AN INTEGRATED APPROACH TO CLIMATE VULNERABILITY AND ADAPTATION ASSESSMENT OF SMALLHOLDER PRODUCTION SYSTEMS: EVIDENCE FROM HORTICULTURAL PRODUCTION IN GHANA

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INCLUSION OF PUBLICATIONS DECLARATION

I confirm that I have been granted permission by the University of Cape Town's Doctoral Degrees Board to include the following publication(s) in my PhD thesis, and where co-authorships are involved, my co-authors have agreed that I may include the publication(s):

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DEDICATION

To my wonderful husband, great enthusiast and friend Edward Kwei Williams as well as my children Elvin, Ellis and Elvis. Your unflinching love, daily prayers, emotional support and encouragement have brought me this far.

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Think globally, act locally!

ABSTRACT

The consequences of changing climate mainly impact negatively on agricultural production, particularly smallholder producers. Despite increased research on vulnerability and adaptation, African countries have still not realized their full potential in adapting to changing climate. Climate vulnerability assessments show limited use in guiding decision support for adopting proposed adaptation responses identified. This study examines climate vulnerability of smallholder producers and economically evaluates adaptation strategies identified. This is to enhance vulnerability assessment practice and provide support for decision-making on adoption to influence local level planning and actions on climate adaptation. The study further explores approaches to vulnerability assessment that link climate adaptation process. Smallholder horticultural production system in Ghana provided an appropriate case for this study. Mixed methods approach that combined field surveys, in-depth interviews, focus group discussions and field observations in two horticultural growing municipalities in Ghana (Keta and Nsawam) were adopted. Both qualitative and quantitative inputs for analysis were obtained. Specifically, a combination of theoretical insights from livelihood analysis (Livelihood Vulnerability Index) with an appraisal method (Cost Benefit Analysis) arising from an investment in adaptation options was used as the analytical framework for the study. Smallholder farmers in both case study sites showed different vulnerabilities based on their levels of exposure, sensitivity and adaptive capacity. Local knowledge, perceptions and effects of climatic trends (eg. increasing temperature and decreasing rainfall) on farmers' livelihoods resulted in identification of about twenty-four strategies practiced by farmers to manage changing climate. Costs and benefits analysis of the first five adaptation strategies indicated economic effectiveness both privately and publicly if adopted. However, in consideration of other factors like capital required, payback period for investments made and risks from implementation, two of the adaptation strategies particularly appeared as most suited choices while the role of targeted and dedicated external institutional, policy and stakeholders' support turned out to be paramount for successful adaptation. These observations have implications for the degree of influence vulnerability assessment has for local level planning and actions on climate adaptation. The study underscores vulnerability and adaptation should be considered synergistically. It therefore proposes a framing of vulnerability assessment to explicitly incorporate adaptation actions and their benefits to reduce vulnerability and provide better linkages to decision-making and policy relevance. Making decision support a major outcome from vulnerability assessment extends assessment outcomes from identification of vulnerable people/places to include identification and evaluation of adaptation responses, which facilitate the prioritization and selection of adaptation options for adoption. It concludes by highlighting pathways to reduce the vulnerability of farming communities such as exploring opportunities to expand a system's adaptive capacity through empowering farmers' socially and economically. Extra knowledge and policy interventions in vulnerability and adaptation discourse are further suggested to promote and encourage adaptation efforts.

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LIST OF ABBREVIATIONS

AP	Adaptation Practice
AEA	Agricultural Extension Agent
AP	Agricultural Production
AIS	Alternative Income Source
ANOVA	Analysis of Variance
ADP	Area Development Programme
AR	Assessment Report
CC	Climate Change
CCA	Climate Change Adaptation
CV	Climate Variability
CRA	Community Risk Assessment
CDD	Consecutive Dry Days
CWD	Consecutive Wet Days
CBA	Cost-Benefit Analysis
DRR	Disaster Risk Reduction
FAO	Food and Agricultural Organisation
FBO	Farmer Based Organization
FGD	Focus Group Discussions
GIS	Geographical Information Services
GCAP	Ghana Commercial Agriculture Project
GIRSAL	Ghana Incentive-Based Risk Sharing System for Agricultural Lending
GMet	Ghana Meteorological Agency
GPRS	Ghana Poverty Reduction Strategy
GSS	Ghana Statistical Service
GHG	Greenhouse Gas
GoG	Government of Ghana
GDP	Gross Domestic Product
IPM	Integrated Pest Management
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
ISI	International Scientific Indexing
KII	Key Informant Interviews
LVI	Livelihood Vulnerability Index
MoFA	Ministry of Food and Agriculture
NPV	Net Present Value

NGO	Non-Governmental Organization
OECD	Organisation for Economic Co-operation and Development
OP	Other Practice
PAR	Participatory Action Research
PCA	Principal Components Analysis
RCP	Representative Concentration Pathway
SIRR	Social Internal Rate of Return
SNPV	Social Net Present Values
SES	Socio-Ecological Systems
SSA	sub-Saharan Africa
SLF	Sustainable Livelihoods Framework
SLA	Sustainable Livelihoods Approach
SLR	Systematic Literature Review
VAoSAS	Vulnerability Assessment of Smallholder Agricultural Systems
WAI	Weighted Average Index

CHAPTER 1

GENERAL INTRODUCTION

This chapter provides a general orientation of the study. It begins by describing the background of the study and putting the study into context. It explains the issues relating to climate adaptation among smallholder farmers in Ghana and Africa. This leads to the problem the thesis addresses. The chapter also provides the study's research question, aim and objectives. The rationale for the study, theoretical and methodological overviews is described emphasizing on the study's contribution to scientific knowledge and policy. Finally structure of the thesis is presented.

1.1 Background to the study

Sub-Saharan Africa (SSA) is considered a rapidly developing region and one of the fastest growing economies in the world (Carabine et al., 2014). Economically, majority of Africans depend on agriculture for their food and income. Rising temperatures and erratic rainfall patterns (two very important variables for crop growth) are affecting agriculture by reducing crop productivity across Africa (Pereira, 2017). There is evidence of warming temperature of 0.5°C or more and erratic changes in rainfall patterns in the last two decades (Niang et al., 2014a). Agriculture in SSA is characterized mainly by rain-fed small scale production systems with limited human, social and economic capacity to adapt to the impacts of changing climate (Filho et al., 2015). Increasing demographic trends denote an increase in demand for food and water sources (Carabine et al., 2014). Climate change is also noted to interact with non-climate drivers and stressors like development processes to exacerbate vulnerability of agricultural systems (Niang et al., 2014a). Additionally, extreme events such as droughts would reduce water resources and further affect crop productivity (Carabine et al., 2014). Consequently, risk to food security could become more intense under a changing climate and possibly feedback into development, thereby increasing poverty (Shackleton et al., 2015). Smallholder production systems provide livelihood to more than half of the total agricultural workforce in SSA (OECD/FAO, 2016a). Interventions that succeed in improving productivity of smallholder farmers have the potential to reduce poverty, improve food security and contribute to climate mitigation and adaptation efforts (Fan et al., 2013) which subsequently addresses achieving some priorities in the United Nations Sustainable Development Goals (SDGs). The overall positive contribution of smallholders to agriculture in SSA economies increases interest for its development. Meanwhile, limited financial resources, over reliance on natural resources, market volatility and changing climatic conditions that further compounds production activities characterizes and underpins smallholders' production activities and limit their uptake of improved technologies and marketing opportunities (Morton, 2007).

There is proliferation of studies on adaptation of smallholder farming systems (Below et al., 2010; Ford et al., 2011; Sietz et al., 2012; Antwi-Agyei, 2012; Burnham and Ma, 2016; Donatti et al., 2018). According to Burnham et al., (2013), without the understanding of how vulnerable a system is to climate and non-climatic stressors, adaptations may inadvertently result in deepened vulnerability and put local actors into an even less advantaged position. Vulnerability assessment forms the basis to identify key risks to respond to and for successful implementation of adaptation practices (Ndamani and Watanabe, 2017). Understanding how smallholder farmers have or have not successfully adapted to changing climate is therefore consequent to understanding how vulnerable their system is. The focus of adaptation strategies in the 2000s on solely technological solutions is evolving toward a broader view that highlights the importance of building resilience through social, institutional and informational approaches (Chambwera and Anderson, 2011). There is a growing recognition that livelihood-vulnerability risks are a challenge for adaptation (Panthi et al., 2016; Rurinda et al., 2014; Tschakert and Dietrich, 2010). Methodologically and conceptually, vulnerability and adaption as separate scholarships are well understood (Preston and Stafford-Smith, 2009; Preston, 2012). However, as recently argued by Donatti et al. (2018), improving linkage between the two concepts for more successful engagement is essential to build better adaptive capacity to risks and stresses under changing climate. Importantly, people's ability to respond to risks is typically determined by dynamic livelihood decisions that depend on household resources and their allocation to generate benefits and pursue a meaningful life (Kelly and Adger, 2000). Livelihood-vulnerability contexts are therefore essential for successful adaptation.

1.2 Problem statement

The African continent is vulnerable to climate variability and change and such impacts are expected to pose further challenges to food security, livelihoods and wellbeing for the remainder of this century (Pereira, 2017). There is the possibility of a faster temperature increase in Africa than in other regions (Riede et al., 2016) while changes in precipitation patterns and existing water stress will be likely amplified, putting even more pressure on agricultural systems (Riede et al., 2016). It is noted that without adequate measures to adapt, these risks could become more intense and under scenarios approaching 4°C warming, the risk to food security in Africa could be very severe with limited potential for reducing risk (IPCC, 2014a). Climatic impacts will affect farmers and their production systems in different ways hence adapting to these impacts will need to be context-specific (Niang et al., 2014b). The Sahel and tropical West Africa for instance are considered hotspots of climate change under both the Representative Concentration Pathway (RCP) 4.5 and RCP8.5 pathways, and it is expected that unprecedented climates will occur earlier in these regions (Mora et al., 2013). This is due to the small natural variability in climate that the region currently experiences (Mora et al., 2013). People's lives and livelihoods are consequently impacted by the seasonal and yearly variability in climate. Depending on the adaptive capacity of a society, these impacts might result in increased vulnerability (Riede et al., 2016). To consider adaptation, emphasis of the process is expected to include learning about risks, evaluating response options and creating the right conditions with interest in decision making for adaptive actions (Ford et al., 2018). Meanwhile, access to information and knowledge networks that build resilience into people's livelihoods, institutions, and ecosystems remain scarce especially at the local level in Africa (Tschakert and Dietrich, 2010; Donatti et al., 2018).

An effective analysis of climate risk and vulnerability in agriculture is fundamental to developing viable adaptation options to manage present and future anticipated risks (Ndamani and Watanabe, 2017). This implies that research efforts should be concerned with the ways in which vulnerability assessments can advance resilience of vulnerable communities to improve their adaptive capacity, planning and actions. Much of the research on vulnerability has been critiqued for its limited influence regarding decision support on climate adaptation (Ford et al., 2018; Donatti et al., 2018; Preston et al., 2011). Growing interest for improvement in the comprehensiveness of the assessment criteria requires contextual activities and processes (Preston, 2012), thus the need for more detailed local-level analyses on climate risk-reduction within the African context. The challenge however is how assessing vulnerability can link to identifying adaptive responses and influence decision-making on adaptation that can facilitate planning and actions. A combination of theoretical insights from livelihood analysis with an appraisal method that best provides analysis on gains and losses arising from investment in adaptation options could enhance understanding the concept of climate vulnerability for improvement in adaptation. This arises from the increasing awareness of potential climatic impacts particularly on smallholders' production system and the consequent need to advance adaptation policies considering this livelihood group. Smallholders operate their farms as entrepreneurs, thereby, raising capital from multiple sources and investing in productive assets, making decisions as well as taking both risks and profits (Rapsomanikis, 2015). According to Gollin (2014), interventions that allow smallholders to overcome transaction costs might be attractive to them. Such ways may be used to target adaptation interventions for the resource constrained smallholder farmers. Nevertheless, at different places and different times, vulnerability and exposure of societies to climate-related hazards consistently vary because of changes in economic, social, demographic, cultural, institutional and governance circumstances (Carabine et al., 2014). This buttresses the need for context specificity in society's adaptive capacity and strategies to strengthen resilience and reduce vulnerability.

Ghana is a West African country and an appropriate case to study the issues raised. Climate variability and change pose a severe threat to its future growth and development (USAID, 2017). Ghana ranked second on the African continent as the most exposed nation to risks from multiple weather-related hazards, closely following Ethiopia (World Bank and ISDR, 2009). Increasing temperature (an average increase of 0.21°C per decade); erratic rainfall patterns (cumulative reduction of 2.4 percent per decade); rise in sea level (63 mm over the past 30years) and average coastal erosion (1.13 m per year) have been identified as the major climate related challenges (Arndt et al., 2015; USAID, 2017). These changes are negatively impacting food security, coastal and agricultural livelihoods. Such changes in climate are projected to continue over the next decades (Stanturf et al., 2011; USAID, 2017). Meanwhile, agricultural production in Ghana mainly relies on small, rain fed plots that are highly vulnerable to the climatic impacts with only 2 percent of the country's irrigation potential being tapped (World Bank, 2011). Despite the country's transition into industry and services-oriented economy, between 2011 and 2017, agriculture contributed an average of 21.4% to Gross Domestic Product (GDP) (ISSER, 2018). Implementation of climate change activities has been slow, but the government has made a concerted effort to integrate climate change objectives and priorities into sector-specific development plans in agriculture, transportation and energy to mainstream climate change strategies (USAID, 2017). With such conditions, assessing risks and vulnerabilities is paramount to enhancing the adaptive capacity, planning and actions of stakeholders (particularly smallholders and policy makers).

There has been policy demands on the quality of food, calling for an increased focus on more nutritious crops, beyond the major energy-providing crops (Pingali, 2015). Even the International Panel of Experts on Sustainable Food Systems have also observed that under the current conditions, agricultural systems fail to address nutritional status of more than 2 billion people who suffer from micro-nutrient deficiencies (IPES-Food, 2016). This has been partly blamed on insufficient production levels of nutrient-rich crops required for healthy human nutrition (Siegel et al., 2014). Vranken et al. (2014) note that future agricultural systems will have to account for increasing changes in consumer demands on more nutritious foods such as horticultural crops (Manners and van Etten, 2018). Horticultural crops (fruits and vegetables) are a rich source of vitamins and minerals essential to human nutrition (Datta, 2013). Trends in demand for and consumption of fruits and vegetables have globally increased in recent years. In Ghana for instance, demand in the domestic vegetable market alone in the past decade has been growing at more than 10 percent per year (NAB Council, 2014). Moreover, promotion of horticultural crops has been on the agenda of successive development plans such as the Vision 2020, Ghana’s 25-year development plan that was drawn for the period 1995 to 2020 and its successor plans, the Ghana Poverty Reduction Strategy (GPRS I & II) and Ghana Shared Growth and Development Agenda (GSGDA I & II) (Williams et al., 2017). Studies on vulnerability and adaptation related to horticultural production have been conducted in India (Sthapit et al., 2012), Australia (Sutherst et al., 2000), and Mozambique (Vilissa, 2016). Such studies are limited in Ghana. Research within the sector has been limited to climate change and variability impact on production (Williams et al., 2017; Guodaar, 2015). Climate plays a significant role in plant growth and productivity and despite the increasing demand rate, a study by Arndt et al. (2015) indicated that yields are expected to decline for horticultural crops under climate scenarios studied in Ghana. Climate related challenges identified within the horticultural sector include limited water availability, crop damage due to high temperature and increasing unpredictability of weather (floods and droughts) with resultant new pests, diseases and weeds attack (Future Farming, 2014). As the effects of climate change become more evident, it is essential that growers develop their production activities to adapt to these changes, maximizing the opportunities and minimizing costs and risks (Future Farming, 2014). Drawing from insights of identified risks and structural limited resourcefulness of farmers, smallholder horticultural production systems in Ghana is a relevant location and socioeconomic context to look at.

This study responds to the need for greater uptake and implementation of adaptation measures as well as generally ensuring adaptation is mainstreamed into agricultural development strategies and plans. As necessary factors of such ambition, vulnerability and adaptation assessment would benefit from establishing an assessment at the local level to integrate appraisal of potential adaptation options. This could enhance stakeholders’ decision making in implementing adaptation options identified given limited resources. Even though farmers are the ones who bear the majority of production costs, Tschakert (2004) notes that without consistent policy support, farmers may not be able to do enough to create a sustainable, productive and resilient agriculture sector. This is because farm businesses devote their resources toward more pressing appropriate response to climate and market opportunities over the next few seasons (Addai, 2013). But adaptation options come with a range of transaction costs (Boko et al., 2007). If this is true, conditions that make adaptation practices financially profitable will likely also be effective at stimulating adoption rates among farmers. A study on economic analysis for small-scale farming systems further revealed that crop management practices that include economically important by-products or ancillary benefits will be more profitable and attractive to farmers, independent of their wealth status (Tschakert, 2004). Therefore economic assessments which enhance understanding likelihood of a practice to be adopted and maintained, complement the understanding of impacts practices will have on specific users and time frames (Daigneault et al., 2016). There is insufficient information regarding the various economic, social and political issues that play a role in constructing farmers' vulnerability and potential returns for adaptation strategies at the farm level (Easterling et al., 2007; Ng'ang'a et al., 2017a). Meanwhile, international discourse of adaptation assessment is changing purposes to a vulnerability led approach as earlier noted. A dedicated framing in terms of conceptualization and methods for local level assessment for smallholders will contribute to knowledge in climate adaptation development practice. This warrants the need for an interdisciplinary approach to holistically assess smallholder-farming system in relation to vulnerability and adaptation to identify climate resilient actions and better understand their effectiveness for implementation and uptake. While the focus of this research is on local level livelihoods of vulnerable smallholders, this is done in order to inform need for adaptation and to guide more efficient use of scarce resources with consequences for increased productivity, policy and projects at multi scale levels more widely.

