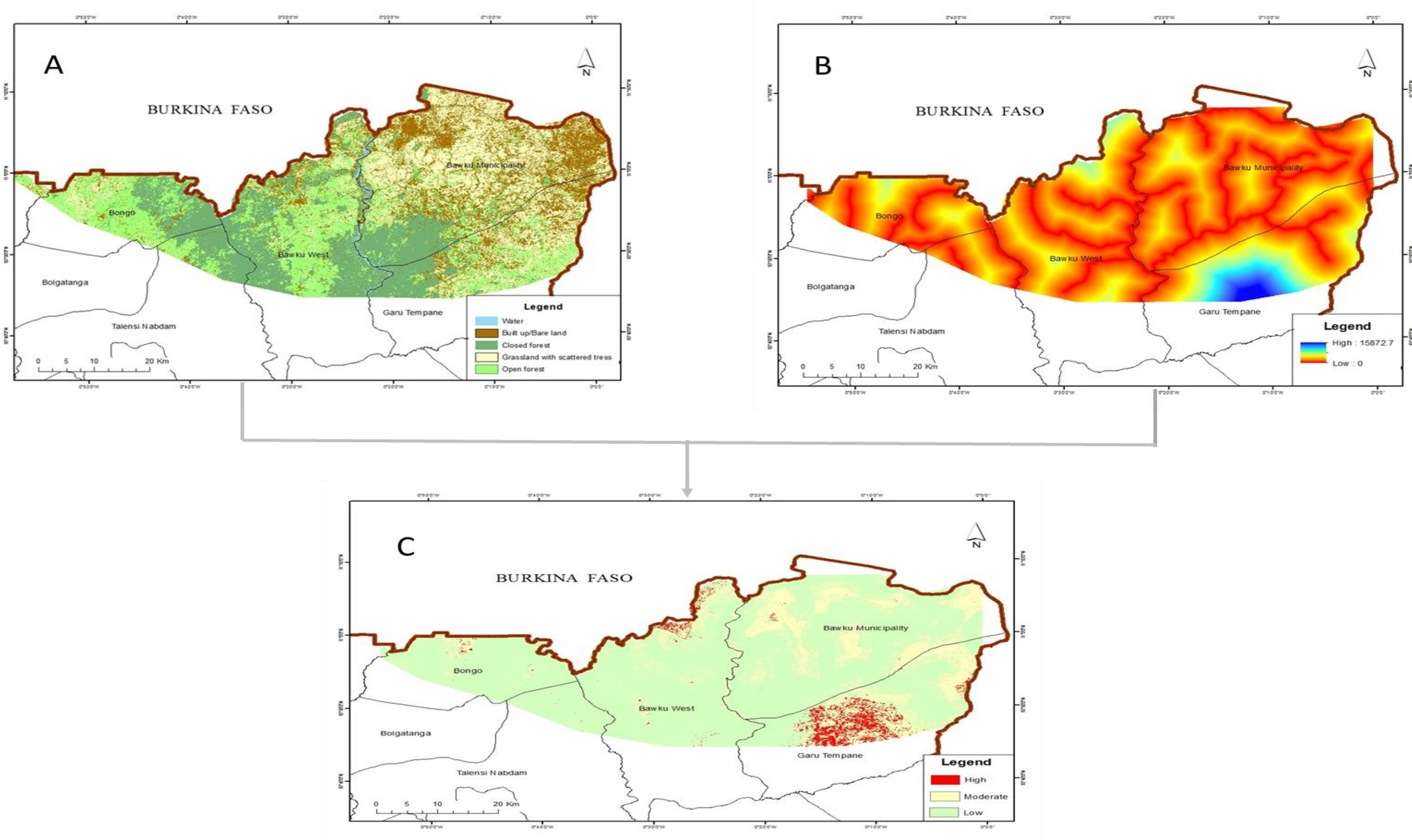
Box 5. 2 Focus group discussion in Garu-Tempane district highlighting changes in land use cover and the impact on crop production

The male Participants generally agreed that relative to recent years, there was thicker vegetation cover that included a mixture of trees, thick shrubs and green grasses three decades ago. They claimed that in those periods tall and thick dawadawa (Sumbala or Parkia biglobosa) and shea trees could be easily located unlike today where one will have to move deep into the wild to find these socioeconomic trees. The various vegetation cover, according to them, were the abode of abundant wildlife, which they hunted to supplement their food intake. They attributed the present sparse and limited vegetation to human activities. They particularly mentioned the cutting of trees for charcoal and lumber, bush fires, extensive farming, over grazing, and private and public infrastructural developments. According to respondents these anthropogenic activities have culminated into the recent soil infertility of their farmlands, further reducing crop yields. They emphasized that previously when one cultivates an acre of maize, it was possible to harvest 10 to 15 bags (100kilo bag) of maize but today due to frequent droughts and soil infertility, the yields are much less.

Source: Climate variability and vulnerability survey, 2017

The susceptibility of a geographic space to the effects of drought hazard is also influenced by the distance to a watershed. Consequently, as a predominant farming zone, proximity to water bodies becomes an important factor during periods of drought hazards (Yiran & Stringer 2016). Figure 5.2B indicates that much of the zone lies within approximately 0-5000m away from water bodies with the exception of some northern parts of Garu-Tempane that fell within 5000m to 15572.2m. In ascertaining the land use and proximity to water, maps for both were overlayed and reclassified to produce the ecological vulnerability for the Sudan Savannah agroecological zone (Figure 5.2C). The most ecologically vulnerable areas were concentrated around the northern parts of Garu-Tempane. Analysis shows that patches of the highly vulnerable areas can also be found at the northern corridors of Bawku West and Bongo. The moderate vulnerability areas spread mainly in Bawku Municipality whilst low vulnerable areas occur through Bawku West and Bongo District. The proximity of a location to a water body has implications for its susceptibility to droughts in the sense that places nearer to rivers, for instance, will be relatively less affected by meteorological and/or agricultural drought episodes (Yiran & Stringer 2016). The inference here is that farms that are closer to ponds, streams and rivers are in a relatively better position to easily access water for irrigative purposes. For example, farmers found in northern Garu-Tempane, southern Bawku West, and southern Bongo will have a higher probability of being severely affected during periods of droughts because they are found relatively farther away from natural water sources.

Figure 5. 2 Ecological drought vulnerability areas in Sudan Savannah Zone (C). A=land use/cover and B=proximity to water

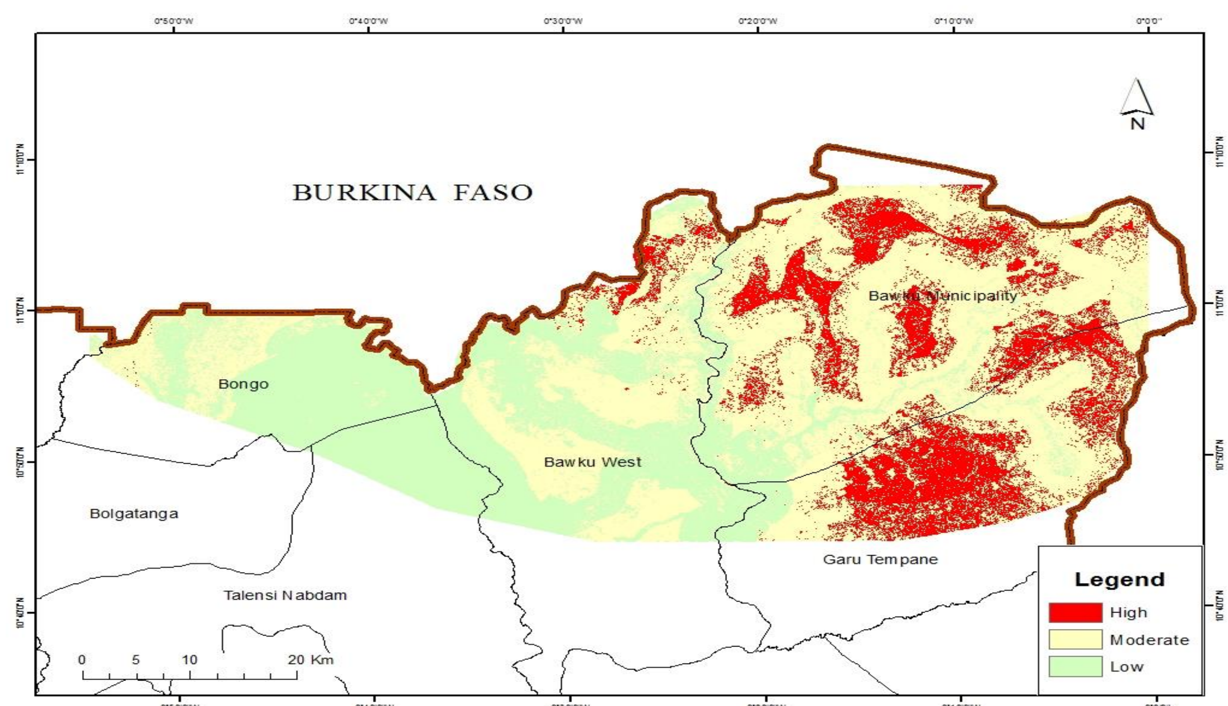


Source: Geospatial analysis of climate risks, 2017

5.5 Spatial distribution of drought risk in the Sudan Savannah Zone

The spatially mapped drought hazard and ecological drought vulnerability were overlayed, reclassified and weighted to produce the drought risk map for the Sudan Savannah agroecological zone (Figure 5.3). It is important to mention that out of the initial five biophysical indicators (i.e. climate, vegetation, soil, land use, proximity to water), analysis demonstrates that three of them significantly influenced the spatial distribution of drought risk in the Sudan Savannah Zone: climate, vegetation and land use. The drought risk probability map showed that nearly 69 percent of the zone (1,900 km^2) fell under moderate to high drought risk, whilst the remaining 31 percent was found to be of low drought risk. The spatial distribution of drought risk as shown in Figure 5.3 is also consistent with the earlier findings from the I_{DM}, NDVI, and the land use land cover analysis (See above Figures 5.2A, 5.1A, and 5.1B). For instance, in Figure 5.3, the moderate to high drought risk areas are concentrated around Bawku Municipality and Garu-Tempane, whilst the low drought risk areas are found mainly in Bawku West and Bongo.

Figure 5. 3 Drought risk map of the Sudan Savannah zone



Source: Climate variability and vulnerability assessment, 2017

As stated earlier, the Sudan Savannah Zone experiences drought every other farming season and dry spells every season. Moreover, the cumulative nature of drought episodes and the relatively high aridity in the area also engender bush fires, further escalating an already precarious situation. This has contributed to the zone's consistent food insecurity (See Wossen et al. 2015; Aniah et al. 2014). This research found that drought risk is generally high and spatially disproportionate across the zone, partly due to locational variations in biophysical specificities. The zone's generally high probability of experiencing actual drought incidence seasonally is not surprising considering that the zone exhibits a warmer climate and significant dryness, with high evapotranspiration. The study further highlights that the probability distribution of drought risk was not even across the districts. For instance, relative to Bongo, Garu-Tempane was found to be more likely to experience drought episodes more frequently. The implication here is that the potential increase of the deficit in plant (crop) water requirement is more likely to be more severe in Garu-Tempane than in the Bongo district. According to Muchow and Bellamy (1991), the high risks of plant-water deficits in semi-arid tropics (like study area) can be attributed to unreliable precipitation, high evapotranspiration and soils with low water-holding capacity.

Plant-soil moisture deficits during early crop growth results in seedling mortality, retarded growth and reduced yields. A recent study by Tabari et al. (2014) similarly suggests that in rain-fed agriculture, rainfall quantity and its temporal distribution and evapotranspiration is a critical determining factor of farming season characteristics. On the bases of all the above, it will suffice to argue that without interventions like regular climate risk assessments, community irrigation facilities, and increased adoption of soil and water conservation methods, smallholder farmers in the study zone could face increasing seasonal reductions in crop yield, increased livestock mortality, and possibly severe household food insecurity. This is particularly valid considering that there is moderate certainty that expected variability in temperature and rainfall over the next decade will be worse over the Northern belt of Ghana (Issahaku et al. 2016; MESTI 2015).

Essentially, it is critical for any proactive climate risk intervention effort to incorporate the distribution of the risk involved (Carrao et al. 2016; Monterroso & Conde 2015; Muller-Mahn & Everts 2013). Relative to the low risk zones, this analysis found that areas that of high risk had high aridity indices, low vegetative cover, and very extensive land use. The high-risk areas are more likely to experience crop failures (resulting in low yields), which may have negative implications for food security among smallholder farm-households. These areas might require critical assessment and interventions.

The spatially differentiation of drought risk as used in this study, is fundamental, particularly since its use could enhance agriculture-related decision support systems in the Sudan Savannah Zone, a tool they currently lack. The drought risk maps generated here give more insights into the probable spatial intensity of the drought hazard at particular locations and aids the identification of exposed and probable vulnerable communities that may require urgent and targeted ex ante interventions. Agricultural support services (e.g. agricultural research and extension) and related institutions at both national and local level, need such climate risk information to effectively plan their activities and provide timely services to their unlimited beneficiaries (e.g. smallholder farmers and livestock herders).

5.6 Conclusion

Agriculture is one of the highly exposed sectors to climate-related hazards. As a result, climate risk mapping within the context of agroecological systems is an essential ingredient that could facilitate effective and proactive management of losses and damages from extreme events like drought hazards. This chapter presented the results on the spatial mapping of climate risk analysis and demonstrates that such tools enacted at this level could enhance decision-support systems and make it easier for practitioners and policy makers to effectively monitor, plan and target coping and adaptation responses. The study advocates for the regular identification of risk exposed areas, considering that climate risk is in constant evolution.

Findings of the study showed that two-thirds of Sudan Savannah Zone had either a moderate or high probability of experiencing droughts every farming season. It also found that relative to Bongo and Bawku West, Garu-Tempane and Bawku Municipal had higher drought risk probabilities, implying that, *ceteris paribus*, most of the smallholder farm-households in these two districts could experience high losses and damages in terms of crop failure, increased food insecurity, and the general loss of livelihood under episodes of drought. Empirically, this project not only demonstrates the importance of climate risk mapping for management and adaptation, but also shows that evidence of risk levels and its distribution is key for both promoting and enabling a paradigm shift from reactive risk responses to proactive risk management.

Chapter 6: Farm-household exposure to climate risks

6.1 Introduction

This chapter presents results from the assessment of exposure levels of farm-households to climate variability and extreme events. Specifically, it describes farmer awareness of changes in the climate (and extremes) and the associated perception of threats to livelihoods. Using results from application of the indicator approach together with data from farmers' observations, the chapter also discusses exposure indices by study district and whether household heads were males or females. For this chapter, respondents were asked questions related to the frequency of extreme events, rainfall and temperature trends, and direct and indirect livelihood threats. See Box 6.1 for the key findings of this chapter. Considering the location specificity of "exposure", the aim here is to advance the understanding of exposure dynamics at the local level.

Box 6.1 Highlight of key findings on farm-households' exposure to climate risks

- Awareness among respondents significantly varied by geographic location, education, and sex; whilst variations in the perception of level of threat was significantly associated with education, age, farming experience and varied between females and males.
- The composite exposure index showed that all study districts were under moderate and high exposure to climate risks. However, female-headed households were relatively less exposed compared to households headed by males.
- The results highlight the relevance of using both hazard characteristics and threat dynamics in the assessment of exposure at the subnational level. The results also show that it will be insufficient for practitioners to base decision making on only the composite exposure index without further considerations for the sub-indices that show the actual dynamics of farm-household exposure to climate risks.

Source: Climate variability and vulnerability survey, 2017.

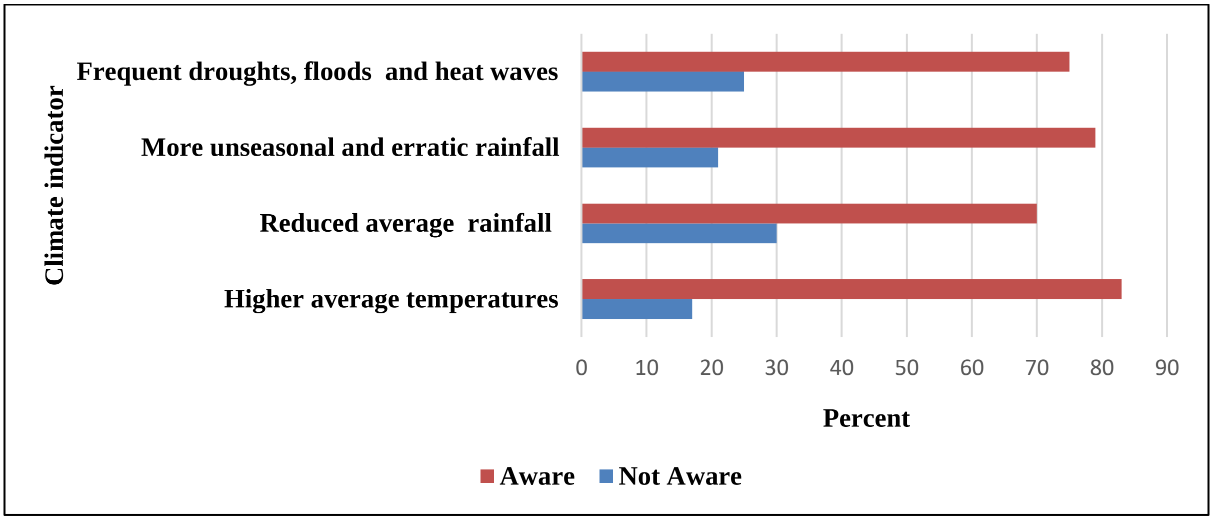
6.2 Awareness and perceptions of smallholders on their exposure to climate risks

This section presents a synthesis of results that explore the awareness of farm-household heads on changes in climate variability and extremes and their perceptions of the associated livelihood consequences in the Sudan Savannah zone of Ghana. Understanding local level awareness and perceptions about climate risks is essentially important for climate responses which is supported by other studies that argue that awareness and perceptions on climate risks vary within and across regions (Ajuang et al. 2016; Arbuckle et al. 2015; Arbuckle et al. 2013; Capstick et al. 2015; Lee et al. 2015; Pugliese & Ray 2009). This diversity is consequential for implementation of responses to climate risks at all levels in the sense that a one-size-fits-all approach to climate communications and adaptation initiatives might not be effective (Arbuckle et al. 2015; Mtambanengwe et al. 2012; Leiserowitz 2006). The results in this section are presented according to district and disaggregated for males and females.

6.2.1 Awareness of farm-households on changes in climate and extreme events

During data collection, respondents were asked about their observations of change relating to certain climatic elements and extreme events over the last 10 years. Figure 6.1 shows the responses from the 230 farm-household heads interviewed and demonstrate that 84 percent of respondents were aware of changes in at least one of the climate indicators in the last 10 years. Most of those aware of changes in climate and extremes observed higher temperatures (83 percent) and more unseasonal and erratic rain (79 percent). More than two thirds of respondents (70 percent) also said they had noticed a reduction in the amount of rainfall in the same period. With regards to extreme climate events (droughts, floods and heat waves), 75 percent of the farm-household heads affirmed an increase in their frequency and severity. These responses suggest most of these randomly selected farmers are, to a large extent, aware of the changes in the selected climate markers. The analysis also tested the statistical significance of the association between respondents' awareness and their background characteristics. With p-values less than 0.05, only District, sex, and education were found to have statistically significant associations with variations in respondents' awareness of changes in climate indicators in the last 10 years.

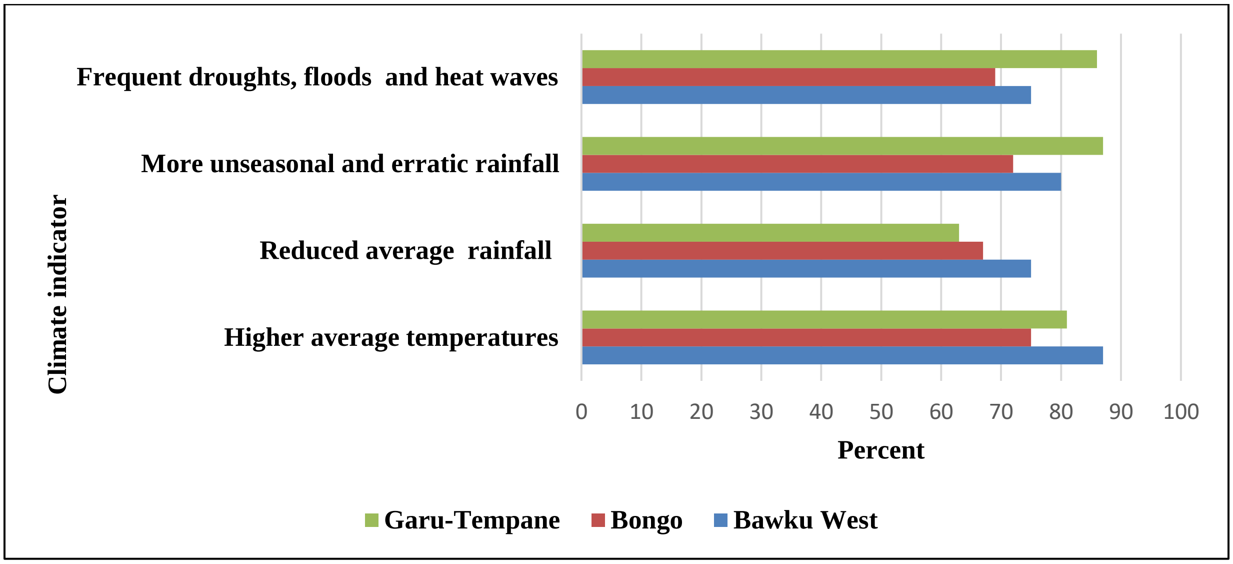
Figure 6. 1 Awareness of respondents to changes in climate markers over the last 10 years



Source: Climate variability and vulnerability survey, 2017

Data on farmers' awareness was also analysed according to geographical location (districts). Awareness was highest in Garu-Tempane (GT) (80 percent), followed by Bawku West district (BW) (78 percent) and Bongo district (BO) (62 percent). Despite the similarity in locational characteristics and proximity to each other, the results show that there was a significant association between geographical location and respondent awareness. Figure 6.2 provides an overview of respondent awareness by district and the various climate markers. In all the three districts, changes in temperature and the unseasonal erratic nature of recent rainfall were the most observed in the last 10 years. Although this trend runs through all districts, respondents in GT and BW were found to be more aware of changes in temperature, seasonal rainfall, and extremes (droughts, floods, rainstorms), than their counterparts in BO. For instance, 87 percent and 81 percent in in BW and GT, respectively, said they had observed higher temperatures and heat waves in the last 10 years compared to 75 percent of respondents in BO. It is also interesting to note that, BO is noted for frequent devastating seasonal floods and rainstorms, yet as many as 31 percent of the selected farmers were not aware of any changes in climate extremes. In all the districts, reduction in seasonal rainfall in the last 10 years was the least observed, although nonetheless over 60 percent said it had reduced. Interestingly, as many as 37 percent of respondents in GT (the most arid per aridity index in Chapter 5) did not observe any changes in the amount of rainfall received in the last 10 years.

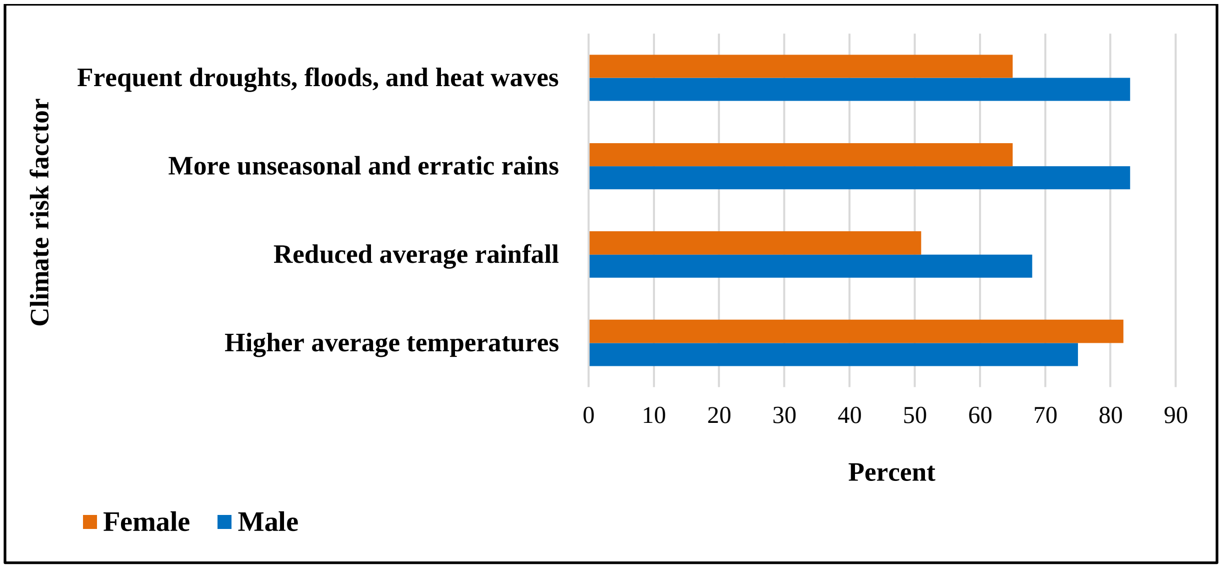
Figure 6. 2 Awareness of respondents to changes in climate markers in the last 10 years by district



Source: Climate variability and vulnerability survey, 2017

Figure 6.3 shows that awareness of changes in climate indicators among male respondents was relatively higher than for females across all climate markers. Of 168 respondents who had observed changes in at least one of the indicators, 67 percent were males, while the remaining 33 percent were females; this is statistically significant (p <0.05). A closer look at the various climate indicators shows that among the female-headed farm-households awareness was highest (75 percent) for changes in climate extremes (frequent droughts, floods, and heat waves), while 57 percent indicated that there had been a reduction in the amount of rainfall over the last 10 years. For the male respondents, awareness was highest for extreme events (83 percent) and unseasonal rains (83 percent), with only 68 percent indicating a reduction in rainfall received. It must be noted, however, that both males and females claimed that temperatures are higher than in the last 10 years.

Figure 6. 3 Awareness of male and female respondents of changes in climate markers in the last 10 years



Source: Climate variability and vulnerability survey, 2017

The above results suggest that the level of awareness of changes in climate and extremes is high among farm-household heads in all of the three study Districts. This finding is consistent with research conducted by Amadou et al. (2015) and Teye et al. (2015) in the Upper East Region (study zone's location). Both studies found that over 80 percent of the farmers they interviewed were highly aware of the changes in climate. Broadly, studies in other parts of the Africa have similar results. In Kenya, Ajuang et al. (2016) found that 91 percent of respondents reported having observed changes in climate in their District. Similarly, Okonya et al. (2013) reported that nearly all the households in an agro-ecological zone in Uganda had observed changes in the local climate (for similar results also See Juana et al. 2013; Deressa et al. 2008). All these studies and the findings from this section could imply that there has been a rapidly increasing trend in awareness since the mid-1990s when the general perception was that climate change awareness in Africa was low, particularly among farmers (See; Ajuang et al. 2016; Juana et al. 2013; Godfrey et al. 2009; Pugliese & Ray 2009; IPCC 1996).

Another finding consistent with existing studies was the fact that awareness of changes in temperature variability was the highest. This is consistent with the finding in Lee et al. (2015), who find that awareness of local temperature was the strongest predictor of risk perception. It is also worth noting that changes in the amount of rainfall received was the least expressed indicator in terms of climate awareness among farm-household heads. This could be attributed to the fact that farmers in this zone experienced more unseasonal and erratic rainstorms (the second highest on farmers awareness), making it difficult for farmers to conceive/observe changes in the actual amount of rain received. This is highlighted in Teye et al. (2015) who found that because both risk factors had dire consequences for crop yield, farmers in the Northern Savannah of Ghana were conflicted in differentiating fluctuations in rainfall regimes from the reduction in the actual amount of rainfall received. The results for farmers' awareness of changes in climate markers is consistent with climate change evidence contained in Ghana's Third Communication to the UNFCCC (See MESTI 2015b).