1.3 Research question, aim and objectives

1.3.1 Research question

The main question guiding this study is: How can vulnerability assessment of smallholder agricultural systems be enhanced to enable effective climate adaptation planning and actions at the local level?

1.3.2 Research aim

The overall aim of this thesis is to link vulnerability and adaptation study approaches by assessing vulnerability of smallholders to climate variability and economically evaluating proposed adaptation strategies. Such an approach is to establish an improved framework for assessing vulnerability to influence local level planning and actions on climate adaptation.

1.3.3 Research objectives

To achieve the aim of this thesis, the specific objectives using smallholder horticultural producers in Ghana as a case are:

1. To assess livelihood vulnerability of smallholder producers to climate variability in Ghana.
2. To determine smallholder producers' adaptive responses that reduces vulnerability of crop production in Ghana.

3. To evaluate the economic effectiveness of adopting the most important adaptation practices identified for decision support on climate adaptation.
4. To establish an improved framework for assessing climate vulnerability and adaptation for improvement of smallholders' planning and actions on climate adaptation.

1.4 Rationale for the study

The performance of agriculture in relation to the effects of climate variability and change is one of the most researched areas especially in developing countries. Several studies have shown that the agricultural sector is one of the sectors most vulnerable to the effects of changing climate (IPCC, 2014a; OECD/FAO, 2016a). According to the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC-AR5), between 1960 and 2013 climate change had more negative than positive impacts on food production systems (IPCC, 2014b). Assessing climate vulnerability of affected sectors like agriculture is important for defining risks posed as well as provide information for identifying measures to adapt to the impacts (Ford and Smit, 2016). Studies on vulnerability assessments have therefore suggested adaptation options to diverse systems including smallholder-farming systems (Rurinda et al., 2014). Despite numerous potential adaptation options identified as a result of increase in research on vulnerability and adaptation, developing regions particularly those in Africa have not realized their full potential in climate adaptation (Kurukulasuriya et al., 2006; Ndamani and Watanabe, 2017). For instance among smallholder production systems in Africa, studies have shown that while the majority of farmers are aware of changing climate, some are still not adapting to the impacts (Bryan et al., 2009; Fosu-Mensah et al., 2012; Shackleton et al., 2015). Limited widespread adoption of adaptation measures is reported hence increased attention is given to understanding factors impeding vulnerable, natural resource dependent communities and livelihoods. A synthesis of empirical literature from sub-Saharan Africa (SSA) broadly attributed this constraint to persistent poverty and socioeconomic inequality, low levels of development, limited economic capacity as well as governance challenges on agricultural production and rural development (Shackleton et al., 2015). Other scholars have also explicitly attributed this to proposed measures failing to adequately address farmers' resource availability, socioeconomic circumstance, perceptions and concerns of climate risks (Nhantumbo et al., 2016); high risk aversion (Antwi-Agyei et al., 2015; Knowler and Bradshaw, 2007); relatively high initial costs (FAO, 2001); weak institutional support (Ngwira et al., 2014); inadequate financial resources, lack of implementing capacity, insufficient information or knowledge and need for farmers to address other more immediate pressures among others (Ndamani and Watanabe, 2017).

Notwithstanding the identified challenges, the IPCC-AR5 confirms Africa's climate is already changing and future changes is likely inevitable (Carabine et al., 2014). It further notes that benefits from global reductions in greenhouse gas emissions now will not make any difference in the climatic impacts in the next few decades until the latter half of the century (Carabine et al., 2014). This cautions that urgent adaptation in Africa will be vital throughout the coming decades. Smallholder agriculture is considered a principal economic activity and will mainly remain so for the foreseeable future (Gollin, 2014). It is therefore essential to improve farmers' productivity amidst challenges of changing climate as well as competing demographic, policy and market pressures, which compound and intensify their production conditions. Adapting to climatic impacts is considered one of the forefronts of scientific inquiry and policy negotiations (Preston et al., 2011). Importantly, adaptation discourse in Africa is growing hence reducing climatic impacts and building resilience is important. This is dependent on enhancing understanding of the process of climate vulnerability and adaptation to facilitate the planning and implementation of sustainable adaptation responses. Understanding vulnerability is a prerequisite for identifying key determinants of successful adaptation (Adger, 2003). However, ongoing scholarship on vulnerability and adaptation provide limited understanding of how decision-making processes shape resilient livelihoods (Ford et al., 2018; Preston, 2012). Adaptation scholarship has been dominant in identifying responses to the impacts of climate variability and change (Ford et al., 2018; Donatti et al., 2018; Preston and Stafford-Smith, 2009; Tschakert and Dietrich, 2010). This concentration is yet to improve our understanding of the kinds of vulnerable, dynamic and challenging climatic and socio-economic production system attributed to smallholders. Subsequently, it has led to a dearth in understanding how to enhance commensurate adaptation practices. This study therefore provides contribution in relation to research and practice of ongoing vulnerability and adaptation studies particularly for smallholder production systems. Small-scale farming systems play a dominant role in growth and poverty reduction in SSA (Gollin, 2014). Addressing issues related to horticultural smallholders and climate adaptation is a global priority in reaching the United Nations Sustainable Development Goals (SDGs) particularly of no poverty (SDG 1), zero hunger (SDG 2), good health and well-being (SDG 3) and climate action (SDG 13).

By using interdisciplinary (livelihoods and risks with economics disciplines) mixed methods for enhancing adaptation approach among smallholders, this study provides outcomes and scientific contributions such as:

- Contributing to improved understanding and theoretical knowledge on livelihood vulnerability of smallholder production systems to climate variability. This is particularly essential for horticultural production in Ghana and applicable to other local areas across Africa.

- Contributing to increased understanding and debate on potential climate adaptation strategies for smallholder production systems to impact specific policy and enhance stakeholder planning and actions on adaptation.
- Contributing to scientific knowledge and debates on the development of integrated assessment approach to vulnerability to influence decision support on climate change adaptation.
- Providing direction for development initiatives on investment in responding to a changing climate and increased understanding of challenges to climate adaptation pathway in the context of smallholder production systems.
- Providing guided policy recommendations to promote climate adaptation and mainstream it into agricultural development strategies and plans particularly in Ghana but broadly applicable.

1.5 Theoretical and conceptual overview of climate vulnerability and adaptation

Climate change literature has no unanimously agreed definition for concepts and terms such as vulnerability and adaptation. Given that definition of such major concepts are often contested in climate change debates and discourses, theoretical framing and operational definitions applicable to this thesis are provided here. Where applicable, further justifications and definitions for other terms are provided in their respective chapters to frame analysis and discussions.

1.5.1 Vulnerability

The meaning of vulnerability has been widely captured with different definitions in literature and depending on the field of study, utility of the concept also varies. O'Brien et al. (2007) identified two succinct interpretations of vulnerability as 'outcome vulnerability' and 'contextual vulnerability'. According to O'Brien et al. (2007), outcome vulnerability results from projected climate impacts on a particular biophysical or social exposure unit, where the result of an analysis is an outcome attributable to climate change. Negative outcomes from such interpretation are associated with vulnerability. Contextual vulnerability is also interpreted as the multidimensional view of climate variability and change interacting with factors such as social structures, institutional, political and economic conditions within a context associated with a particular exposure unit. Under such interpretation, the contextual conditions influence potential responses. Kelly and Adger (2000) have also identified two main approaches to vulnerability in the climate change literature as the ‘end-point’ and ‘starting-point’. The distinction between end-point and starting-point vulnerability studies exemplifies the differences between the two main interpretations of vulnerability by O’Brien et al. (2007). End-point studies see vulnerability as net impacts and determined by framing adaptive options in terms of technology, which will minimize particular impacts that have been projected while ‘starting-point’ approach shows vulnerability as pre-existing and determined by multiple processes that affects the ability to respond to stress (Kelly & Adger, 2000). Earlier on, O’Brien, et al. (2004) emphasized that, viewing vulnerability as an end point does not address underlying causes of vulnerability but focuses on symptoms. They noted that, greater insight could be found by analysing current and past contexts, which is the approach of considering vulnerability as the starting point. This study therefore employs the ‘starting point’ approach using past and current processes to assess farmers’ livelihoods to climate vulnerability. Again, it adopts contextual vulnerability which reduces vulnerability so that various stakeholders can better respond to changing climatic conditions.

Vulnerability has been established to be primarily linked to risk, impacts and adaptation discourses. A review on transformational analysis of vulnerability assessment by Tschakert et al. (2013) indicated that, within 20 years (comprising two generational eras), research on vulnerability assessment has moved from science predictions of large-scale climate effects to normative, stakeholder-driven goals for adaptation decision making and policy guidance on adaptation and mitigation. The first generation of vulnerability assessment was noted to be largely visionless on local dynamics as it attempted to highlight societal effects in the process given people’s inherent vulnerabilities (Tschakert et al., 2013). The second generation of vulnerability assessments has considered people’s capacity to adapt to climatic and non-climatic stressors at the core of the assessment process after recognizing the need to implement feasible adaptation options. This new generation of assessment applies a stronger social framing, often rooted in the analyses of economic and political processes with a strong focus on people’s assets and access to resources, which results in a growing understanding of who and what is vulnerable (Cannon and Mu¨ller-Mahn, 2010). The key highlights from the second generation of vulnerability assessments are that vulnerability indicators appeared the most common and appropriate for assessing people’s adaptive capacity through identification of vulnerable groups at the local level within defined boundaries. Numerous studies have developed diverse multilevel indicators from generic indicators (Brooks et al., 2005a) to national-level vulnerability metrics (Brooks et al., 2005b) and local level livelihood vulnerability studies (Hahn et al., 2009). This approach has however been critiqued to miss structural factors and is less suitable for complex social–ecological systems (Hinkel, 2011) as well as ignoring the root causes of vulnerability in some cases (Veland et al., 2013).

With a main focus of ensuring feasible adaptation outcome, this study falls within the second generation of vulnerability assessments adopting the vulnerability indicator approach by employing local level vulnerability assessment process. It engages with the criticism of indicator approaches by defining systemic drivers of vulnerability and conceptualizing its relevance for informing adaptation process to serve as decision support within a defined context. It further adds to the debate on understanding the metrics and significance of vulnerability assessments considering the dynamic dimensions of people's vulnerabilities. To operationalise the term as a contextual, starting point and indicator based, vulnerability as used in this thesis is considered as a function of the magnitude of climate variation to which the farming system is exposed to (illustrating biophysical phenomenon), its sensitivity (illustrating social and biophysical phenomenon), and its adaptive capacity (illustrating social phenomenon) as shown by Fussel and Klein (2006) and the IPPC Assessment Report. It is acknowledged that considering the term vulnerability as construct of the IPCC's exposure, sensitivity and adaptive capacity is reflecting the fourth Assessment Report (AR4) while this has been revised in the latest Assessment Report (AR5). This route taken may seem tangential to the current meaning of the term but the argument is that most of the fundamental ideas of the earlier meaning is appropriate and still pertinent for the context of this study and in fulfilling rigorous scientific exploration and excellence. It is well documented and adequately suits requirements for research excellence. Subsequently various research still engage with it presently and has applied this earlier interpretation with varying degrees of success (Madhuri et al., 2014; Panthi et al., 2016; Abeje et al., 2019; Lee and Choi, 2019; Thao et al., 2019). In applying AR4 to this thesis, vulnerability is unpacked noting the importance of understanding and addressing the socio-economic factors that determine vulnerability through the subjective selection of the indicators used. The approach is also useful in discussing important relational aspect of vulnerability (subjective selection of indicators) and boost adaptive capacity of the vulnerable people and places (provision of practical guidance to support adaptation planning and actions). Few studies on vulnerability assessment have been identified to inform adaptation processes (Tschakert et al., 2013). Most vulnerability assessments lack directions for decision-making on adaptation priorities, funding and explicit linkage to adaptation processes. A shifting discourse for vulnerability assessments calls for responsiveness in methodological design that addresses the weaknesses and criticisms in the conventional assessment design for feasible outcomes. A more comprehensive focus on analysis of vulnerability that provides a starting point for the determination of effective means of promoting actions to limit impacts by facilitating adaptation actions is critical at such a time when millions of farmers remain poor and marginalized.

1.5.2 Adaptation

Greenhouse gas emissions keep rising and impacts of climatic change on natural and social systems have become evident resulting in the critical need for climate adaptation actions. Two fundamental responses to the climatic effects are coping and adaptation strategies. While coping is used to refer to short-term mechanisms to ensure survival, longer-term shifts in behavior and practices, which reduces underlying vulnerability are basically used to denote adaptation (Vincent et al. 2013). However, adaptation scholars acknowledge that the conceptual separation of the meaning of coping and adaptation strategies is futile, as the term could be used interchangeably and not definitively differentiated (Schipper and Burton, 2009; Brockhaus, Djoudi & Locatelli 2013). Smit & Wandel, (2006) view adaptation as anticipatory, concurrent or reactive based on timing in addition to degree of spontaneity either autonomous or planned. Smit et al. (2001) advance the meaning of adaptation as an adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. IPCC in its latest report also defines adaptation as adjustments made in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2014). The theoretical definitions of adaptation keep expanding but there are indeed no universally agreed definitions for adaptation within the adaptation literature. Since coping and adaptation are often applied interchangeably, this study does not attempt to separate the two concepts. Adaptation in this study is considered as autonomous strategies adopted to reduce negative climatic effects. Adaptation is promoted nationally and internationally, between sectors, regions as well as locally. Implementation of adaptation measures remains a challenge to stakeholders including policymakers, NGOs, development agencies and individuals (Schipper and Burton, 2009). With the myriad of existing adaptation measures, tracing constraints limiting the uptake of adaptation measures would improve understanding of climate adaptation for sustainable development.

Although the theoretical definition of adaptation is noted to be expanding in climate debates, it is highlighted on another level that the actual practice of adaptation has been slow (Pittock and Jones, 2000; Kurukulasuriya et al., 2006; Ndamani and Watanabe, 2015). This study attempts to create a bridge between theory and some practical considerations by arguing that research need to be explicit on providing detailed information on climate adaptation for decision makers to leverage on during implementation. This is because adaptation requires resources in terms of funding and capacity to develop. Importantly, funding for adaptation has been another recurring theme throughout scholarly discussions on adaptation. There is increased recognition of the need for more information about the exact costs of adaptation (Boko et al., 2007; Wise and Capon, 2016; Daigneault et al., 2016). While attempts have been made to estimate the cost of adaptation at various levels and within certain sectors of an economy (Schipper and Burton, 2009), a sense of the magnitude of costs associated with local level adaptation is limited. According to Wise et al. (2014), there are varying approaches in the design and implementation of adaptation effort. Making explicit the distinction in the level of responses to change is key to understanding the different intentions, outcomes, planning horizons and the different capabilities and processes required for implementation (Wise et al., 2014). Adaptation occurs either at micro or macro level focusing on an individual making tactical decisions in response to weather variations or national/regional scale, specifically on national strategic decisions on climate variations that are usually long term respectively (Dube et al., 2018). According to Veland et al. (2013), to ensure that the procedural assessment of adaptation has epistemological proofing, involvement of local participation is key. Evidence also shows that, the local level is a significant foci for climate impacts and adaptation research since many investment and consumption decisions that affect individual vulnerability to climate hazards, as well as system resilience, are made at this scale (Waitt et al., 2012; Eakin and Wehbe, 2009). This study is therefore framed at the micro level where household asset composition influences capacity to adapt.

1.5.3 Vulnerability and adaptation assessments

Growth in the concept of adaptation has come to be closely associated with the ideas of vulnerability and resilience (Schipper and Burton, 2009). This implies discussions about adaptation must also include exploration of the related concepts on vulnerability. The interpretation of vulnerability for instance affects the type of adaptation that is promoted, influencing decisions on what, how, and who to fund (Huq and Burton, 2003). From sustainable livelihood literature stance, ability of households to adapt to stressors such as climate variability, influences the extent to which they are vulnerable or can be harmed (Paavola, 2008). Operationalisation of adaptation options applied to particular systems where vulnerability is not combined with the adaptation evaluation limits the exploration of the systems vulnerability. Assessment of vulnerability at the local level, as well as external assessment of adaptation strategies as separate assessments under different contexts has been done in various studies. Sustainable livelihoods (Chambers and Conway, 1992; Scoones, 1998) and political ecology (Wisner et al., 2003) have contributed valuable concept and operational perspectives. With sustainable livelihoods, it is related to sustainability underlying processes such as, livelihood diversification. Political ecology illustrates how inequalities in access to resources (e.g. access to land), access to technological innovation (e.g. irrigation systems) and public policies play a determining role in the vulnerability process (Vásquez-León et al., 2003). Decision-making around the management of vulnerability involves determining why one plausible management strategy is preferable to an alternative (Sain et al., 2017; Clark and Clark, 2002). It is further believed that, adaptation decisions taken at local level are often outputs of processing multiple criteria and objectives that local communities face day to day (Delaney et al., 2014).