In Ghana's first biennial update report to the UNFCCC, for instance, variations in levels of climate change impacts in the country are largely defined by geographic location, gender, and the incidence of poverty (See MESTI 2015a). It is unsurprising therefore that geographic location (districts), gender, and education of farm-household heads were found to be significantly associated with the variations in awareness (See Figures 6.2 and 6.3). Despite the similarity in locational characteristics and proximity to each other, these results show that the District a farm-household head belonged to was significantly associated with her/his awareness level. Generally, farmers in Bongo were relatively less likely to notice changes in climate and extremes in the last 10 years than their counterparts in Bawku West and Garu-Tempane. However, a further disaggregation of the composite awareness variable by climate markers revealed that awareness of extreme events was relatively higher in Garu-Tempane than in Bawku West. On the other hand, awareness of changes in temperature and rainfall was found to be relatively higher in Bawku West than in Garu-Tempane. This finding is consistent with the results from the spatial analysis which shows that Garu-Tempane was ecologically highly exposed to climate risks, followed by Bawku West, and Bongo in that order (See chapter 5). These findings are also in line with those of Ajuang et al. (2016) and Teye et al. (2015). Teye et al. (2015) in Northern Savannah of Ghana studied six towns and found significant variations in the level of awareness across all the communities and climate markers. In Kenya, Ajuang et al. (2016) found statistically significant difference across 11 sub-locations in the Upper Nyakach Division. Further analysis also showed that variation in farmers' awareness is significantly associated with their gender of household head and educational background. This research found that male household heads were more likely to observe changes in climate elements and extreme events than female counterparts ($p < 0.05$). According to

Maddison (2006), those who solely depended on weather for all their livelihood activities were more likely to be aware of changes in climate and extremes. If this assertion holds, then it is consistent to say that the gender differential in awareness as identified here, is due to the fact that two thirds of the 55 percent of respondents who engaged in other livelihood activities were women. The implication is that because livelihood diversity is relatively higher among the female-headed farm-households, they tend not to observe medium- to long-term changes in climate and extremes. This assertion is supported by Teye et al. (2015). They found that although women in Northern Ghana also worked on farms, they were mostly associated with off-farm livelihood activities and sometimes even considered farming as secondary. The education levels of respondents is also significantly associated with their awareness levels. Again, this finding corresponds with those in several other academic studies, notable among them being the global level study by Lee et al (2015). These studies found that educational attainment is the single strongest predictor of climate change awareness. Similar findings are also captured in local level studies by Ajuang et al. (2016), Maponya et al. 2013, Maponya and Mpandeli (2012), Ndambiri et al. (2012) and Deressa et al. (2008).

6.2.2 Perceptions of farm-household heads on climate-related threats

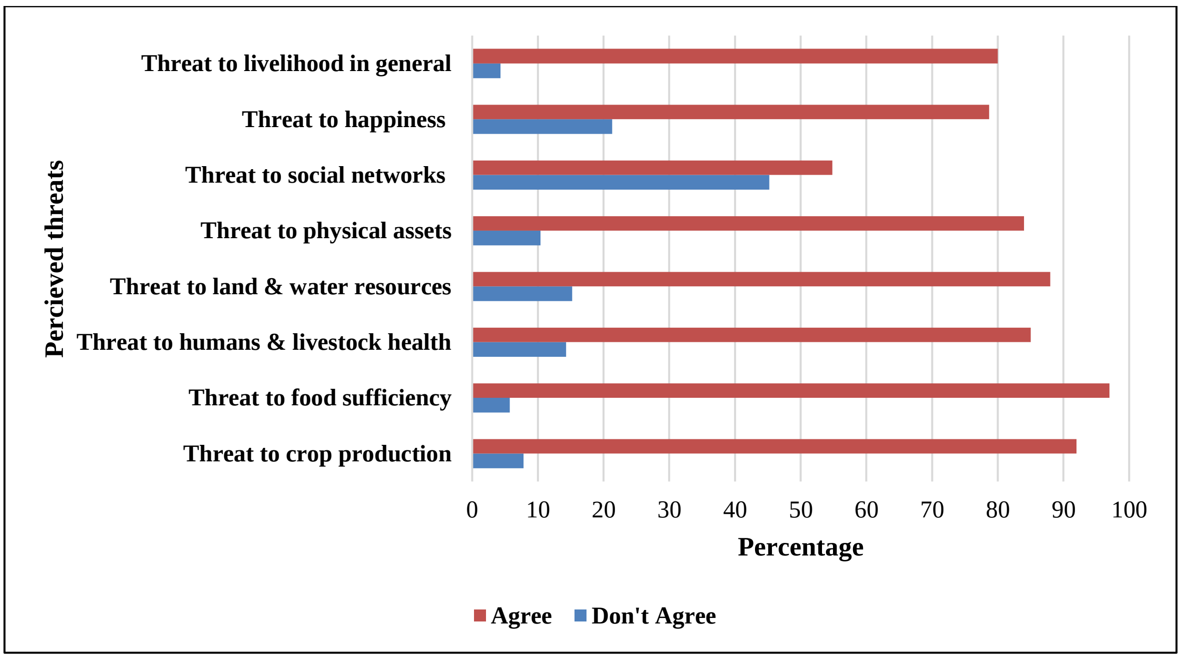
> "It is only when situations are perceived as problems that attitudes regarding potential ameliorative actions are more predictive of behaviour change". (McCown 2005: p11)

In this thesis, threat perception is defined as farmers' concerns/anxieties about negative impacts from past, current, and future occurrences of changes in climate and extreme events on their livelihood assets (See Ndamani & Watanabe 2017). Spatially, the manifestations of these impacts may vary, implying that perceptions too may differ by individual or group within and across communities (Ajuang et al. 2016; Niles & Mueller 2016; Arbuckle et al. 2015; Lee et al. 2015). Therefore, local level perception assessments could be considered consequential for the development of effective coping strategies (Arbuckle et al. 2015; McCown 2005).

The threat perception indicator showed that 82 percent of farm-household heads perceived at least one climate related livelihood threat. Generally, the majority of respondents agreed that changes in climate variability and extremes either affected or could have an impact on all their livelihood assets (i.e. social, human, physical, financial, and natural assets). However, Figure 6.4 shows that the major threat apprehension among respondents was related to food insufficiency (97 percent), effects on crop production (92 percent), and impacts on their lands and water resources (88 percent). The least perceived, but still significant, was the impacts of climate variability and extremes on their social assets (55 percent).

This study also tested the significance of the association between variations in respondents' perceptions and their background attributes. The chi square test results (at $p < 0.05$) showed that respondents' gender, education, age, and number of years in farming had statistically significant association with variations in their threat perceptions.

Figure 6. 4 Climate related livelihood threat perceptions among respondents

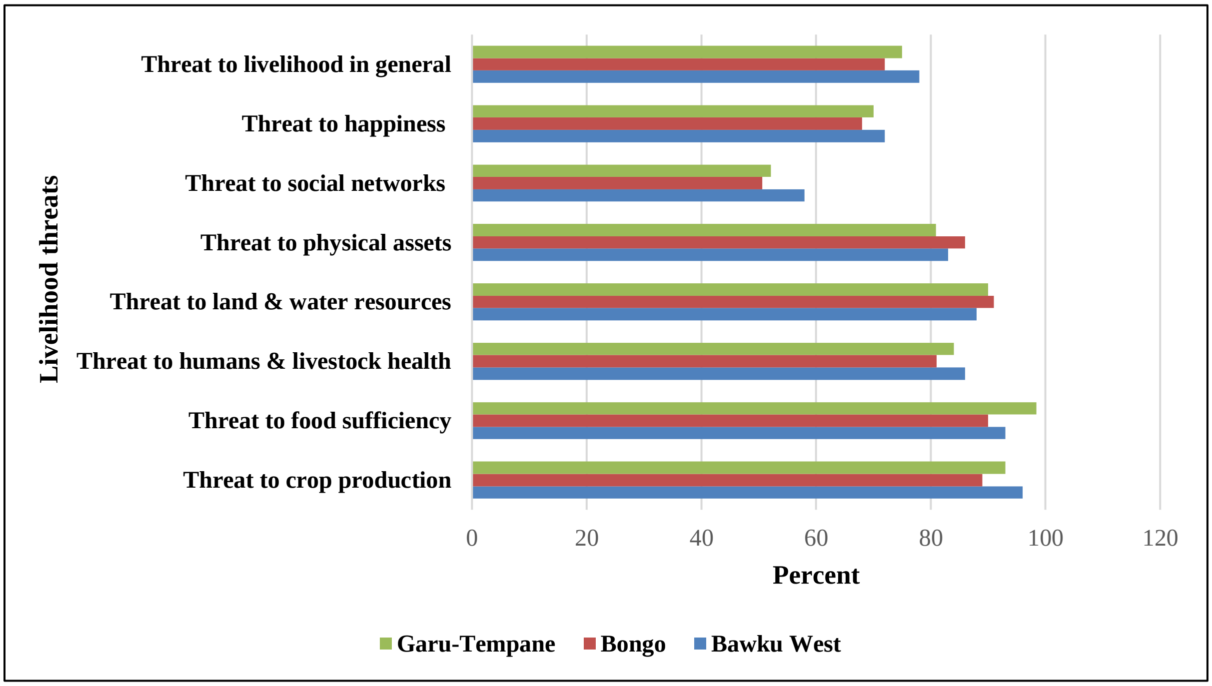


Source: Climate variability and vulnerability survey, 2017

Figure 6.5 provides an overview of threat perception by district. The general impression from the results is that farm-household heads are moderately to highly perceptive of climate related threats to their livelihood assets. More farmers in Garu-Tempane (GT) (87 percent) were perceptive of at least one climate related threat, followed by Bawku West (BW) (83 percent). Relatively, farm-household heads in Bongo district (BO) were the least perceptive of threats, considering that only 62 percent of them perceived at least one climate-related threat. The top three concerns across all districts are climate related food insufficiency, crop yield reduction, land and water threats.

However, the order of importance varied by district. For instance, in BW the most important concern was threats to crop production (96 percent), whilst in GT most respondents referred to food insecurity (98 percent) as the most important. In BO the most perceived was threats to lands and water resources. Across all districts, however, threats to social assets/network and general happiness were much lower, though above 50 percent.

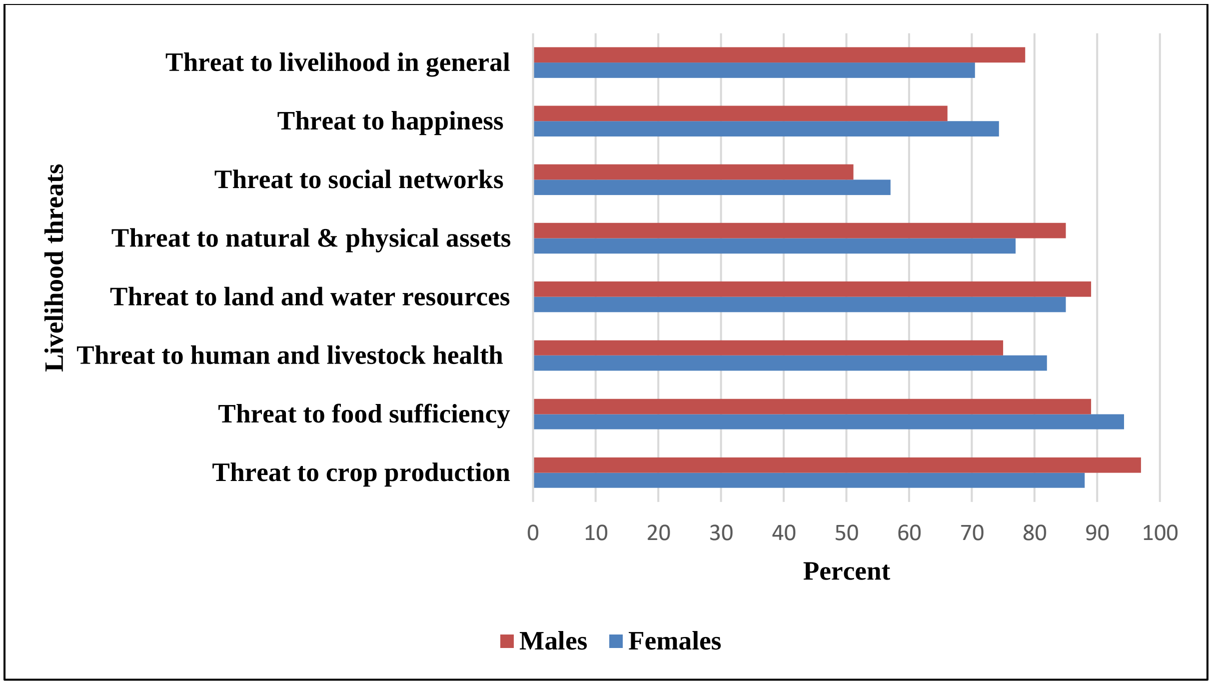
Figure 6. 5 Climate related livelihood threat perceptions among respondents by district



Source: Climate variability and vulnerability survey, 2017

Figure 6.6 shows that males (85 percent) perceive more climate related livelihood threats than females (63 percent). This variation as mentioned earlier was found to be statistically significant. Although threats to food sufficiency, crop production, and natural assets were perceived as major threats for both males and females, the order of importance varied. It is also obvious that males perceived livelihood threats associated with household crop production, natural, and physical assets, whereas females perceived threats to human and social assets (happiness, social network, food sufficiency, and health) as of greater importance. This could be attributed to the widely accepted assertion that women are more inclined to focus on threats that have serious consequences for the wellbeing of their households, while males mostly concern themselves with threats that have direct implications on their productive assets (See also Lambrou & Nelson 2010; Singh et al. 2010; ECA 2009; Terry 2009; Cannon 2002;).

Figure 6. 6 Climate related livelihood threat perceptions among male and female respondents



Source: Climate variability and vulnerability survey, 2017

In examining farm-household heads' perceptions on livelihood threats associated with changes in climate and extremes, it was found that respondents, generally, were highly perceptive of climate-related livelihood threats. However, it was also found that the variations in perception were significantly associated with sex, education, age, and farming experience. It is important to mention that although male respondents were found to be relatively more perceptive of threats compared to females, a disaggregation of the threat perception variable into the various threat factors showed a different trend. The results showed that males were more perceptive of threats associated with economic, physical, and natural assets, while females were more perceptive of threats on household food sufficiency, health, happiness, and social networks.

The survey also showed that the level of education of a household head was a significant arbiter of perception ($p < 0.05$). The inference, therefore, is that the more educated a farmer is, the more likely it is for her/him to be perceptive of climate threats Another variable that had a significant association with the differentials in threat perceptions was age. It is no surprise that the number of years involved in farming was also found to significantly relate to farmer perception. The argument here is that the older a farmer the more experienced her/he is in terms witnessing medium- to longer-term changes in climate and extremes. Ayal and Filho gives further credence to this argument by emphasising that:

> "…unless extraneous variables give advantages to younger farmers, the age factor alone would favour older individuals, in the sense that they can observe the changes and impacts and report it with legitimacy" (Ayal and Filho 2017: p26).

Another interesting result was the fact that respondents perceived the least threat was to their social network (social bonds). The possible explanation for this may be that familial bonds are relatively still stronger in the study zone despite existing evidence of environment-related out-migration, which is largely rural-urban migration (See Geest 2011). Rural farming communities in northern Ghana tend to have strong extended family bonds relative to the southern parts (which have more urban and cosmopolitan areas). Consequently, even if family members travel for "greener pastures" in urban areas (due to prolonged drought for instance), that social bond with household or extended family members remains largely intact. In this instance, members might not perceive the climate risks as threat to their social capital. Thus, the perception that climate change presents low threat to their social networks may be suggestion that the socio-economic benefits from social bonds are not severed during an environment-related crisis and any subsequent out-migration. The probable explanation is that there are strong social bonds among community members belonging to both extended and nuclear families. However, it also important not to lose sight of the possible reason why some survey respondents perceived climate risks as threat to their social network. The impacts of climate variability and extremes may cause individual members of families who have relatively better adaptive capacity to move out of the community in search of better livelihood opportunities, leaving behind dependents who will now have to fend for themselves until the one who travelled secures a livelihood. These dependents could now be left without the social and/or economic support they used to receive from these social networks.

Considering the above findings on climate threat perceptions, one argument that comes to mind is the fact that farm-household systems vary in terms of what really connects them with the issues of climate variability and extreme events (Ndamani & Watanabe 2015). Intuitively, livelihood threat perceptions among farm-households may also vary by spatial scale and context. Accordingly, Howden et al. (2007) argues that farmers concerns should be considered fundamental to successful mitigation and adaptation. Similarly, Arbuckle et al. (2013) and Prokopy et al. (2008) emphasise in their work that the willingness of farmers to adopt climate adaptation strategies is partly contingent on their awareness of the changes and perceptions of how it affects their livelihoods. The findings of this study and other studies in Ghana (e.g. Ndamani & Watanabe 2017; Amadou et al. 2015; Teye et al. 2015), shows that farmers are generally aware of climate change. However, a significant proportion of these farmers are either not using any adaptation strategies championed by both government and NGOs or inappropriately using these strategies (Wossen & Berger 2015; Fosu-Mensah et al. 2012). This could largely be attributed to the fact that proposed measures have failed over the years to adequately capture farmers' perceptions and concerns about climate change threats Ndamani and Watanabe (2017).

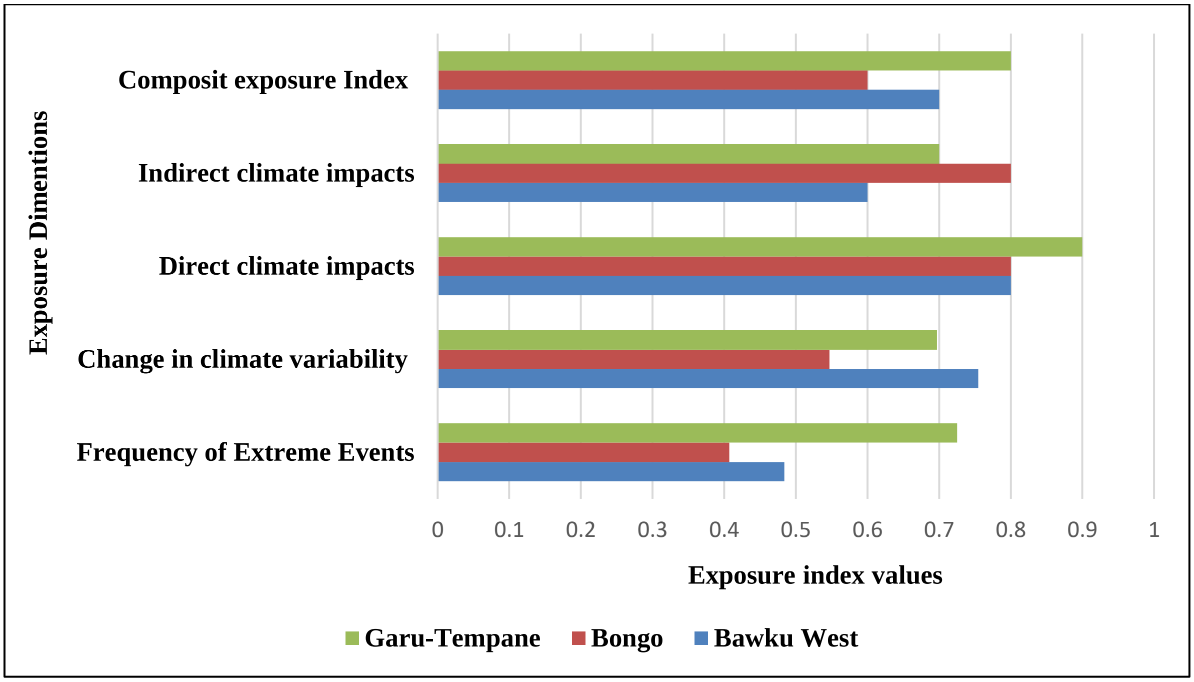
6.3 Farm-household exposure indices

Understanding exposure is an important prerequisite for assessing vulnerability dynamics and subsequently, adaptation planning and targeting (See Monterroso & Conde 2015; Garlati 2013). As a result, knowledge of the extent of exposure becomes a useful guide for reduction of both exposure and vulnerability to climate related hazards through adaptive actions. To examine the exposure of farm-households to climate variability and extremes, this research used the climate exposure index approach. Here, exposure was looked at from four dimensions; frequency of extreme events, changes in the variability of climate elements, perceived direct impacts and indirect impacts of both extreme events and climate variability. The indices were calculated exclusively using primary data on respondents' awareness of, and perceptions on, twelve theoretically selected risk factors. The results in this section are presented according to exposure dimensions, study districts and disaggregated for males and females.

Categorisation of exposure indices, for the purposes of this study, are defined as: low exposure (0.0-0.3), moderate exposure (0.4-0.6), and high exposure (0.7-1.0) (Garlati 2013). Per these categories the composite exposure index indicate that all the study districts fell under moderate and high exposure to climate risk (Figure 6.6), with Garu-Tempane the most exposed (0.82), followed by Bawku West (0.71), and Bongo (0.64) in that order. The composite exposure index showed that farm-households in all study districts were under moderate and high climate exposure.

Based on the composite exposure index, it was also obvious that farm-households in some districts were more exposed than others. The fact that farm-households in Garu-Tempane had a relatively higher exposure index was not unexpected considering that the probability of a climate hazard (i.e. drought risk) occurring was highest in that district compared to Bawku West and Bongo.

Figure 6. 7 Climate exposure indices by dimensions and study districts



Source: Climate variability and vulnerability survey, 2017

It is, however, important to also emphasise that when the results were considered according to exposure dimensions, a different trend was noticed. For instance, in relative terms looking at frequency of extreme events Garu-Tempane was the most exposed (0.73), but when considering exposure to indirect climate impacts, Bongo was found to be the most exposed (0.69). It is also observable that farm-households in the Bawku West district were the most exposed (0.75) under changes in climate variability compared to Garu-Tempane (0.69) and Bongo (0.55). Similar dynamics could be seen when dimensions are further disaggregated by risk factors as shown in Table 6.1. For example, although Garu-Tempane was found to be the most exposed under the frequency of extreme events dimension, Bongo was relatively more exposed when it comes to flood frequency (0.49) than was the case in Garu-Tempane (0.33) and Bawku West (0.34). A similar trend could be seen under the direct climate impact dimension (Table 6.1). The revelation of the above dynamics justifies the argument that users of indices (e.g. adaptation decision makers) must consider what is "behind" the composite index values to be able to make well informed decisions. This is because disaggregation of the composite exposure index by dimension and district showed how respondents' in particular districts were more or less exposed to specific risk dimensions.

Table 6. 1 Exposure indices by dimensions, risk factor and districts

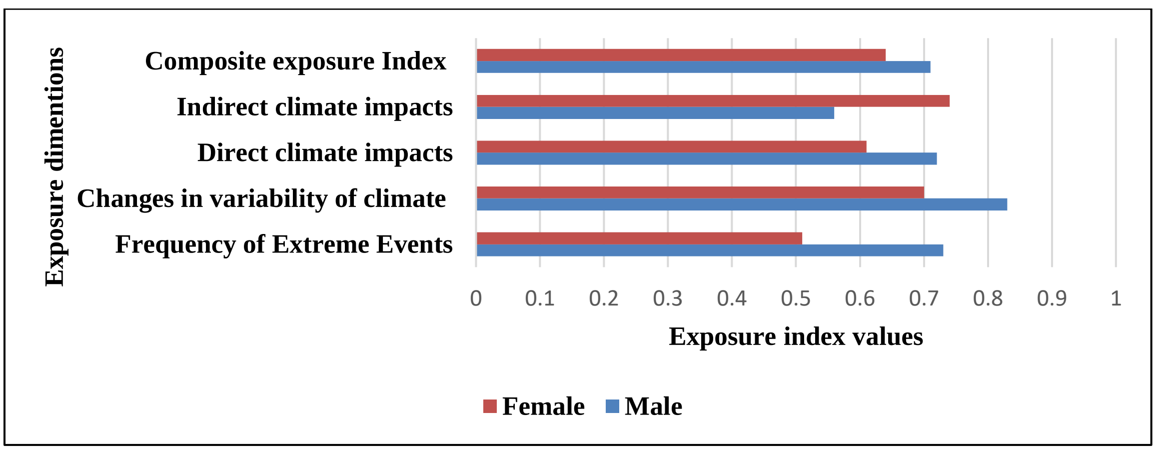
Dimension	**Risk factor**	**Normalised values by Districts**			**Sub-index by Districts**		
		BW	**BO**	**GT**	**BW**	**BO**	**GT**
Extreme Events	Droughts	0.51	0.37	0.90	0.48	0.41	0.73
	Floods	0.34	0.49	0.33			
	Unseasonal and erratic rainstorms	0.62	0.41	0.80			
	Heat waves (severe hotter conditions)	0.48	0.52	0.71			
Variability in climate	Rainfall variability	0.71	0.50	0.64	0.76	0.54	0.70
	Temperature variability	0.80	0.59	0.76			
Direct climate impacts	Threat to crop production	0.96	0.81	0.89	0.80	0.80	0.90
	Threat to land and water resources	0.83	0.80	0.91			
	Threat to household physical assets	0.71	0.76	0.90			
Indirect climate impacts	Threats to human and livestock health	0.81	0.93	0.84	0.61	0.80	0.70
	Threat to social assets	0.42	0.58	0.52			
	Threat to food sufficiency	0.61	0.79	0.65			

Source: Climate variability and vulnerability survey, 2017
Note: BW = Bawku West; BO = Bongo; and GT = Garu-Tempane

Respondents in Garu-Tempane, for instance, were relatively more exposed to extreme events and direct impacts/threats than their counterparts in the other districts. Respondents from the Bongo district were also found to be relatively more exposed to indirect threats from climate related hazards compared to those in Bawku West and Garu-Tempane. A look at the changes in rainfall and temperature variability dimension showed that farm-households in Bawku West had a relatively higher exposure index compared to Bongo and Garu-Tempane. The implication of these dynamics is that it will be insufficient for practitioners to base decision making only on the composite exposure index without further considerations for the sub-indices that highlight the actual dynamics of exposure. Understanding a farm-household's or a community's climate exposure dynamics facilitates effective targeting of initiatives intended to reduce exposure levels.

The survey also examined the gender differentials with regards to the composite exposure index and the sub-indices. Figure 6.8 shows that the composite climate exposure index for male-headed farm-households was found to be relatively higher (0.71) than for those households headed by females (0.64). However, disaggregating the composite index into exposure dimensions highlighted some interesting dynamics. For instance, the result shows female-headed farm-households were significantly more exposed to indirect climate impacts (0.74), whereas male-headed households were relatively more exposed to changes in variability and extreme events (0.83 and 0.73 respectively). This was not unexpected because indirect impacts of climate are largely related to household wellbeing, which is at the core of female responsibilities in the study area.

Figure 6. 8 Climate exposure index by dimensions and for male and female respondents



Source: Climate variability and vulnerability survey, 2017

A further disaggregation of the dimensions by risk factors further showed some complexity in household exposure dynamics. Table 6.2 shows that although female-headed households were found to be relatively less exposed under the extreme events dimension, they were relatively more exposed to the risk factor, heat waves (0.70), than the male-headed households (0.62). However, male-headed households were relatively more exposed to the dimension, direct climate impacts, and less exposed to the risk factor, threat to household physical assets (0.62) than the households headed by their female counterparts. This could be because females are more responsible for domestic household activities.

Table 6. 2 Exposure indices by dimensions, risk factor and by male and female

		Normalised values by sex		**Index by sex**	
Dimension	**Risk Factor**	**Male**	**Female**	**Male**	**Female**
Extreme Events	Drought	0.79	0.51	0.73	0.54
	Flood	0.63	0.43		
	Unseasonal and rainstorms	0.79	0.51		
	Heat waves (sever heat conditions)	0.62	0.7		
Changes in Variability of climate	Rainfall Variability	0.76	0.63	0.82	0.70
	Temperature Variability	0.87	0.77		
Direct climate impacts	Threats to crop production	0.87	0.71		
	Threats to land and water resources	0.66	0.51		
	Threats to household physical assets	0.62	0.7		
Indirect climate impacts	Threats to human and livestock health	0.63	0.75	0.56	0.74
	Threat to social assets	0.43	0.67		
	Food Sufficiency	0.61	0.81		

Source: Climate variability and vulnerability survey, 2017

The finding that male-headed farm-households and their female counterparts are affected differently by different climate markers is indicative of the fact that any blanket or general assertion with regards to which household type is most exposed might be misleading. This emphasises the view that gender-differentiation of impacts must be identified and captured in the development of effective adaptation programs and policies (Mignaquy 2014). It is also important to mention that the finding that households headed by males were slightly more exposed than female-headed households was unexpected considering that it is widely accepted in literature (e.g. Nursey-Bray 2014; IPCC 2012; Alston 2011; Singh et al. 2010; ECA 2009; WEDO 2009) that women are, and will continue to be, relatively more vulnerable to climate risks than men. Consequently, one would have expected that in the same direction women would also be more exposed to climate risk than men. The probable reason is that out of the 33 percent of household heads who were divorced/separated or never married, 75 percent were males (Chapter 4, section 5.6.1), implying that this group of male-headed households did not have the support of a spouse in taking care of the household, especially during or after climate hazards. Male heads of households who were married generally had more than one livelihood activity, the head focussed on farming while the spouse focussed on a secondary household activity like petty trading, shea butter processing and weaving. Consequently, during bad farming seasons, the household relied on the secondary household activity. Essentially, this finding tends to reinforce the assertion that exposure is not a sufficient condition for vulnerability (Cardona et al. 2012).

6.4 Conclusions

The chapter showed that although there were significant variations (by district, sex, education, age, and farming experience), farm-household heads in the study area were both highly aware of the changes in climate variability and extremes and also highly perceptive of the associated livelihood threats. This chapter emphasises that understanding local level awareness and perceptions of climate hazards is fundamental to the success of any climate-related farm-household engagements. The high awareness and threat perceptions translated into moderate to high exposure indices among farm-households in all the study districts, and for both female and male respondents. It was also found that, although not statistically significant, male-headed households were more exposed than households headed by females. However, disaggregating the composite exposure index into dimensions and risk factors, showed some dynamics with regards to which household type was more or less exposed to which specific type of climate risk factor. A similar trend was found when exposure index was examined based on the district a household belonged. Relatively, farm-households in Garu were more exposed than those in other districts. But a disaggregation of the composite exposure index revealed that depending the district, households where more or less exposed to different types of risk factors. The implication is that understanding exposure dynamics at the local level is crucial for targeting climate exposure reduction initiatives.

Chapter 7: Farm-household vulnerability to climate risks

7.1 Introduction

This chapter presents climate vulnerability profiles of smallholder farm-households for the three districts in the Sudan Savannah Zone of Ghana, highlighting the defining determinants of variance, and used cluster and index approaches for the vulnerability assessment. It begins with a classification of respondents' vulnerability to climate risks in the last ten years, followed by a detailed examination of the composition of these vulnerabilities. The results in this chapter are disaggregated using geographic location (District), gender, and vulnerability components. This chapter is based on two premises: i) vulnerable individuals, groups and communities in already marginalised environments are facing serious problems such as food insecurity and loss of livelihoods, due to the accumulative impacts from climate variability and extremes; and ii) vulnerability assessment is a critical ingredient for sustainable adaptation and resilience building at the local level. See Box 7.1 for major conclusions.

Box 7. 1 Highlight of key findings on farm-households' vulnerability to climate risk

- Vulnerability of farm-households is generally high and a little over two-thirds of surveyed farm-households are in the high vulnerability category. Vulnerability cluster variance is significantly associated with food sufficiency, sex, geographic location, access to credit and livelihood diversity.

- Farm-households in Garu-Tempane are significantly more likely to have higher vulnerability levels relative to Bawku West and Bongo. The significant variance across study districts affirms that vulnerability is contextual and heterogeneous in space, even at local scale.

- Female-headed households are comparatively more likely to have higher susceptibility to climate risks. The gendered asymmetry in farm-household vulnerability is primarily rooted in the inequalities in livelihood diversification opportunities, household finance, and household human and natural assets base.

- The comparisons made here are deemed essentially critical for two reasons:
    - They provide a baseline benchmark to inform macro level policy and decisions on resource allocation; and
    - They may facilitate micro level adaptation planning by aiding prioritisation of vulnerable households, communities, and districts, while targeting underlying determinants of their vulnerabilities.

Source: Climate variability and vulnerability survey, 2017

7.2 Clustering of farm-household vulnerabilities in Sudan Savannah Zone

In Ghana, farmers, especially smallholders in the northern Savannahs will continue to experience higher losses and damages due to climate related hazards every second or third farming season (Antwi-Agyei et al. 2017; Derbile et al. 2016; Aniah et al. 2014; Acheampong et al. 2014). Consequently, this section discusses the categorisation of smallholders' vulnerability to these climate related losses and damages using Principal Component Analysis (PCA) and Cluster Analysis (CA) within the study area.

The PCA yielded six principal components (PCs), with saved component scores standardised to ensure that measurement units were the same. The Eigen value rule was used to determine the number of components to be retained. Table 7.1 shows PCs with Eigen values less than 1 that were included. The retained PCs were named making inference to the variables that constituted the component. These were: agriculture and non-agriculture livelihood activities (PC1); food and health (PC2); perceived soil fertility and access to irrigation (PC3); literacy, access to climate information and farmer experience (PC4); socio-demographics (PC5); and household finance (PC6). The six PCs cumulatively explained about 68 percent of the variance in the data, which is statistically acceptable. To determine the importance of a variable to a PC, Stevens's table of critical values was used (Stevens 2012). With all factor sample sizes ranging between 200 and 230, any loading above 0.364 was considered important to that particular PC. The value of the Kaiser-Meyer-Olkin (KMO) test showed a sampling adequacy ($KMO = 0.615$), whilst the Bartlett's test ($p < 0.05$) was significant ($\chi^2 = 43.61, p = 0.012$), indicating that component variance was not the same and that PCA was appropriate for the data analysis (Snedecor & Cochran 1983).

Table 7. 1 Principal components retained for the cluster analysis

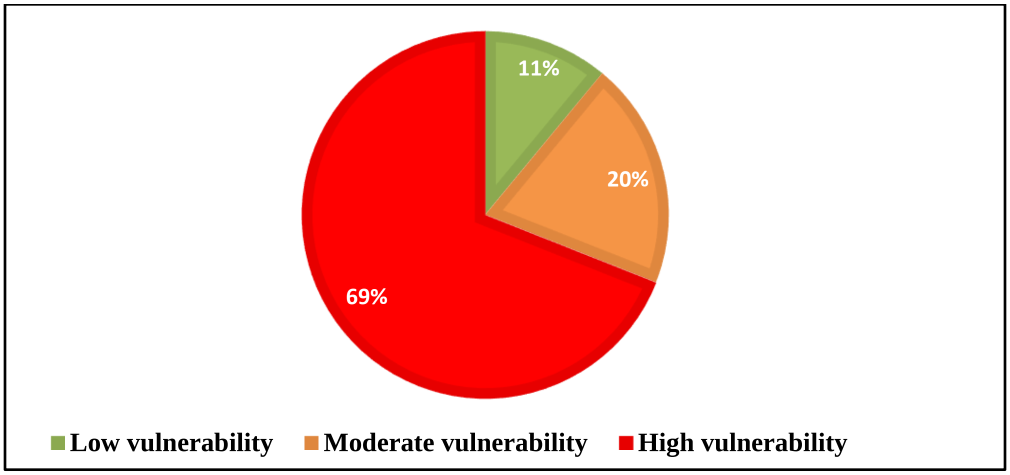
Variables	PC1	PC2	PC3	PC4	PC5	PC6
Non-farming livelihood diversity index	**.681**	.082	-.150	-.056	-.087	.096
Crop diversity index	**.410**	.118	.010	-.091	-.022	-.162
Households who owned sets of livestock	**.373**	-.107	-.185	-.036	.192	-.052
Access to health facility	.333	**.534**	-.008	-.071	-.682	-.077
Households able to produce 75percent of their food needs in a year.	.005	**.414**	.147	-.010	-.297	-.037
Number of months in a year it was difficult to provide food for household	.012	**.372**	.222	.207	.054	-.062
Perceived soil fertility	.092	-.199	**.571**	.022	-.080	-.110
Access to irrigation facilities	.166	.185	**.446**	.118	-.091	.149
Literacy of household head	-.118	.200	-.099	**.559**	-.042	-.232
Access to climate information	.138	-.135	.042	**.518**	.066	-.144
Farming experience	-.114	-.027	.037	**.381**	-.047	.003
Household size	.033	.020	.022	-.196	**.684**	.098
Dependency ratio	.247	.052	-.025	.112	**.427**	-.085
Sex of household head	.012	.044	.012	.201	**.371**	-.152
Access to credit	-.110	-.199	.092	.022	-.080	**.771**
Households who receive remittance	-.094	.004	-.028	-.088	-.272	**.503**
Eigen value	**2.154**	**1.842**	**1.728**	**1.539**	**1.427**	**1.304**
Proportion	**21.021**	**15.647**	**13.851**	**09.104**	**04.711**	**03.422**
Cumulative	**21.021**	**36.668**	**50.159**	**59.623**	**64.334**	**67.756**

Source: Climate variability and vulnerability survey, 2017

Figure 7.1 provides details of the cluster analysis of the standardised principal components. The K-means cluster analysis generated three approximate vulnerability patterns (low, moderate, and high) with distinct farm-household attributes. The results show that the differences among means of variables within-vulnerability clusters were statistically not significant ($p > 0.05$), implying that farm-households within a vulnerability class had similar characteristics (Henning 2015; Levia & Page 2000). The analysis also showed that despite the differences in socioeconomic context across study districts, between-vulnerability cluster means were significantly different ($p < 0.05$). The inference here is that identified vulnerability classes were sufficiently distinct (Henning 2015).

The cluster analysis presents a general overview of farm-household vulnerability classes in the Sudan Savannah Zone (SSZ). The results showed that two-thirds of the 230 farm-households (69 percent) were highly vulnerable to climate variability and extremes, whilst only 11 percent were found in the low vulnerability class. Once classified, the vulnerability classification association with cluster membership attributes was analysed. This was done by testing cluster association with farm-household characteristics. The Chi square test ($p < 0.05$) showed that food sufficiency, sex, district, access to credit, receipt of remittances and livelihood diversity were statistically significant in explaining the variation between vulnerability clusters.

Figure 7. 1 Farm-household vulnerability clusters



Source: Climate variability and vulnerability survey, 2017

Relative to low vulnerability households the majority of farm-households within the high vulnerability cluster were not able to produce 75 percent (as advocated by FAO 2010) of their grain/cereal need, with the majority growing 1 or 2 types of crops (low crop diversity index), and most were relying solely on their farm produce for grains. Theoretically, this dependency (undiversified food source) increases their sensitivity to climate variability and extreme events. Another interesting revelation is that, proportionally, 35 percent of high vulnerability households had more families living in urban centres compared to those under moderate (18 percent) and low (25 percent) vulnerability classes. However, it was interesting to find out that out of the 25 percent of low vulnerability households who had relatives in urban areas, 90 percent of them stated they actually had received remittances, especially during and after hazard events. Conversely, only 49 percent of the high vulnerability households who had family members in urban areas had received remittances.

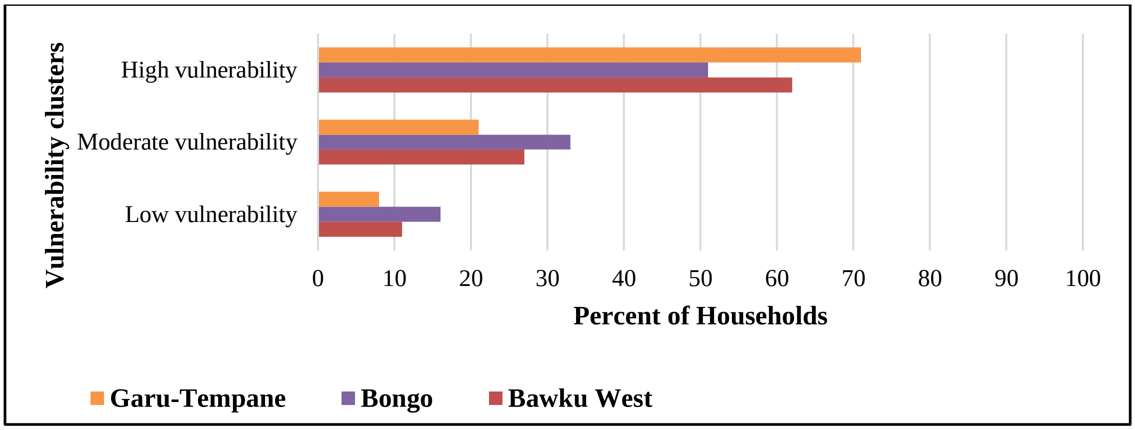
This study also found that relative to households with moderate and high vulnerability clusters, a major characteristic of the low vulnerability households was that they had better diversified livelihoods (with an average non-farm livelihood diversity index of 1.9). The high vulnerability cluster is associated with lack of livelihood alternatives and the capacity to avoid or cope with climate-related events. Among the low vulnerability group, however, farm-households can spread the climate risks associated with crop failure because they have secondary livelihood activities. In the process, they can build livelihood resilience at the household level. This corroborates the fact that the non-farm economy and access to credit is crucial to the prospects and livelihood security among smallholder farmers (Haggblade et al. 2010). However, it is important to acknowledge that some non-farm livelihood diversification strategies have implications crop production. A typical example is when the migration of labour (as a livelihood alternative) leads to the depletion of the local productive work force, causing low crop productivity and food insecurity.

7.2.1 Clustering of farm-household vulnerability by district

This sub-section presents a comparison of the study districts in relation to the percent of farm-households within various vulnerability clusters. This was done primarily because the vulnerability classification was found to be significantly associated with the district in which a farm-household belonged. Generally, Figure 7.2 shows that in each of the study districts, the majority of surveyed farm-households were in the cluster of high vulnerability. However, significant differences were found among districts in terms of the proportion of households who were in the high vulnerability category ($p < 0.01$). Garu-Tempane had the highest proportion of households under high vulnerability category (71 percent), followed by Bawku West with 62 percent and Bongo 51 percent respectively. Garu's relatively high vulnerability could be associated to the fact that it is a new district compared to the other study districts. Consequently, certain livelihood capitals (e.g. socio-economic infrastructure) are limited in the districts. This revelation is important for adaptation targeting in the sense that it could facilitate the prioritisation of scarce resources both at the local and national level.

Figure 7.2 also confirms that farm-households in Bongo, proportional terms, dominated the moderate and low vulnerability clusters (33 percent and 16 percent respectively). Compared to Garu-Tempane and Bawku West, Bongo had more farm-households who were relatively less vulnerable to climate variability and extremes. The results on farm-household characteristics suggest that farm-households in Bongo were better off in terms of availability and accessibility to most of the livelihood assets, than their counterparts in Bawku West and Garu-Tempane (i.e. food sufficiency, livelihood diversity, and finance). Another possible factor for the district's relatively less vulnerability could be its relative nearness to the regional capital, Bolgatanga, which is the biggest urban centre in the study zone. The assumption here is that, the closer a rural community is to an urban centre, the higher the opportunities for the improvement of livelihoods.

Figure 7. 2 Vulnerability clusters by districts



Source: Climate variability and vulnerability survey, 2017

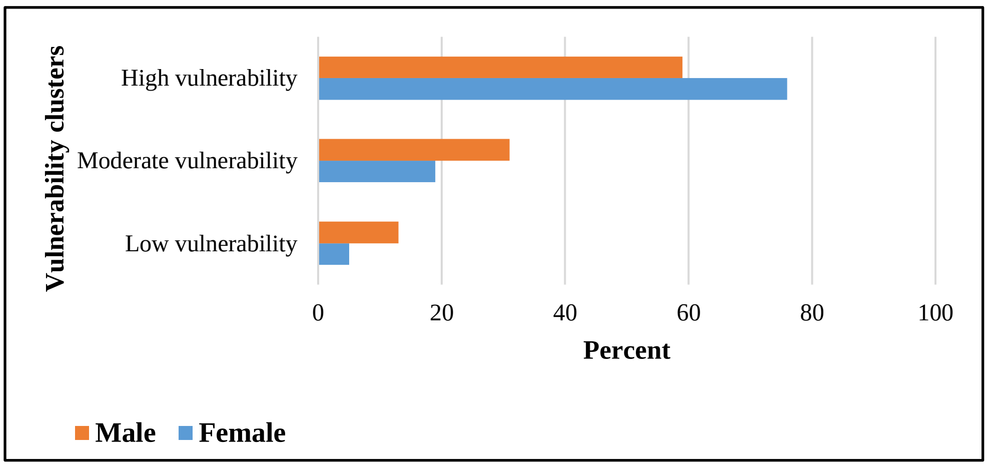
The above findings are consistent with reports prepared in the 2016, The *Ghana Poverty and Inequality Report* (Cooke et al. 2016), and another in 2015 titled *Ghana Poverty Mapping Report* (Ghana Statistical Service [GSS] 2015). A review of the latter report, for instance, showed that Bongo had the least number of poor persons (56,622) relative to Bawku West (63,315) and Garu-Tempane (70,087). In the same report wealth inequality was lower in Bongo (54.4 percent) relative to Bawku West (57.9 percent) and Garu-Tempane (55.8 percent). Intuitively, it was expected that the vulnerability farm-households to climate risks in Bongo district will be lower compared to their counterparts in the other study districts.

7.2.2 Clustering of farm-household vulnerability by male and female

It is imperative to emphasise that the discussions on gender in this subsection (and in subsequent sections of this chapter) do not consider gender differentiation based on only biological or physical difference, but also in the context of socio-economic, institutional and political relations. As a result, high or low vulnerability of a female- or male-headed household is regarded as a product of the interaction of factors that influence ownership and use rights of sustainable livelihood assets.

Figure 7.3 shows that although the majority of both the female- and male-headed farm-households were found to be in high vulnerability clusters, proportionally, there were more female-headed households (76 percent) in this cluster than males (59 percent). On the other hand, there were proportionally more male-headed households in the moderate and low vulnerability clusters (31 and 13 percent more than that for the female-headed household respectively). This finding could be related to differential access to livelihood assets, especially when socio-cultural values and norms in the study area create access bias in favour of men. Women have been found to play a key role in household food security (and livelihood security in general), but lack of political capital required to make decisions on, for example, leasing a piece of an extended family land to raise money for potential investment in non-farm livelihood activities, is hindering their ability to cope or adapt to climate risks. Affirmatively, Abdul-Razak and Kruse (2017) raised similar concerns when they found that women's access to technology and economic resources in Northern Savannah was limited by socio-cultural norms and practices. In this case the results highlight the need for empowerment of women socio-economically, to improve their participation in livelihood decision.

Figure 7. 3 Vulnerability clustering of farm-households by male and female



Source: Climate variability and vulnerability survey, 2017

Although these biases are gradually fading (due largely to modernisation and urbanisation), in Ghana's rural Savannah it is still a major hindrance to women's access to livelihood capital. Rao et al. (2017) highlight the significance of gender balanced resource access and go further to emphasise, most importantly, the need to explore how socio-cultural values and identities in different contexts define the gender-differentials in ownership and use rights. Hence, it is imperative for assessments to move beyond just the composite aggregation of gendered vulnerability towards investigating the intricate non-climatic factors (e.g. socio-cultural, economic, and power relations), that deny equal opportunities and rights to livelihood assets required for climate adaptation. Interrogating these factors broadens the understanding of gendered climate vulnerability as it emerges from poverty and socio-cultural practices in different political and geographic contexts. In the subsequent sections of this chapter, these inhibiting factors are discussed in detail.

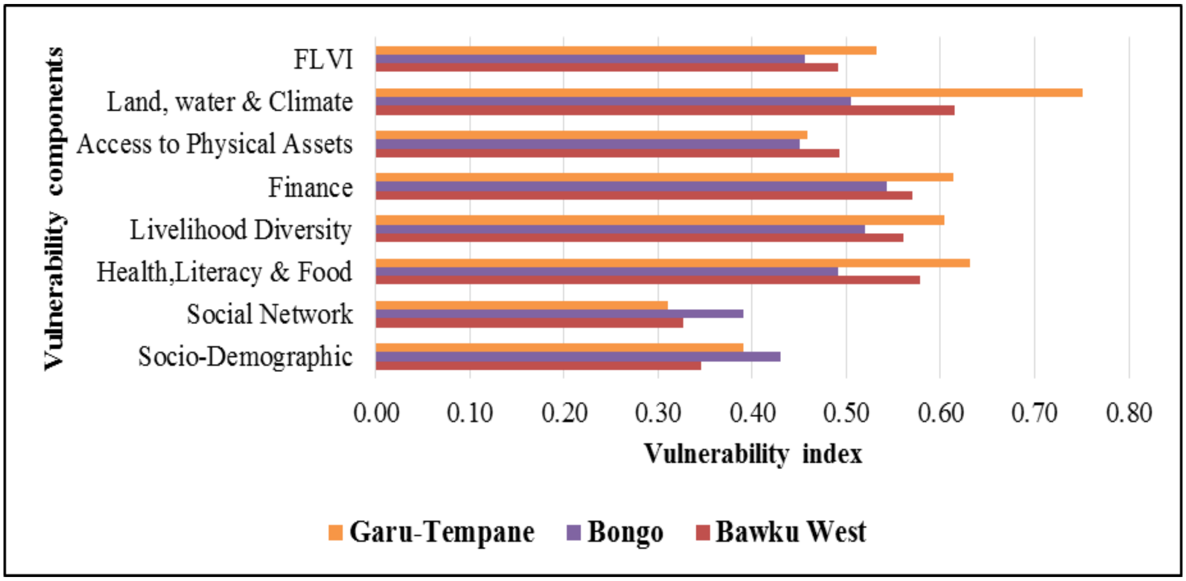
7.3 Vulnerability dynamics in the Sudan Savannah Zone

The vulnerability of any human population to climate risk is contingent on the socioeconomic, environmental, and the geopolitical context within which they interact with the risk (Kok et al. 2016; Adger et al. 2006). Consequently, Hahn et al. (2009: p75) argue that "climate change adds complexity to household livelihood security". To unpack this complexity, this thesis built on the Livelihood Vulnerability Index (LVI) framework as used by Shah et al. (2013) and Hahn et al. (2009) to examine farm-household vulnerability dynamics in the Sudan Savannah zone (SSZ). This section presents the analysis of the factors that play in concert to increase or reduce household vulnerability to climate risks. The results are disaggregated by district and gender.

7.3.1 Farm-household livelihood vulnerability dynamics by district

Figure 7.4 presents the major components of the composite farm-household livelihood vulnerability index (FLVI) by district. The results showed that farm-households in Garu-Tempane had a higher mean index score (0.55) relative to Bawku West (0.49) and Bongo (0.44), indicating the district's slightly greater vulnerability to climate variability and extremes. A quick glance at the composite FLVI suggests minimal vulnerability variance among the three study districts. However, a disaggregation of the composite FLVI into major components showed the contribution of each of the livelihood assets to a farm-household's overall vulnerability. In Garu the highest and least vulnerability sub-index score among households was land, water, and climate (0.75) and social network (0.31). This was an expected result in the sense that Garu was found to be the most biophysically vulnerable district relative to the others but households in this area tend to have strong social bonding, particularly in terms of extended family network. These networks are very key during and after climate disasters since they serve as extra livelihood security. In Bongo, however, there was a different mix of vulnerability components among farm-households. The highest and the least sub-index for this district was finance (0.54) and social network (0.39) respectively. Among all the study districts, Bongo has the highest standard of living so it will suffice to expect that household finance may be the highest contributor to climate vulnerability. As previously alluded to, social network in the entire study zone was found be strong (least contributory factor in all districts) but comparison of study districts showed that farm-households in Bongo had limited social network. Again, this goes to buttress the view that the more urbanised a society is, the less socially networked it will be.

Figure 7. 4 Mean farm-household vulnerability indices by districts



Source: Climate variability and vulnerability survey, 2017

In the case of Bawku West there was also a different mix, the highest sub-index was land, water, and climate (0.62) and the least was socio-demographic related (0.33). In this instance reference can also be made to the geospatial and exposure analysis in previous chapters, where Bawku was found to be the second most risky in terms drought occurrence and the second most exposed to climate variability. It is therefore not surprising that soil fertility, water stress and severe variability in rainfall and temperature are the most important contributors to the vulnerability of farm-households in the district. Socio-demographic variables) contributed the least to the vulnerability of farm-households in Bawku. This could be attributed to the fact that household heads in the area, relative to Garu and Bongo, had a lower median age, with relatively lower average household size and dependency ratio.

Table 7.4 also shows that there was no significant variance among respondents across all study districts in terms of ownership and/or access to household physical assets ($p < 0.05$). Farm-households in all the study districts were similar in terms of ownership of household goods, ownership of homes, and condition of house structure and land tenure. More than two-thirds of farm-households in the study area, for instance, said they owned radio and mobile sets, owned their homes, but reported a poor condition of their house structure. The Upper East Region, where the study districts are located, shares a border with Togo to the north. As a result, most of these household physical goods are exported from Togo and sold at a cheaper price, making it easy for households to buy. It is, therefore, not surprising that mean vulnerability scores did not significantly differ among study districts.

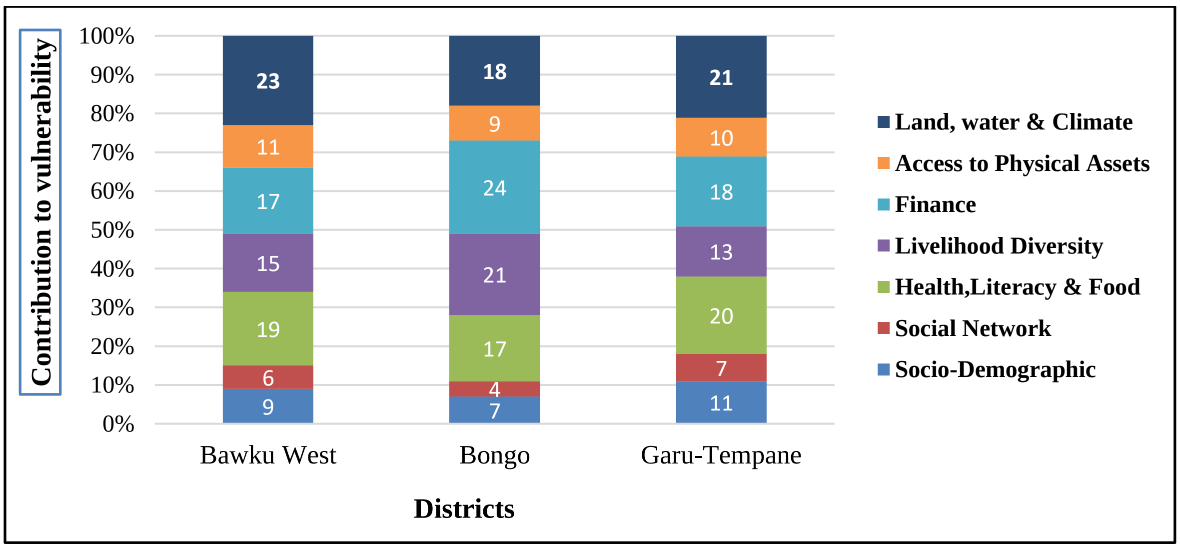
There were however, significant variations among districts in terms of vulnerability scores on social capital. In Figure 7.4, for example, farm-households in Bongo had relatively higher vulnerability index scores under the socio-demographic component (mean score of 0.43), compared to those in Garu (0.39) and Bawku (0.35). A similar trend could be seen under the social network component, where respondents in Bongo were again found to be more vulnerable with a mean score of 0.39, relative to those in Bawku (0.33) and Garu (0.31). A further disaggregation showed that despite their relatively less vulnerability measured by their socio-demographic profile, household heads in Garu and Bawku had higher mean index scores for the dependency ratio (0.26 and 0.23 respectively), and median age of household head (0.48 and 0.43 respectively).