The context of this study is on climate vulnerability of agricultural production system focusing on autonomous adaptation strategies mostly used by smallholder farmers in two areas to show whether the areas differ in the application of adaptation strategies. The interest is to explore how farmers' independently respond to the negative effects of past or current climatic variation. Smallholders provide over 80% of the food consumed in the developing world (UNEP, 2013). With such importance in the agricultural sector, they are usually characterized by unstable market prices for their commodities (Morton, 2007), low capacity to adapt to climatic changes (Adger et al., 2003), limited resources to maintain or increase agricultural productivity and dependent on environmental conditions such as temperature, nutrient availability and water accessibility (Lobell et al., 2011), which often undermine their household food and income security. This makes them concurrently pivotal in agricultural and economic development but particularly vulnerable to climatic changes, hence the importance given to reducing vulnerability of such agricultural systems in developing countries including Africa. There is an urgent need to focus attention on identifying adaptation measures that can help these farmers reduce their vulnerability to climate change and improve their productivity.

Adaptation process has been described to include identification and learning about risks, evaluating response mechanisms, creating enabling conditions, mobilising resources, implementing adaptation options, and revising choices with new learning (Moser and Ekstrom, 2010). Yet, potential implementation barriers that inhibit the action of those adaptation processes among smallholders across SSA generally fall within the consideration of resources such as financial, biophysical, informational and governance (Shackleton et al., 2015). These resources indicate needs not exclusive to risk reduction but also important for improved production systems and farmers' adaptive capacity, which can make them vulnerable. According to Carabine et al., (2014), effective adaptation strategies are believed to strengthen livelihoods and enhance wellbeing and subsequently reduce poverty today.

1.5.4 Farming systems in Ghana

The study is situated in Ghana, which is located between latitudes 4.5^0N and 11.5^0N and longitudes 3.5^0W and 1.3^0E of the West Coast of Africa. Ghana has a warm, humid climate. Mean annual rainfall of the country is estimated at 1187 mm. Mean annual temperatures ranges between 26.1°C near the coast and 28.9°C in the extreme north (Antwi-agyei, 2012). Rain-fed agriculture is predominant and average farm size is small (< 1.2 ha), thus smallholder farms dominate the agricultural sector, accounting for about 80% of total agricultural production (World Bank, 2011). Growing land scarcity due to factors such as population increase is affecting farmers' practices and desire in achieving their desired level of production. In Ghana three main systems of land ownership are dominant. These include public, customary and vested (hybrid between public and customary) lands. About 78% of all land is held under customary system, which is land mainly owned communally along ethno-tribal and family lines, 20% is held by government for developmental projects whilst 2% is held in a dual ownership between government and customary owners (Yeboah and Shaw, 2013). Farmer's access to land is mainly through direct ownership or designated traditional authorities responsible for its management as trustees (Kasanga and Kotey, 2001). The issue of food insecurity in Ghana is compounded by inadequate agro-processing facilities for agricultural products (FAO, 2005). The rapidly growing population again challenges the ability to achieve food security in Ghana.

Farming conditions in Ghana and more broadly in Africa have witnessed significant changes in recent times that are affecting agricultural activities. These include the rise in population densities; improved access to modern inputs; growing land scarcity, growing urban demand for major food staples, fruits and vegetables, and a favorable policy environment for African agriculture (Pingali, 2012). Attempts by scholars to explain shortcomings of African agriculture taking into consideration major progress made by Asia during the Green Revolution in the 1960s (characterized by an increase in land productivity as land became increasingly scarce owing to rapid population growth) revealed that agriculture has not intensified among smallholders on the African continent despite decades of efforts (Pingali, 2012). Lower population density in Africa compared to Asia, weaker states of rural infrastructure (example roads and irrigation) and less developed markets were highlighted. Although population growth has been rapidly growing in recent times, evidence of low technology adoption rates and productivity growth occurring in Africa reflects the believe of a stagnant African agriculture presently (Houssou et al., 2016). For instance Djurfeldt and Djurfeldt, (2013) review of eight African countries concluded that there was little evidence of structural transformation within smallholder agriculture. While grain production had intensified, productivity gains could be explained by more intensive use of labor rather than by technological change. Also in Ghana, a study by Nin-pratt and Mcbride, (2014) also revealed no Asian-style agricultural intensification occurring. Rather, high labor costs despite rapid population growth is evident. The above conditions together with limited resources and changing environmental conditions persistent among smallholder production systems indicate their inability to improve production, challenge their livelihood and food security as well as increase their vulnerability.

1.5.5 Conceptual framing of vulnerability and adaptation assessments

As it has become clear that climate impacts in the next few decades are inevitable irrespective of any mitigative actions undertaken in present times, informing adaptation decision-making on adoption of adaptive responses is crucial. This study is motivated by the concern that research on vulnerability and adaptation has limited capacity to inform decision-making. Building on insights from vulnerability and adaptation scholarships and following the ongoing debates in vulnerability and adaptation discourse, this study advocate for the need to create stronger linkage between vulnerability and adaptation assessments conceptually. The emphasis is on a more inclusive vulnerability assessment process with identification of adaptation strategies and evaluation of the strategies. This explicitly extends the debate on enhancing the relationship between the two concepts and informing the decision-making process on adaptation. According to O'Brien et al. (2007), interpretations of vulnerability (which is a prerequisite for adaptation) are fundamentally about framing of the problem. Beside the need to connect climate adaptation to vulnerability, vulnerability assessment frameworks combining smallholders' vulnerability and adaptation are limited. Approaches to vulnerability from the natural hazards, rural livelihoods and poverty literatures exist in climate change research (e.g. Kelly and Adger, 2000; Wisner et al., 2003; Turner et al., 2003; Fussel and Klein, 2006). Existing frameworks in smallholder vulnerability studies include Vulnerability as Expected Poverty (Mutsvangwa, 2010), Livelihood Vulnerability Index (Hahn et al., 2009), Asset Vulnerability (Dasgupta and Baschieri, 2010), Livelihood Trajectories (Sallu et al., 2010) and Patterns of Smallholder Vulnerability (Sietz et al., 2012). While such diverse frameworks exist and have been applied under different contexts to improve understanding of smallholders' vulnerability, there is a need for context-specific information regarding adaptation responses and their effectiveness if implemented.

Figure 1.1 depicts steps in the design and practice of the vulnerability assessment of the smallholder farmers to improve the conceptualization of vulnerability and adaptation assessments for this study. The term vulnerability as defined under Section 1.5.1 is introduced and placed within the IPCC vulnerability framework to enhance its operationalisation within climate variability context, livelihoods (smallholder horticultural production) and development. It also builds on the discussions from previous scholars regarding development and/or modification of indicators. The local level vulnerability assessment involved application of the key constructs of vulnerability within the IPCC framework; thus, exposure to climate induced shocks, sensitivity of the unit of analysis to climatic shocks and adaptive capacity to handle such shocks (Figure 1.1). Climate variability and extremes have long been important in many decision-making contexts. Climate-related risks are now evolving over time due to both climate change and development (IPCC, 2014a).

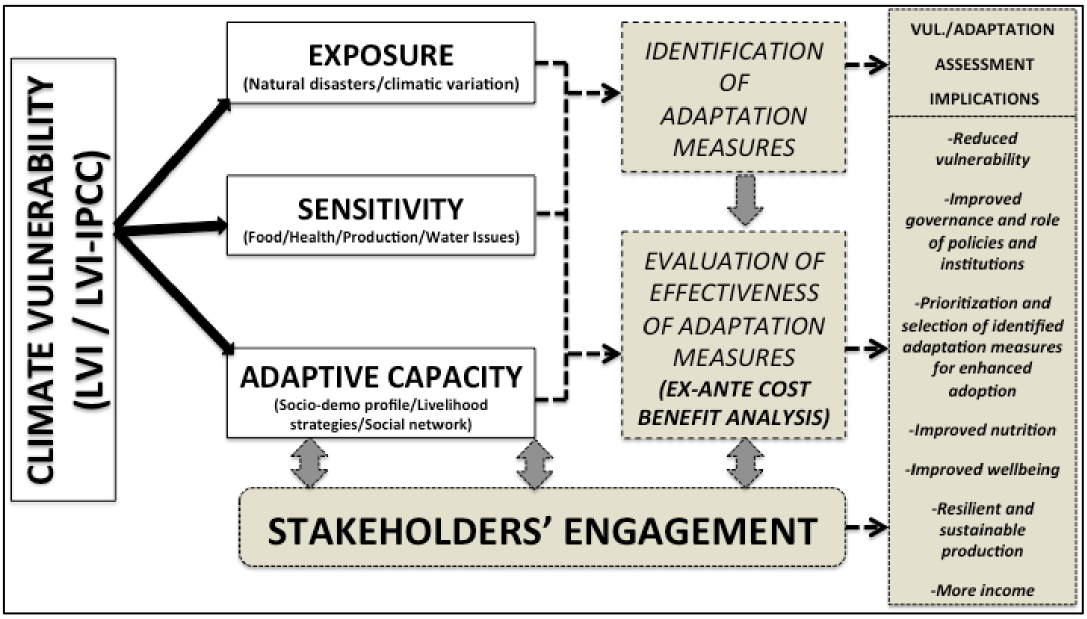


Figure 1.1: Conceptual framework used to define smallholders' vulnerability and the adaptation responses

Under the three major constructs of the IPCC framework: exposure, sensitivity and adaptive capacity, exposure considers the frequency, magnitude and duration to which the system is subject to climate-related hazards such as drought. Information from the past and present weather extremes, natural disasters, weather patterns and long-term climate trends help to understand local adaptive mechanisms (Preston, 2012). The sensitivity of a system is determined by the extent to which environmental and human characteristics are affected by exposures. Finally, the adaptive capacity of a system refers to the system's ability to cope and adapt to the impact. An elaboration of smallholders' adaptive capacity is made particularly on capacity to manage extremes or explore alternative livelihood opportunities. Adaptation planning and implementation are then dependent on how adaptation strategies are framed in particular contexts (Mimura et al., 2014). The vulnerability assessment presented in this study engages with some of the critiques of vulnerability research already highlighted. It is designed using the Livelihood Vulnerability Index (LVI). This was done by creating an index of vulnerability from indicators under a specified context. A major weakness of vulnerability indicators and indices approach has been concerns over the usability of the knowledge generated due to the static notion of vulnerability (Eriksen and Kelly, 2007; Hinkel, 2011). However, at the level of livelihoods and for practical adaptation research, the indicator approach provides the opportunity of revealing a community's multidimensional vulnerability by engaging with people's experiences through bottom up participatory approaches and involving the vulnerable people themselves (Smit and Wandel, 2006). It allows for assessments of assets and institutional channels to information and technical resources, or lack thereof. Attention is given to examining how assessment practice contributes to decision support on adaptation by identifying adaptive responses to reduce observed vulnerability and evaluating the costs and benefits of adopting selected adaptive responses. Further suggestion on fostering collaboration across diverse stakeholders to leverage and build on the strengths of divergent intellectual traditions involved in vulnerability research and linking research to the practical realities of decision-making is given. Overall, the assessment process has implications of influencing decision support on adoption of adaptive responses. Such approach improves the relational and dynamic aspect of the practice and guide stakeholder's decision-making process. Participatory and learning processes employed are noted to assist the identified vulnerable entity with practical solutions and boost their adaptive capacity (Tschakert et al., 2013). The subsequent chapters explore vulnerability and adaptation assessment through a case study.

1.6 Methodological overview of study

1.6.1 Research Design

This study uses an interdisciplinary mixed methods to advance climate vulnerability and adaptation assessment among smallholders. The research design involves quantitative assessment of vulnerability and experts survey to assess gains and losses from implementation of adaptation measures. Qualitative approaches such as participatory workshops for indicator selection in assessing vulnerability and Focus Group Discussions (FGDs) were also employed to augment the quantitative nature of indicator-based methods for in-depth responses and understanding of vulnerability and adaptation. Thus the mixed method approach was adopted to allow a broader sociological and human ecology perspective of the study context to be unraveled and discussed, as climate change is a complex problem. Adequate flexibility in understanding what is observable is further allowed without restricting the analysis and discussion to a single lens or just a small part of the farming system. It is opined that surveys often describe the situation at a point and provide little insight into change (Wiggins, 1995; Dube et al., 2018). Application of inclusive and participatory approaches during an assessment process are acknowledged to support awareness creation and improvement in the quality and relevance of data used in an assessment process (Raemaekers & Sowman, 2015**;** Tiani et al. 2015). This addresses the challenge of indicator-based approach by reducing subjectivity in the selection process**.** Meanwhile been mindful of the fact that qualitative approaches challenge the ability of a study's outcome to be generalized to a broader population (Guba and Lincoln, 2005), a deeper understanding and implications of issues of interest are inferred from the qualitative responses. The qualitative responses for this study were generally used in the interpretation, discussions and implications drawn from the findings of the study. Some specific qualitative responses explaining farmer's perspectives relied on for implications drawn from the study are presented in Appendix VIII.

According to Panthi et al. (2016), pragmatic approach to vulnerability assessment involves studying how vulnerable a system is compared to another and which component pushes up the level of vulnerability. A system in this case may be the population, geographic region or human environment been studied. Major decisions about vulnerability and adaptation to climate change for agriculture include production and consumption of inputs, resources and products (Antwi-agyei, 2012). Such decisions are taken at the household level hence situating the study within the household scale in relation to the use of productive resources. Data collection was done in two interlinked phases (Fig 1.2). The first phase involved the use of both primary (through survey of farming households) and secondary data (use of historical climate data) to assess livelihood vulnerability of smallholder producers to climate variability and identify smallholder producers' adaptive responses that reduces vulnerability of crop production. The second phase involved the use of primary survey of households and experts to evaluate the economic effectiveness of adopting the most important adaptation practices identified in Phase 1 for decision support on climate adaptation.

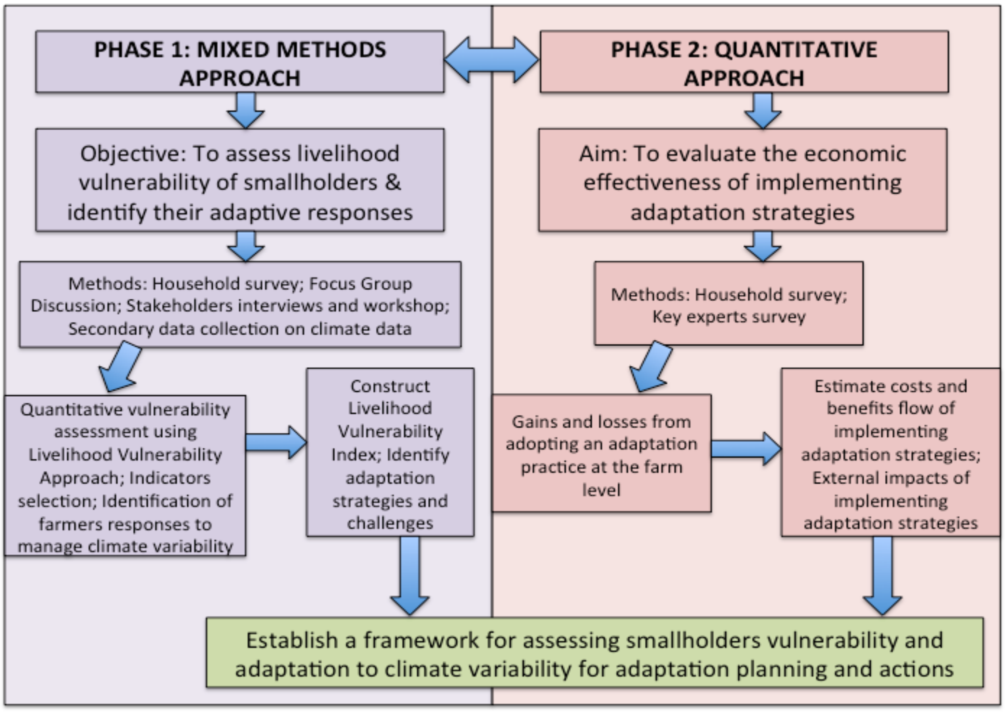


Figure 1.2: Research approach with methods and objectives for data collection

1.6.2 Case study sites

The study sites for this study are two of the major horticultural producing municipalities in Ghana with distinct characteristics. These are Keta Municipality representing Coastal Savanna Agro-Ecological Zone (a coastal area) in the Volta Region of Ghana and Nsawam

Adoagyiri Municipality representing Semi Deciduous Agro-Ecological Zone (an inland area) in the Eastern Region of Ghana (Fig. 1.3).