The disaggregation of composite indices into major components and subcomponents, helps reveal the varied mixture of underlying determinants of a households' vulnerability profile. A household can generally be less vulnerable under a major component, but a further interrogation of subcomponents may reveal issues that require interventions. These dynamics indicate that, spatially, farm-households can be varied in terms of what mixture of factors make them vulnerable. Each variable contributes differently to vulnerability depending on the farm-household setting. The implication here is that it is always very important to disaggregate composite indices in order to ascertain the critical variables in such an index. Moreover, disaggregating composite vulnerability indices improves the targeting of adaptation measures in the sense that decision makers are able to apply scarce resources efficiently by targeting the most important factors behind the vulnerability of farm-households.

The contribution of each major component is captured in Figure 7.5. Obviously, natural capital, household finance, livelihood diversity, and human capital were the major underlying factors of vulnerability among farm-households in the study area, even though the order of importance varied by district. The survey found that farm-households in Garu-Tempane and Bawku West districts were relatively more agroecologically constrained than their counterparts in Bongo, a finding that converges with the conclusions from the geospatial assessment climate risks as outlined in Chapter 5. The implication here is that these two districts are both socially and ecolocally likely to be more vulnerable to climate variability and extremes. For farm-households in Garu-Tempane and Bawku West the most important contributors to their vulnerability were limited availability of fertile land, water, and stable climatic conditions (land, water, and climate), contributing 23 and 21percent of their respective composite FLVIs. The subcomponents showed that respondents in Garu and Bawku were relatively more perceptive of changes in climate and its effects over the last 10 years and reported relatively high frequencies of extreme events (in the same period), they were more perceptive/aware of the infertility of their farmlands, and used mainly natural water sources for domestic purposes. The natural capital needs of farm-households have implications for livelihood security, especially in rural settings. This research argues that agriculture-dependent households in rural savannah who have limited access to natural capital tend to be associated with limited economic opportunities.

Contrary to the situation in Garu and Bawku, Figure 7.5 shows that respondents from Bongo, on the other hand, were more concerned with their financial/economic susceptibility during and after climate events. Farm-household finances contributed most to their vulnerability (24 percent). Respondents in Bongo were particular about their limited access to the credit needed to cope or recover from bad farming seasons caused by late rains, droughts or floods. However, it is important to also acknowledge that under this finance component, Bongo was the least vulnerable relative to Garu-Tempane and Bawku West. Under this major component, three variables were considered: receipt of remittances in the last 12 months, sets of livestock owned and access to credit. Bongo was relatively less vulnerable under all these subcomponents. In the rural setting, remittances from family and friends is an important factor for coping with climate related livelihood challenges (Musah-Surugu et al. 2017). It is the assumption of this research that households who receive remittances have a better diversified income source and thus are better situated to withstand the shocks from natural hazards. Therefore, households without livestock or only have a few sets, are expected to struggle to cope or recover. Other studies have found that when hazard episodes culminate in crop failure and household hardship, livestock offer readily available income during and after (Hesselberg & Yaro 2006). On the issue of access to credit, it was found to be the single most important challenge among smallholder farmers in the sense that it had direct implications for climate change vulnerability and adaptation. The thesis argues that households with no credit, or with limited access to it, are likely to be very susceptible to impacts since they may not have the financial capacity to adapt their livelihoods, especially in this case where household income sources are generally undiversified.

Figure 7. 5 Components' contribution to vulnerability by districts



Source: Climate variability and vulnerability survey, 2017

Figure 7.5 also shows that livelihood diversity was the second most important vulnerability component among households in Bongo, contributing 21 percent to the composite farm-household vulnerability. Even though livelihood diversity was the second major contributor to vulnerability among respondents in Bongo, farm-households in this district were found to be, relatively, higher livelihood diversifiers compared to Garu (13 percent) and Bawku (15 percent). Bongo had a relatively small percent of households (35 percent) who depended *solely* on farming for income and a relatively high non-agriculture livelihood diversification index of 1.8 compare to Bawku and Garu with 1.51, and 1.7 respectively. Farm-households in Bongo can be regarded as multi-activity households who engaged in one primary livelihood activity (smallholder farming) with one or more complementary livelihood strategies (e.g. petty trading, shea butter processing, and weaving of smocks, baskets, hats, etc.). This allowed households to diversify their income sources. As a component of wellbeing, this survey has proven that improved income through complementary activities enhances the financial space of farm-households, allowing them to fulfil their needs and acquire the requisite climate adaptation inputs.

Hypothetically, under poor natural capital situations (e.g. low soil fertility and severe climate variability), farm-households with stronger finances are in a much better position to adjust their crop production (e.g. adopt new farming methods). Further, they are also able to enhance their access to other livelihood needs like food and health under severe climate variability and extremes such as droughts (See Kimenju & Tschirley 2009). The relatively highly diversified livelihoods among farm-households in Bongo does not diminish the pre-eminent role of crop farming in reducing household vulnerabilities to climate risks. This is primarily because smallholder farming employs nearly 80 percent of adults in the entire Bongo district (GSS 2014).

For farm-households in Garu-Tempane and Bawku West, the second highest contributor to their respective vulnerabilities was the Health, Literacy and Food component, contributing 20 and 19 percent to their respective composite household vulnerabilities (Figure 7.5). The subcomponents revealed that high illiteracy and food insecurity was the bane of farm-households in these two districts. There was generally high illiteracy among sampled respondents in all districts. However, the respondents' socio-demographic characteristics assessment confirmed that Bawku West and Garu-Tempane had comparatively higher percentages of illiterate farm-household heads (81.5 and 74.5 percent respectively). As low levels of literacy reduce the capacity of households to access climate information, this may influence their willingness to accept agricultural innovations and new technologies required for livelihood adjustments under climate variability and extremes (Leichenko & O'Brien 2002).

Farm-households in Garu (20 percent) and Bawku (19 percent) were also found to be more susceptible to changes in household food production and consumption due to climate related events. The results revealed that food insecurity in these two districts was relatively higher than in Bongo (17 percent). As many as 83 percent of respondents in Bawku West produced less than 75 percent of their household grain requirement, while in Garu-Tempane the figure was 78 percent. Moreover, the number of months farm-households struggled to provide food for its members were higher in Garu and Bawku relative to Bongo. Bongo's relatively high resilience to food shortage may be attributed to the fact that some of its households claimed that in bad seasons they engaged in picking wild foods, such as Shea nuts, berries, mushrooms, and hunted for bush meat (e.g. bushbuck and wild guinea fowls). These are very important sources of food during or after periods of climate-related bad seasons.

Bongo, in relation to the Health, Literacy, and Food component, was generally better off relative to that of Garu-Tempane and Bawku West (Figure 7.5). It should also be noted, however, that a disaggregation of this vulnerability component revealed that despite Bongo's relatively better resilience under this component, farm-households in the district were the most vulnerable in terms of ease of access to health facilities. This is understandable considering that the Ghana Health Services (GHS) annual report for 2016 (GHS 2017) indicates that there were relatively less functioning Community Health Improvement Services (CHIPS) compounds in Bongo, compared to Garu-Tempane and Bawku West (GHS 2017). The aim of these CHIPS compounds is to move primary health services to community locations, empower women and vulnerable groups, and improve the interaction between health providers on the one hand, and households and community on the other. Thus, households or communities within CHIPS zones with functional health posts, are likely to have relatively easier access to health services, which reduces vulnerability during and after climate extreme episodes.

Household ownership of, and and/or access to, physical assets in the three districts was also examined. Analysis of this component included the following constituents: home ownership, condition of house structure, ownership of TV and Radio sets, ownership of main farmland, and access or ownership of irrigation facilities. Household physical capital is significant in its capacity to reduce vulnerability or increase resilience (Naab and Koranteng 2012, Gbetibouo et al. 2010). However, in the context of this research, as can be seen from Figure 7.5, this major component contributed relatively less to the vulnerabilities of farm-households in all the study districts. This is consistent with the findings of Antwi-Agyei et al. (2013), when they found that physical capital was a least contributing factor to the vulnerability of households in Vea, Adaboya, and Ayelbia, all located in the Sudan Savannah Zone.

Analysis of how social capital contributes to farm-household vulnerability shows that in all the study districts socio-demographic and social networks were the least contributing factors (See

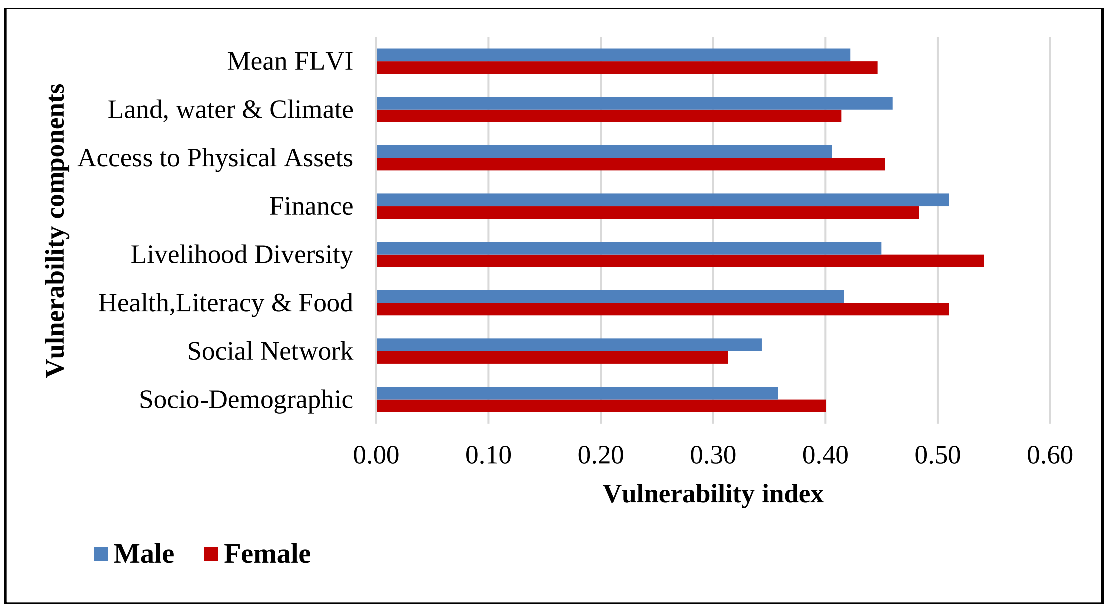
Figure 7.5). Social capital is a crucial ingredient for climate adaptation (Pelling and High 2005; Adger 2003). Apart from the potential material support households may get from social networks during and after hazard events (Hahn et al. 2009), networks usually also serve as a source of information on various issues, including climate/weather variability and how to adapt, the availability of a new variety of crops, and the appropriate application of fertilizer (Shah et al. 2013). In this survey, it was found that most of the households in the low and moderate vulnerability clusters one association or the other (e.g. farmer associations, churchbased associations, community men or women association). In this survey socio-demographics of households was also been found to be statistically associated with whether a household will be vulnerable or not ($p < 0.05$). This may be attributable to the view that households in the study area generally have better access to bonding, bridging and linking social capital through family, ethic ties, and association with social groups. This will not be surprising because in the northern savannah zones of Ghana, unlike the relatively developed South, social capital is still an important fabric of every aspect of the household and community.

7.3.2 Gender differentials in farm-household vulnerability dynamics

The importance of gender differentiation of climate vulnerability dynamics in both developed and developing countries is widely espoused in literature (e.g. Wilheminaet al. 2019; FlatØ et al. 2017; Buckingham 2016; Chanamuto & Hall 2015; Klasen et al. 2015; Owusu-Afriyie & Nketiah-Amponsah 2014; Alston 2013; Denton 2010; Dankelman et al. 2008). In most of these studies on climate change and gender, ownership of, and access to, sustainable livelihood assets is considered important for vulnerability reduction and positive development outcomes in general (Wilhemina et al. 2019). Hence, any disparity in ownership or use rights along gender lines may have implications for vulnerability variance. In the context of Ghana, particularly in the northern parts, evidence suggests that the increasing feminization of poverty and agriculture (in terms of women's labour contribution to agriculture) and the increasing proportion of female-headed households have not resulted in the realignment of ownership or access to livelihood assets (Owusu-Afriyie & Nketiah-Amponsah 2014; Dankelman et al. 2008). On this basis, the analysis of gender differentials was merited. The analysis was undertaken in terms of trying to understand gender related access to sustainable livelihood assets in the three districts within the Sudan Savannah Zone (SSZ) and how (and whether) the dynamics translate into gender-differentiated climate vulnerabilities.

Figure 7.6 presents a comparison of how female- and male-headed households differ in terms of vulnerability under the various major components. The mean Farm-household Livelihood Vulnerability Index (FLVI) showed that female-run households (with a mean score of 0.45) were relatively more likely to be vulnerable than male-run households (with mean score of 0.42), although the difference was not statistically significant ($p < 0.01$). Figure 7.6 shows that out of the seven vulnerability components, female-headed households were relatively more likely to be susceptible in four: livelihood diversity; health, literacy and food; socio-demographic profile and access to physical assets. This differentiated vulnerability is an indication that the tendency to make blanket presumptions that women are the most vulnerable during and after climate related disasters, without properly understanding of the various components of such vulnerabilities, may lead to misleading conclusions and even maladaptation. The mean FLVI for both female- and male-headed households does not contradict what is widely captured qualitatively and quantitatively in literature (e.g. Tibesigwa et al. 2015; Shah et al. 2013: Denton 2010).

Figure 7. 6 Mean farm-household vulnerability indices by males and females



Source: Climate variability and vulnerability survey, 2017

Figure 7.6 shows that households with women heads were relatively more likely to be vulnerable under the livelihood diversity component, with an index score of 0.54 than their male-run households (0.45). Relative to male-headed households, livelihood diversity was the most important contributing factor to the vulnerability of female-headed households. A disaggregation of this component revealed that households headed by females were relatively more vulnerable under non-farm livelihood diversity (with an index score of 0.67), and sole dependence on farm income (with a score of 0.55). A plausible explanation is that female-headed households tend be more averse to investing (time and finance) in complementary non-farm livelihood strategies, because they tend to have relatively more social/household responsibilities (Rao et al. 2017; Naab & Koranteng 2012; Denton 2010). Livelihood diversification is not only important for poverty reduction among rural farm-households, but also critically essential for the reduction of their vulnerability to current and anticipated changes in climate and extremes (Asfaw et al. 2017; Gecho 2016; Seng 2015). However, evidence shows that the type of farm-household headship is significantly associated with household participation in alternative livelihood activities. In Ethiopia, Asfaw et al. (2017) found that female-headed households were relatively less likely to engage in non-farm economic activities.

The results showed that there is significant difference in female- and male-headed household scores for the major component, health, literacy, and food ($p < 0.05$). In Figure 7.6, households with female headship were found to be significantly more vulnerable under this component, (with a score of 0.51) compared to male-headed households (0.42). This component was the second most important determining factor of vulnerability among female-headed households. Five subcomponents were aggregated into the human capital component: easy access to health facilities; literacy of household head; sole-reliance on produce for food; being able to produce 75 percent of grain needs; and the number of months in a year food is scarce. Under these subcomponents (variables) of human capital, the study found that households with female headships were the most susceptible. This may be attributed to the fact that female-headed households in the study zone tend to have relatively limited access to education, training, and information required to improve their human capital base. Human capital has been found to be one of the key factors that create variance between female- and male-headed households in terms of vulnerability to climate change (Klasen et al. 2015; Tibesigwa et al. 2015; UNDP 2012). In line with this, the WHO, FAO and World Bank have at various instances acknowledged the health and food security implications of climate change for women and highlighted the need for climate responses to be sensitive to gender dimensions of health care and food security (WHO 2014; FAO 2012; IBRD &World Bank 2012).

Figure 7.6 also shows that households with female headship (0.40) were relatively more vulnerable under the major component, socio-demographic profile compared to the male-headed households (0.31). This is not surprising in the sense that the role of a female household head, predominantly, centres on care for household members and mobilising household necessities, which means fewer hours of work or even lower pay. Moreover, in this research households maintained by females, especially in rural areas tend to have a comparatively higher household dependency ratio, which tends to put pressure on farm-household. All these socio-demographic variables tend to play a role in making female-households disproportionately vulnerable to climate risks. This finding is consistent with results from a study by Rao et al. (2017) in semi-arid regions of Ghana, which found that socio-demographic profile is a critical explanatory factor for the variance in level of vulnerability among households.

Again, from Figure 7.6 it is obvious access to and ownership of physical assets was one of the major components under which female-run households were relatively more vulnerable, with an average vulnerability score of 0.45 compared to 0.41 for male-headed households. It was found that a limited number of female heads owned the houses in which they lived, and the majority lived in houses with poor conditions, one third of them farmed on extended family lands, and none of them had access to irrigation facilities. Intuitively, households with these characteristics are expected to be excessively affected by climate related events due to their limited adaptive capacity. Consistent with this finding are the works of Dumenu and Obeng (2016) and Dankelman et al. (2008). Both studies emphasised how limited access to, or availability of, physical assets present a barrier for women farmers in their effort to harness the opportunities from planned adaptation, rendering them relatively more vulnerable to climate related hazards. Similarly, the World Bank and UNDP assert that households headed by women in most African countries remain at a disadvantage in terms of access to physical assets (IBRD &World Bank 2012; UNDP 2012).

In this study, in contrast to the long-standing notion that women-run households are placed at a disadvantage in terms of access to economic and financial resources (e.g. Rao et al. 2017; Flatø et al. 2017; Antwi-Agyei et al 2013), male-headed households were relatively more financially vulnerable within the context of climate related events (Figure 7.6). Among the male-headed households, finance was the most important vulnerability factor, with a mean score of 0.51. For households with female headships, the finance component was the third most important vulnerability factor, with a mean index of 0.48. Financial assets do not only serve as cushion for farm-households during and after episodes of climate hazards, but also influence their medium to long-term adaptation financing (Musah-Surugu et al. 2017; Deressa et al. 2009). Consequently, any variance in access to financial resources along gender lines in the study Districts will invariably have implications for gendered-differentials in climate vulnerability.

A disaggregation of the finance component, made up of livestock ownership, access to credit/savings, and remittance from family and friends, revealed that female households were less vulnerable under access to credit/savings and remittance receipts. Their better access to credit/savings in this context, could be attributed to the fact that financial institutions (local banks, microfinance, 'Susu' groups), tend to be more inclined to do business with females due to their proven better savings attitude and 'loan pay back' rates. Moreover, existing studies have shown that over the years most credit- or finance-related interventions by governments and NGOs in the study zone, have focused on women, especially single mothers, widows and elderly women (Abdul-Razak & Kruse 2017; Antwi-Agyei et al. 2014). These institutions have a strong focus in Northern Ghana in terms of providing credit and financial assistance to those identified as vulnerable communities and households (particularly women in smallholder farming).

With regards to the remittance subcomponent of finance, female managed households were relatively less vulnerable, with an index score of 0.4 compared to that of the male-run household with 0.45. This a confirmation of the relatively high proportion of females who had received remittance (See Chapter 4 section 4.6 of this thesis). Appleton (1996: p1823) argues that high remittance receipts among women headed households play "…a key role in improving economic parity between women and men-headed households". If this holds, then it could be argued that the better remittance receipts among female-headed households has the potential of narrowing the climate vulnerability gap between the two types of farm-households.

Two explanations about high remittances among women is offered in several studies (Musah-Surugu et al. 2017; Rao et al. 2017; Appleton 1996; Stark & Lucas 1988). There is a claim that familial intertemporal contracts or bonds between migrants and remittance receivers tend to be relatively stronger among households with female headship (Musah-Surugu et al. 2017; Appleton 1996; Stark & Lucas 1988). Rao et al. (2017) offer an alternative explanation when they found that:

> "…women are fast reaching the limit to which they can stretch themselves, and are turning to family and friends, renegotiating them in the best way they can to ensure not just survival but a degree of stability in their lives" (Rao et al. 2017:p9).

In relation to the latter explanation, female respondents who received remittances said that during episodes of climate related crises they solicited support from family and friends, some of whom were resided in the same community, with the majority urban cities. In some cases, husbands tend to go away to urban centres to work leaving behind their wives and other family members. In this context, the husbands are able to remit the family they left behind during hazard episodes.

Male-headed households were also relatively more vulnerable under the natural assets component (land, water, and climate), with a mean score of 0.46, (Figure 7.6). This finding is contrary to prior expectations of this research. However, a plausible explanation could be that households headed by men in the study zone are inclined to take fewer precautionary measures in the context of climate risks. Within the natural asset component, perspectives were elicited on soil fertility of their farmlands, the state of their domestic water sources; rainfall and temperature changes in the last 10 years, and the frequency of extreme events like droughts, floods, unseasonal rain storms in the same period. It is important to mention that although in the aggregate, male-headed households were more susceptible under this component, female-headed ones were found to be relatively more vulnerable under the floods and droughts subcomponents (extreme events).

This thesis emphasises the significance of assets for climate vulnerability and its role in adaptation and resilience building, especially at the household and individual levels. How farm-households encounter impacts of climate hazards is shaped, to a large extent, by their ownership and use rights of sustainable livelihood assets. It will suffice, therefore, to argue that the relatively higher susceptibility among female-headed households in the Sudan Savana Zone is strongly linked to their limited control over livelihood assets.

7.4 Conclusion

The results presented in this chapter empirically demonstrate that using different vulnerability assessment methods does not only validate methods and findings, but also unravels the complexity of climate-related vulnerabilities at the local level. From a methodological point of view, another important finding is that it highlights the merits of comparing farm-household livelihood vulnerabilities (e.g. by district and gender), and the relevance of incorporating variables that have local significance (i.e. locally important climate perspectives and livelihood assets that have bearing on vulnerability). The Cluster analysis and farm-household livelihood vulnerability index (FLVI) allowed for comparison across district, across-gender and components. The results showed that three districts or 2 types of farm-household headships, had different combinations of components and subcomponents that defined their levels of vulnerability. The implication of this variance is that each combination of components (and by default, subcomponents) require a different mix of adaptation strategies.

The findings also revealed that vulnerability among farm-households in the Sudan Savannah Zone was generally high, with a little over two-thirds of them in the high vulnerability category. The vulnerability cluster variance was significantly associated with food sufficiency, access to credit, the household livelihood diversity index, sex of household head and the district in which they lived. The chapter identified farm-households in Garu-Tempane district as more likely to have higher vulnerability levels, relative to Bawku West and Bongo. The significant variance across study districts is indicative of the fact that vulnerability is contextual and heterogeneous in space, even at the subnational level.

In terms of gender, female-headed households were comparatively more likely to have higher susceptibility to climate risks. However, the results confirmed that merely identifying female-households as more vulnerable is necessary, but not sufficient, for a comprehensive understanding of the underlying factors of their vulnerabilities. Being able to identify the level of their predisposition must be complemented with a vivid understanding of the "how" and "why" they are vulnerable. Consequently, a further disaggregation of the FLVI revealed that the gendered asymmetry in farm-household vulnerability was largely rooted in the inequalities in livelihood diversification opportunities, household finance, household human capital base and the household natural asset base.

The analysis in this chapter, and the comparisons made in this chapter are essentially critical for two reasons: i) it provides a baseline benchmark that could inform macro level policy and decisions on resource allocation; and ii) it could facilitate micro level adaptation planning by aiding the prioritisation of vulnerable households, communities, and districts while targeting the underlying determinants of their vulnerabilities.

Chapter 8: Farm-household coping and adaptation to climate risks

8.1 Introduction

The focus of this chapter is to present the main farm-household coping and adaptation strategies in the Sudan Savannah Zone (SSZ) of Ghana that resulted from triangulated analysis of both quantitative and qualitative research data. The chapter unpacks the complex suite of actions taken by farm-households to respond to the exposure and vulnerability explored in the last three chapters. First, the chapter outlines respondents' climate-related coping and adaptation actions, and then evaluates the determinants of such choices. It concludes with a discussion of the barriers that farm-households encounter when undertaking coping and adaptation actions (See Box 8.1 for major conclusions). Theoretically, the basis for this chapter is located in two assumptions: firstly, that smallholders' reliance on past experiences to predict and adjust their livelihoods in the context of current and future climate change is becoming increasingly unreliable; and secondly, that vulnerable communities in developing countries continue to find themselves in a vortex of persistent "adaptation deficit" due to underdevelopment which constrains adaptive capacity.

Box 8. 1 Highlight of key findings on farm-households' adaptation to climate risks

- Farm-households adopted a mix of nine different types of coping strategies, with the majority adopting between 2 to 4 measures. Most popular measures included: food compromising strategies; selling household livestock; offering casual labour; and relying on family and friends.
- Although livelihood diversification was found to be generally low, some respondents engaged in the following diversification strategies: petty trading; temporary migration; sale of harvested firewood and charcoal; and becoming (?) food vendors.
- Farmers were found to engage in on-farm adaptation. The majority of respondents, however, were found to engage in mainly crop management strategies like mixed farming, mixed cropping, and varying planting times.
- There is a statistically significant relationship between the type of vulnerability cluster a household belonged to and the mix of adaptation strategies they adopted.
- The underlying determinants of the choice of adaptation strategy included: sex of household head; age; education; farming experience; access to credit; livelihood diversification; and land tenure.
- Knowledge of farmers' choice of strategy and what informs such choices is important to any initiative that seeks to reduce adaptation deficit among smallholders.
- Barriers to climate adaptation in the study area were mainly related to the issues of farm-household finance, cost of farm inputs, socio-cultural structure (which define relationships in these communities), and the issue of availability of and accessibility to infrastructure.

Source: Climate variability and vulnerability survey, 2017

8.2 Coping and adaptation strategies among farm-households in Sudan Savannah Zone

This section outlines the coping and adaptation activities undertaken by farm-households to reduce the adverse impacts of changes in climate variability and extreme events. As discussed in preceding chapters, results indicated that farm-households in the Sudan Savanah Zone (SSZ) of Ghana, generally, had high probability of being exposed and vulnerable to changes in climate variability and extremes. Taking into consideration climate change projections for the country, the implication is that, with limited livelihood alternatives and the lack of adaptive capacity, farm-households within the zone could find themselves in a maelstrom of recurrent food insecurity and loss of livelihoods. This study found that over the years, farm-households autonomously made some adjustments to their livelihood activities, or benefited from planned interventions, before, during, or after climate hazards. The section is divided into three sub-sections: (i) short-term coping measures, (ii) livelihood diversification options relevant to coping and adaptation, and (iii) on-farm adaptation strategies.

It is important to state upfront that unlike previous chapters where results were presented according to gender of the household head and the district they belonged, results in this section and subsequent sections in this present chapter give a general picture of climate coping and adaptation dynamics in the entire Sudan Savannah Zone (SSZ). This was merited because there was no significant difference ($p > 0.05$) among districts and also between the two types of household headship with regards to the type of methods they used, and the level of coping and adaptation measures they employed. A probable explanation could be the fact that the nature of agriculture (e.g. agriculture holding characteristics, farmland tenure, farm practices, crop and livestock types, soil characteristics, etc.) is comparable in the whole of northern savannah.

Table 8.1 indicates that the majority of respondents across the study districts adopted a mix of off-farm and on-farm strategies when faced with climate related impacts. The table also reveals a relationship between the vulnerability cluster a household belongs to and the mix of strategies they adopted. For instance, in relation to the on-farm section of the table, it can be observed that relative to the low vulnerability group of households (mainly male-headed households in Bongo), those in the high vulnerability class (who largely female-headed households in Garu) did not have access to irrigation facilities, they planted only indigenous crop varieties, and did not adopt soil and water conservation (SWC) methods or use fertilizers. Again, in contrast to low vulnerability households, those within the high cluster relied on the reduction in food quantity and quality and temporary rural-urban migration. Those within the moderate vulnerability cluster (largely male-headed households Bongo and Bawku) also did not engage in irrigation as an on-farm strategy.

With regards to the off-farm adaptation section, again there is a different suit of measures for the various vulnerability clusters. The table e shows that farm-households in the moderate to high vulnerability groups (generally in Bawku and Garu, with the majority of household headed by females) use more off-farm measures than those in the low vulnerability cluster. It should also be noted that off-farm measures such as consumption reduction, changing diet and gathering wild foods are mainly undertaken by those in the moderate and high vulnerability groups who are mainly in Bawku and Garu. The implication is that these vulnerability groups are more likely to engage in short-term coping strategies than in medium- to long-term on-farm measures. This may because most the off-farm short-term coping methods are less cost intensive, considering that these household lack the resources to adopt most of the on-farm methods that require relatively huge investments.

Table 8.1 Coping and adaptation methods by categories and vulnerability grouping

	Household vulnerability groups		
Strategy category	**Low vulnerability households**	**Moderate vulnerability households**	**High vulnerability households**
Off-farm	Rely on salaried job	Change diet	Reducing consumption
	Casual labour	Casual labour	Change diet
	Relying on family and friends (social network)	Rely on salaried job	Wild fruit gathering and hunting
	Selling physical assets	Selling livestock	Casual labour
	Livestock trade	Selling physical assets	Temporary migration
	Government and NGO assistance	Relying on family and friends	Selling livestock
	Livelihood diversification	Government and NGO assistance	Livelihood diversification
		Livelihood diversification	Government and NGO assistance
		Temporary migration	
On-farm	Varying planting time	Varying planting time	Varying planting time
	Mixed cropping	Mixed cropping	Mixed cropping
	Enhanced crop varieties	Enhanced crop varieties	Mixed farming
	Adopt SWC methods	Adopt SWC methods	Compost manure
	Mixed farming	Mixed farming	
	Irrigation	Fertilizer/compost manure	
	Fertilizer		

Source: Climate variability and vulnerability survey, 2017

Another point worth noting about the characteristics of respondents' climate coping and adaptation, is the fact that these measures were not implemented in same period of the year, although it is possible that implementation may overlap as shown in Table 8.2. Across all districts, all on-farm strategies were implemented within the farming season (with the exception of irrigation, where few farmers did off-season vegetable farming). However, some of the off-farm strategies were implemented either before or after the farming season. For example, reducing food consumption among households headed by women and temporary migration (among most male-headed households) were undertaken during the farming season or just after the household had experienced weather/climate-related bad farming season. The table also shows that any attempt at diversifying their livelihood, was mainly after the farming season, an indication that most households are only prompted to diversify their livelihoods when a climate disaster hits (a reactionary approach to livelihood diversification).

Interestingly, the research found that the few farm-households who had access to irrigation engaged in farming all year round. These households, primarily, engaged in crop farming during the farming season and then small-scale vegetable farming in the off-season. Most of these respondents were largely within the low vulnerability bracket and had access to public irrigation schemes, most of whom were found in the Bongo district.

Table 8.2 Period of the year coping and adaptation strategies are implemented

Periods coping and adaptation measures were undertaken		
Before farming season	**During farming season**	**After farming season**
Relying on family and friends	Wild fruit gathering and hunting	Temporary migration
Selling livestock	Varying planting time	Livelihood diversification
Government and NGO assistance	Mixed cropping	Reducing consumption or change diet
Reducing consumption or change diet	Enhanced crop varieties	Wild fruit gathering and hunting
Wild fruit gathering and hunting	Adopt SWC methods	Relying on family and friends
Irrigation	Mixed farming	Selling livestock
Government and NGO assistance	Irrigation	Government and NGO assistance
	Fertilizer/compost manure	Irrigation
	Government and NGO assistance	
	Temporary migration	

Source: Climate variability and vulnerability survey, 2017

Further, some of these adjustments, especially the livelihood diversification component were not undertaken entirely because of climate impacts but could have also been a reaction to other livelihood disturbances (Mertz et al. 2010; O'Keefe et al. 2008). Some of these strategies could be in response to stressors like poverty, tribal conflicts, and environmental degradation, which are highly prevalent in the study area (see Chapter 4). However, as this study conceptualises adaptation as a continuum (which includes general private and public development interventions), this implies that the responses to non-climatic perturbation will have implications for coping and adaptation to impacts from climatic stressors (O'Keefe et al. 2008; Huq & Ayers 2008a). Statements from focus group discussants in Garu-Tempane lend credence to the fact that farm-households usually adjust their livelihood activities in response to multiple climate and non-climate stressors (See Box 8.2):

Box 8.2 Focus group discussion on main development challenges in Garu-Tempane

What are the major development challenges in your community?

- **Response from some female discussants:**

"Over the years our inability to access credit facilities for small-scale trading, lack of irrigation dam, and the limited access to clean drinking water has led to severe poverty and hunger in this community. We women suffer most, especially during the dry season when we have no jobs to do"

"Our children suffer a lot because we don't have a clinic and school in the community. They have to walk very long (about 2km to 5km) to school every day and when they (children) are sick, we the mothers have to take them to Garu (that is if there is money to take them)"

- **Response from some male discussants**

"We the men in this community believe that farming is increasingly becoming difficult due to erratic rainfall patterns and droughts leading to the loss of our livelihoods; there is also severe poverty which has led to our inability to get money to buy farm inputs such as fertilizers, cattle for ploughing; and also to acquire seedlings and improved crop varieties"

"The unavailability of irrigation facilities (dam) and the low soil fertility also causes low crop output which contributes to the high poverty levels of households and the community at large"

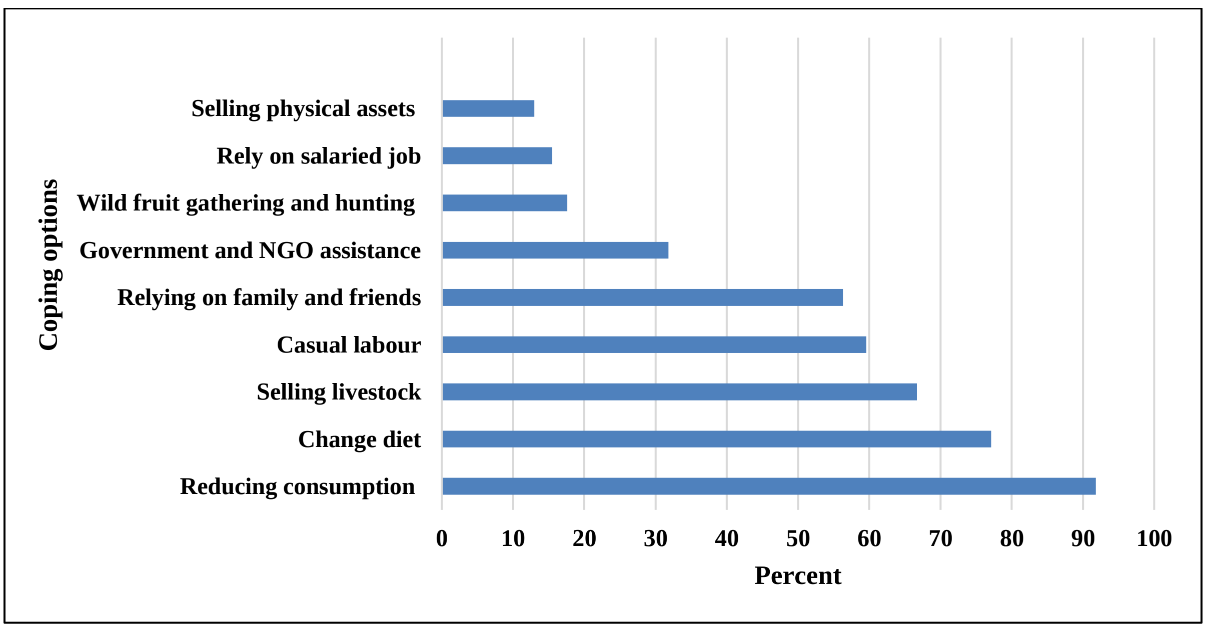
Source: Climate variability and vulnerability survey, 2017

8.2.1 Coping strategies among farm-households

Participants from focus group discussions (FGDs) indicated that food stress periods usually started from December (3 to 4 months after harvesting) and peaked in April (just before the rains start). This reflects an instance when the harvest is good. In the context of bad seasons, the food stress period was much longer. During this period of food insecurity and other climate related stress, most of the study households adopted multiple non-farm coping activities.

The survey found that among the 230 farm-households studied, 8 coping strategies were highlighted, with each household adopting between 1 to 3 measures. Figure 8.1 shows that the most popular coping strategies among farm-households in SSZ were the reduction in consumption including food (91.8 percent), change in diet (77.1 percent), selling livestock (66.7 percent), casual labour (59.6 percent), and relying on family and friends (56.3 percent). It is important to emphasise that although wild fruit gathering and hunting (17.6 percent) and selling of disposable household physical assets (13 percent) were not popular among respondents, they were deemed extremely important for coping among those who adopted them (largely among female maintain households), since they had limited alternatives.

Figure 8. 1 Coping options among respondents



Source: Climate variability and vulnerability survey, 2017

The survey found that most of the farm-households were significantly inclined to adopt food compromising coping options and the sale of livestock during or after episodes of climate shocks (Figure 8.1). A review of adaptation literature on Ghana and elsewhere in Sub-Sahara Africa, found that this coping strategy is also widely adopted by smallholder households (e.g. Antwi-Agyei et al. 2018; FAO 2016; Zewdie 2014; Regassa 2011). For instance, Antwi-Agyei et al. (2018) found that in the Central Gonja district (Northern Ghana), the most popular coping mechanisms among households was to reduce consumption (including food intake) and by changing their diet (i.e. purchasing less preferred foods). Elsewhere in Ethiopia, Regassa (2011) found that 54 percent of households experienced food insecurity and minimised the number of meals per day and the amount of food they consumed as coping strategies. In this regard, climate related risks become "food preference shifters", reflecting the argument that people, especially in marginalised communities, tend to adapt to climate change by suppressing their wants and needs. Changes in food quantity (and sometimes quality) means farm-household members may have to have less meals per day or endure some form of hunger, which has dire consequences for health, especially when children and the aged are involved (Antwi-Agyei et al. 2018; FAO 2016).

According to study respondents, livestock was the third most important livelihood asset as it served as an insurance mechanism during and after climate related shocks (Figure 8.1). The sale of livestock meant increased pecuniary stability for farm-households, meaning they could now buy food and other household needs, and also even purchase farm inputs needed for on-farm adaptation. A different perspective is offered by Haggblade et al. (2010), who in a different study found that the selling of livestock depletes farm-households' stock of livestock, further perpetuating poverty. However, in this thesis, beyond selling livestock to augment household income, the rearing of livestock was considered a critical coping strategy from the perspective that it served important household nutritional needs during bad farming seasons. A household head's query of a moderator in one of the FGD sessions sums up the importance of livestock sale to farmers during climate-related bad seasons:

> *"My younger brother, let me tell you something, the selling of our animals is now our only insurance in bad periods. When rains don't come at the right time and our crop yields reduce what else can we rely on apart from our animals? Right now, am thinking of starting a guinea fowl rearing business to supplement my maize and millet farming. That way my household can feed when droughts come." (Male FGD participant, Garu-Tempane, 2nd April, 2017)*

The sale of labour and a reliance on family and friends were also popular as climate coping mechanisms among farm-households in the study regions (Figure 8.1). During drought or flood periods, for example, some of the farmers who were affected were inclined to offer their services on other people's farms and in some other non-farm activities (e.g. local construction work). Although, there are usually fewer labouring opportunities at the community level, the selling of labour helps to augment farm-household income, food stock, and other needs, which is contrary to Antwi-Agyei et al. (2018), who argues that the selling of labour may reduce the workforce of the affected farm-household (in the sense that they would have limited time to work on their own farmlands which has implications for crop yield).

In this case, to the reliance on family and friends, was asserted by a significant proportion of respondents to be significant, and they claimed to have received various kinds of support from neighbours and friends (bridging network benefits), and relatives (bonding network benefits), during and after droughts and floods in the last 10 years. These bridging and bonding network benefits included, but were not limited to: food, clothing, help to repair shelter, temporal accommodation (if house was destroyed), remittances, assistance to get a loan, information on where to access planned interventions and information on opportunities for temporary migration. This delegation of benefits and support is essential for the less privileged farm-households who were not able to compete for the already limited external relief provisions. It is important, however, to also point out that the level of support from these social networks, be it bonding or bridging, is contingent on the level of trust and existing norms of reciprocity, and whether or not the community is homogenous (tight-knit) or heterogeneous, a point made in many other studies (Masud-All-Kamal & Hassan 2018). The analysis for this study suggests that any in-depth assessment of the role of social networks in climate risk reduction/coping in the SSZ must endeavour to probe the underlying determinants of the strength of such networks.

A substantial proportion of farm-households (31.5 percent) also claimed to have received some external support from Government and NGO institutions before, during and after climate hazard episodes (Figure 8.1). At the subnational level, relevant government institutions include the district assemblies, agents of relevant ministries, and national disaster mobilization organisations (NADMOs). Within the study zone institutions such as district assemblies, extension services department of the Ministry of Food and Agriculture (MoFA), NADMO, NGOs, Micro-finance institutions, community health posts of the Ministry of Health (MoH), and religious organisations are important enabling institutions within the context of climate adaptation and other development issues. Assistance from these institutions ranged from provision of social services, economic empowerment (especially among female-headed households), provision of infrastructure, skills and knowledge development and technology transfer.

According to those respondents who had contact with the personnel from the extension services department of MoFA, they had benefited from the provision of fertilizer (for the declining soil fertility), the introduction to high yielding crop varieties, training on farm management, and provision of information on climate change. In addition to the adaptation support offered by MoFA, NADMO in collaboration with the various district assemblies provided short-term interventions, and relief services to climate disaster-affected communities. These interventions ameliorated short-term shocks and facilitated farm recovery or medium to long term adjustment. Respondents in Bongo, for instances, readily cited the 2007 floods when thousands of hectares of crops were destroyed and the intervention they received, to highlight the key role NADMO, World Food Programme (WFP), CARE-Ghana and the district assembly played in terms of short-term farm-household coping. A male farm-household head in Bongo who lost his 2-hectare maize farm to the 2007 floods had this to say:

> "*That flood left me with nothing left. That year too, the millet yield which my family could have relied on did not also yield well because of the June/July draughts. During this difficult period the government and some NGOs came to our aid with food and blankets, which really helped us. But after a month the support stopped coming, we were back to our old situation, since we did not have anything left to depend on. In fact, that year I felt my family and I were finished*" (*Male FGD participant, Bongo, 12th March, 2017)*

Disaster episodes are critical periods in the lives of people in marginalised areas because the savings which they could have relied on as their insurance is invested in farm-household assets, which are most vulnerable to climate extremes (Yaro et al. 2015). Consequently, these are periods that farm-households are in more need of external responses/interventions from government and non-governmental institutions. A notable response from the survey (83% of respondents) was the general agreement that medium- to long-term external responses to slow-setting hazards (e.g. drought), were less visible than short-term external responses for climate hazards given that the onslaught only took moments (e.g. floods, storms, etc.), and were accompanied with immediate visible losses and damages.

This trend also appears in work that assessed the role of local institutions in building adaptive capacity in Northern Ghana (Yaro et al. 2015). They found that government institutions like NADMO were only "…useful in helping in the short-term coping of victims of climate disasters, but unfortunately have not been prominent in rebuilding medium- to long-term adaptive capacities" (Yaro et al. 2015: p 239). It is important for state institutions to recognise that helping climate disaster victims to cope during episodes is as important as aiding their medium- to long-term adjustment. Thus, putting in place enabling conditions should be an avowed aim of government institutions.

Northern Ghana has been more or less an incubator for most of national and international NGOs, and most of the communities in SSZ have had their fair share of NGO presence. These NGOs vary in both their role and capacity to effect change in society. However, respondents in the study areas generally claimed NGOs were passively engaged in climate-related awareness creation, technical, and financial capacity building. Passive in the sense that climate change was not necessarily the focal point of their operations, but rather it was to aid them build capacity within the context of general livelihood challenges. However, through these activities NGOs nonetheless promote both direct and indirect enabling conditions for climate adaptive actions and capacity building. For instance, NGO engagement in climate awareness creation is critical because it has the potential to trigger autonomous climate responses among farm-households in the study area.

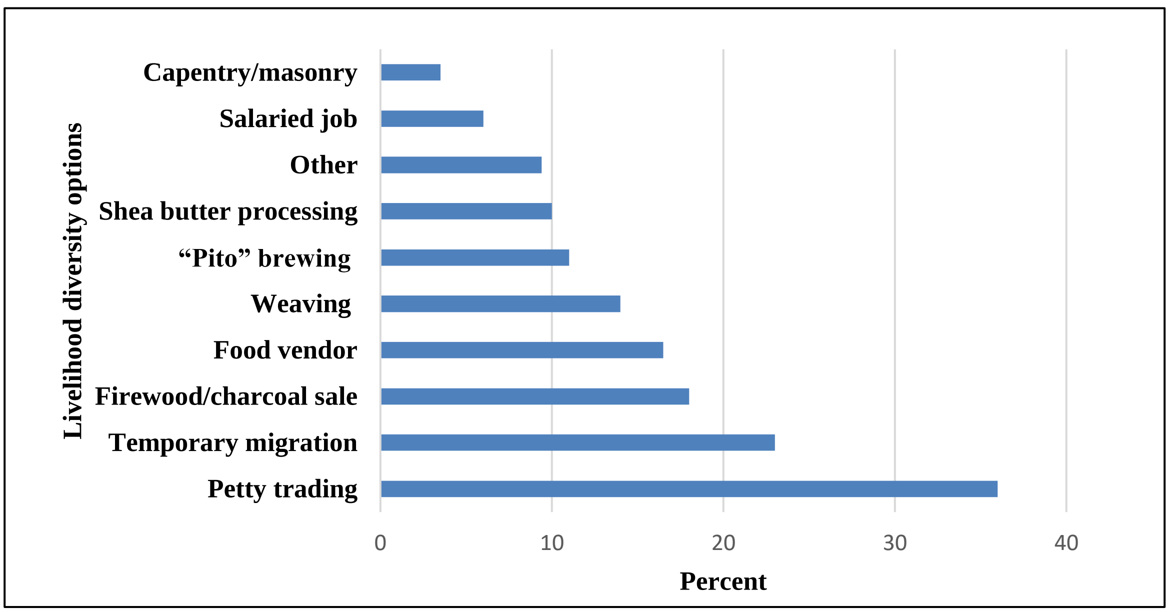
In fact, this study found a significant association between access to climate information and respondents' climate awareness and perception ($p < 0.05$). The survey further found a significant relationship between the adoption of on-farm adaptation measures and respondents' awareness and perceptions ($p < 0.05$). The more respondents were aware and perceptive of climate threats, the more likely the will be willing uptake coping and adaptation strategies. One of the issues as highlighted during an informal conversation with an Assemblyman in one of the study districts is that NGOs operated according to their project timelines and available resources, and thus usually did not function in medium to long term in a particular community. In this instance, there is the tendency for some beneficiary households to lose some of the gains from their engagement with these NGOs. Nonetheless, NGO efforts towards improving skills and knowledge and financial capacities could enable farm-households to build their livelihood assets base to respond adequately to climate-related stressors.

8.2.2 Livelihood diversification strategies relevant to climate coping and adaptation

Before proceeding it is important to reiterate that the survey showed that most of the off-farm coping and adaptation strategies were generally related to farm-household livelihood diversification activities (risk spreading). Figure 8.2 shows that respondents who diversified their livelihoods indicated they engaged in petty trading, temporary migration, sale of harvested firewood and charcoal, food vendor, *pito* brewing (local alcohol brewing), weaving, shea butter processing, salaried employment, carpentry/masonry and other activities like casual jobs, livestock trading, and sand mining (these are ranked in order of importance). Despite the importance of livelihood diversification as an adaptation option, the impression from the survey results is that livelihood diversification is generally low in the district regions of the Sudan Savannah Zone (SSZ). Regardless of the livelihood diversification options, the proportion of the 230 farm-households surveyed who diversified their livelihoods was less than 40 percent. Relative to the adoption of short-term emergency coping options, farm-households were less inclined towards adopting medium- to long-term livelihood diversification options. This is a concern given the importance of livelihood diversification as a coping strategy, as Asfaw et al. (2017) found in a study exploring diversification of livelihoods as a survival strategy option in agrarian environments subject to climate impact.

The most popular livelihood strategies among respondents were petty trading and temporary migration (Figure 8.2). Petty trading, a female-dominated livelihood activity, was the most popular off-farm activity in the study zone. Petty trading in the context of this work refers to non/off-farm economic activities involving buying and selling of goods in small scale, ranging from local farm produce, imported consumables, to other consumer goods (Bulty & Tulu 2016). Analysis in this context found that petty trading was largely done for sustenance and not for assets building. In the study area, petty traders fall under two categories: those who buy from community members and sell within or outside the community; and those who import essential consumer goods from other places (mostly urban centres) and sell in their own communities. Those who engaged in petty trading sold, among other items, farm produce, imported food items, medicine, baskets, smocks, second hand clothing, pottery, simple farm inputs (e.g. hoe, cutlass, etc.), and general wares. Their activities were mainly funded with socially forced savings (locally called "Susu"/rotating savings), small loans from local microfinance institutions, or start-ups from governmental and non-governmental institutions. This activity was most predominant among households in the low vulnerability class. During episodes of climate extremes (e.g. floods or droughts), apart from the benefits their households enjoyed from diversifying their farming activities (e.g. household flood risk spreading), they also served a multitude of community members through their role in the distribution (sale) of essential goods (e.g. food items, second hand clothing, sachet water, medicine, etc.). On this basis, it could be argued that any sustainable development-related or climate-related intervention that targets the relatively more vulnerable people, will not only be increasing household welfare, but that of the entire community.

Figure 8.2 Coping- and adaptation-relevant livelihood diversification among smallholders



Source: Climate variability and vulnerability survey, 2017

On the issue of temporary migration, although sometimes undertaken to escape social crises and endemic poverty, the survey results found that, respectively, about 30 percent and a further 21 percent of those under high and moderate vulnerability clusters had at least one household member migrating to urban centres or farming communities in southern Ghana in the last 10 years as a strategy to cope with drought or floods (Table 8.3). Results from the FGDs also showed that respondents or other household members temporarily moved out of community in search of "greener pastures" not only to improve their livelihood, but also the wellbeing of immediate family, relatives, and sometimes friends they have left behind. A male FGD participant in Bongo emphasised the extent to which migration is important to his household during dry seasons, especially immediately after climate-related bad farming seasons:

> *"After the farming season, particularly when due to rains our crops don't yield much, my eldest son goes to my friend who is now settled in a cocoa growing community in Ashanti region of Ghana. When the farming season is bad here, I quickly advise him to go. There he is able to work throughout the year as an on-farm labourer to earn some money for himself and the household, especially his younger brother and sister who are still in school. Even with my son's support, in those periods we sometimes eat once or twice a day, so imagine if he didn't migrate." (Male FGD participant, Bongo, 12th March, 2017)*

In all the FGDs, the majority of participants confirmed that during dry seasons when their household food and income is depleted, many of the household heads (especially the younger males), or other members of the household migrate to southern Ghana to find jobs in order to replenish household stocks through remittances. The majority of these farmer migrants move to communities in the Ashanti region, Brong Ahafo region, Greater Accra region, or Western region, where they experience two rainy seasons, presenting a conducive farming environment to these migrants. Other informal low income jobs these migrants engaged in include, but are not limited to: *kayayei* (a local term for "head porters), hawking (i.e. the sale of like dog chains, soft drinks, fruits, padlocks, etc. on the on the streets of urban cities like Kumasi, Accra, Techiman, etc.), and informal security services (popularly known as "watchman" in local lexicon). Respondents' who engaged in temporary migration said it reduces stress on farm-household food reserves and other assets and helps the diversification of incomes, improving the ability to adjust to climate and other environmental changes, while improving household livelihood. There are, however, counter arguments (e.g. Ionesco & Chazalnoel 2015) seeking to suggest that migrating temporarily can deplete farm labour at origin and could reduce farmers ability to plan household farm operations, which might then lead to missing out on critical farming periods.

Table 8.3 Livelihood diversification by vulnerability and by male and female respondents

Livelihood strategy	Household vulnerability groups			
	Low vulnerability households (n = 55)	Moderate vulnerability households (n = 92)	High vulnerability households (n = 83)	Total (n =230)
	Percent of cluster total			
Temporary migration	18.2	20.7	28.9	23.0
Pito brewing [F]	23.6	4.3	9.6	10.9
Weaving	16.4	12.0	14.5	13.9
Food vendor [F]	34.5	63.2	8.4	16.5
Petty trading [F]	69.1	31.5	20.5	36.1
Firewood /charcoal sale [F]	9.1	19.6	21.7	17.8
Carpentry/Masonry [M]	14.5	0.0	0.0	3.5
Shea nut picking & processing [F]	7.3	7	13.3	10.2
Salaried job [M]	20	5.5	0.0	6.1
Others (livestock trade, sand mining, casual jobs know us "by-day") [M]	10.9	12.7	10.8	9.6

Note: Descriptive statistics on proportion of female- and male-headed households who indicated adopting particular livelihood diversification strategy was used to derive the gender dominance in each measure. [F] superscript denotes female-dominated while [M] denote male dominance. Activities without superscripts mean those were gender neutral.

Source: Climate variability and vulnerability survey, 2017

The relevance of temporary migration as an adaptation strategy in this study resonates with several studies on climate change and migration conducted in Ghana's savannahs, and other similar environments in Sub-Sahara Africa (Antwi-Agyei et al. 2014; Kelpsaite & Mach 2015; Gemenne 2011; McLeman & Hunter 2010). It has been a major coping and adaptation strategy for severe seasonal climate/weather variability and during extreme events (Ahmed et al. 2016; Antwi-Agyei et al. 2014; Laube et al 2012). Indeed, Ahmed et al. (2016: p53) found in Ghana's northern Savanah that "…seasonal climate variability had motivated recent patterns of migration". Similarly, Antwi-Agyei et al. (2014) argue that despite the historical significance of emigration among households in Northern Ghana, droughts in the last 40 years have expanded the dimension of the importance of temporary out-migration as a climate adaptation strategy.

Another notable livelihood diversification option among respondents in the study districts was the engagement in cottage industry-related activities involving weaving of smocks, hats, and baskets, and the processing of shea nut (*Vitellaria paradoxa)* for butter (either for sale and/or cooking purposes). Weaving of smocks was generally done by males, while the females engaged in hats and basket weaving. Shea butter processing was mainly female business. About 90 percent of those who engage in weaving said they did much of this activity in the off-season to get money, which helped to replenish their food supplies and other household needs. This is particularly crucial when farm-households experienced a bad harvest due to late rains, floods, or droughts.

In highlighting the importance of weaving, it is relevant to also note that in the study zone not many farm-households engaged in this activity. This could be attributed partly to the high investment involved (especial the initial start-up cost) and partly because weaving in the study area represents a certain socio-cultural identity and was handed down from one relative to another. For instance, in Bongo there are particular clans or 'houses' who are noted for weaving brands of smocks. As a result, when you see someone wearing that type of smock, you can tell the clan or 'house' that produced it. Members of such 'houses' or clans are relatively more likely to engage in smock weaving. A farm-household head whose father or mother engaged in weaving is more likely to also engage in such an activity than a head who had no relatives engaged in weaving. The disincentive for the latter is that she or he will have to pay to learn weaving, whereas the former would have learnt the skill for free from relatives.