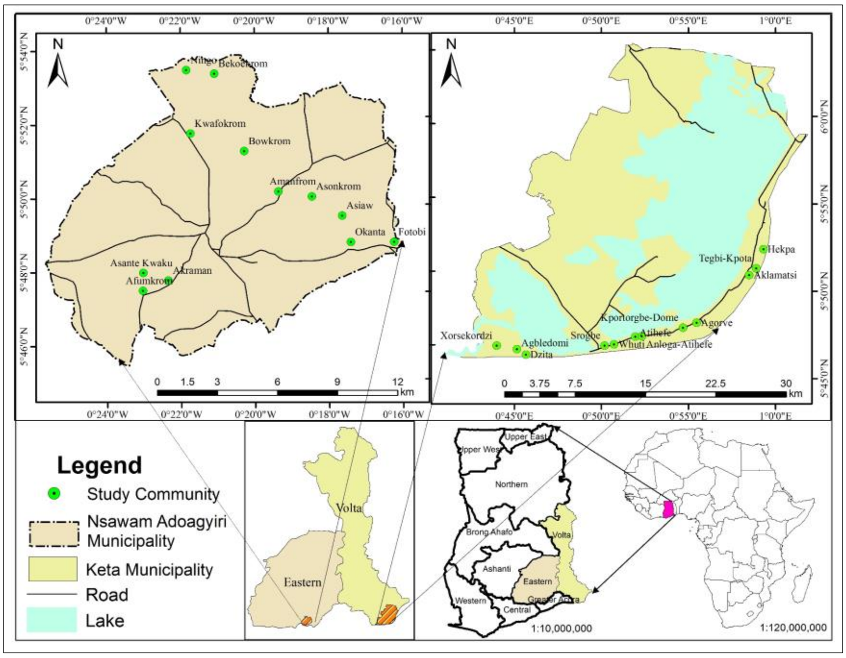


Figure 1.3: Map of Africa and Ghana showing location of the study sites

According to the 2010 Population and Housing Census (the latest existing census data) the population of Keta municipality consist of 46.4% males and 53.6% females (GSS, 2014a). The average household size is 3.8 persons. The agricultural sector dominates employment within the municipality (34.8%), 21.8% are into services, 25.4% are in craft and related work and 2.3% are engaged in other businesses. Most (67.7%) households in the municipality are engaged in crop farming. Keta Municipality is a low-lying coastal plain with the highest point of 53 metres above sea level and the lowest between 1 to 3.5 metres below sea level thereby making it vulnerable to tidal waves and sea erosion (GSS, 2014a). The population of Nsawam Adoagyiri Municipality also constitutes 49.7% male and 50.3% female (GSS, 2014b). The average household size in the municipality is 4.1 persons per household. According to the 2010 Population and Housing Census, about 86% of the population within the area is literate. Employment in Nsawam Adoagyiri municipality is dominated by the service sector (28.7%), agriculture (22.5%), crafts and related work (17.5%) and manufacturing sector (13%) of the working population. Crop farming is the predominant (94%) agricultural activity. Nsawam Municipality is also located on plains and given the inadequate drainage facilities, parts of the town are liable to floods. These areas have been selected because they are representative of the main seasonal horticulture cropping areas in Ghana. Agricultural production in the areas is characterized by smallholder production system that is highly climate dependent and susceptible to the impacts of climate variability and change. Production activities for farmers within the two localities are resource constrained. Detailed description of the study communities are given in Chapter 3.

The field survey was conducted between October and November 2017 in both study municipalities. Four key fruit and vegetable cropping areas named 'agricultural operational areas' where considerable changes in climate were happening under different agro-climates in each municipality were purposively selected. This study was limited by lack of data on exact population of smallholder households in identified operational areas. Therefore upon consultation with the Agricultural Extension Agents (AEAs), and to ensure thorough representation of communities in selected areas, three communities were subsequently selected randomly from each agricultural operational area making a total of 12 communities from each municipality. Depending on availability and willingness of household heads to respond to survey, approximately 20 households were randomly selected and interviewed from each community. A total number of 480 smallholder households were interviewed in both study areas (60 households from each of the 4 agricultural operational areas and 240 from each district). The total sample size of 480 household heads/respondents captured is considered sufficient, as it allows conclusions to be drawn from the data analysis (Cochran, 1977). Three enumerators assisted with the data collection process. The enumerators received training on the survey instrument and research ethics considerations for the study. Surveys were conducted with ethical approval from the Faculty of Science Research Ethics Committee at University of Cape Town (Reference number FSREC 64-2017). Prior verbal consent was obtained from each household head before the interview after which a written consent was either signed or thumb-printed. Questionnaire administration was at the household level and each interview lasted between 30 and 40 minutes. A "household" was identified in this study as a farm family unit that consist of a group of interrelated people living together in the same house, combining labour to manage their farm and making farm-level decisions (including adaptation) under the primary leadership of a household head (Davies & Bennett, 2007). Secondary data on climate (daily precipitation, minimum and maximum temperatures) from the nearest meteorological station in each municipality between 2007 and 2016 was also collected from the Ghana Meteorological Agency.

1.7 Definition of other key terms as applied in the thesis

Climate: In this thesis, climate refers to "the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years" (Agard et al., 2014; p. 1760). According to IPCC, the classical period for averaging the variables is 30 years and the relevant quantities are most often surface variables such as temperature, precipitation, and wind. This thesis considers only temperature and precipitation. Changing climate as referred to in various sections of the thesis denotes change in 'climate' conditions.

Climate change: The thesis adopts IPCC's definition of climate change as a "change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer" (Agard et al., 2014; p. 1760). IPCC explains climate change may be due to natural internal processes or external forcings and persistent anthropogenic changes in the composition of the atmosphere or in land use. Thus climate change denotes a shift in the long-term (usually 30 year) mean and a change in frequency and severity in extreme events.

Climate variability: This thesis adopts IPCC's definition of climate variability as "variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events" (Agard et al., 2014; p. 1761). As explained by IPCC, variability may be due to natural internal processes within a climate system or to variations in natural or anthropogenic external forcing. It is through the varying character of these events that any long-term change in climate will first be manifest. Thus, climate variability is the year-to-year variation of climatic conditions.

It is important to note that, the above terms are not used interchangeably in this thesis and the mention of it in the various sections has its meaning as described above. In the context of this study, the fundamental concern of the case studies (thus the empirical chapters) however, is with vulnerability to short term stresses or extreme climate events happening on inter annual or seasonal timescales that smallholder producers experience and react to rather than long term trends. The year-to-year variability that farmers experience is not considered the same as adjusting to a shift that is unlikely to be reversed in years to come.

1.8 Structure of the thesis

This thesis is organized into seven thematically coherent chapters that are linked to the research objectives. Chapters 2, 3, 4, 5 and 6 are presented as papers already published and/or under review or yet to be submitted for publication in International Scientific Indexing (ISI) peer reviewed journals and are included in this thesis at various stages of publication. Chapter one presents the orientation of the study. It highlights the background of the research and introduces the integral problem the thesis is addressing. It further sets the aim and objectives of the thesis and outlines its envisaged outcomes.

Chapter 2 systematically reviews studies on how vulnerability of smallholder production systems has been assessed across Africa in the past decade. It highlights the current status of vulnerability assessments, conceptual frameworks used in operationalizing vulnerability, the diverse methods employed and links outcomes of assessments to climate adaptation. Emphasis is given to gaps identified in past studies. This chapter is published as: Williams P. A., Crespo O., Mumuni A. and Simpson N. P. (2018) A systematic review of how vulnerability of smallholder agricultural systems to changing climate is assessed in Africa. *Environ. Res. Lett.* Vol. 13(10) https://doi.org/10.1088/1748-9326/aae026

Chapter 3 assesses smallholder horticultural producers' vulnerability to climate applying the Livelihood Vulnerability Index (LVI). In relation to indicators of exposure, sensitivity and adaptive capacity, it identifies the most vulnerable farmers in the study locations. Potential areas for intervention to reduce vulnerability are highlighted thereby addressing Objective 1. This chapter is published as Williams P. A., Crespo O. and Mumuni A. (2018) Assessing vulnerability of horticultural smallholders to climate variability in Ghana: applying the livelihood vulnerability approach. *Environment, Development and Sustainability* https://doi.org/10.1007/s10668-018-0292-y

Chapter 4 addresses Objective 2 by examining the climatic trend in the two study areas in Ghana and how smallholder horticultural farmers perceive this changing climate. It further explores how smallholders are responding to perceived effects from changing climate. A range of farmer driven soil, water and crop conservation measures and farm management practices being adopted are identified and the most important adaptation practices highlighted. This chapter is published as: Williams P. A., Crespo O. and Mumuni A. (2019) Adapting to changing climate through improving adaptive capacity at the local level – The case of smallholder horticultural producers in Ghana. *Climate Risk Management* - https://doi.org/10.1016/j.crm.2018.12.004

Chapter 5 builds on Chapter 4 by conducting an ex-ante in-depth empirical analysis of the costs and benefits of implementing the five most important adaptation practices identified among smallholder horticultural farmers in Ghana. Profitability indicators as well as evaluation of environmental and social externalities are used to comparatively estimate the cost-effectiveness of the practices from private and public perspectives. Detailed considerations of the Net Present Value (NPV), Internal Rate of Return (IRR), capital required, payback period for investments made and risks from implementation are used as criteria guiding selection of practices. This chapter proposes integration of localized climate vulnerability and economic assessments if enhanced climate adaptation actions is to be obtained. It addresses Objective 3. The chapter is submitted and under review as: Williams P.A., Nganga S.K., Crespo O. and Mumuni A. (2019) “Economic analysis of climate adaption strategies among smallholder horticultural producers in Ghana”. *Climate Services.*

Chapter 6 discusses the theoretical need to strengthen vulnerability practice and enhance its relevance for decision support to improve adaption planning and actions. It argues for an integrated approach to vulnerability assessment whereby identification and evaluation of adaptation strategies is included as a routine component of an assessment practice. The chapter describes the operationalization of localized vulnerability and adaptation demonstrated by the previous chapters where lessons and insights are highlighted. It indicates combination of the two advances to build upon the utility of existing frameworks and methods and to guide adaptation planning and actions. The chapter therefore addresses Objective 4. It has been submitted to Climate and Development journal as: Williams P. A., Crespo O. and Mumuni A. “Advancing local vulnerability assessment framing to enhance climate adaptation planning and actions: Insights from smallholder production systems in Ghana”.

Chapter 7 synthesizes the key findings of the thesis in relation to the overarching research question and study objectives. It outlines the main summaries and conclusions by exploring relevant implications of linking climate vulnerability and adaptation and understanding pathways of reducing vulnerability. Priorities for future studies and recommendations are also presented to conclude the thesis.

CHAPTER 2

A SYSTEMATIC REVIEW OF HOW VULNERABILITY OF SMALLHOLDER AGRICULTURAL SYSTEMS TO CHANGING CLIMATE IS ASSESSED IN AFRICA

This chapter starts by systematically examining literature on how vulnerability of smallholder production systems has been assessed across Africa. It highlights the current status of vulnerability assessments, conceptual frameworks used in operationalising vulnerability, the diverse methods employed and further links outcomes of assessments to climate adaptation. The chapter identifies theoretical frameworks proposed from past studies to assess vulnerability. It concludes by providing synthesis of the findings and highlighting the main research gaps that this thesis addresses.

Summary

The impacts of changing climate on agriculture have consequences on livelihoods and food security. Smallholder farmers, who have heterogeneous farming systems and limited resources, compounded with multiple risks, are greatly affected. There has been limited research showing how vulnerability assessments have evolved in the smallholder agricultural sector of Africa overtime. This study systematically reviewed recent publications on vulnerability studies, especially among smallholder agricultural systems, to provide an overview of current developments in theory and practice of vulnerability in Africa over the last decade. The findings indicate an increase in vulnerability assessments undertaken across sub-Saharan Africa. Despite progress made in the application of enhanced conceptual frameworks and methods, at least four important gaps exist in the assessment process namely, inadequate engagement of local perspectives and knowledge, lack of clarity in the operationalization of vulnerability, lack of comprehensiveness of measurement criteria employed and relevance of assessment in decision support. Notwithstanding these challenges, there exist opportunities to geographically improve assessments across Africa. In order to produce knowledge to traverse projected changes in climate systems for agricultural economies and to ensure sustainable smallholder livelihoods, we suggest that future research efforts should be oriented towards providing more information to enlighten science, policy and practice for informed decision-making and evidenced based policies. This requires evaluation of adaptation capacity as a critical aspect of vulnerability assessment to provide guidance and informs effective decision-making on allocation of scarce resources

(prioritization), understand trade-offs management and implementation to build understanding among stakeholders to guide possible pathways to reduce vulnerability.

2.1 Introduction

Changing climate is considered a precarious challenge facing humanity. The impacts of climate variability and change are manifested in regime changes of floods, droughts, unseasonal rains and extreme events. This creates enormous developmental challenges for developing countries and economically vulnerable communities (Morgan, 2011). According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), further changes in climate is inevitable in the coming decades (Carabine et al., 2014). The effects are forecasted to be more severe in the agriculture sector (both rain-fed and irrigated agriculture), one of the most sensitive sectors to climate change. People in developing countries whose livelihood depends mainly on agriculture and livestock production are particularly vulnerable (Panthi et al., 2016).

Sub-Saharan Africa (SSA) has been identified as one of the most vulnerable regions to the impacts of changing climate as many areas inherently receive unpredictable rainfall (IPCC, 2014; Serdeczny *et al.*, 2016), which has been evident in several recent studies (Asante and Amuakwa-Mensah, 2015; Angula and Kaundjua, 2016). SSA's economy remains strongly dependent on agriculture relative to other regions (Livingston et al., 2011). The sector's importance in the region is evident in its contribution to total Gross Domestic Product (GDP). For instance in 2014, the agriculture sector in SSA contributed 15% of total GDP, which was comparatively high in the global context (OECD/FAO, 2016b). It further employs more than half of the total labour force of the rural population, providing a valued livelihood for multitudes of small-scale producers (OECD/FAO, 2016b).

The negative effects of the changing climate severely affect smallholder and subsistence farmers due to their overreliance on natural resources compounded by factors such as widespread poverty and various socioeconomic, demographic, and policy trends such as limited production capacity and income, poor land tenure arrangements and unstable prices for commodities, all reducing their adaptive capacity (Morton, 2007; Hitayezu, Zegeye and Ortmann, 2014). According to Sietz, Choque and Lüdeke (2012), smallholder livelihoods are frequently threatened by weather extremes. Recently, the severity of the 2015-16 drought across the region (an El Niño episode accompanied by exceptionally dry conditions), resulted in the lowest annual rainfall in 30 years in Ethiopia and the lowest annual rainfall since 1904 in South Africa, illustrating potentially disastrous impacts of climate change in Africa and raising concerns for food security (OECD/FAO, 2016b). A recent study also highlighted that agricultural productivity in rural areas is severely affected by climate variability which elevates the vulnerability of rural households to food insecurity in Africa (Mohmmed et al., 2018). Such effects together with projected impacts of climate variability and change on the sector indicates that resilience to changing climate will likely soon be undermined within the region. To this end, a better understanding of the vulnerability assessment of smallholders agricultural systems, which constitute approximately 80% of all farms with livelihoods directly threatened by weather extremes (AGRA, 2017), is paramount.

Vulnerability is used in diverse scholarly contexts including poverty and development, ecology, secure livelihoods and famine, sustainability science, land change as well as climate impacts and adaptation (Fussel, 2007). Theoretical frameworks enable some level of understanding and definition of vulnerability during assessments. Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) research are common theoretical concepts dealing with vulnerability (Tánago et al., 2016). Naumann *et al.* (2014), defines DRR approach in terms of a person or group's capacity to anticipate, resist, cope with, and recover from the impact of natural or man-made hazards. Hahn, Riederer and Foster (2009), observed that the field of climate vulnerability assessment has emerged to address the need to quantify how such communities will adapt to changing environmental conditions. Research on vulnerability assessment of systems to climate variability and change has emerged in studies and in scientific reports contributing to scientific knowledge in the area (Nyamwanza *et al.*, 2017; Dumenu and Obeng, 2016; Jakpa, 2015). CCA falls under the IPCC definition of vulnerability, which is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate (IPCC, 2007). While DRR aims at highlighting means for risk reduction in response to shocks, CCA is concerned with for the most efficient way to adapt to impacts derived from climate change (Romieu et al., 2010). Identification of determinants of vulnerability that show where, how, and why people are affected by changes in the climate system, are the main focus of vulnerability assessments (Ford and Smit, 2016; Smit and Wandel, 2006). The diversity of possible implications of climate change however, mean that the question of what is vulnerable varies significantly from one study to another (Preston, 2012).

There has been limited research focusing on how vulnerability studies have evolved in the agricultural sector of Africa overtime. Yet, the research agenda has seen a significant growth in interest with 70% (n= 25) of the peer-reviewed articles reviewed here being published in the last five years (from 2013 to 2017). Despite this increase, however, this research which identifies the fact that vulnerability scholarship focusing on smallholders in Africa has made limited progress in empowering farmers' adaptation planning. Some recent reviews on vulnerability have been conducted from different contexts. Some examples are how human and biophysical stresses interact to affect vulnerability and problem identification (Mcdowell, Ford and Jones, 2016; Delaney *et al.*, 2014), drought vulnerability (Tánago et al., 2016), dynamism in vulnerability by defining risks posed by changing climate (Jurgilevich et al., 2017), with focus mainly on Central America and Mexico (Donatti et al., 2018), India (Singh et al., 2016) and Canada (Ford and Pearce, 2010). However, none of these studies have neither exclusively paid attention to smallholder agricultural systems nor have their studies been Africa-centered. Examining the state of this field will address this research gap. There is also growing demand among stakeholders for explicit information regarding vulnerability to climate change at the local level (Preston et al., 2011), in order to identify where efforts to strengthen adaptive capacity should be made and aid decision makers at sub-national and local levels (Bisaro et al., 2010). This paper systematically reviews existing literature that address Vulnerability Assessment of Smallholder Agricultural Systems (VAoSAS) in Africa, guided by the following research questions: what is the state of vulnerability assessment of smallholder agriculture in Africa (2008-2017); how has vulnerability of smallholders in Africa been conceptually and theoretically framed; what methods are used in assessing vulnerability of smallholder farmers in Africa and what are the implications of the outcomes of vulnerability assessment for future use? This would contribute to the current dearth of studies on vulnerability assessment in the region, improve understanding and knowledge of vulnerability of smallholders as well as guide decision making to enhance climate adaptation planning and actions.

2.1.1 Definition of smallholder agricultural systems

In addition to crop production, livestock, fisheries and aquaculture contribute to the agricultural farming system in sub-Saharan Africa. Even though the crop sector dominates total agricultural production value, accounting on average for almost 85% of total production, the remaining total value of agricultural output in the region is derived from the livestock and fishery sectors (OECD/FAO, 2016b). This paper considers the vulnerability of smallholder agricultural systems whose livelihoods and well-being are climate dependent in Africa. Regional differences in scale of production, agroecological and cultural diversity exist among this population broadly referred to as subsistence, small scale or smallholder farmers. Most farmers in Africa are considered smallholders, farming on small farms, facing varying livelihood prospects depending on their assets and aspirations as well as their regional and country contexts (AGRA, 2017; OECD/FAO, 2016b).

In targeting small farm assistance, Hazell & Rahman (2014) classified three groups of smallholder farm households depending on scale of production and proportion of produce marketed from high to the low, namely, commercial farmers, transition farmers and subsistence farmers. An early definition of smallholders conceptualized rural producers, mainly in developing countries, as those who employ mostly family labour and for whom farming provides the primary source of income (Cornish, 1998). Barnett (1997) extended this definition to associated activities that together form a livelihood strategy where the main output is directly consumed and only a minor proportion is marketed. Smallholder farmers in SSA have been recognized as a group of little uptake of improved and introduced production technologies due to constrained resources, which involve trade-offs with other activities from which they generate their livelihood (Giller et al., 2009). Morton (2007) also described smallholder farmers to be found on a continuum between subsistence production and crop production for the market. Morton's definition encompassed pastoralists who depend on the sale of livestock and livestock products to buy staple foods and other necessities as well as people who depend on fisheries and aquaculture enterprises. Smallholders are believed to suffer similar problems including isolation, low levels of technology, unpredictable exposure to world markets, generally of small scale, often farming under traditional or informal tenure and in marginal or risk-prone environments (Morton, 2007).

Following the foregoing definitions, in the context of this study, "smallholder agricultural systems" is used throughout the paper to refer to a livelihood system comprising rural populations grouped as smallholders that includes crop producers, agropastoralists and/or agrosilvopastoralists within a SSA country with limited resources of production and exposed to both climatic and non-climatic stresses. Particular interest in rural areas was taken in this case as agricultural livelihoods are considered most sensitive to climate change impacts in rural communities which are commonly socio-economically disadvantaged, hence inherently vulnerable (Singh et al., 2017). More so, despite growth in urbanisation, rural population in Africa is considered still dominant (OECD/FAO, 2016b) with depopulation having significant impact in differing ways on vulnerability, and directly affecting resilience of rural livelihoods and productivity under changing climate (OECD/FAO, 2016b; Livingston et al., 2011).

2.2 Methods

2.2.1 Systematic literature review

This study employed a Systematic Literature Review (SLR) method to examine progress of climate vulnerability assessments conducted in SSA between 2008 and 2017 at the local level. SLR is a literature review methodology commonly used to analyse the state of knowledge related to a topic (Ford, Berrang-Ford and Paterson, 2011a; Ford and Pearce, 2010). SLR is progressively being used in climate change field to assess and interpret the state of knowledge in this area and to identify directions for further research efforts (Ford & Pearce 2010; Delaney et al., 2014; Mcdowell, Ford and Jones, 2016). This study adopted the SLR approach because systematic reviews are considered more rigorous, structured and robust (Ford et al., 2011), making it more appropriate to structure observations of emerging literatures. Another strength of SLR is its ability to identify gaps and provide information through detailed summaries of evidence found in a specific literature database, based on clearly defined research questions and methods (Tánago et al., 2016). This study followed the criteria of systematically selecting and examining documents found in selected literature databases. We conducted the SLR following identification of literature using keywords, creation of inclusion/exclusion criteria for the selection of publications and through analysis using both descriptive and qualitative methods.

2.2.2 Data selection process

Four databases (search engines) were used in the literature search. These were Google scholar, Web of Science, JSTOR and AGRIS. These databases were chosen due to their extensive and current coverage of interdisciplinary academic literature (Spires et al., 2014). The time frame for the search covered publications from the 1st of January 2008 until the 31st of December 2017. This period was selected after the results from an initial search for the period 1998 to 2017 showed that the period between 2008 and 2017 accounted for more than 85% of the overall results. In addition, most global information on seminal vulnerability studies prior to 2008 is summarized in the annotated bibliography of agricultural vulnerability to climate change by Barsley, De Young and Brugere (2013). Therefore, a review of the last decade suitably provides for reflection on significant trends and progress made in VAoSAS in Africa. The terms used in searching for relevant articles were [Climat*] ["Vulnerability * assessment" OR adaptation] [Africa]. The process was iterative allowing for different key words to be explored. ['Smallholder' OR 'agriculture'] in the search terms yielded very limited results. ['Adaptation'] was included to ensure that all studies on adaptation capturing vulnerability assessment, as an aspect of study was not missed. Even though the final search terms were quite broad, the results followed strict inclusion/exclusion criteria for the selection of relevant studies that dealt with VAoSAS at the local level in Africa. Table 2.1 presents details of the inclusion/exclusion criteria used in the selection of relevant published studies.

Table 2.1: Criteria for literature selection

Search protocol	Inclusion criteria	Exclusion criteria
Initial database and document search	• English literature • Local level vulnerability assessment	• Any non-English literature • National, regional and global studies

	• Vulnerability assessment of agricultural systems/agricultural productivity	• Vulnerability assessment of other sectors such as biodiversity, water resources, health, coastal and human settlement, hydrology, tourism, engineering (more broadly)
	• Vulnerability and adaptation assessment	• Perception, impact assessment and exclusively adaptation assessment
	• Assessment in sub-Saharan Africa	• Anywhere else
	• Single studies	• Duplicated studies from the different databases
Review of title and abstract	• Human systems and/or coupled human environment systems	• Explicitly focused on natural systems (forest, fishes, aquatic ecosystem
	• Assessment of/with smallholder farmers	• Assessment of/with medium scale and commercial farmers
	• Vulnerability to climate risk, including non-climate risk	• Focused exclusively on vulnerability to non-climatic risk
Full paper review	• Original studies	• Literature review or discourse analysis
	• Rural livelihoods and household assessment	• Urban and peri-urban settlement assessments
	• Subnational unit of analysis	• National, regional and global level analysis
	• Vulnerability assessment of agricultural systems/agricultural productivity	• Vulnerability assessment of other sectors

A total of 1074 studies were identified from the four databases during the initial search (Fig. 2.1). This constituted both peer reviewed articles and grey literature (e.g. working papers, published thesis, conference proceedings, and project reports). The first stage screening removed all duplicates. Title screening followed, and all publications not directly related to the study aim were removed. Abstract and full text screening completed the next step. Figure 2.1 summarizes the screening process, ultimately leading to thirty-six studies. (Appendix V provides complete references). It was observed that even though studies on 'vulnerability' in general exist in the region, there is dearth of studies on the 'assessment of vulnerability at the local level', which was the main focus of this review.

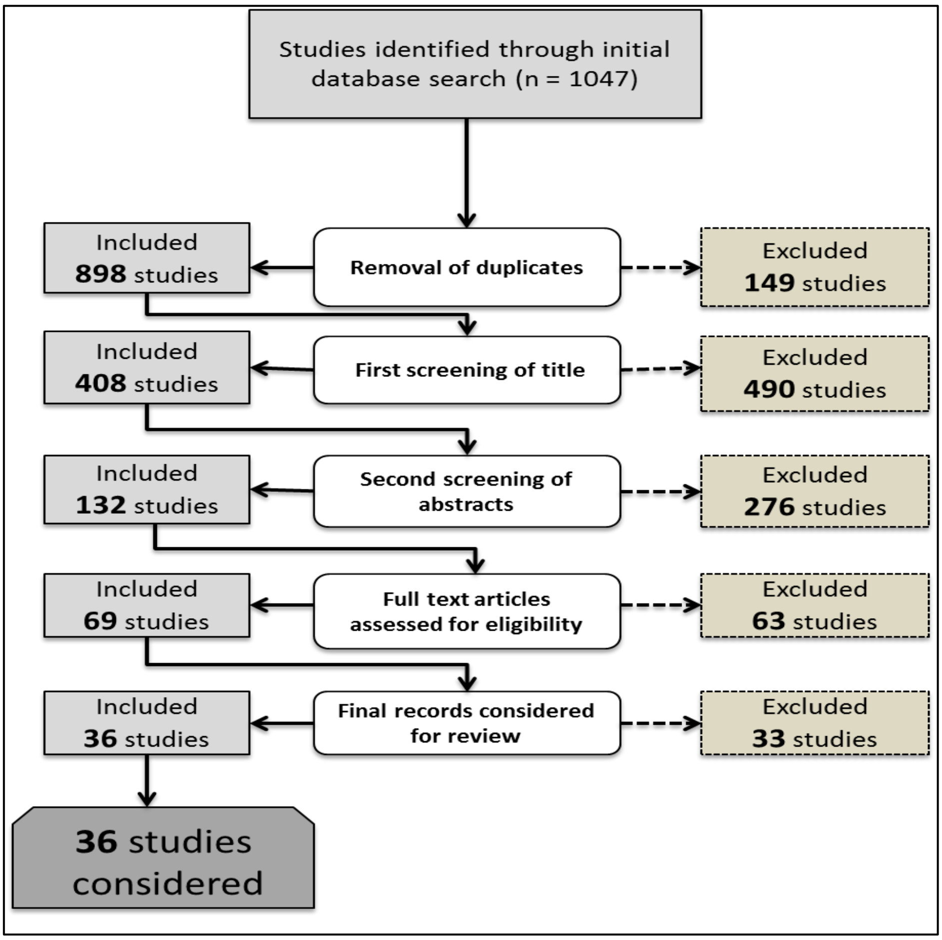


Figure 2.1: Summary diagram of literature screening process

Out of the 36 studies considered for in-depth review, 29 (81%) constituted peer reviewed studies and 7 (19%) were grey literature studies. Reviews of relevant grey literature has been recognized as valuable for climate change studies, especially in providing local information, policy responses, and practice that often lie outside peer reviewed journals (Singh et al., 2017).

2.2.3 Review analysis

The selected studies were analyzed using both qualitative (thematic analysis) and quantitative (descriptive statistics) methods to explore all possible responses using the defined research questions for this study. The selected studies were coded for information and grouped into emergent themes and categories such as geographical location of study; primary focus of study, nature of exposed hazard; conceptual framework used; dimensions of vulnerability factors used; methods employed in assessment; basis for vulnerability factors selection; subsector studied; enabler of assessment; unit of analysis; indications for adaptation options; recommendations for future studies and finally, mention of challenges constraining response to vulnerability. These categories reflect the breadth of thematic coverage as well as illustrate how vulnerability assessment has become a complex and multidimensional concept.

2.3 Results

2.3.1 State of climate vulnerability assessment of smallholder agricultural systems

The majority of identified assessments were from Southern and Western Africa (Figure 2.2) with Southern Africa having the highest share (40%). In contrast, Central and Eastern Africa indicate a dearth of vulnerability assessment research. Regional differences in the relative contribution of agricultural output in SSA seem to be reflected in the geographical distribution of vulnerability assessment identified in this review. Western and Southern African countries accounted for more than 80% of the total value of agricultural output in SSA (between 1990 and 2013), that is, 60% and 22% respectively (OECD/FAO, 2016a). The predominance of vulnerability assessment found in Southern and Western Africa regions therefore depicts focus of assessments on areas contributing more to agricultural output (with greater emphases on crop production and less focus on livestock and fisheries).

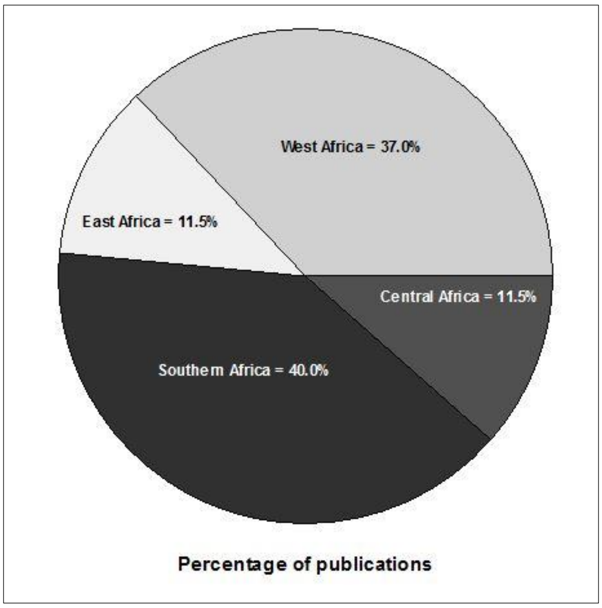


Figure 2.2: Regional distribution of reviewed vulnerability assessments across sub-Saharan Africa

A positive trend was observed in the time evolution of vulnerability assessments conducted across Africa among smallholders in the past decade. This is especially so in the last five years (from 2013 to 2017) where about 70% (n= 25) of the reviewed publications could be found. In the last ten years, vulnerability assessments conducted in relation to smallholder agricultural systems in Africa are mainly (58%) focused on primary crop producers (Table 2). Despite efforts taken to capture all sectors of agriculture during the literature search, few of the VAoSAS were found dealing with agropastoralists (19%) and agrosilvopastoralists (6%). Some of the subsectors studied mainly dealt with annual food crop producers and their suitable locations across the regions (e.g. cereals, roots and tubers, legumes). Perennial crops such as cocoa were studied in West and Central Africa (e.g. Ghana and Cameroon).

Coffee and tea were studied in central Africa (e.g. Rwanda). Agropastoralists with pasture-based production relying on fodder availability as well as marine and inland fisheries were prominent in studies from Southern, East and Central Africa (Table 2.1). About 17% of the studies mentioned smallholder production systems in general without a clear indication of which specific subsector is vulnerable. Because we explicitly sought for assessments in relation to smallholders, the unit of assessment was limited at the local level, thus at the community, village, household or individual levels.

Academic researchers solely authored and led about half (50%) of assessments reviewed. Collaboration between donor funders, academic researchers (including non-university researchers), NGOs and government agencies also led about 44% of the findings. Few (6%) resulted solely from donor funders such as the Food and Agricultural Organization. These findings by multi-author teams encouragingly depicts the diversity of stakeholders with almost equal interests from donors, decision makers, academics and non-academics, which likely contributes towards more robust and comprehensive vulnerability research. Due to the multidimensional nature of vulnerability, scholars of vulnerability argue assessments should be integrative to incorporate different dimensions (e.g. social, economic, physical, environmental, and institutional) as no single measure can fully capture its complexity (Gbetibouo and Ringler, 2009; Preston, 2012; Tánago *et al.*, 2016). However, it is apparent that studies conducting VAoSAS in Africa have not adequately been integrative. Of the total vulnerability assessments reviewed, about 61% primarily focused on social assessment (assessments based mainly on socio-economic determinants such human resources, while 39% used a combination of biophysical (climate conditions, topography, land cover, natural hazards) and social assessment (demographic, economic and social factors to assess vulnerability). None of the assessments exclusively focused on biophysical process as shown in Table 2.2.