The results show that as part of the cottage industry, respondents also engaged in Shea butter production (Figure 8.2). From the FGDs, those who engaged in this activity primary did so for the purposes of eating, selling (and use some of the proceeds to purchase other food items), and to use as body lotion, especially during the hamattan (dusty dry season). The survey analysis found that this livelihood diversification strategy was dominated by females, and most popular among high vulnerability households (Table 8.3). During the female-only FGDs, it was explained that women within study communities usually put themselves into associations in order to carry out this activity. They also emphasised that for some, the shea butter production becomes their main source of livelihood during bad farming seasons and in off-farming periods. A female-household head highlighted the importance of being part of a women shea butter processing association:

"In 2015 I cultivated half an acre of millet, beans, and vegetables when the rains came in early May. However, I had poor harvest because the crops were badly affected by the drought that year. I could not even harvest one 50 kilo bag of any of the crops I sowed. Since then I decided to join the Asongtaaba (literally means helping each other in local dialect) women association so that I could take part in the shea butter production to earn money. I still work on my farm every season though, but being a part of this association and earning some money for the household is an insurance during drought periods." (Female participant in Garu Tempane, FGD, 2nd April, 2017).

Cottage industry is a very important livelihood alternative in rural savannah areas and most NGOs, through this industry, have empowered rural folks, especially women. According to respondents', shea butter production, for instance, enabled them to maintain a stable household income and improved food security. The end product, shea butter, is either sold locally or merchants go around rural areas to purchase it for international exports. Despite the benefits from this livelihood alternative, analysis shows that there was limited involvement of study farm-households in the industry. This could be attributed to the laborious nature of the activity and the very low initial net returns to investment (money and time), especially when using the indigenous method of production. It is, however, refreshing to notice that in the last 4 years shea nut processing is increasingly becoming a lucrative livelihood activity among rural communities in northern savannah zones, especially with the recent involvement of government and NGOs. Government in its bid to build adaptive capacity in the study zone, have supported cottage industry related associates/groups with credit and training.

Firewood harvesting and charcoal production are interrelated activities that farm-households also engage in as a way of diversifying their livelihoods. They are interrelated because those who harvest firewood either burnt them as charcoal or sold to those who burn charcoal or use it themselves as household energy. The respondents who engaged in these activities were largely females under moderate to high vulnerability clusters. In the study zone, firewood and/or charcoal are the major sources of household energy, especially for domestic purposes. Considering the low living standards of the rural poor, the use of gas and electricity for cooking and other domestic energy related activities is very rare. Consequently, firewood and charcoal sale is to some extent lucrative within the rural context, regardless of the environmental implications of harvesting and burning wood.

Realising the environmental degradation/desertification associated with these activities, the government embarked on the rural electrification project, and the supply of gas cookers and cylinders to rural communities within the study zone and other rural areas in the country. However, this project has done little to reduce firewood harvesting and charcoal production. Rural farm-households who had access to electricity and gas-fired cooking stoves, explained they were not using them because of the high cost associated with their utility. Some also mentioned they only used them when they had external visitors and need to quickly fix a meal for them. For instance, some focus group discussants explained:

> *"In my house we put of the electricity metre in the morning and only put it on in the evening for 3 to 5 hours for the school children to read and do their assignments. We have to do that to avoid paying high light bills". (Male FGD participant, Bongo, 12th March, 2017).*

> *"I had gas cylinder and a stove from the District Assembly so my wife stopped using charcoal and firewood. However, in recent times I asked my wife to use more of firewood for cooking and boiling water. The gas is now very expensive but with the firewood I bring some home anytime I go to the bush" (Male FGD participant, Bawku West, 26th March, 2017)*

Associated with firewood harvesting and charcoal production are the local beer brewing (*pito*) and food vending activities. Charcoal and firewood are the only sources of energy for those who engaged in these livelihood activities. For those who were into food vending (sale of prepared meals), this activity emerged as critical for their survival during bad episodes because it did not only provide household members with food (especially breakfast), but also provided money for other household needs like medicine, school fees, clothing, replacement of simple farm tools during farming seasons, etc. This activity is done frequently throughout the year but most profitable during the lean season when food stocks of community members had runout. During climate disasters, households who are affected and are not in the position to prepare meals at home, tend to rely on these vendors for household food.

Pito on the other hand is a popular local alcoholic drink made from sorghum, millet or maize, and it is brewed year-round. The fact that its production is year-round means farm-households who engage in this activity have alternative source on income in the event of a bad farming season. Just like firewood and charcoal production, the brewing of this drink is completely a female activity and was found to be most predominant among households with a low probability of being climate vulnerable (Table 8.3). Apart from the high patronage for this locally brewed beverage (which brings in substantial income), culturally, it is used in every festival and funeral in the study zone. Comparatively, this drink is far cheaper than exported alcoholic beverages and is touted as having nutritional and medicinal value. As it is having high patronage and is produced every three days for most of the year, farm-households who engage in this activity tend to have a relatively better insurance during and after climate-related bad farming season. Analysis revealed that the livelihood portfolio of those engaged in pito brewing also included petty trading and food vending, an indication that farming in essence may no longer be the main source of livelihood for these households. A 51year old female FGD discussant who engaged in *pito* brewing for example had this to say:

> *"About 12 years ago I used to farm on two pieces of land, one for groundnuts and beans and the other for millet and sorghum. Today as I am talking to you I farm on half of one of the plots, sowing millet and sorghum, which I need for my brewing business. I invested a lot in my farming in 2008 and the rains failed me, so I lost everything. My brother who was then abroad gave me money and advised me to use it and focus on my pito business. Since it is this bar that is sustaining me and my household, so every farming season we work on the half plot and brew pito. That way if the season goes bad, I don't lose much." (Female FGD participant, Bawku West, 2nd April, 2017)*

Overall, FGD participants agreed that most of the complementary activities they undertook, as described above, were generally to diversify farm-household livelihood security, and not necessarily for climate coping or adaptation. However, respondents also acknowledged that during bad seasons or climate extreme events, these augmenters served as a cushioning mechanism, or provided them with the capacity to take short- to medium-term adaptive actions. This is in tangent with Huq and Ayers conclusion that "good (or sustainable) development can (and often does) lead to building adaptive capacity" and that "doing adaptation to climate change often also means doing good (or sustainable) development" (Huq & Ayers 2008: p 52).

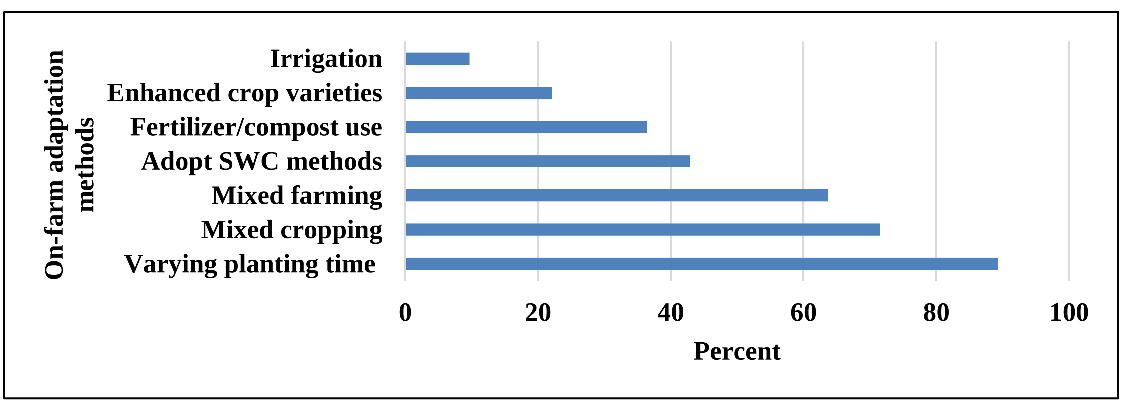
8.2.3 On-farm adaptation strategies among respondents

The survey found that apart from non- or off-farm strategies, farm-households also adopted various on-farm measures to lessen the burden from not only the impacts of climate variability and extremes on crop yield but also other environmental problems like erosion and low soil fertility. It was further established that while most adopted just one strategy category (either on-farm or off-farm), most farm-households used both complementarily. The implication is that the preference for a suite of strategies is contingent on individual farm-household circumstances.

Globally, crop management as a climate adaptive action has been found to have the potential to increase yields by 7 to 15 percent on average, although this may vary according to region and by type of crop (Elliott & Muller 2015). In this study, the primary crop management techniques used by farmers were; the timing of farm operations (or varying planting time), mixed cropping, and mixed farming. These were the three most popular on-farm strategies among respondents in the three study areas. Figure 8.3 shows that 89 percent of farm-households engaged in the practice of varying timing of farm operations. Instead of restricting themselves to the regular seasonal timetable (beginning in April/May), respondents said they varied their operations/activities according to the number of continuous rainy days at the beginning of the season (usually 3 to 5 continuous rainy days). Consequently, in some seasons they engage in early-planting and in others, late sowing.

The timing of farming operations has been a long-standing indigenous practice among smallholders in arid and semi-arid regions. Based on indigenous knowledge and experiences, farmers understood the risks and uncertainties of seasonal climatic/weather conditions and adjusted their farming operations accordingly. However, in recent times due to severe variability in climate and weather events, coupled with the spread of farming into peripheral environments, the practice has been found to be unreliable within the context of climate change adaptation (IFAD 2012).

Figure 8. 3 On-farm adaptation measures adopted by respondents



Source: Climate Variability and Vulnerability survey, 2017

Figure 8.3 also shows that respondents also engaged in mixed cropping to increase productivity or reduce yield losses during bad seasons (72 percent). This type of farming involves the simultaneous sowing of two or more crops on the same farmland, interspersed in space and time. Respondents in this study claimed they interlaced the main crops (maize, millet, sorghum, etc.) with leguminous plants (such as beans, peanuts, bambara beans, soybeans, etc.). In semi-arid communities, like the three study areas, where farming is mainly rainfed, these grain legumes not only serve as important sources of household protein, carbohydrates, dietary fibre and minerals, but also critical sources of soil-enhancing green manure (with soil nitrogen-fixing potential) and livestock forage. Theoretically, it could be argued that relative to those who engaged in monoculture, mixed cropping farm-households have a better chance of enjoying benefits such as enhanced balance of inputs, controlled soil erosion, controlled weeds and insects, offer resistance to climate extremes like droughts, judicious use of scarce resources (e.g. land), and the overall increase in farm productivity and household food security.

The survey found that almost 64 percent of farm-households engaged in mixed farming, that is, apart from subsistence crop farming, they also reared animals such as dogs, pigs, goats, sheep, cattle, donkeys, guinea fowls, and chickens. Engaging in mixed farming meant that household labour usually is divided, with children in charge of animal care, while the household head (and sometimes with wife/husband and elderly children) work on the farmlands. It needs to be emphasised that farm-households' rearing of livestock has always been a cultural norm among farmers in much of rural Northern Savannah. In the study area, for instance, livestock is used for dowry purposes, indigenous religious sacrifices, and a sign of prestige within a community (i.e. the number of a livestock you had showed your level of wealth). These animals were barely sold or regarded as part of household farming practice. However, respondents claimed that they now consider animal rearing as part of their farming activities because crop farming alone no longer covers household sustenance for most of the year. Their argument is that reduced rains, late rains, recurrent droughts, and reduced soil fertility continue to hamper their crop production (low yields) season after season. The results in chapter 4 (farm-household characteristics), which suggest that the average number of months a farm-household struggled to feed themselves was between 5 and 8months corroborate this finding. With recurrent droughts and declining soil fertility, animal rearing also provides farmers with manure (particularly in the case of those who cannot afford fertilizer) and enhances their farmland traction ability (e.g. Ox traction). According to Whitehead

(2002), most households who engage in mixed farming are better off in terms of household income, nutrition, and farmland management capacity, hence capable of autonomously adapting to climate change: results from this study are consistent with this case.

Other on-farm adaptation strategies included the use of soil and water conservation (SWC) methods, fertilizer/compost manure use, use of enhanced crop varieties (e.g. early maturing and drought resilient), and irrigation. A major effect of climate variability and change is the altering of rainfall and water availability patterns. Consequently, the capacity to deal with water over-abundance or scarcity in the context of rainfed agriculture, becomes critical for maintaining or increasing crop production. Figure 8.3 shows that 43 percent of farm-household heads admitted they adopted SWC measures to combat seasonal droughts and limited soil fertility, while only 10 percent used irrigation. In the context of increasing variability in and/or reduced amount of precipitation, farmers adopted water harvesting and retention methods such as retaining ridges, pits (or pools), stone bonding, and tried to increase soil organic matter (e.g. through mulching) to raise soil water retention capacity. Mulching is particularly effective, and as other studies show, prevent soil erosion, protect soil moisture, improve soil fertility, protect soil from excessive heat, and subsequently improve crop yield (Antwi-Agyei et al. 2018). On irrigation as a strategy, farmers and communities relied on government executed irrigation projects (e.g. Vea irrigation dam in Bongo District) and only a few of the farmers had personal irrigation pumps. There are a limited number of government-related irrigation schemes in the study zone, implying it is only farmers in communities nearer to these dams who could potentially benefit (limited availability of and accessibility to irrigation facilities).

Figure 8.3 highlights results that show that in the face of recurrent droughts and declining soil fertility (as occasioned by inappropriate use of land and severe variability in climate/weather) in the Sudan Savannah Zone (SSZ), farmers adopted fertilizer and compost manure to enhance crop productivity. Most of the 36 percent of respondents who claimed to use this strategy tended to use organic compost as artificial fertilizer was not affordable. Even with the implementation of the fertilizer subsidy program in 2008 by the government, 83 percent of farmers indicated that the fertilizer were still not affordable. Over the years, the fertilizer distribution program has also been associated corruption and smuggling among officials responsible for the distribution. As a result, most government subsidized fertilizer never got to end-users (smallholder farmers). Compost manure on the other hand is relatively cheaper and readily available, since it is made from decaying or decayed organic matter, usually plant material and animal faecal matter (e.g. cow dung/pats).

The use of improved crop varieties like early maturing and drought resilient crops increases on-farm water-use efficiency, and thus enables crops to escape long dry spells that are usually towards the end of the growing season (Shongwe 2013). Similarly, Thornton and Herrero (2014) show that intercropping varieties with different phonological character (like maturity time) spreads the risk of droughts. However, in this study, the use of enhanced crop varieties was one of the least adopted on-farm adaptation strategies among farm-households in the study zone (Figure 8.3). Only 22 percent of respondents admitted to using this technique as an adaptive measure and cited reasons such as the potential of being affected by very long drought spells and being capital intensive in terms of seeds and fertilizer.

8.3 Socio-economic determinants of on-farm adaptation strategy choices

The influence of the availability and/or accessibility to socio-economic assets on farm-household choice(s) of on-farm adaptation strategies also emerged as important This chapter presents the results of the binary logistic regression on farm-household aggregate decision to adopt or not adopt adaptation strategies, as a dependent variable (yes = 1, no =0) against some selected socio-economic explanatory variables. The selection of the explanatory factors was done on the basis of a theoretical hypothesis, empirical literature review, and available data. Although fifteen socio-economic variables were selected for the analysis, this section only reports on variables that were significant on at least one adaptation strategy. Second, in order to understand the individual strategy choice determinants, the research ran 7 binary logistic regression models for each of the adaptation strategies against the same socio-economic variables used in model 1 (Table 8.4). The advantage here is that it allows for the examination of individual decisions and the associated probabilities for the choice of a method. Moreover, the analysis of each adaptation strategy separately eliminates the statistical effects of one choice of adaptation over the other. Before proceeding, note that this analysis introduced a variable that has not been included in any other empirical analysis on determinants of climate adaptation choices: as the survey results established that livelihood diversity was significantly associated with household exposure and vulnerability, the influence of this factor as to whether a farmer will adopt a strategy was explored.

Table 8. 4 Socio-economic determinants of climate adaptation and choice of strategies among farm-households

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
Strategies / **Determinants**	Adaptation (yes=1, no=0)	Varying planting time	Mixed cropping	Enhanced crop variety	Adopt SWC methods	Mixed farming	Irrigation	Fertilizer/ compost manure
Age of HH	1.19 (1.21)	3.18(23.85)**	1.62(5.26)	0.09(1.09)	0.83(2.29)	-1.89(0.15)	-0.07(0.93)	-0.10(0.90)
Sex of HH	-1.08 (0.34) *	0.65 (1.92)	1.26(1.98) **	-0.51(0.53)	-0.44(0.75)*	-0.24(0.78)	-0.14(0.87)***	-1.3(0.27)
Education of HH	-0.98 (0.21)	-0.27(0.76)	1.60(4.49)	-2.47(0.08)	1.72(5.62)	0.65(1.92)	-0.18(0.92)	1.49(0.88)*
Farming experience	1.01 (2.74)**	-0.22(0.58)***	0.73(2.19)	0.49(1.64)	0.75(3.13)**	0.18(1.22)	0.39(1.48)	-0.70().49)
Access to credit	3.13 (1.14)	0.98(2.64)	2.51(8.61)**	2.95(19.12)*	2.39(10.96)	0.22(3.40)	-0.65(0.52)	0.95(10.75)***
Livelihood Diversity Index (LDI)	1.07 (1.91)	0.37(1.39)	1.15(3.15)	0.52(1.69)	0.10(1.11)	0.019(1.03)*	-0.07(1.07)***	0.34(1.40)
Land Tenure	-0.47 (0.63)	1.73(5.62)	-0.86(0.42)	-0.43(0.65)	1.04(2.91)***	0.37(1.39)	0.12(1.69)	0.27(8.76)
Climate-related threat perception	1.17 (3.37)	0.68(5.14)**	-0.15(0.84)	1.14(3.14)	1.66(5.24)	0.95(2.57)	1.48(4.23)	-0.02(0.08)
Perception of soil fertility	1.66 (5.24)	-0.12(0.87)	-0.17(0.83)	0.23(1.25)	0.04(1.04)	-0.43(0.65)	0.07(1.07)	0.79(13.23)*

Source: Source: Climate variability and vulnerability survey, 2017

Note: Values outside parenthesis are the estimated coefficients (β), values inside the brackets are the odd ratios (OR).

*** Significant at 1percent

** Significant at 5percent

* Significant at 10percent

Table 8.4 shows that the probability of a farm-household adopting at least one measure is significantly influenced by a limited number of variables. The research found that only gender of the household head and farming experience increased the probability of adopting at least one on-farm adaptation strategy. The results showed gender of the household head had an inverse relationship with whether they will adopt at least one strategy or not ($\beta = -1.08$, $p < 0.1$). This finding is in consonance with the *a priori* hypothesis on the expected relationship between gender and adaptation decisions. The inference here is that male-headed households have a higher probability of adopting climate adaptation measures than women-managed households. The odds ratio (0.34) confirms this assertion. The odds show that there is a greater probability of male-headed households to adopt at least one measure. This finding could be attributed to the variation in terms of access to assets like education, land, credit, technology and input supply, as highlighted in previous chapters of this thesis. On this basis, it could be argued that male- and female headed households differ significantly in their ability and choices in climate adaptation strategies. The implication here is that adaptation initiatives should to a large extent target female-headed household, keeping in mind the underlying determinants of their choices.

Farming experience was found to have a positive and significant relationship with farm-household decisions to adapt or not ($\beta = 1.01$, $p < 0.05$). As one becomes more experienced in farming, it is an expectation that there is a higher probability of adjusting their farming activities to reduce the impacts of climate variability and extremes relative to less experienced farmers. From Table 8.4, the odds are that households with longer farming experience are 2.7 times more likely to use at least one adaptation measure relative to those with shorter farm experience. Debalke (2014) found that farmers with relatively longer experience are better positioned to predict and adjust their farm production accordingly. In this study, given that age is associated with experience, it was interesting to find that age, though positive, did not significantly explain farmers' decision to adapt or not. The literature presents mixed explanations for this. Although researchers have found no relationship between adaptation and age (e.g. Bekele & Drake 2003;), others like Anley et al. (2007) have found that age is significantly and negatively related to adaptation decisions. Hassan & Nchmachena (2008) on the other hand found significant and positive association between age and adaptation decision making. These anomalies are explained by the inference that as age is associated with more experience, that *ipso facto* older farmers will adapt more than younger ones.

In this study, older farmers adopted more than the younger ones and used more of medium- to long-term adaptation strategies, relative to their younger counterparts.

The remaining 7 socioeconomic factors were not found to be statistically significant in explaining farm-household decision to adopt or not (at all significant levels). This makes extrapolating and firm conclusions from model 1 (adaptation in Table 8.4) alone difficult in the sense that individual adaptation choices (models 2 to model 8) that underlie the aggregate dependent variable (i.e. model 1), are influenced by different combinations of socioeconomic factors. Consequently, it is very unlikely for the mix of factors that influence the probability of adopting one strategy in the study region to be the same as those that influence the adoption of another method. As evidenced in Table 8.4, there are different sets of explanatory variables that appear to significantly influence the individual adaptation strategies.

Table 8.4 shows that the decision to vary planting operations has been shown to be significantly influenced by age of household head ($p < 0.05$), past experience in farming ($p < 0.01$), and their perception of climate-related threat ($p < 0.05$). Conversely, the adoption of fertilizer use was found to be statistically associated with education ($p < 0.01$), access to credit ($p < 0.1$), and respondent perception of the soil fertility of their main farmland.

Another notable distinction with regards to the combination of variables determining farmers' adaptation strategy choices is between mixed cropping and mixed farming. The gender of the farm-household head and access to credit were found to be positive and statistically significant in explaining the decision to adopt mixed cropping. For mixed farming, on the other hand, only livelihood diversity was found to be statistically significant ($p < 0.01$) to that strategy choice. It is also notable from Table 8.4 that difference could also be drawn between factors that significantly influenced the choice of adopting soil and water conservation (SWC) methods and the use enhanced crop varieties. Deciding to use the latter was found to be influenced by one variable, access to credit ($p < 0.01$). However, adopting SWC measures was significantly influenced by the land ownership type ($p < 0.1$), farming experience ($p < 0.05$), and gender of the household head ($p < 0.01$).

The above dynamics introduces the overarching question of what informs a farm-household's choice of a method or the combination of methods. Understanding the probable factors that may play in concert to determine what adaptation method a farmer, or group of farmers will use to facilitate the design and targeting of adaptation responses. Knowledge of farmers' choices, and what informs such choices could be fundamental to any initiative that seeks to reduce climate adaptation deficit, particularly in the Sudan Savanah zone and other places with similar attributes. Having prior knowledge of these dynamics could also lead to a reduction of maladaptation in the medium- to long-term.

8.4 Barriers to climate coping and adaptation

The level of coping and adaptation in the Sudan Savannah Zone raises two questions: what hinders the process of adaptation among farm-households? Are there windows of opportunities farm-households could access to enhance or enable sustained adaptation? Despite the numerous coping and adaptation strategies identified in this study districts, respondents outlined some barriers which were found to be related to: limited financial resources and access to credit; complex land tenure system and gender issues; Inadequate or lack of irrigation facilities; inadequate or lack of institutional support; and the lack or poor state of socio-economic infrastructure.

8.4.1 Limited financial resources and access to credit

Table 8.5 indicates that limited farm-house financial resources and access to credit constitute the biggest challenge to effective and efficient implementation adaptation measures among respondents (86 percent). This was not unexpected considering that the study zone is largely rural, with a high incidence of poverty (Ghana Statistical Service [GSS] 2010). Moreover, literature confirms that access to financial resources is one of the most important ingredients for sustained climate change coping and adaptation, especially in poor rural communities (e.g. Dasgupta & Baschieri 2012; Deressa et al. 2009). In fact, lack of access to financial resources has the potential to limit the number of adaptation and coping options available to smallholder farmers.

Farm-households in this study who lamented their lack of financial resources as a barrier, mostly did so in relation to its impact on livelihood diversification (especially in bad seasons), how it hindered their adoption of soil and water conservation (SWC) methods, and their ability to afford farm inputs like fertilizer and enhanced crop varieties. During an informal discussion with a leader from a women's group in Bawku West, it came up that they were being encouraged by most of the NGOs to diversify their livelihoods, but the high cost of access to credit to do so is discouraging them. She remarked that the microfinance institution was exploiting them through high interest rates and they could not also go to the local money lenders because they are worse culprits.

> *"Most of us in this community really want to do other activities to be able to take care of our families, but the banks and microfinance institutions want collateral and besides that they give us the same interest rate like the rich people. Until the government introduced microfinance and small loans centre (MASLOC), this was what we faced. Now even with MASLOC if your party is not in government you might not be able to access it" (Female FGD participant* Bawku West, *26th March, 2017)*

It is important to note that the remaining 14 percent of respondents who did not consider finance/credit as a key challenge could be considered outliers. These are mainly farm-households who demonstrated low vulnerability (See Chapter 7). In this regard, it may be argued that barriers related to household financial resource/access to credit are a reflection of the farm-household socio-economic status. The social status of these farm-households within the community could also be an explanation. Heads of farm-households who hold key political and social positions in the community have the advantage of using their status to access financial resources to lessen their vulnerability.

8.4.2 Complex land tenure system and gender issues

Another climate adaptation barrier that was prominent among farm-households was the issue of the complex land tenure system and gender disparities in access to livelihood resources (Table 8.5). In societies where the predominant livelihood is agriculture-related, land tends to be the most important asset. Consequently, investments in climate-related adaptation to a large extent is contingent on secure land tenure, a trend documented by others (Antwi-Agyei et al. 2014). The 1992 constitution of Ghana captures two types of land tenure systems, which are the public and customary systems. With the customary land tenure system, which is the predominant system in northern savannah Ghana, all land resources are vested in the "Skin" (chief). This has created a complex land tenancy system in this part of the country. In Northern Ghana (and by extension the Sudan Savannah Zone), it is the *Tendana* (literally means Owner of the Land) who has the allodal title to all lands in a community. Under the customary system in the study area, the *Tendana* who in most cases is the descendant of the "first settler" family in a community is the only one allowed to grant land use rights to individuals and families in that particular community (Yaro 2010:2012). The implication is that access to land for the purposes of agriculture, for instance, is mainly through the customary tenure system (Yaro 2012; Kasanga et al. 1996). While indigenous people may obtain land for farming offering traditional gifts to a *Tendana*, the non-indigenous can only enter into contractual arrangements with the customary leader since they have no rights to community lands (Kasanga 2001).

Table 8.5 shows that more than half of the respondents (52 percent) considered the existing complex land tenure system and gender issues as challenges to their adaptation efforts. In these study communities migrant farm-households (non-indigenous households) and farm-households headed by females may be disadvantaged under these circumstances. This is because the majority of those who perceived land tenure and gender as barriers were migrant settlers and female respondents (83 percent). In the study zone, the land tenure structure is such that it is difficult for migrant settlers to own land, especially in a closed rural system where land is rarely sold but considered genetic family property. At best these migrants may be allowed (for free or rent) to farm on the land as long as the owners do not want to farm at present. In this instance, these farmers have a future guarantee and may not take up soil conservation or medium- to long-term adaptation plans (Damnyag et al. 2012). Although contested, the evidence in most literature suggests that farmers tend to have weak/little incentive to invest in appropriate farmland management practices when they have limited land rights (Antwi-Agyie et al. 2014; Damnyag et al. 2012).

Table 8. 5 Percent of farm-households who identified with particular barrier to adaptation

Barrier to adaptation	No. of respondents (*n* = 230)	#Percent	Adaptation methods influenced by barrier
Limited of financial resources & access to credit	198	86.1	Livelihood diversification strategies, changing food diet, use of enhanced crop varieties, adopt SWC methods, irrigation
Limited institutional support	68	29.6	Reliance on Gov't and NGO support, use of fertilizer, use of enhances crop variety & use of other farm inputs, casual labour, irrigation, adopt SWC methods
Lack or poor socio-economic infrastructure	22	9.6	Casual labour, Livelihood diversification strategies, use of irrigation,
Complex land tenure & Gender	120	52.2	Adopt SWC methods, use of fertilizer, use of enhances crop variety, use of other farm inputs, Temporary migration
Inadequate or lack of irrigation facilities	83	44.8	Use of irrigation, use of enhanced crop varieties, mixed farming, mixed cropping

Source: Climate variability and vulnerability survey, 2017
Note: # most of the households stated multiple barriers

Results also show that female-headed households may be disadvantaged due to the patriarchal system of inheriting land (socio-cultural discrimination). Although this cultural more is increasingly changing in the study area, the distribution and ownership of farm lands is still skewed in favour of males. In most cases, particularly rural agrarian communities, women obtain usufruct land through marriage since their rights to land is not recognised in the customary law (Yaro 2010). In this case if the unforeseen happens (e.g. separation or divorce), the woman loses the land. In the instance where a husband dies, the wife can only access the land if she has male children. Antwi-Agyei et al. (2013) found that land use and ownership rights among women in northern Ghana who are not married was very limited and when they do get access, they were given the most unproductive farmlands. Gender differentiation, in the context of farmland use and ownership rights created by socio-cultural discrimination, has grave implications for climate-related exposures (discussed in Chapter 6), vulnerabilities (in Chapter 7) and coping and adaptations (as discussed in the present chapter). The reason being that females and for that female heads play a vital role in farm-household level resilience (Ibnouf 2011).

8.4.3 Inadequate or lack of irrigation facilities

In chapter 5, the results showed that the Sudan Savannah Zone (SSZ) had high aridity values (corresponding to semi-arid regions). It was also found that a larger area (69 percent) of the zone had high probability of experiencing drought during farming seasons. Based on this probability it could be argued that the success of climate adaptation among smallholder farmers is contingent on the availability/accessibility to fresh water (e.g. public or private irrigation systems). Therefore, it is not surprising that inadequate or lack of irrigation facilities was found to be the third most important challenge among farm-household heads (45 percent of respondents). As discussed in section 8.1.3 of this chapter, only 9 percent of farmers engaged in irrigation and most of these farmers used personal motorised irrigation pumps. The study area is drained by the Red and White Volta Rivers so farmers closer to these rivers, and who have the finance/credit to purchase personal irrigation pumps, can cultivate all year round. In this way they reduce their exposure and vulnerability to the unexpected impacts from climate/whether variability and droughts. However, with inadequate public extension services, farmers have been experimenting on how to apply these irrigation pumps to their farms.

Obviously, in this era of changing climate and severe extremes the importance of having a communal irrigation facility, or a personal motorised pump, cannot to be overstated. However, the cost involved in acquiring these facilities (particularly for personal irrigation pumps) constitutes a hindrance especially for the moderate to highly vulnerable farm-households and communities in the study area. Although this study acknowledges the efforts of various governments to provide public irrigation schemes to communities in the three study districts, for varied reasons the management and outreach of these schemes in most cases leaves much to be desired. These reasons include (but are not limited to);

- Politicization of site selection of these irrigation schemes which sometimes lead to alienation of the most exposed and vulnerable;
- The management of these schemes by Water Users Associations (WUA) in these communities in most cases is fraught with inefficiencies due to the lack of capacity; and
- Financial issues relating to the maintenance of public irrigation schemes, which is largely placed on government.

8.4.4 Inadequate or lack of institutional support

Institutions (i.e. formal or informal and local or national) play an important role in enabling or enhancing climate adaptive capacities and actions in local communities (Yaro et al. 2015). It has been argued that institutions at the local level situate the interaction between individuals, groups and the state through the regulatory structuring of adaptation options, opportunities, and limitations (Dovers & Hezri 2010; Whitehead 2002). Thus, institutions provide the framework within which households can make specific adaptation choices. In the study area the major public institutions charged with the responsibility of supporting farmers at the community level are the district agriculture extension services of Ministry of Food and Agriculture (MoFA), and the district agriculture development units (DADU) under the various district assemblies. DADU is expected to play the roles of developing, implementing and monitoring agriculture programs at the local level. The extension officers on the other hand are supposed to be the link between the scientific research community and farmers at the community level. They are tasked with the responsibility of enabling the flow of information on new scientific and innovative methods of farming to farmers.

However, 30 percent of respondents identified limited institutional support as a barrier to their efforts to cope and adapt to climate variability and extreme events (Table 8.5). This barrier, according to respondents hampered their ability to obtain and apply fertilizer and to adopt soil and water conservation methods. Respondents generally referred to poor and inadequate services from extension officers and lack of support from the DADU. A review of government documents revealed that the major issues with these two agencies is the lack of institutional capacity (in terms of human resources), and limited financial allocation from the central government. For instance, according to MoFA (2017), the agriculture extension officer to farmer ratio is 1:1500 in Ghana, which by FAO standards (1:400) is very high (See FAOSTAT). The implication is that extension officers in the study districts may be overwhelmed by both the number of communities and farmers they serve. This may not only reduce the number of farmers they can serve, but also the quality of service they deliver.

The consequences of poor or inadequate extension service delivery to smallholder farm-households could lead to: low climate adaptive capacity, poor agronomic practices, post-harvest management constraints, inefficient use of farm inputs, and poor access to other ancillary information that could help reduce current and projected food insecurity. In this regard, institutions such as district extension services and DADU will be of critical importance to the region if adaptation initiatives in SSZ farming communities are to succeed. This is because it is through these agencies that new knowledge and ideas are introduced in rural communities to facilitate change and improvement in the lives of farm-households. In essence, a lack of agriculture-related institutional support or its inadequacy, coupled with increasing variability in inter- and intra-seasonal rainfall could have devastating consequences for food security in the study zone.

8.4.5 Lack or poor state of socio-economic infrastructure

In Ghana, rural infrastructure has been at the centre of poverty reduction strategies since the 1980s. However, limited progress has been made in this regard largely due to the inability of successive governments to mobilise the necessary resources for implementation. Socio-economic infrastructure can be viewed as a critical ingredient in rural livelihood systems in the sense that it facilitates and integrates socio-economic activities. For instance, a smallholder may adopt a new farming method which may increase crop output. The extra produce may be worthless without a storage facility nearby in the community, market centre in the community, or transport infrastructure to facilitate movement outside the community to sell the extra output. Fundamentally, the lack or inadequate infrastructural development in rural farming communities could, therefore, present a challenge to climate coping and adaptation initiatives. From Table 8.5, 10 percent of farm-households in the study zone identified lack or poor state of socio-economic infrastructure as an important obstacle to their efforts at climate adaptation. To these farm-households, the lack of infrastructure limited their ability to diversify their livelihoods during the dry season, and also during farming seasons when the rains fail them. Examples of socio-economic infrastructure cited by respondents included roads, storage facilities, electricity, water (including irrigation) and market centre. Farm-household access to this infrastructure may essentially improve their socio-economic condition, which has important implications for whether they will adopt a climate adaptation strategy.

8.5 Conclusions

Climate variability and extremes (e.g. droughts) will continue to impact natural resource-dependent livelihoods, particularly smallholder farm-households in semi-arid environments whose livelihood activities are contingent on rainfall. The urgency of the need for sustainable adaptation strategies to deal with current and looming impacts cannot to be overstated. This chapter contributes to the climate adaptation discourse by providing regional empirical evidence on three issues: types and application of coping and adaptation measures in semi-arid regions; determinants of farm-household choice of adaptation in savannah regions; and barriers to smallholders' efforts towards climate adaptation. The results from this chapter showed that a significant relationship exists between the vulnerability clusters a household belonged to and the mix of adaptation strategies they adopted. It was also shown that the timing of implementing off-farm adaptation measures varied according to the period of the year (before, during, after farming season).

Overall, farm-households associated themselves with nine main coping strategies with most household adopting a mix of measures (between 2 to 4 measures). The most popular among these were: food quantity and quality reduction options, selling of livestock, offering casual labour, and relying on family and friends. Farm-households also engaged in livelihood diversification which this thesis found relevant to climate coping and adaptation. The prevalent ones included: petty trading, temporary migration, sale of harvested firewood and charcoal, and food vendor. It should be noted that the study farm-households engaged more in coping mechanisms than in diversifying their livelihoods. Respondents also adopted certain on-farm strategies to reduce the burden of climate impacts. Crop management strategies like varying the planting time, mixed cropping, and mixed farming were found to be the widely used, while the least applied was irrigation (both by personal irrigation pumps and communal irrigation schemes).

The chapter also examined the socio-economic determinants underlying the farm-household's choice of an adaptation strategy. The results showed that the aggregate decision to adopt or not was significantly influenced by limited factors. These were the gender and farming experience of the household head. However, the binary logistic regression for each of the adaptation strategies showed that every measure had a blend of factors that played in concert to influence the choice of a particular strategy. The conclusion is that while understanding why farmers engage in adaptation is necessary, it is not sufficient: it is knowledge of farmers' choices of adaptation methods and what informs such choices that is fundamental to any initiative that seeks to reduce adaptation deficits among smallholders.

Finally, this chapter explored the question of what constrains the process of adaptation among farm-households in the Sudan Savannah Zone. It found that climate adaptation barriers in the study zone related to farm-household finance, complex land tenure systems and gender issues, inadequate or lack of irrigation facilities, inadequate or lack of institutional support, and lack or poor state of socio-economic infrastructure. The interaction of these barriers and their operations at the different stages of the adaptation process may have implications for food security and agriculture-related livelihoods in the Sudan Savannah Zone. There is a need to address these barriers since they could have far-reaching implications for adaptation policy design and implementation.

Chapter 9: Conclusion and implications

9.1 Introduction

While each result chapter has discussed the individual findings in the context of the field, this concluding chapter discusses the overall key findings of this research project and maps them against the main research objective which was "exploring the social-ecological systemic (SES) factors underlying the exposure, vulnerability and adaptation of farm-households to climate-related risk in the Sudan Savannah Zone (SSZ) of Ghana". The chapter then discusses the implications of this project's findings for food security and agriculture-related livelihoods and policies in Ghana, and the wider context of Sub-Sahara Africa. It proceeds to outline further avenues for future research, concluding with some final remarks about the research findings.

9.2 Summary of key findings

Chapters 5, 6, 7 and 8 are result chapters addressing the spatial distribution of climate risks, exposure to climate risks, vulnerability to climate risks, and coping and adaptation to climate risks, respectively. The research draws on both quantitative and qualitative data to underscore complex dynamics associated with climate-related risks and coping and adaptation strategies in response to these risks. This section summarises the key findings, which are related to the objectives and questions posed in this research.

9.2.1 Geospatial distribution of climate risk, showing the probability of experiencing regular drought

The geospatial analysis showed that 70 percent of the total area of Sudan Savannah Zone had a moderate to high probability of experiencing drought every farming season. Relative to Bongo and Bawku West, Garu-Tempane and Bawku Municipal had higher drought risk probabilities, implying that, all factors held constant, most smallholder farm-households in these two districts are likely to experience relatively higher losses and damages in terms of crop failure, increased food insecurity, and the general loss of livelihood due to drought. The research also showed that although districts were in the same agroecological zone, there were significant spatial variations in terms of the distribution of climate risk. Out of the five biophysical factors used in the geospatial analysis, aridity, vegetation cover, and land use/cover significantly explained the spatial variance in risk levels.

9.2.2 Farm households' risk exposure mediated by awareness and perceptions

The thesis developed climate exposure indices for study households. It was found that although there were significant variations in farm-household heads' climate awareness and threat perceptions in the study area, factors such as district, gender, education level, age, and the farming experience of respondents were significantly associated with the variations. It was also found that there was a high probability of farm-households likely to be exposed to climate variability and extremes in the future. The climate exposure indices (CEI) showed that farm-households in all the study districts, and for both female- and male-headed households, were within the range of moderate to high. However, a disaggregation of the composite exposure index showed that it is imperative for practitioners or policy makers to explore the sub-indices that highlight the actual dynamics of farm-household exposure to climate risks.

9.2.3 Incorporation of locally significant variables enable better understanding of the dynamics of farm-households' vulnerability to climate variability and extremes

The thesis highlights the merit of comparing farm-household livelihood vulnerabilities (by district and gender), and the relevance of incorporating variables that have local significance (i.e. locally important climate perspectives and livelihood assets that have bearing on vulnerability). Using cluster analysis and the farm-household livelihood vulnerability index (FLVI) allowed for the across-district, across-gender and across-component comparison of results. The results showed that the three districts and the 2 types of farm-household headships had a different mix of components and subcomponents that defined their levels of vulnerability. The implication here is that each combination of components (and by default, subcomponents) together with the type of household headship, require a different mix of adaptation strategies. The findings also showed that vulnerability among farm-households in the Sudan Savannah Zone was generally high. The vulnerability was associated with food sufficiency, access to credit, household livelihood diversity index, sex of household head, and the district in which they live. The thesis identified farm-households in Garu-Tempane district as more likely to have higher vulnerability levels relative to Bawku West and Bongo. This variance in vulnerability confirms the argument that even at the local level, vulnerability is contextual and heterogeneous in space. Most importantly, female-headed households, comparatively, were found to be more likely to have higher susceptibility to climate risks. However, it should also be noted that identifying female-households as more vulnerable is necessary, but not sufficient for a comprehensive understanding of the underlying factors of their vulnerabilities. Being able to identify the level of their predisposition must be complemented with an in-depth understanding of the dynamics of their vulnerability. The FLVI showed that the gendered asymmetry in farm-household vulnerability was largely rooted in the inequalities in livelihood diversification opportunities, household finance, household human capital base, and the household natural asset base. The central point here is that gender-differentiation of rights to livelihood assets, and its consequences for climate vulnerability, vary by geographical and socio-cultural context.

9.2.4 A range of farm-household coping and adaptation strategies exist in the Sudan Savannah Zone

The research found that farm-households engaged in three categories of adaptation; short-term coping mechanisms, livelihood diversification-related coping and adaptation measures, and on-farm adaptation strategies. Short-term coping methods included the reduction of food quantity and quality coping options (i.e. reducing amount of food taken in a day or changing diet), selling livestock, casual labour, and relying on family and friends. It was also found that coping and adaptation strategies were generally related to farm-household livelihood diversification activities. These activities were: petty trading, temporary migration, sale of harvested firewood and charcoal, food vendor, *pito* brewing (local alcohol brewing), cottage industry activities, salaried employment, carpentry/masonry and other activities like livestock trading and sand mining. Some of these adjustments, especially the livelihood diversification component, were not mainly undertaken for climate change purposes. Most of the activities, though with relevance for climate change adaptation, were undertaken in reaction to other livelihood disturbances. The research found that the crop management techniques such as mixed cropping, and mixed farming and the timing of farm operations were the most used among farm-households. However, farmers who used these measures indicated that they did not have the required capacity to properly implement them and, therefore, did not reap the full benefits of engaging in such measures. Capital and technologically intensive measures such as soil and water conservation methods, irrigation, enhanced crop variety, and fertilizer were found to be the least popular strategies among farm-households. The project also established a relationship between the vulnerability cluster a household belonged and the mix of strategies they adopted. Another important characteristic of respondents' climate coping and adaptation was that strategies were not implemented in the same period of the year, although the implementation of some of the measures overlapped. Obviously, all on-farm strategies were implemented within the farming season. However, some of the off-farm strategies were implemented either before or after the farming season.

The thesis showed that the probability of a household adopting at least one measure is significantly influenced by a limited number of variables. Only gender of household head and farming experience influenced the adaptation decision of a respondent. However, an assessment of adaptation choices showed that each choice of strategy was significantly associated with a different mix of determinants. These dynamics confirmed that the blend of factors underlying why smallholders choose to adopt a particular measure or not, is substantially contingent on the type of adaptation strategy and the prevailing individual socio-economic context.

9.3 Implications for climate-agriculture policy, projects and programmes

This section highlights the probable implications of the study findings for climate-agriculture policies, projects and programs in Ghana, particularly highlighting the relevance to areas with similar characteristics to the Sudan Savannah zone.

9.3.1 Mapping of climate risks for proactive management and adaptation

The spatial differentiation of risk, as has been done in this research, has the potential of facilitating ex ante climate strategies and policy planning. For the study zone it is particularly important since maps like this could enhance the decision support systems of various District Agricultural Development Units (DADUs) in the Sudan Savannah Zone, a tool they currently lack. Such maps could make it easier for implementing officers to effectively monitor, plan and target management and adaptation responses. Regular or periodic risk mapping since climate related risks like droughts are in constant evolution is advocated.

In recent times, there have been increasing concerns and a number of studies on the changing trends in drought frequency and severity, and how they impact agriculture livelihoods both in Ghana and elsewhere (Brown et al. 2017; FAO 2017b; Carrao et al. 2016; Dai 2011). The increase in concerns has generally been linked to the consequences, which can be stark and usually reverses the gains in food security and poverty reduction (FAOa 2017: p 5). However, most of the studies have focused on drought as a natural hazard, and thus do not provide consistent drought risk assessment frameworks that could be useful for proactive drought management and adaptation (Crausbay et al. 2018; Brown et al. 2017; Kim et al 2015; Wilhite et al. 2014). Moreover, drought management in most developing countries like Ghana have been reactive (short-term crises management approaches), which are usually untimely and poorly coordinated. Considering recent trends in the frequency and severity of climate variability and extremes, coupled with the spread of agriculture into peripheral environments, there is the need for regular risk assessments to aid agriculture-related decision support systems.

9.3.2 Exposure showed levels of variability across the study districts

This study developed exposure indices using farm-households' awareness of changes in climate and their livelihood threat perceptions. The research estimated the exposure extent of farm-households in the Sudan Savannah Zone and theoretically explored the possible underlying factors.

First, the study found that respondents' awareness and perceptions, though high, significantly varied by the district a household belonged to, and the gender of household head. Understanding smallholders' awareness and perceptions is critical for effective designing and implementation of local level coping and adaptation strategies. The argument here is that the manifestation of climate related impacts may be varied in space, implying these awareness and perceptions may vary by individuals, groups, or communities depending on where they are located. It is important to highlight that decision makers need to understand the climate knowledge base and concerns of farm-households. In doing so it does not only facilitate community level engagement, but also enhance the willingness of farmers to adopt, which could improve the sustainability of planned adaptation measures (Ndamani & Watanabe 2017; Howden et al. 2007).

Second, the research used primary household data and the justification is that, it gives a relatively better picture of the extent of farm-household exposure levels. The research found that farm-households generally had moderate to high exposure levels, and that levels of exposure in the Sudan Savannah Zone varied by the district a farm-household belonged to, gender of the household head, farming experience and education level of the respondents. This is confirmation that even at the subnational level, variability may exist in the extent of exposure of farm-households and communities. Such information may be important to decision makers at the national and subnational levels for improving the targeting of households who may be most exposed to climate variability and extreme events. There is a considerable amount of literature suggesting that for most hazards, ‘exposure dynamics’ is a major driving force behind observed trends in disaster losses and damages, rather than just changes in hazard characteristics (Kreienkamp & Vanhala 2017; Arbuckle et al. 2015; Garlati 2013). Consequently, the estimation of the extent of climate exposure at the subnational level could aid the identification of exposed groups and communities, informing national level policies and district level strategies and programs, that seek to reduce climate related losses and damages.

9.3.3 Climate vulnerability assessment as a necessity for sustainable Adaptation

Vulnerability indices and indicators over the years have become increasingly useful for identifying vulnerable groups and communities, monitoring vulnerability levels over space and time, identifying determinants, and prioritizing coping and adaptation strategies (Burnham & Ma 2016; Shah et al 2013; Adger et al. 2009). One of the essential qualities of vulnerability as an assessment tool is that it should inform policy (Shah et al. 2013). The use of livelihood vulnerability index (LVI) requires minimal training, suggesting that practitioners can easily use it for regular assessment of farm-households within their catchment areas.

The results suggest an urgent need for a review of adaptation policies and strategies, both at the national and subnational levels, in Ghana. The findings suggest generally high levels of vulnerability among farm-households in the Sudan Savannah Zone. What is interesting here is the fact that each vulnerability cluster, gender type and district had different combinations of variables (related to sustainable livelihood assets) that determined the extent of vulnerability. These variables are directly or indirectly linked to the adaptation barriers discussed in this research, implying that adaptation interventions undertaken by government and NGOs should be informed by a priori knowledge of the underlying factors of farm-household vulnerability. In this thesis, the factors that rendered farm-households vulnerable or constrained their adaptation efforts (their actions and/or capacity), included limited financial resources or access to credit facilities; limited livelihood diversification opportunities; poor institutional support; complex land tenure; gender differentials in the access to livelihood assets; and the lack of irrigation facilities. The following recommendations are made:

- Provision of agriculture-related subsidies and credit facilities
- Enhancing livelihood diversification opportunities at local level
- Improved institutional access and support for farm-households

- Reform of existing land tenure system and increased efforts at bridging gender inequality
- Expansion of irrigation schemes to the most exposed and vulnerable communities

Access to and provision of agriculture-related subsidies and credit facilities affects vulnerability

Household financial resources and access to credit facilities were found to be major factors contributing to respondents' vulnerability, and their inability to adopt or enhance their adaptation to climate variability and extreme events. It is recommended that adequate credit facilities should be targeted at farm-households to enable them to implement apposite climate adaptation measures. Given adequate financial resources, farmers will be able to timely purchase the needed farm inputs (e.g. fertilizer, enhanced crop varieties, farm equipment, private irrigation facilities, etc.). It is obvious farm-households cannot provide the required collateral to secure credit from financial institutions (banks, microfinance, credit unions, etc.). As a result, the government of Ghana through Ministry of Food and Agriculture (MoFA is the sector ministry), should liaise with financial institutions to enable credit access to these smallholder farmers, particularly to female-headed households.

Currently the Agriculture Development Bank (ADB) provides facilities to farmers as part of its core mandate. However, the bank seems to focus on large commercial agriculture to the neglect of smallholders, especially those who are not in farmer associations. It is recommended that the ADB expands its catchment to include smallholder farmers, and encourages farmers to join or create associations in order to stand a better chance for them to access credit from financial institutions. Another critical finance-related issue is the timing of financial assistance to smallholder farmers. Obviously, farmers need financial capital at the beginning of the farming season, especially so they can take advantage of early rains (if it happens). Consequently, the processes involved in accessing and granting credit must be started long before the beginning of the farming season.

The (re-)introduction of agriculture-related subsidies could go a long way to improve food security in rural communities. After the Ghanaian government adopted the structural adjustment programme of the IMF in the 1980s, subsidies on farm inputs like agrochemicals and seeds were removed. Over the years this has had serious food security problems, especially for poor rural farm-households. Re-introducing subsidies particularly on the main staple crops (e.g. millet, maize, and sorghum), could improve production levels. However, such a programme needs to target the most vulnerable smallholder farmers. The introduction of subsidies in other parts of Sub-Sahara Africa have led to a tremendous increase in crop production. A good example is the Malawian case where subsidies were found to have increased maize production among smallholders. It is the expectation of this thesis that MoFA in its next review of the Food and Agriculture Sector Development Policy (FASDEP) will give due consideration to this issue.

Enhancing livelihood diversification opportunities at local level

The findings from this thesis indicate that livelihood diversification in the Sudan Savannah zone is generally low. However, it was a prominent issue because a considerable number of farm-households attributed their vulnerability and adaptation deficit to the lack of livelihood diversification opportunities in their communities. Further, farm-households who diversified their livelihood activities were relatively less vulnerable to climate related impacts and used a suite of adaptation strategies (3 coping and adaptation measures on the average). Contrarily, households in the high vulnerability cluster generally engaged in livelihood diversification and usually adopted only one adaptation strategy. On this foundation, this thesis recommends that in collaboration with NGOs (e.g. Oxfam, ADRA, ActionAid), departments and agencies under Ministry of Food and Agriculture (MoFA) and the Ministry of Local Government and Rural Development (MLGRD), should create the enabling environment at the local level for smallholders to diversify their livelihoods. These government institutions are responsible for developing suitable programmes and projects that foster livelihood asset building at the national and subnational levels. These programmes and projects may include, but are not limited to, skills training, educating farmers on the benefits and how to restructure their farming activities (e.g. mixed farming), and helping farmers start micro-enterprises. Micro-enterprises are very crucial in the sense that they generate employment and incomes in the rural economy. According to the FAO (2011), rural micro-enterprise provides between 20 percent to 45 percent fulltime employment and 30 percent to 50 percent of farm-household income in Africa. Based on this it will be an effort in the right direction if the appropriate institutions consider establishing micro-enterprises or create the enabling environment for rural farm-households to start on their own.

Improved institutional access and support for farm-households

More than a quarter of respondents claimed that limited support from mainly government institutions, accounted for their vulnerability and limited adaptive capacity. They generally talked about limited government support after extreme events, inadequate agriculture extension services, and support for obtaining and applying farm inputs like fertilizer and enhanced varieties of seeds. First, the government through MoFA needs to improve the extension officer-farmer ratio. The results showed that farmers were not getting the needed extension services, and this constrained their farm production. These are largely illiterate farmers and thus need to be trained on how to use new farming technologies and adaptation strategies. Consequently, if the needed explanation does not reach them, it could lead to either non-adoption or maladaptation. Apart from increasing number of officers, this research recommends that MoFA and government at large, need to invest heavily in training these extension officers to bring them up-to-date on current farming practices, particularly on sorghum, millet, and maize which are staple crops in Northern Ghana.

Government and its development partners could also support these smallholder farmers by investing in early warning systems for rural farming communities. It is interesting to note that none of the study communities had any warning system in place. The respondents lamented that they only see local government officials from the district capital after floods have already shattered their lives. Government through the Ghana Meteorological Agency should improve access to climate information among rural smallholders. In this regard, already existing communication infrastructure like local radio stations could be used to broadcast climate/weather information and warmings in the local languages. There is also a need for greater decentralization of adaptation strategies and enhanced coordination among agriculture-related institutions and mandated climate change adaptation institutions. The fragmentation of climate change information/data among government agencies and departments constrains in-depth evaluation of adaptation alternatives.

Reform of existing land tenure system and increased efforts at bridging gender inequality

Land is the foundation of food production and other economic activities implying every individual or group, directly or indirectly depend on it. In rural areas it is considered the primary source of power, wealth, and social status. As alluded to earlier, in Ghana 80 percent of the total land area is owned by “stools”, “skins”, clans, and families. Consequently, depending on which part of Ghana you come from, the customary land tenure system is discriminatory and breeds inequality in land use and ownership rights. This is because gender differences are location and culture specific. In the Sudan Savannah Zone (found in northern Ghana), the customary inheritance system limits or even excludes women from the succession of land rights because it is patrilineal. Moreover, Kuusaana et al. (2013) found that in Northern Ghana, a woman's access to agricultural lands in her matrimonial home is contingent on the stability or success of the marriage. It is also important to state that women who tend to have access to farm lands found not have the ownership security. Women are not prevented from buying lands, but most of them do not have the resources to afford to do so. This has serious implications for women's vulnerability and adaptation to climate variability and extremes. In this thesis, ownership of land was generally low among female respondents, and from the focus group discussions with women, it was a key reason why they did not invest much in farming activities and adaptation. Studies by IFAD and FAO have both shown that women's inaccessibility and/or insecurity affects the type of crops they grow, access to credit, and discourages land conservation.

Women's rights regarding use and ownership rights need to be acknowledged and clearly defined in the next review of Ghana's land policy. There is an urgent need for both central and local governments to create gender-responsive policies, specifically targeted at empowering vulnerable female-headed households through guaranteed land rights and equal socio-economic opportunities. It is important that relevant institutions begin conscious discussions on how to reduce, or eliminate entirely, the socio-cultural discriminations against women. The national land policy which recognises the customary land tenure system could be amended to ensure that women land rights are guaranteed. All this can be possible if stakeholders like traditional leaders are properly sensitized through educational programmes. Another consideration for stakeholders might be a second look at the issue of legal pluralism with regards to legislation governing lands in Ghana. For instance, the co-existence of statutory and customary legal systems on land administration in Ghana, generates uncertainty, and could be one of the underlying factors for gender inequality in land use and ownership rights. Statutory law which does not allow for discrimination tends to be constrained by the persistence of customary law, which is guided by socio-cultural values and norms.