Table 2.2: Details of information on sectors/subsectors, cropping systems, location, source, unit and basis of assessment for reviewed studies

Sector/subsector studied	Cropping system	Unit of analysis	Enabler of research		Primary basis of assessment		Country (ies) of study	Representative studies
			Individual	Project	Social	Biophysical		
Agro pastoral	N. S.	Village	✓		✓	✓	Tanzania, South Africa	Grothmann et al. 2017
Food crops	Maize, sweet potato	Household	✓		✓		Uganda	Cooper & Wheeler 2017
N. S.	N. S.	Rural community		✓	✓	✓	Burkina Faso, Benin, Ghana	Asare-Kyei et al. 2017
Agro pastoral	N. S.	Village	✓		✓		Chad	Okpara, Stringer & Dougill 2017
Food crops	Maize, rice, legume, sweet potato	Community		✓	✓		Ghana	Derbile, File & Dongzagla 2016
Cash crop	Cocoa	Household		✓	✓		Ghana	Dumenu & Obeng 2016
N. S.	N. S.	Community		✓	✓	✓	Ghana	Westerhoff & Smit 2009
Fishery	Fishery	Community		✓	✓		Namibia, Angola, South Africa	Raemaekers & Sowman 2015
Agro pastoral	N. S.	Community		✓	✓		Burkina Faso	Choptiany et al. 2017
Cash crop	Cocoa	Community		✓	✓		Cameroun	van Vliet 2010
Food crops	N. S.	District	✓		✓	✓	Kenya	Oluoko-odingo 2011

Food crops, vegetables	N. S.	Community		✓	✓		DR Congo	Bele, Sonwa & Tiani 2014
Cash crops	Coffee, tea, cocoa	District		✓	✓		Rwanda	Pavageau, Butterfield & Tiani 2013
Food crops	Maize, cassava	Community		✓	✓		Zimbabwe, Ghana	Mapfumo et al. 2013
Cereals	N. S.	Household		✓	✓	✓	Ethiopia	Tesso, Emana & Ketema 2012
Not specified	N. S.	Household		✓	✓	✓	Ethiopia	Deressa, Hassan & Ringler 2009
Agro pastoral	N. S.	Community	✓		✓		Namibia	Angula & Kaundjua 2016
Cereal, legume, root and tuber	N. S.	Community	✓		✓		Ghana	Derbile & File 2016
N. S.	N. S.	District	✓		✓	✓	Mozambique	Kienberger 2012
Cereal	Maize, sorghum	Community		✓	✓		Botswana	Molefe & Masundire 2016
Food crops	Cassava, beans	Village	✓		✓	✓	Tanzania	Sorey 2011
Food crops, fishery, horticultural crops	N. S.	Community		✓	✓	✓	Ghana	Effah 2014
Food and cash crops	N. S.	Community	✓		✓		Nigeria	Umoh et al. 2014
Food crops	Potato, maize, beans	Village	✓		✓	✓	DR Congo, Cameroun, Equatorial Guinea	Tiani et al. 2015

Food crops	Pearl millet, sorghum, maize cowpea	Village	✓		✓		Namibia	Hotz 2010
Food crops, horticultural crops	Rice, maize, sorghum, vegetables	Community	✓		✓		Ghana	Jakpa 2015
Agro pastoral	N. S.	Village	✓		✓	✓	Botswana	Sallu, Twyman & Stringer 2010
Agro pastoral	N. S.	District		✓	✓		Mozambique	Notenbaert et al. 2013
Food crops	Maize, beans, groundnut	Household	✓		✓		Swaziland	Nkondze, Masuku & Manyatsi 2013
Agro pastoral	N. S.	Household		✓	✓		Mozambique	Ng'ang'a et al. 2012
N. S.	N. S.	Household	✓		✓	✓	Ghana	Dasgupta & Baschieri 2010
Cereals	N. S.	Community		✓	✓	✓	Ghana	Etwire et al. 2013
N. S.	N. S.	Household		✓	✓		Mozambique	Hahn, Riederer & Foster 2009
Cereals	Maize	Community	✓		✓		Ghana	Antwi-Agyei et al. 2013a
Agro pastoral	N. S.	Household	✓		✓	✓	Zimbabwe	Rurinda et al. 2014
Horticulture crops	N. S.	Household	✓		✓		Mozambique	Vilissa 2016

Note: N.S means information was not specified in study

2.3.2 Theoretical and conceptual framing of the vulnerability assessments

Some conceptual frameworks for expressing vulnerability across different disciplines such as the Pressure and Release model (represented by 33% of assessments), the Political Economy/Ecology model (represented by 50% of assessments), the Resilience Model (represented by 10% of assessments) and the Expanded Vulnerability model (represented by 7% of assessments) are presented in Table 2.3. The remaining assessments did not make clear distinctions as to what framework is specifically guiding their analysis. Theoretical framings used, guide conceptual frameworks adopted in a study and later the operationalization of vulnerability assessments (Preston, 2012). It also indicates a diversity of emphases in what is deemed important within particular disciplinary approaches as well as applied contexts. This is well illustrated in the aforementioned foci of VAoSAS demonstrating both a plurality of ontological and epistemological presuppositions. VAoSAS drew their conceptual framing from concepts including Sustainable Livelihoods, Social Protection, Hazard and Human Ecology, Political Economy, Entitlement or Resource Endowment, Poverty and Development Studies (Table 2.3). Detailed description of models, examples of analytical frameworks adopted in the reviewed papers, and their representative studies identified from the review can be found in Table 2.3.

The studies used different definitions to build a composite index in operationalizing vulnerability. These included the risk and hazard concepts, socio-economic and political structures and processors, ecological resilience concept, human environmental system concept and vulnerability to poverty approach (See Appendix VI for details on conceptual definitions, hazards and variables for characterizing vulnerability of reviewed studies). Overall, the reviewed studies mainly assessed vulnerability of systems to climatic risks comprising climate change, climate variability and disasters (58%). About 22% attributed vulnerability to both climatic and non-climatic risks such as climate-water conflict, food insecurity and climate change as well as poverty and climate variability. About 20% of the studies did not however indicate clearly what their system of study was vulnerable to.

2.3.3 Types of methods used in the design and analysis of VAoSAS

As vulnerability cannot be observed directly, the various analytical approaches used in operationalizing vulnerability in the 36 studies reviewed are presented in Table 2.4. The methods most commonly used across the studies were the indicator-based approach and the participatory/qualitative methods. The indicator-based approaches mainly employed proxy indicators in the construction of vulnerability indices while the participatory approaches were broadly case study based (Table 2.4). Statistical analysis was recorded in 7 of the studies reviewed using regression models and a multivariate statistical dimension reduction technique (Principal Component Analysis). Integrated/comprehensive approaches were observed in 6 studies combining proxy indicators, statistical and qualitative approaches (namely, Angula & Kaundjua 2016; Antwi-Agyei et al. 2013a; Rurinda et al. 2014; Jakpa 2015; Sallu, Twyman & Stringer 2010; Sorey 2011). The least reported methods included model simulation and spatial mapping approaches reported in Kienberger (2012) and Asare-Kyei et al. (2017), respectively. Data sources for assessments included both primary sources (basically through surveys using questionnaires, Focus Group Discussions [FGD] and Key Informant Interviews [KII]) and secondary sources (largely climate data from meteorological agencies in respective countries). Data sources for spatial mapping technique relied on spatial indicators like land cover, land use, road network and other landmarks with some component of build up from local knowledge. Only two studies presented differences in time scale in their assessment using primary information from census data. These were on Ghana (Dasgupta and Baschieri, 2010) and Swaziland (Nkondze et al., 2013) and concluded that the dynamic nature of vulnerability is understudied. According to Singh, Deshpande and Basu (2017), lack of attention paid to temporal scales during vulnerability assessments has implications on reporting differences in vulnerability over different timescales to understand dynamism of vulnerability, especially in the context of seasonality and rural livelihoods in Africa.

The selection of vulnerability factors influences methodological quality in the design and operationalization of vulnerability assessments (Tánago et al., 2016). As depicted in Table 2.3, the VAoSAS reviewed showed that 17 studies (47%) based the selection of their vulnerability variables solely on previous studies in literature (theoretical underpinnings) with modifications made in relation to location, context and data availability during assessment. Variable selections in about 10 studies (28%) were exclusively subjective, based on expert and/or various stakeholders' knowledge and judgment. The remaining 9 studies involved both theory and subjective processes in the selection of vulnerability factors.

Table 2.3: Conceptual frameworks with representative studies adopted in reviewed assessments

Assessment framework	Description [*source:* (Fussel, 2007)*;* (Eakin and Luers, 2006)*;*(Turner II et al., 2003) (Adger and Nelly, 1999)]	Examples of analytical frameworks adopted in reviewed papers	Representative studies (Reference[s]) – [*Note: Six of the reviewed studies did not explicitly indicate the conceptual /analytical framework adopted hence not reported*]
Pressure and Release model	Applied to and human ecology studies. Considers risk as an attribute of hazard and vulnerability. It synthesizes social and physical vulnerability	• Sustainable Livelihood Approach (from Scoones 1998) • Resilience Framework (from Berkes, Colding &Folke, 2003) • Integrated assessment framework (from Fussel and Klein 2006) • Vulnerability and Risk Framework (from Downing et al. 2001)	Westerhoff & Smit 2009 Choptiany et al. 2017 Tesso, Emana & Ketema 2012 Derbile & File 2016 Sorey 2011 Effah 2014 Umoh et al. 2014 Etwire et al. 2013 Hahn, Riederer & Foster 2009 Rurinda et al. 2014
Political Ecology model	It is used in development, climate change and disaster risk and hazard assessments. Consists of internal social vulnerability or cross-scale social vulnerability state of being due to different exposure, impacts and capacities	• IPCC Vulnerability to Climate Risk (from Eakin, Luers, 2006); (Adger et al. 2006) • Poverty Framework (from Sen and Subbarao, 2004) • Sustainable Livelihood Approach (from Scoones 1998) • Moser Asset Vulnerability Framework (from Moser 1998) • Model of Vulnerability to Poverty (from Chaudhuri, 2002)	Derbile, File & Dongzagla 2016 Cooper & Wheeler 2017 Dumenu & Obeng 2016 Oluoko-odingo 2011 Bele, Sonwa & Tiani 2014 Deressa, Hassan & Ringler 2009 Tiani et al. 2015 Hotz 2010 Jakpa 2015 Notenbaert et al. 2013 Nkondze, Masuku & Manyatsi 2013 Ng'ang'a et al. 2012 Dasgupta & Baschieri 2010 Antwi-Agyei et al. 2013a Pavageau, Butterfield & Tiani 2013
Resilience	Applied to coupled human-environment	• Socio Ecological Systems	Grothmann et al. 2017

Model	systems and considers dynamic aspects of vulnerability. Contributes to understanding the dynamics of change/transition, reorganization and capacity	Framework (from Ostrom 2009) • Livelihood Trajectory Approach (Fraser 2006) • Resilience Framework (from Masten et al., 2003)	Raemaekers & Sowman 2015 Sallu, Twyman & Stringer 2010
Expanded Vulnerability model	Applied to coupled human-environment systems, the vulnerability and sustainability of which are predicted on synergy between the human and biophysical subsystems as different spatiotemporal scales affect them.	• Multi-Hazard Vulnerability and Risk Assessment Framework	Asare-Kyei et al. 2017 Kienberger 2012

Table 2.4: Information of sources of data and instruments used, basis of variable selection and analytical approaches employed by reviewed studies

Reference(s)	Sources of data		Data collection tools/instruments employed	Basis of variable selection		Main analytical approach for operationalizing vulnerability
	Primary	Secondary		Theory	Subjective	
Grothmann et al. 2017	✓	✓	Focus Group Discussions (FGDs), questionnaires. interviews, stakeholders workshop, observation	✓		Statistical (logistic regression models and index computations)
Cooper & Wheeler 2017	✓		Interviews, semi structured questionnaire, FGD	✓		Indicator based (descriptive and thematic analysis)
Asare-Kyei et al. 2017	✓		Statistical remote sensing, Geographical Information Services (GIS)	✓	✓	Spatial mapping (Remote sensing and GIS techniques and re-scaling normalization technique)
Okpara, Stringer & Dougill 2017	✓		Semi structured interviews, FGDs	✓	✓	Indicator based (Weighting and averaging indicators)

Derbile, File & Dongzagla 2016	✓			In-depth interviews, FGDs		✓	Participatory/qualitative (Descriptive, climate learning ladder approach)
Dumenu & Obeng 2016	✓			Interviews, FGD, questionnaire	✓	✓	Indicator based (Descriptive, weighting and averaging indicators)
Westerhoff & Smit 2009	✓			Semi-structured questionnaire, in-depth interviews, FGDs	✓		Indicator based (Community based analytical approach)
Raemaekers & Sowman 2015	✓			Community workshop, FGDs, Key Informant Interviews (KIIs)		✓	Participatory/qualitative (thematic and content analysis)
Choptiany et al. 2017	✓			Multi-stakeholder workshop, structured and semi structured questionnaires	✓	✓	Indicator based (Descriptive, Self evaluation and holistic assessment of climate change resilience technique)
van Vliet 2010	✓			Questionnaires, interviews		✓	Participatory/qualitative (participatory community mapping, scoring systems, historical trend analyses and participatory wealth ranking)
Oluoko-odingo 2011	✓	✓		Questionnaires, interviews, general observations, remote sensing techniques.	✓		Indicator based (multiple correlation and regression analysis, stepwise multiple regression analysis, principal components analysis, factor analysis, and cluster analysis.
Bele, Sonwa & Tiani 2014	✓			FGDs, KIIs, Field observation	✓		Participatory/qualitative (Brainstorming, historical trend analysis and diagnosis)
Pavageau, Butterfield & Tiani 2013	✓			District level workshops		✓	Participatory/qualitative (Field based farmer learning approach)
Mapfumo et al. 2013	✓			Expert consultations, KIIs, Field-based farmer learning centers	✓	✓	Participatory/qualitative (Feedback analysis)
Tesso, Emana & Ketema 2012	✓			Structured questionnaires, FGDs		✓	Statistical (Descriptive, Principal Component Analysis and probit regression model)
Deressa, Hassan & Ringler 2009	✓		✓	Questionnaires	✓		Statistical (descriptive, expected poverty and proxy analysis)
Angula & Kaundjua 2016	✓			FGDs, in-depth interviews, questionnaires	✓		Integrated/comprehensive (Mapping out, statistical estimations)

Derbile & File 2016	✓		KIIs, FGDs		✓	Participatory/qualitative (seasonal calendar analysis; two generational analytical framework)
Kienberger 2012	✓	✓	GIS, expert interviews	✓	✓	Model simulation (Integrated modeling using algorithms for interpolation, weighting of indicators through spatio-temporal context)
Molefe & Masundire 2016	✓		Workshop		✓	Participatory/qualitative (content analysis)
Sorey 2011	✓		FGDs, KIIs, observation	✓		Integrated/comprehensive (Resource mapping, hydro-climate characterization with percentages and mathematical formulae)
Effah 2014	✓	✓	Survey questionnaire, interviews	✓		Statistical (linear regression analysis and descriptive statistics)
Umoh et al. 2014	✓		Questionnaire, FGDs, In-depth interviews		✓	Indicator based (Mean scoring and averaging indicators)
Tiani et al. 2015	✓		FGDs, Workshops		✓	Participatory/qualitative (Profile analysis and resource mapping, interpretation of narratives, historical analysis, flows analysis)
Hotz 2010	✓		KIIs, interviews, community workshops, observation,	✓	✓	Participatory/qualitative (Ethnographic approach and analysis)
Jakpa 2015	✓		GIS, semi- structured questionnaires, FGDs, interviews, transect walk		✓	Integrated/comprehensive (Logical analysis and separation biases and stereotypes, cross-checking, triangulating data sources, weighting and averaging indicators and GIS mapping)
Sallu, Twyman & Stringer 2010	✓	✓	GIS, oral history	✓	✓	Integrated/comprehensive (in-depth livelihood trajectory mapping, thematic analysis, descriptive, multivariate statistics cluster analysis and correlations using Principal Components Analysis (PCA), Landsat images
Notenbaert et al. 2013	✓		Survey questionnaire	✓		Statistical (correlation and binary logit regression)

Nkondze, Masuku & Manyatsi 2013	✓	✓	Personal interviews, secondary sources	✓		Statistical (Descriptive statistics, multinomial logistic regression
Ng’ang’a et al. 2012	✓		Structured questionnaire	✓		Statistical (Descriptive statistical analysis, frequencies, percentages, means and standard deviation)
Dasgupta & Baschieri 2010		✓	Secondary sources using data from Living Standards Cross sectional Survey	✓		Indicator based (Principal Component Analysis and weighting for each variable)
Etwire et al. 2013	✓	✓	Survey questionnaire	✓		Indicator based (Weighting and averaging indicators)
Hahn, Riederer & Foster 2009	✓		Survey questionnaire	✓		Indicator based (Weighting and averaging indicators)
Antwi-Agyei et al. 2013a	✓		Survey questionnaire, KIIs, FGDs	✓		Integrated/comprehensive (content analysis, ANOVA K-means cluster analysis)
Rurinda et al. 2014	✓	✓	Survey questionnaire, FGDs, KIIs, community workshops, farm diaries	✓	✓	Integrated/comprehensive (Participatory diagnostic techniques, descriptive statistics, trend analysis)
Vilissa 2016	✓	✓	Semi-structured interviews, questionnaire, KIIs	✓		Participatory/qualitative (Content analysis, trend analysis)

2.3.4 Interpretations of the VAoSAS

According to Preston (2012), most vulnerability assessments should target identification of the problem orientation, methodological framing or enabling support to decision making. Following Preston's explanation, to identify and understand the implications of the assessments reviewed in this study, the key objective and conclusion for the reviewed studies were categorised according to the following outcomes:

- Vulnerability identification for different sub-sectors, systems, people and places,
- Contribution to complementing/enhancing/developing vulnerability assessment methods/concepts,
- Facilitation of decision-making.