Expansion of irrigation schemes to most exposed and vulnerable communities

Throughout this thesis, the characteristics of the study zone was made explicit. The farm-households in the zone depend on the single maxima rainfall season (May/June to September/October) for their farming activities. It was also established that the zone had a high probability of experiencing droughts in every other farming season and short dry spells every farming season. Coupled with the inherent low soil fertility and low application of fertilizer, the majority of farm-households are, in most cases, not able to obtain good yields at the end of the farming season. Moreover, in the seasons in which rains don't come, households are faced with devastating food insecurity (e.g. in 2008 and 2015). Over the years, governments have made efforts towards constructing dams in much of the northern savannah belt (e.g. Fumbisi, Tolon and Vea irrigation dams). However, most farming communities in this largely dry zone are without irrigation facilities. As a policy recommendation, it is the expectation of this thesis that the current Ghana government's initiative of providing a dam or dug-out for each farming village will materialize. This initiative is laudable since it seeks to construct small to medium irrigation dams in farming communities in the country. The problem however is that the current initiative for the last two years has been nothing but a policy document. Checks with MoFA indicate that not even a single dam has yet been built. The construction of these dams will be crucial for food security and agriculture related livelihoods in the sense that farmers can now grow crops both in the raining season and the off dry season. In the construction of these dams, due consideration should be given to the most vulnerable communities. Apart from the construction of dams, it is suggested that conscious efforts should be made by MoFA to encourage and train farm-households to engage in on-farm water harvesting technologies, which could facilitate adaptation to dry spells during farming seasons and encourage dry season vegetable farming.

9.4 Limitations and recommendations for further research

Understanding the various climate dimensions and risk factors, as presented in the exposure chapter (Chapter 6), may require further empirical research. This thesis interrogated the extent to which farm-households may be exposed to climate risks based on their awareness of the changes in risks and their associated livelihood threat perceptions. However, the thesis does not comprehensively and empirically explore why and how farm-households may be exposed to specific climate risk factors. This is particularly important because establishing the extent of exposure, though important for use on risk communication mediums and for policy design, it is not sufficient. In using the extent of exposure only, some vital information about the complexities and dynamics of farm-household exposure to specific climate risk factors could be masked. This thesis, however, in using existing literature and results from the risk mapping, highlighted probable reasons for "why", for instance, farm-households in Garu-Tempane were likely to have a higher exposure levels (climate exposure index) than those in Bongo district. For any replication of this study, it will be important to empirically show the underlying factors behind the extent of exposure, particularly in the study zone. Again, it is possible to overlay exposed populations on identified risk areas. Accordingly, any replication of this in the study zone or other areas with similar physiognomies could integrate these two for a better appreciation of the spatial distribution of the exposed units of analysis.

It is widely accepted that vulnerability indicators and indices have become useful tools employed for encapsulating complex realities in simple comprehensible terms (Vincent 2004). Adopting these tools in climate vulnerability research permits comparisons across groups, space and time. However, while indicators and indices have important academic and policy applications, their selection and construction have also raised a number of possible directions for further research. An indicator or index provides useful summary information. Nevertheless, the subjective argument of this research is that there is a danger they may not accurately represent the condition or process under investigation (invalidity) (Vincent 2004).

In this thesis, principal component analysis (PCA) was conducted alongside the farm-household livelihood vulnerability index FLVI), as a way of improving validity of the results (Easter, 1999). However, it is argued that to ensure robust results, indicators and indices must be considered to be in a process of evolution rather than complete (Vincent 2004). In this instance, the inference is that a tentative theoretical hypothesis is continually empirically tested, and the results fed back into the conceptual development. By doing this the result is in progressive enhancement in a way that the indicators and index get the highest possible validity. The proposition for further research is that any replication of this project should endeavour to hypothesise new indicators (and by extension variables), since this could ensure the continual development of policy-relevant research. It must also be noted that since this thesis adopted the indicator approach for characterising exposure extent, this proposition also applies to any replication of the exposure assessment. Finally, any future assessment of household vulnerability that uses the livelihood approach could try to refine some of the sub-components in order to get more accurate results. For instance, the refinement of social network sub-component, as used in this project, could be refined to include social bonds, which may lead to a different conclusion about the importance of social network among rural farm-households.

Another area that may need increased empirical research is the circumstances under which existing climate related institutions and adaptation strategies enable or constrain long-term adaptation in farming systems. The study found that most of the institutions (both government and NGOs) largely engaged with farmers on short-term coping strategies and medium-term adaptation measures. Yet studies show that both formal and informal institutions are relevant to adaptation in the sense that they legitimize practice and rules of conduct, which are imperative in defining access to resources and the different adaptive capacities of individuals, households, and communities (Yaro et al. 2015). It has also been argued that institutions tend to situate the interaction between individuals, groups and the state through the regulatory structuring of coping and adaptation options, opportunities, and limitations (Dovers & Hezri 2010; Whitehead 2002). If it holds true that institutions provide the framework within which households, groups and communities can make specific adaptation choices (Perrin et al. 2008), then its critical to intensify empirical research, particularly at the local level to ascertain how these institutions operate, and whether their *modus operandi* enhance or provide means for adaptation beyond the short-term. The results from this thesis indicate that there is an adaptation deficit in the study zone, further giving impetus to this proposition.

9.5 Conclusion

Theoretically, this research contributes to the understanding on how social-ecological factors demonstrate a mix of climate risk markers in various livelihood contexts, particularly in rural settings that are dominated by smallholder farm-households. This study, particularly contributes to the improvement of existing knowledge on the geospatial variability in climate risks in drylands, considering that not much priority has been given this subject in literature (Ericksen et al. 2011; Thornton et al. 2008). Moreover, the assessment of climate exposure at the local level constitutes a key prerequisite for understanding vulnerability and adaptation dynamics at that level. This research recognises the importance of national, regional, and global level vulnerability assessments since they provide a strong foundation for more detailed research. However, it must be said that these assessments tend to be limited in terms of their relevance to improved understanding at the local level, in the sense that such higher-scale analyses, usually, are not able to capture the heterogeneity in the vulnerability of individuals, households, and communities. This thesis, in this regard has demonstrated how baseline data – usually lacking but highly important – for action at the local level can be produced to enhance adaptation policy development and targeting. Again, understanding what influences the strategy preferences of farm-household adaptation will not only aid practitioners and policy makers to reduce maladaptation but could also facilitate the reduction of current and future adaptation deficits. This research also provides some useful insights on the nature of adaptation barriers and their sources, providing the in-depth knowledge required for future adaptation initiatives that seek to at avoid, eliminate or lessen the possibility of maladaptation (Moser & Ekstrom 2010; National Research Council [NRC] 2010; Adger 2007).

In Ghanaian context, as in most developing countries, there is broader consensus that climate related risks and their associated implications for ecological resource-dependent livelihoods and food security (availability, access, utility), will be enormous in coming decades. Particularly, it is expected that these climate related impacts will be high among smallholder farm-households, considering that they are already among the most vulnerable in terms of pest and disease outbreaks, market shocks, and extreme events (e.g. droughts and floods). Moreover, the milieu for farm-household livelihoods in Ghana, especially in the northern parts, is already being altered by recent trends in climate variability and extremes. Most notably are those within the Sudan Savannah Zone, where livelihoods are largely related to rain-fed agriculture. With all these acknowledgements by stakeholders, it is interesting to note that declines in crop yield, the resultant food insecurity, and general loss of livelihoods still constitute a major problem in the zone.

This project found that there are significant relationships between the availability of, and accessibility to, sustainable livelihood assets and the extent to which a farm-household may be exposed, vulnerable and able to engage in adaptation. This research also demonstrated that using both secondary biophysical data and farm-household level primary data within the ambit of mixed methods, allows for a more holistic and nuanced discussion and understanding of how social-ecological systemic (SES) determinants shape the exposure, vulnerability, and adaptation dynamics in farm-household systems. This thesis is founded on the argument that the effectiveness and proactive management of the direct and indirect impacts from climate variability and extremes on farm-households in Ghana may be contingent on how researchers and decision makers properly understand the dynamics within these farming systems. Again, the disaggregation of results by gender of household head and district, presented a detailed picture of how climate exposure and vulnerability varied at the local level. Understanding these variations is fundamental to the success of any adaptation initiative, particularly at the local level. These dynamics, as established in this thesis, is empirical confirmation that a one-size-fits-all approach to climate related responses may only lead to maladaptation.

Climate risk mapping of the study area offers a real opportunity for decision makers who seek to understand the dynamics of climate relate impacts, and to ensure sustainable agriculture under changing climatic conditions. The research also showed the potential of vulnerability assessment to provide both baseline benchmarks that could inform decisions on macro level resource allocation for vulnerable sectors (and regions), facilitate subnational level prioritisation of vulnerable households and communities, and target the underlying determinants of their vulnerabilities. Given that profound societal changes are needed for sustainable climate adaptation, understanding local level awareness of climate risk factors, the related threat perceptions, determinants of, and barriers to, local level adaptation efforts constitute essential ingredients for the improvement of any climate-related household and community engagement in the context of resilience building.

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Appendices

Appendix A: Ethics approval letter

THE UNIVERSITY of ADELAIDE

RESEARCH BRANCH
OFFICE OF RESEARCH ETHICS, COMPLIANCE AND INTEGRITY
THE UNIVERSITY OF ADELAIDE

LEVEL 4, RUNDLE MALL PLAZA
50 RUNDLE MALL
ADELAIDE SA 5000 AUSTRALIA

TELEPHONE +61 8 8313 5137
FACSIMILE +61 8 8313 3700
EMAIL hrec@adelaide.edu.au

CRICOS Provider Number 00123M

30 June 2016

Associate Professor M Nursey-Bray
School of Social Sciences

Dear Associate Professor Nursey-Bray

ETHICS APPROVAL No: **H-2016-139**

PROJECT TITLE: **Climate variability and smallholder farming systems in the Sudan Savannah zone, Ghana**

The ethics application for the above project has been reviewed by the Low Risk Human Research Ethics Review Group (Faculty of Arts and Faculty of the Professions) and is deemed to meet the requirements of the *National Statement on Ethical Conduct in Human Research (2007)* involving no more than low risk for research participants. You are authorised to commence your research on **30 Jun 2016**.

Ethics approval is granted for three years and is subject to satisfactory annual reporting. The form titled *Annual Report on Project Status* is to be used when reporting annual progress and project completion and can be downloaded at http://www.adelaide.edu.au/ethics/human/guidelines/reporting. Prior to expiry, ethics approval may be extended for a further period.

Participants in the study are to be given a copy of the Information Sheet and the signed Consent Form to retain. It is also a condition of approval that you **immediately report** anything which might warrant review of ethical approval including:

- serious or unexpected adverse effects on participants,
- previously unforeseen events which might affect continued ethical acceptability of the project,
- proposed changes to the protocol; and
- the project is discontinued before the expected date of completion.

Please refer to the following ethics approval document for any additional conditions that may apply to this project.

Yours sincerely

DR JOHN TIBBY
Co-Convenor
Low Risk Human Research Ethics Review Group
(Faculty of Arts and Faculty of the Professions)

Appendix B: Farm-household survey questionnaire

Research title:

Climate Variability and Smallholder Farming System in the Sudan Savannah zone of Ghana

Project summary

This project seeks to assess the social-ecological systemic (SES) characteristics underlying smallholder farmers and communities vulnerable or resilience to droughts in the Sudan Savannah agroecological zone of Ghana. Addressing these gap in this research will provide useful insights into the characteristics and drivers of vulnerability, presenting lessons for adaptation in smallholder farming in your community and Ghana in general.

This research is supported by the Department of Geography, Environment, and Population in the University of Adelaide, Australia. It is supervised by Dr. Melissa Nursey-Bray and Dr. Dianne Rudd, all from the above mentioned Department. For any enquiries contact the following:

Name: Dr. Melissa Nursey-Bray

Tel:

Email: melissa.nursey-bray@adelaide.edu.au

OR

Name**:** Dr. Dianne Rudd

Tel:

Email: Dianne.rudd@adelaide.edu.au

Declaration

The data sort during this survey is mainly for academic purposes. As a result, the confidentiality of your identity and the other information you may divulge is assured.

Identification

Household ID:	Date:
**Are you the Household Head? Yes[ ] No[ ]	**If yes, What is your name:
Zone ID:	District name:
Community Name:	Community code:
Enumerator name:	
Start time:	End time:
**Note: Crosscheck the name of the household head with the name on the sampled list. If he is not the HH probe till you get the HH or an appropriate household reference person.	

A. Household characteristics

A1. How many persons currently live in this household?..

A2. Could you please supply the following information for all persons currently living here:

Person No.	**Relationship with head/reference person**	**Age (years)**	**Sex**	**Marital status**	**Education attainment**	**Farming experience (in years)**
a						
b						
c						
d						
e						
f						
G						
	1. Head/reference person 2. Spouse 3. Daughter 4. Son 5. Grandchild 6. Parent/parent in-law 7. Other…………	Age in years	1. Male 2. Female	1. Never married 2. Married 3.Separated 4. Divorced 5.Widowed	1. No formal education 2. Basic (primary /junior secondary/ middle school 3. Secondary (Senior secondary/ vocational training 4. Tertiary (University/ polytechnic/ collage of education)	Years of farming

A3. House ownership: 1. Owned [ ] 2. Family owned [ ] 3. Rented [ ] 4. Other [ ], please specify…………………………………………………………………………..

A4. House Structure:
a. Roof: 1. Thatch [ ] 2. Iron sheet [ ] 3. Mixed 4. Other [ ], please specify…………

b. Walls: 1. Wood [ ] 2. Concrete [ ] 3. Mixed [ ] 4. Other [ ], please specify………..

c. Floor: 1. Earthen [ ] 2. Wood [ ] 3. Concrete [ ] 4. Mixed [ ] 5. Other [ ], please specify..

d. Overall condition: 1. good [ ] 2. Average [ ] 3. Poor / needs repair

A5. Household water source:

a. For domestic purposes: 1. Pipe-borne [ ] 2. Borehole 3. Dugout well [ ] 4. Stream water [ ] 5. Other [ ], please specify……….....
b. For farming purposes: 1. Pipe-borne [ ] 2. Borehole 3. Dugout well [ ] 4. Stream water [ ] 5. Other [ ], please specify……………
c. Other [ ], please specify……………………………………………………

B. Household farm characteristics

Could you please tell us about the characteristics of your main farm by supplying information on the following questions:

B1. How many farmlands (properties) do you have?......................

B2. Could you please estimate the size of your main farmland (Property)?.........................

B3. What type of tenure does your main farmland have?

1. Owner
2. Family owned
3. Short rent
4. Long rent
5. Others, please specify……………………………………………..

B4. How do you rank the soil fertility of your main farmland?

1. Low
2. Medium
3. **3.** High

B5. Please explain your answer in question B4?…………………………………
…………………………………………………………………………………….
…………………………………………………………………………………….

C. Household food production and consumption

C1. Please supply information on crop production in the last season:

No.	**Crops**	**Yield**	**Quantity consumed**	**Quantity sold**	**Income from sale**
a	Maize				
b	Millet				
c	Sorghum				
d	Rice				
e	Soya beans				
f	Bambara beans				
g	Vegetables				
h	Tree crops (cash crops)				
i	Other, specify… ………………..				
Notes:					

C2. Does your household depend on its own production of food?

1. Yes [ ] Go to question C3
2. No [ ] Go to question D1

C3. What percentage of your household food do you produce?

1. ≤ 20%

2. 21-40
3. 41-60
4. 61-80
5. ≥ 81

E. Household food security

D1. Are there times within the year that your household does not have enough food?

1. Yes [ ] Go to questions D2, D3, & D4
2. No [ ] Go to question E1

D2. How many months in a year does your household struggle to get enough food?

1. 1-3 months
2. 3-6 months
3. > 6 months

D3. During which period of the year does your household struggle the most to get enough food? **(Multiple answers allowed)**

1. January to April
2. May – August
3. September - December

D4. How does the household cope with food shortages during these periods? (**Multiple answers allowed**)

1. Buy food from market
2. Friends and relatives bring us food
3. Reduce food intake
4. Other, please specify…………………………………………………………….

E. Household Livestock

E1. Does your household own any livestock?

1. Yes [ ] Go to question E2
2. No [ ] Go to question F1

E2. Please supply information on household livestock in the following table (**Multiple answers allowed):**

No.	**Livestock/poultry**	**Quantity**	**Estimated income**
a	Goats		
b	Sheep		
c	Cattle		
d	Pigs		
e	Drought animals (e.g. bullocks and donkeys)		
f	Chickens		
g	Guinea Fowls		

h	Ducks		
i	Others, please specify………………..		

F. Household livelihood diversification and alternative income sources

F1. Do you or any members of your household engage in any other livelihood activities apart from farming?

1. Yes [ ] Go questions F2 and F3
2. No [ ] Go to question G1

F2. How many members of your household engage in other livelihood activities?
………………………………………………………………………………….

F3. Do you or other household members of your household engage in any of the following livelihood activities? (**Multiple answers allowed**)

No.	Livelihood activities	Tick box	
		Yes	No
a	Occasional off-farm work (e.g. labour)		
b	Handicrafts (e.g. weaving and wood carving)		
c	Fishing		
d	Commerce (small scale trading)		
e	Mining		
f	Salaried permanent work		
g	Charcoal production		
h	Logging		
i	Shea butter processing		
j	Rice processing		
k	Local alcohol brewing		
l	Other, please specify………		

G. External income and migration

G1. Do you have family members and/or friends working outside the community?

1. Yes
2. No

G2. Do you receive any remittance from family members and/or friends who live outside this community?

1. Yes [   ] Go to question G3
2. No [   ] Go to question G4

G3. Approximately, how much do you receive as remittance from relatives and/or friends in a year?

1. ≤ 100 GhS
2. 101 – 300 GhS
3. 301 – 400 GhS
4. 401- 500 GhS

5. ≥ 501 GhS

G4. Do you have any intentions of moving away from this community or sending any household member to the city?

1. Yes [ ] Go to question G5 & G6
2. No [ ] Go to question H1

G5. Who in the household is most likely to go?

1. Household head
2. Spouse
3. Son/daughter
4. Brother/sister
5. Other, please specify………………….

G6. What are the reasons for moving away from this community or sending any household member to the city? ………………………………………………………….
………………………………………………………………………………………………
……………………………………………………………………………………………...

H. Social network

H1. Do you belong to any group or association?

1. Yes [ ] Go to question H2
2. No [ ] Go to question I1

H2. Could you please supply information on the type of group, the benefits from the group, and your contribution to the group: **Multiple answers allowed.**

No.	Name of group/association	Name of group	Benefits from the group	Contribution to the group
a	Faith-based			
b	Communal			
c	Farm-based			
d	Other, please specify………................. ……………………………			

I. Household physical assets

I1. Do you or any member of your household own any of the following assets? **(Multiple answers allowed)**

No.	Physical assets	Tick box	
		Yes	No
a	Radio set		
b	TV set		
c	Mobile phone/Landline		
d	Mosquito nets		
e	Tricycle/Bicycle		
f	Car/Motor bicycle		
g	Sewing machine		
h	Water tank/Well		
i	Hoe/cutlass/pickaxe/shovel		
j	Tractor		
k	Plough (wooden/Iron)		
l	Pesticide/weedicide sprayer		
m	Wheel Barrow		
n	Diesel/electric irrigation pump		
o	Fodder cutting machine		

J. Public services

J2. How do you rate your satisfaction with the services you have used in this community? Please choose any number from 1(very unsatisfactory) to 5 (very satisfactory) that best describes your opinion.

No.	Services	Very unsatisfactory		Average		Very satisfactory
a	Agricultural extension services	1	2	3	4	5
b	Access to credit (formal & informal)	1	2	3	4	5
c	Irrigation Services	1	2	3	4	5
d	Market (input/output)	1	2	3	4	5
e	Education services(public/private	1	2	3	4	5
f	Health care services (public/private)	1	2	3	4	5

K. Awareness of Climate variability (droughts) and its effect on livelihood

K1. To what extent do you agree with the following statements? Please choose any number from 1 (strongly disagree) to 5(strongly agree) that best fits your opinion.

No.	Statement	Strongly disagree		Neutral\DK		Strongly agree
a	The average temperature in recent years is higher than 10 years ago	1	2	3	4	5
b	The average rainfall in recent years is higher than 10 years ago	1	2	3	4	5
c	Unseasonal and erratic rainfall is more frequent now than 10 years ago	1	2	3	4	5
d	Droughts, floods, storms in recent years are more frequent than 10 years ago	1	2	3	4	5
e	The dry season comes sooner now than 10 years ago	1	2	3	4	5

K2. How many times have you witnessed the following climatic phenomena in the last five (5) years?

No.	Climate phenomena	Number of times
a	Severe drought	
b	Severe floods	
c	Unseasonal and erratic rainfall (storms)	
d	Hotter weather conditions (heat waves)	
e	Lower river/dam/stream/Well levels	

K3. Could you tell us to what extent you agree with the following statements? Please choose any number from 1 (strongly disagree) to 5(strongly agree) that best fits your opinion.

No.	Statement	Strongly disagree		Neutral/DK		Strongly agree
a	Unusual timing of season negatively affects crop productivity	1	2	3	4	5
b	Higher temperatures cause more diseases for humans, livestock, and crops	1	2	3	4	5
c	Prolonged droughts negatively affect crop output	1	2	3	4	5
d	Droughts, floods, storms cause damage to human, natural, and physical assets	1	2	3	4	5

K4. To what extent do you think climate variability could threaten the following dimensions of your life in the coming years? Please choose any number from 1(very unlikely) to 5(very likely) that best fit your opinion.

No.	Dimensions	Very unlikely		Average/DK		Very likely
a	Physical health, diseases	1	2	3	4	5
b	Income	1	2	3	4	5
c	Physical assets (e.g. house, land, furniture, farm machines etc.)	1	2	3	4	5
d	Natural capital (e.g. water sources, soil nutrients, etc.)					
e	Crop and livestock productivity	1	2	3	4	5
f	Social networks (e.g. friends, relatives, neighbors, etc.)	1	2	3	4	5
g	Food intake					
h	Happiness in general					

L. Household climate adaptation strategies

L1. Have you ever used any of the following measures in response to climate variability on your own without external initiative? **If none, go to question N1.**

No.	Adaptive measures	Tick box	
		Yes	No
1a	Early planting or harvesting		
1b	Shortening the growing seasoning		
2a	Changing the irrigation method		
2b	Changing fertilizer use		
2c	Changing tilling method		
3a	Growing several crops		
3b	Using different varieties		
3c	Using crop rotation		
4a	Using soil conservation methods		
5a	Combining non-farm and farm activities		
5b	Combining crop production and livestock rearing		
6a	Relocating or reinforcing houses		
6b	Planting trees		
6c	Buying insurance (human, physical assets, agricultural insurance)		
6d	Migrating to other communities		

L2. How do you perceive your own ability to use/perform the adaptive measures? ……………………………………………………………………………………………………… ……………………………………………………………………………………………

L3. How would you rate the cost of implementing the above adaptive measures (in terms of money, time, and effort)?

1. High
2. Medium
3. Low

M. Public/community climate adaptation strategies

M1. Could you please indicate whether any of the following public/community adaptive measures have been implemented by any institution (local authorities, government, NGOs, CBOs etc.).

No.	Public adaptive measures	Tick box	
		Yes	No
a	Propagating disaster warning information through public media		
b	Training in drought or flood management		
c	Building drought or flood management plans		
d	Building irrigation facilities		
e	Introducing and encouraging farmers to grow new varieties (drought-resistant)		
f	Encouraging farmers to switch crops in response to variability in climate by providing varieties and support		
g	Building and circulating planting calendar		
h	Planting trees		
i	Other, please specify………………		

M2. To what extent do you agree with the following statements? Please choose any number from 1 (strongly disagree) to 5 (strongly agree) that best describes your opinion.

No.	Statement	Strongly disagree		Neutral/ Don't Know		Strongly agree
a	Public adaptation measures are implemented well in advance	1	2	3	4	5
b	Public adaptation measures are very effective	1	2	3	4	5
c	The government provides early warning information					
d	Public disaster warning system is effective	1	2	3	4	5
e	Formal and informal institutions have prompt solutions to post-disaster problems	1	2	3	4	5
f	Formal and informal institutions support the buying of agricultural insurance for poor households	1	2	3	4	5
g	Increase in utility tariffs, fuel, and fees are a disincentive to adaptation (e.g. electricity, water, health insurance levies, school fees etc.)	1	2	3	4	5

N. Information sources

N1. Do you use any of the following information sources?

No.	**Sources**	**Tick Box**	
		Yes	**No**
a	Public Media (newspapers, radio, television, etc.)		
b	Friends, relatives, neighbors,		
c	Farmer associations		
d	Formal and informal institutions who come around regularly (DADU, extension officers, NGOs, CBOs, etc.)		

N2. How does the information you receive aid your livelihood activities?
……………………………………………………………………………………………………
……………………………………………………………………………………………………
N3. How satisfied are you with the information from the following sources? Please choose any number from 1(very unsatisfactory) to 5 (very satisfactory) that best describes your opinion.

No.	Sources	Very unsatisfactory		Average		Very satisfactory
a	Public Media (newspapers, radio, television, etc.)	1	2	3	4	5
b	Friends, relatives, neighbors,	1	2	3	4	5
c	Farmer associations	1	2	3	4	5
d	Formal and informal institutions who come around regularly (DADU, extension officers, NGOs, CBOs, etc.)	1	2	3	4	5

O4. In general, what would you say are the main three issues when it comes to climate variability and livelihoods in this community?

a. ……………………………………………………………………………………..
b. ……………………………………………………………………………………..
c. ……………………………………………………………………………………..

Your time in this interview is very much appreciated. Thank you very much.

Appendix C: Focus Group Discussion (FGDs) guide

Focus Group Discussion (FGDs) with selected farm-household heads

Project title: Climate variability and smallholder farming systems in the Sudan Savannah of Ghana

A. General development challenges

1. What are the major development challenges in this community?
2. What steps have been taken over the years to reduce these challenges?
3. Have these interventions been successful? If no, why? If yes, how?

B. Climate variability and extreme events

1. What does climate variability and change mean to you?
2. In the last 10 years, what climate-related events have you experienced in this community in recent years? Which of these events have you been experiencing frequently? Please kindly rank the climate related events in order of frequency of occurrence.
3. What has been the impacts of these climate events on your livelihoods? Kindly rank these impacts in order of severity.

C. Adaptive capacities

1. What types of livelihood assets (Financial, human, social, natural, physical resources) are mostly owned and controlled by a farm-household? Please kindly rank these resources based on their importance during climate-related events (droughts).
2. What types of livelihood assets (Financial, human, social, natural, physical resources) are mostly owned and controlled by the community? Please kindly rank these resources based on their importance during climate-related events (droughts).
3. In what ways are these livelihood assets (Financial, human, social, natural, physical resources) vulnerable or resilient to climate events?
4. What type of relationship exists among community members? Is it supportive or exploitative, especially during periods of climate extremes (droughts/floods)?
5. What is the basis of this relationship among community members?

6. What institutions (formal or informal) have been involved in building adaptive capacity (enhanced availability of and access to livelihood assets) in this community? Please rank these institutions by their relevance, especially during climate events.
7. Are you involved in the decision making processes in these institutions, especially on issues concerning your household and this community? If yes, how are you involved? If no, what do you think is/are the reason(s)?

D. Adaptive actions

1. What strategies do you, as a household, undertake to adapt to climate events (e.g. droughts/floods)?
2. What strategies do you, as a community, undertake to adapt to climate events (e.g. droughts/floods)?
3. Do you receive any support from the formal and informal institutions with regards to these strategies? If yes, what are the specific opportunities/benefits presented by these institutions, especially during climate events? If no, what are the barriers to your access of the opportunities/benefits from these institutions?
4. Are you aware of any climate mitigation or adaptations plans by the District Assembly, District Agricultural Development Unit, District Environmental Committee, Environmental protection Agency, Community council, or Area Unit Committee? If yes, what are these plans?