Vulnerability identification and methodological contribution relate to the examination and understanding of the nature and determinants of vulnerability, as well as of the methods employed and various concepts framed for analyzing vulnerability. The last category relates to supporting decision-making for either policy or practice on adaptation. The most common outcome of the examined assessments identifies the determinants and vulnerability of sub-sectors, systems, people and places (58%) followed by methodological contribution (25%) and decision support (17%). See Appendix V for details of summary of outcomes and implications of vulnerability assessments from reviewed studies.

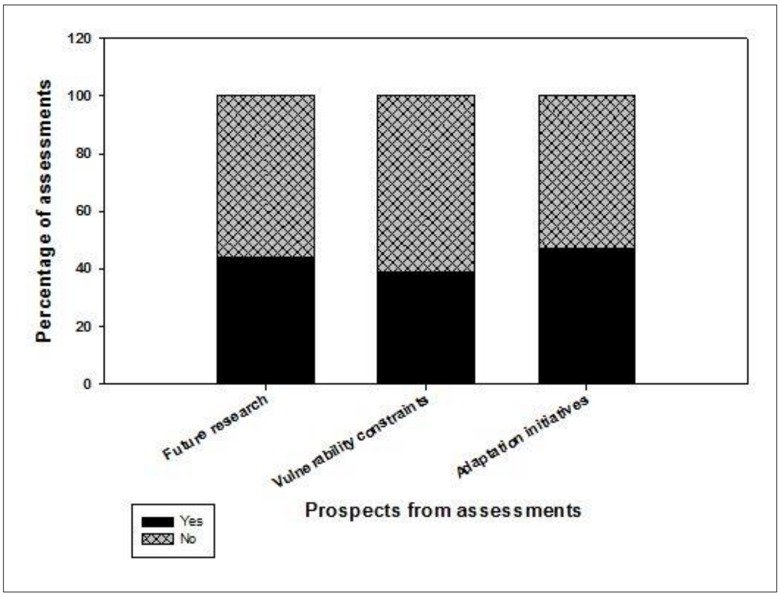


Figure 2.3: Percentage of assessments indicating prospects for future studies, vulnerability challenges and adaptation initiatives

Further analysis of the results, discussion and conclusion sections of the reviewed assessments tried to link the findings of the assessments to vulnerability and adaptation planning. This helps identify the potential implications of enhancing adaptation practice on the basis of the assessments conducted. The intended end-users of vulnerability assessments include policy makers, decision makers (government and farmers) and other stakeholders (for example, researchers, community/village groups, NGOs). Among the studies reviewed, only 44% linked their findings with recommendations for future research (either into methodological aspect of assessing vulnerability; or into furthering the conceptual understanding of vulnerability or adaptation planning) (Figure 2.3). Only 47% of the assessments expressly reported on adaptation/coping initiatives practiced in the studied communities, with the intent to inform policy or practice. Also, 39% of the examined studies mentioned constraints hindering their study systems' response to vulnerability (Figure 2.3).

2.4 Discussion

2.4.1 Current status of smallholder vulnerability assessment in Africa

Over the last decade, the rise in vulnerability assessments and research in Africa has begun to focus on smallholder livelihoods and communities. A steady rise in annual studies has been evident since 2013. The greater number of assessments in recent years reflects the growing awareness of the impacts of climate change on the continent. As a consequence, increasing assessments have been conducted to identify vulnerable people as well as places to support decision-making and effectiveness of adaptation planning. Our review indicates that assessments have particularly been focused on Western and Southern Africa. This is consistent with areas contributing the most to agricultural output in Africa. The crop sector dominates total agricultural production value (almost 85%) with the Western and Southern Africa also accounting for a comparatively large publications share across Africa (OECD/FAO, 2016a). This geographical distribution highlights notable gaps for many countries from Eastern and Central Africa where livestock production is a clear contributor to agricultural output. The gap in research in these areas is potentially problematic as Eastern and Central Africa are also regarded as two of the most sensitive areas to El Niño episodes, threatening food security in the area (OECD/FAO, 2016b). This trend suggests that vulnerability assessments in Africa are not necessarily driven by characteristics of inherent vulnerability, but are geospatially linked to research institution, market and productivity intelligence.

Although it is generally recognized that assessing vulnerability of particular groups enables clearer and more effective responses to be directly targeted towards them (Barsley et al., 2013), guidance for specific subsector assessments were limited in the literature covered. More than half of the studies did not specify the exact cropping systems covered in their studies. Producers and production areas for mostly cereal, root and tuber, legume and other cash crop production without clear or detailed inclusion of other subsectors like the horticultural sector was observed. The horticultural sector however constitutes an important source of revenue for smallholder producers and provides rural households with employment opportunities in a number of countries in SSA (OECD/FAO, 2016a). It is clear from the gaps noted from dearth of studies in spatial distribution and sectorial coverage that more context specific assessments should be developed and more studies on vulnerability assessments should be promoted across Africa.

Furthermore, scholarly evolution contributing to vulnerability research, has moved from assessments focused on solely biophysical or socioeconomic factors as observed in more than half of the reviewed studies (see Table 2), towards a broader concept of multi-disciplinary (combining socioeconomic and biophysical factors), and multi stressors vulnerability research approaches (Luers et al., 2003; Bisaro, Wolf and Hinkel, 2010; Delaney et al., 2014; Devisscher et al., 2018). The majority of studies were exclusively focused on climatic risk. Others were unclear as to what their study systems are vulnerable to, reflecting a lack of specificity and generally poor recognition of the multiplicity of stressors in shaping vulnerability among smallholders (O'Brien, Quinlan and Ziervogel, 2009). There is the need for future research studies to make adequate progress to invigorate all interlocking stressors of vulnerability other than climate climatic risks or social factors.

2.4.2 Conceptual framing and operationalisation of vulnerability among smallholders in Africa

Political Ecology and Pressure and Release models are the most dominant theories for vulnerability studies in Africa. The theories mainly originated from Climate Change Adaptation studies and consider states of being due to different exposure, impacts and capacities and risk as an attribute of hazard and vulnerability. Studies by scholars such as Hahn, Riederer & Foster (2009) and Rurinda et al. (2014) among the reviewed studies applying models from political ecology and sustainable livelihoods backgrounds give valuable contribution and perspectives in comparing rural livelihoods of different sociopolitical and economic contexts. The conceptual framings identified however spanned different disciplinary paradigms including hazard and human ecology, development, climate change and disaster risk and hazard assessments as well as coupled human-environment studies. Notably, gender concerns were limited. The varied disciplines guided the diverse conceptual underpinning in framing and conducting VAoSAS over the past decade. Consequentially, heterogeneity in adopted conceptual frameworks is reflected in the diverse definition and operationalisation of vulnerability. With different conceptual frameworks, ranging from Sustainable Livelihoods, Social Protection, Hazard and Human Ecology, Political Economy, Entitlement or Resource Endowment, Poverty and Development Studies, definitions of vulnerability varied across the studies. There is increasing attention given to the conceptualization of vulnerability, to enhance the consensus of assessments, and to provide more adapted information (Preston, Yuen and Westaway, 2011; Singh, Deshpande and Basu, 2017). Our results show that studies from Africa still lack consistent framework and a clear concept guiding assessments. The 13 analytical frameworks highlighted were drawn from 13 different studies. Such progress emphasizes the increasing concern in lack of consensus regarding frameworks and the varied definitions used in constructing vulnerability assessments among scholars (Preston, Yuen and Westaway, 2011; Delaney et al., 2014; Tánago et al., 2016; Singh, Deshpande and Basu, 2017).

Climatic risks with few interactions of both climatic and non-climatic risks drove majority of the reviewed studies while some could not also exclusively indicate what is driving vulnerability of their study systems. Studies not explicitly specifying the concept underlying their assessment and/or what drives vulnerability is a limitation and reflects a general lack of systems approach to assessments. Dominance of studies taking climatic perspectives such as droughts, floods, hailstorm and strong winds, and non-climatic perspectives but related to changing climate as vulnerability drivers could however partly result from the present review focusing on climate variability and climate change. Identifying vulnerability drivers potentially enables subsequent identification of measures to reduce that vulnerability. More generally, vulnerability constitutes the difference between the adaptive capacity of a household in response to its sensitivity and exposure to climate-induced hazards. Assessments were generally conceptualized based on the systems exposure to hazards as a function of both magnitude and scope of perturbation. It involves the system it influences, as well as risk of being affected by extreme events or stressors. The main foci of such assessments were on current vulnerability, risk of present and future climatic variations and best responses to reduce present vulnerability and improve resilience to future risk. There is need for improvement in this approach with possible consideration of the recognition of how other non-climatic stressors shape vulnerability. Drivers of vulnerability inform the theoretical framings used, guides the conceptual framework adopted and later the operationalization of vulnerability assessments. Improved integration of other stressors related to demographic, economic and social factors interacting with climatic risks in assessing vulnerability is important and could contribute to the improved framing of vulnerability and to address the causes of all hazards. These need to be considered and given attention during future assessments to demonstrate the relevance of how vulnerability, other than climatic factors, can be applied for improved operationalisation of vulnerability within specific concepts and context.

2.4.3 Methods used in assessing vulnerability of smallholders in Africa

The diverse conceptual framings and definitions of vulnerability earlier noted are reflected in the variety of analytical approaches employed (See Table 2.3). Lack of a standardized way of analyzing vulnerability data in the reviewed studies corroborates similar findings in other regions of the world (Preston, Yuen and Westaway, 2011; Tánago et al., 2016; Singh, Deshpande and Basu, 2017). Six major methodological approaches employed to interpret the vulnerability of smallholder livelihoods in Africa show dominance in the utilization of qualitative and indicative-based methods across Africa. Each of the six methods faces some level of criticism and difficulty in evaluating vulnerability. Most local level vulnerability assessments have been widely critiqued globally for not using principles of participatory design and engaging local perspectives and knowledge as important information sources during assessments (Raemaekers and Sowman, 2015; Mcdowell, Ford and Jones, 2016). Vulnerability assessments related to smallholder livelihoods in Africa in the last 10 years show some level of improvement in this regard however as diverse participatory approaches such as participatory community mapping, scoring systems, historical trend analyses, generational analysis and participatory wealth ranking were evident. With regards to local level engagements however, efforts need to be further encouraged to formally consider both subjective and theoretical aspects in variable selection for assessment by incorporating local perspectives and knowledge as source of information.

Assessments based on integrated dynamic modeling and spatial approaches at the local level however is uncommon in Africa, with only two notable exceptions, Asare-Kyei et al. (2017) and Kienberger (2012) from the studies reviewed. This underrepresentation may result in limited understanding of future vulnerability. During vulnerability assessments in Africa, limited attention is given to evaluation at temporal scales that has implications in understanding the dynamism of vulnerability across the region overtime affecting future projections. This limitation is attributed to high data requirement for model calibration and uncertainties regarding human decision-making. Set of spatial indicators constituting vulnerability units and characterizing an area considered such as land cover/land use, road network needed may not be readily available. Additionally, existing data on national census and climate for example, which includes data on education, gender, market accessibility, age, climatic variables (temperature and rainfall) among others are usually incomplete, insufficient and inconsistent geographically. There is need for more explicit and complete data for evaluating vulnerability and improve capacity of smallholders to vulnerability if assessments should rely basically on existing (secondary) and spatial data for evaluation. It implies regularly updating all relevant and available data including census and climate data. This is more relevant as increased consideration in the scientific community for both biophysical and social vulnerability has resulted in calls for a more comprehensive approach in evaluating vulnerability (O'Brien et al., 2004; Sietz, Choque and Lüdeke, 2012). Vulnerability assessments across Africa have started to give attention to the development of comprehensive methods with efforts in applying integrated approaches using comprehensive analysis of proxy indicators, statistical and qualitative approaches and both primary and secondary data sources. This should be further promoted. That is, due to the multidimensionality of vulnerability, future studies need to develop more rigorous and replicable local and context specific variables critical for uptake at different localities across the geographical and sectoral settings for smallholder agricultural systems context.

2.4.4 Outcome of vulnerability assessments

At the local level, understanding current vulnerability is considered a prerequisite for identifying key determinants of successful adaptation in the future (Adger, 2003). Assisting households manage current climate variability by assessing their coping capacity would be a first step in preparing for expected increases in extreme events (Notenbaert et al., 2013). Coping and adaptation at the local level is noted to be autonomous and farmers are essentially acknowledged as the main facilitators expending their own social capital and resources (Notenbaert et al., 2013). These arguments have practical implications for the outcome of vulnerability assessments for smallholders. Vulnerability assessments are expected to provide adequate understanding, information and practical guidance to support farmers' decision making on adaptation planning beside vulnerability identification. The main outcome of vulnerability assessments conducted among smallholder farmers in Africa for the past ten years have mainly been to identify determinants and vulnerability of sub-sectors, systems, people and places. Other studies also broadly focused on enhancing conceptualisation of vulnerability and contributing to methods employed in the assessment process. The least produced outcome was directed towards facilitating decision making among stakeholders. This finding implies that vulnerability scholarship focusing on smallholders in Africa has made limited progress in empowering farmers who are the main actors of adaptation planning at the local level to informed decision making and uptake of adaptation.

Importantly, the relevance of vulnerability research for decision-making on adaptation planning for other key decision-makers is limited (governments and policy makers). Meanwhile, various stakeholders including policy makers, researchers, community/village groups and Non-Governmental Organisations (NGOs) are intended enablers and users of vulnerability assessments. This indicates that reports of African countries still not realizing their potential in climate adaptation is still pertinent (Kurukulasuriya *et al.*, 2006; Ndamani and Watanabe, 2017). There is need for research findings from VAoSAS to improve communication and enlighten science, policy and practice for informed decision-making and evidenced based policies. Furthermore, anticipated end-users of assessments should be involved in the assessment process as earlier indicated. Similar recommendations have been at the center of recent systematic reviews of vulnerability assessments in different contexts (Tánago et al., 2016; Mcdowell, Ford and Jones, 2016; Donatti et al. 2018).

Our study further explored the linkage between assessment outcomes and attempts to develop options for promoting resilient smallholder agricultural systems. It is important to identify how vulnerability can be reduced to direct government policies. Range of adaptation measures specified to reduce vulnerability from reviewed studies included diversification of crops and income sources, planting different crop varieties, such as better organization at local level (i.e. cooperatives) and improvement of infrastructure. These strategies could build on some adaptive measures in agricultural programmes that already exist to improve it. Assessments reviewed however showed insufficiencies in identifying adaptation/coping measures after assessment for possible policy interventions. The same limitation applies to indicating responses constraining farmer's response to vulnerability for concrete policy and practical solutions to identified challenges. Scientists also successfully use assessments to understand general principles of a system and what can be improved from observed situations but limited recommendations for direct future research were not specified.

In order to advance the science and practice of vulnerability assessment in Africa, there is need to conduct assessments based on specific sector/sub sector for identification of explicit potential climate adaptation strategies to improve understanding and knowledge of adaption among different smallholder agricultural systems. To give guidance and policy suggestions from vulnerability assessments however, outcomes from the process need to inform development of policies. Even though some of the studies reviewed identified various adaptation options, the effectiveness of such measures to support decision-making is not known. For instance, to inform the development of climate adaptation programmes and policies, the assessment process needs to provide information to guide and inform effective decision-making on allocation of scarce resources through prioritization for more relevant and targeted responses. Specifically, generation of information on the costs and benefits from the implementation of climate adaptation options could direct development initiatives on investment in responding to changing climate. Farmers could also benefit from such information to understand trade-offs management and implementation to build understanding and strategically pursue possible responses to reduce their vulnerability. Information on guided policy recommendations to mainstream climate adaptation into agricultural development strategies and plans also need to be highlighted in vulnerability assessments for policy actions.

2.5 Conclusions

In presenting the progress made in Africa over the last decade, this review focused on providing an overview of vulnerability assessments and how it has been conducted and interpreted among smallholder agricultural systems. Despite the growing interest in the scholarship across the region, we observed geographical and sectorial dearth in studies on Vulnerability Assessment of Smallholder Agricultural Systems (VAoSAS) in Africa. Particularly, East and Central Africa regions could benefit from less spatially partial and more regionally balanced VAoSAS while more assessments of sub-sectors of smallholder agriculture, such as livestock and horticulture production could be improved across the region. The role of both climatic and non-climatic stressors and their relative importance should both be considered in assessing smallholders' vulnerability. Even though there is widespread development of methods and concepts for VAoSAS in Africa, there are still opportunities that this study highlights as target for improvement in future assessments. We suggest the engagement of greater diversity of stakeholders as participants throughout the assessment process to make it a more inclusive method. Generally, focus of smallholder climate vulnerability research is increasingly moving towards human-environment coupling system hence vulnerability estimation should also move more towards a comprehensive approach. Relativity of indices to systems studied that is used in current indicator based approach need to be enhanced and complemented to construct a reasonable indicator system. Overall, comparing the assessments reviewed on smallholder agricultural systems in Africa to current scientific knowledge on vulnerability research that is argued to have a multidimensional nature, we suggest an integrated approach to the assessment process.

At the conceptualisation and methodological level, strengths observed in the literature indicate the future of vulnerability assessment in Africa requires a holistic and multidimensional approach. It needs to be integrative to avoid ambiguity in understanding the system assessed as well as comprehensive enough to understand the human and environment system relationship better. Furthermore, best practice links vulnerability assessment outputs with adaptation policy and measures regarding the relevance of assessments to end-users. The scarcity of evaluation of economic effectiveness of adaptation strategies as critical aspect of vulnerability assessment literature in Africa requires improvement in future research. This would empower exposure units to address the causes of hazard they are being exposed to; provide guidance and inform effective decision-making on allocation of scarce resources (prioritization); understand trade-offs management and implementation to build understanding among stakeholders (farmers and policy makers) to pursue possible responses to reduce vulnerability.

Chapter Synthesis

This literature review has given an overview on the state of vulnerability assessments among smallholder agricultural systems with reference to Africa. It has reviewed relevant literature on the topic and provided useful insights for the thesis's conceptual and theoretical framework. The chapter shows there has been growing number of publications related to vulnerability assessments in recent times in Africa. Attempts have been made to apply this emergent knowledge to assess vulnerability, pointing to the effects of climate on smallholder agricultural systems (who are resource poor and face multiple stressors) to estimate vulnerability of farming systems at the local level. Such attempts have however resulted in diverse conceptualization and methods in conducting assessments with no consensus in defining and operationalising vulnerability among scholars. This challenges common understanding of the assessment process. It also makes assessment of vulnerability of smallholder systems a complex discourse. Despite the growing interest in the scholarship over the past decade across the continent, more assessments of smallholder production systems needs to be encouraged in Africa. This is due to the dearth of studies identified for thematic and sub-sector specific assessment efforts especially for subsectors such as livestock and horticulture for more context specific assessments and also in other regional locations. This further provides justification for the context of this thesis on smallholder horticultural producers in West Africa.

The chapter identifies gaps in literature that informs appropriate research methodology adopted in subsequent chapters of the thesis. With the widespread development of methods and concepts for the assessment practice, the review demonstrated that there are still opportunities that need to be targeted for improvement in future assessments. These included the engagement of greater diversity of stakeholders as participants throughout the assessment process to make it a social learning process. Focus of smallholder climate vulnerability research is increasingly moving towards human-environment coupling system hence vulnerability estimation should also move more towards similar comprehensive approaches. Furthermore, relativity of indices to systems studied that is used in current indicator based approach need to be enhanced and complemented to construct a reasonable indicator system. Additionally, the role of both climatic and non-climatic stressors and their relative importance needs to be considered in assessing smallholders' vulnerability.

Overall, comparing the assessments reviewed on smallholder agricultural systems in Africa to current scientific knowledge on vulnerability research that is argued to have a multidimensional nature, an integrated approach to the assessment process is emphasized. At the conceptualization and methodology level, sub-sector specific guidance that will have a holistic multidimensional approach and will be integrative to avoid ambiguity in understanding the system assessed is stressed. Moreover, linking vulnerability assessment outputs with adaptation policy and measures regarding the relevance of assessments to end-users is highlighted. The scarcity of evaluation of adaptation capacity as critical aspect of vulnerability assessment literature in Africa is also highlighted. This included dearth of studies that assess the effectiveness and economic performance of possible adaptation strategies. It also included lack of studies that integrates vulnerability assessment and assessment of evolving potential adaptation responses at the farm-level to improve decision making on implementing the evolved measures. Attempts will be made throughout the thesis to address these gaps identified from this literature review and considered through Chapters 3 to 6. These knowledge gaps justify the research design and approach for this thesis, as done from Chapters 3 to 6. The LVI is adopted as the most appropriate considering the context (resource constrained smallholder farmers). It is acknowledged that other frameworks exist including the 'risk framework' by the IPCC, Multi-Hazard Vulnerability and Risk Assessment Framework, Livelihood Trajectory Approach among others (see Table 2.3, Chapter 2). Whilst the other frameworks also provide understanding for risk, their operationalisation is quite unpopular and its concepts not directly relevant for the context of this thesis and as compared to the Livelihood Vulnerability Approach. Adopting the Livelihood Vulnerability Approach is known to significantly provide a richer understanding of different relational dimensions between vulnerability and adaptation. As explained by Tschakert et al. (2013) in Chapter 1, using the indicator based approach supports calls for the need for a relational approach to assessing vulnerability. The importance of understanding the socio-economic and political factors that influence levels of vulnerability through subjective selection of the indicators used in this thesis addresses issues of indicator-based approaches neglected in other studies. Horticulture production is a specific subsector where case studies of its vulnerability and adaptation are lacking. The next chapter (Chapter 3) employs the LVI to climate vulnerability assessment and to explore the extent of vulnerability of horticultural production systems between the two municipalities in Ghana.

CHAPTER 3

ASSESSING VULNERABILITY OF HORTICULTURAL SMALLHOLDERS' TO CLIMATE VARIABILITY IN GHANA: APPLYING THE LIVELIHOOD VULNERABILITY APPROACH

This chapter describes the livelihood vulnerability of smallholders to climate variability in Ghana. It shows the data collected through participatory methods, focus group discussion and questionnaire survey as well as results from the evaluation and comparison of climate vulnerability among smallholder horticultural producers in two selected municipalities in Ghana (Objective 1). Applying the LVI, the chapter looks at how exposed, sensitive and the adaptive capacity of smallholder horticultural households are to changing climate; how applicable the LVI is in assessing sector specific vulnerability assessments; and how the livelihood vulnerability approach provides insights for future assessments and linkage to adaptation planning. It does this through a field survey by selecting indicators for components of the LVI.

Summary

Changing climate is posing considerable threats to agriculture, the most vulnerable sector and to smallholder farming systems the predominant agricultural livelihood activity in Africa. The study of specific systems enables clearer and more effective responses to be directly targeted for enhanced adaptation but there is limited knowledge guiding specific subsector vulnerability assessments. We applied the Livelihood Vulnerability Index in order to understand and identify the nature and sources of vulnerability among smallholder horticultural farming households to climate variability in two districts in Ghana. A total of 480 households engaging in fruit and vegetable crop production were surveyed in Keta and Nsawam districts of Ghana. Data was collected on indicators for Livelihood Vulnerability Index components such as socio-demographic profiles, livelihood strategies, social networking, health, food, production, water, natural disasters and climate variability. The vulnerability-contributing factors were aggregated in a composite index and differences compared. The results indicate that smallholder horticultural farmers in Keta are more vulnerable in relation to high exposure and high sensitivity to climate variability while smallholders in Nsawam are more vulnerable in terms of low capacity to adapt to climate variability. As it is the case for smallholder horticultural farming communities, the study suggests that Livelihood Vulnerability Index can be broadly applied to highlight potential

areas for intervention and reduce the vulnerability of sector specific farming communities within local and national levels.

3.1 Introduction

The latest Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), indicates widespread impacts from observed changing climate on all continents (IPCC, 2014). The report highlights Africa's high exposure to climatic events coupled with low adaptive capacity making the continent one of the most vulnerable regions. Agriculture is Africa's major economic sector (Challinor et al. 2007; OECD/FAO 2016a), and it is also considered as the most vulnerable sector posing considerable threats to farming systems, particularly to smallholder farming systems (Rurinda et al., 2014). Smallholder farming systems support livelihoods and economic growth over most countries as they mainly constitute majority (about 80%) of all the farms in Africa (AGRA, 2017) but are characterized by various climatic, demographic and socioeconomic stresses limiting adaptive capacity (Morton, 2007).

Further changes in climate is inevitable for Africa in the coming decades (IPCC, 2013) and climate projections suggest likely increase in variability over the coming decade threatening food security in the sub-Saharan Africa (SSA) (OECD/FAO, 2016b). Impacts from changing climate differ among regions in SSA, subsectors and from country to country (Adger et al., 2004). Western Africa is of particular concern since instability of total agricultural production since 2007 has been mainly through them (OECD/FAO, 2016b). For about 24 years, West Africa mainly accounts for the total value of outputs from agriculture (60%) within Africa (OECD/FAO, 2016b). West African countries including Ghana is also expected to strongly experience temperature increase and rainfall variability (Riede et al., 2016). Projections into the future reported in the AR5 over West Africa show increase in temperature between 3°C and 6°C and rise in rainfall variability (Riede et al., 2016). Ghana also came second after Ethiopia as the most exposed to climate-related hazards and its risks on the African continent (World Bank, 2009). Expectedly, impacts from changing climate including floods and droughts will continue in Ghana and that incidence of events such as these would become more intense and frequent (Alley, 2014).

A number of studies in Ghana have shown that impacts of climatic changes are already manifesting in response to increased temperatures and rainfall variability (Arndt, Asante & Thurlow, 2015; Anim-Kwapong & Frimpong 2005) as well as in response to rise in sea level (Stanturf et al., 2011). Consequently, various studies have indicated that change in climatic variability leads to significant negative effects on livelihoods and food resources particularly among subsistence and small scale agricultural production, whose activities are mostly land and natural resources dependent (Laube, Schraven & Awo, 2012; Fosu-Mensah, Vlek & MacCarthy, 2012). This increases vulnerability of people involved in such production systems, which poses threat to their lives, property and livelihoods in the country. Assessing agricultural sector's vulnerability to changing climate is therefore essential as it defines risks posed by climate as well as provide information for identifying measures to adapt to the impacts (Fussel, 2007; Preston, Yuen & Westaway 2011; Preston et al., 2011). It further informs policy planning on climate risk reduction (Fussel and Klein, 2006) and assists households to manage current climate variability by assessing their coping capacity (Notenbaert et al., 2013). As a first step towards preparing against increases in extreme events, understanding and assessing current vulnerability is considered a prerequisite (Adger, 2003).

According to Chambers & Conway (1992), for sustainable living, vulnerability assessment ought to provide explicit indications required on capabilities, assets, and activities. Vulnerability research has developed in the last four decades and advanced from initial natural hazards discipline to encompass Socio-Ecological Systems (SES) and Sustainable Livelihoods Framework (SLF) (Barsley, De Young & Brugere, 2013). Sustainable Livelihoods Framework (SLF) is a common conceptual framework dominant in understanding livelihoods of resource-constrained individuals and their environment. It uses multiple indicators to assess households' exposure, sensitivity and adaptive capacity to impacts from climate change (Chambers & Conway, 1992). It has been employed by various scholars under distinctive contexts (Hahn, Riederer & Foster, 2009; Gbetibouo, Ringler & Hassan, 2010; Antwi-Agyei et al., 2013). The Livelihood Vulnerability Index (LVI) by Hahn, Riederer & Foster (2009), provides an insightful way of assessing vulnerability at the community-level using household-level data. It draws out critical differences in exposure, sensitivity to climate variability and households' adaptive capacity to inform policy and strategic community level planning in Mozambique, Southern Africa. Although it is generally recognized that assessing vulnerability of specific systems enables clearer and more effective responses to be directly targeted (Barsley, De Young & Brugere, 2013), there are dearth of studies guiding specific subsector assessments. Understanding vulnerability of specific sector is essential to identify exposure, sensitivity and adaptive capacity for guidance on 'best fit' adaptation options effective for improved production (Hinkel, 2011). More so, given the context specificity from climate variability and change impacts, subsector specific vulnerability analysis is needed for enhancing resilience of communities particularly smallholder livelihoods. Drawing on the LVI by Hahn, Riederer & Foster (2009), this study exploits applicability of the LVI to understand and identify the sources and nature of vulnerability to climate variability among smallholder horticultural households in two municipalities of Ghana.

Changing climate is reported to have direct implications on different aspects of horticultural production including challenging sustainable production and competitiveness due to the growing demands in the environment with declining land and water resulting in price hike for fruits and vegetable crops and/or reducing livelihood options for rural producers (Malhotra, 2017). Williams et al. (2017) also showed consequences of climate variability on pineapple fruit quality and quantity during production in Ghana. High temperature as well as limited and excess moisture stresses are the major causes of low yields in vegetable production (Malhotra, 2017). Such climatic effects compounds with other existing local stressors (economic and social wellbeing), including poor markets and weak institutional support, (Abdulai et al., 2017) to exacerbate the vulnerability of people involved in the production system. Meanwhile, domestic market for vegetable production in Ghana has been growing at more than 10% in recent times and the potential value for vegetable export is estimated at US$250 million with overall turnover of around US$ 800 million (NAB Council, 2014). Horticulture production provides income for smallholders and creates household employment opportunities at the farm level (Abdulai et al., 2017). Proceeds from sales of fruits and vegetables also enable farmers to access essential staples as food and other goods and services (OECD/FAO, 2016a).

Most studies conducted on vulnerability assessments of farming households in Ghana have so far focused on studying production systems of smallholders in general (Dumenu & Obeng, 2016; Etwire et al., 2013) and major crops such as cereals (Antwi-Agyei et al., 2013) without adequate attention on horticultural production. Generally, vulnerability studies are not yet addressing fruit and vegetable producers and production areas. With little information on how vulnerable smallholder horticultural production systems' are to climate variability, this paper aims to evaluate and compare climate vulnerability of smallholder horticultural producers in two distinct districts in Ghana applying the LVI. Specifically, it looks at how exposed, sensitive and the adaptive capacity of smallholder horticultural households are to changing climate; how applicable the LVI is in assessing sector specific vulnerability assessments; and how the livelihood vulnerability approach provides insights for future assessments and linkage to adaptation planning. Such contribution provides sector and context specific knowledge for improving production and informing local adaptation planning for resilience of horticultural producing communities in a changing environment.

3.1.1 Concept of Livelihood Vulnerability Index (LVI)

Sustainable Livelihood Framework (SLF) employed in conceptualising vulnerability assessment is from IPCC which depicts vulnerability as exposure to natural disasters and climate variability; climate sensitivity to health, food and water resource characteristics; and households' socio-economic characteristics that affect their adaptive capacity (Chambers & Conway, 1992). Analyzing SLF is generally using either an econometric approach or an indicator approach (Gbetibouo, Ringler & Hassan, 2010). According to Gbetibouo, Ringler & Hassan (2010), econometric approach is reported to indicate vulnerability of a given place but does not sufficiently capture the dimensionality of vulnerability. Indicator-based approach also captures the three dimensions of vulnerability in a comprehensible form though limited in subjectivity in selection of indicators for assessments (Adger et al. 2004; Bisaro, Wolf & Hinkel, 2010). Most recent approaches combine diverse subcomponents (also referred as indicators) into a single composite index of vulnerability using primary data, to better characterize and quantify the multidimensionality of conditions studied (Shah et al., 2013).

Adapting the SLF, Hahn, Riederer & Foster (2009) developed an indicator-based LVI to provide understanding of the contributions of factors such as social, demographic and physical as a practical tool to identify areas for possible interventions. The LVI uses household level data combined with secondary data on climate exposures to capture differences in community/district level vulnerability into a single composite index of vulnerability (Hahn, Riederer & Foster, 2009). LVI comprises seven major components namely social networks, livelihood strategies, access to food, water and health, socio-demographic profile as well as climate variability and natural disaster risks. We added 'production' as a major component (Figure 3.1). Production is considered due to the high perishability and susceptibility of horticultural crops to post harvest losses as well as pest and disease attacks, and allows to better capture the susceptibility of households' production to climate variability. Details of indicators considered under the production component are shown in Table 3.2. We split up natural disaster risks from climate variability components as separate factors. We also included climate extreme indicators considered as relevant for the daily activities in the production of fruits and vegetables. A total of nine major components (instead of seven) were therefore used in this LVI evaluation of horticultural producing areas in Ghana (Figure 3.1). Further connected to the LVI is the LVI-IPCC method developed by (Hahn et al., 2009) which is also used for calculating climate vulnerability based on categorization of the main components of LVI framework into IPCC vulnerability framework; exposure, sensitivity and adaptive capacity as illustrated in Figure 3.1. The same subcomponents used in the calculation of LVI are employed in the calculation of LVI - IPCC with divergence in the combination of the major components. That is, rather than computing the LVI by combining the major components in the initial step, they were firstly merged according to the three main IPCC categorizations; exposure, sensitivity and adaptive capacity. Both methods estimate climate vulnerability. Scores from LVI-IPCC has however been noted to be used with caution, as they could lead to counterintuitive results with LVI especially when greater value of adaptive capacity compared to the exposure factor and increased sensitivity actually reduces vulnerability (Panthi et al., 2016). Comparison of the IPCC contributing factors rather than the overall score is applied in this study.

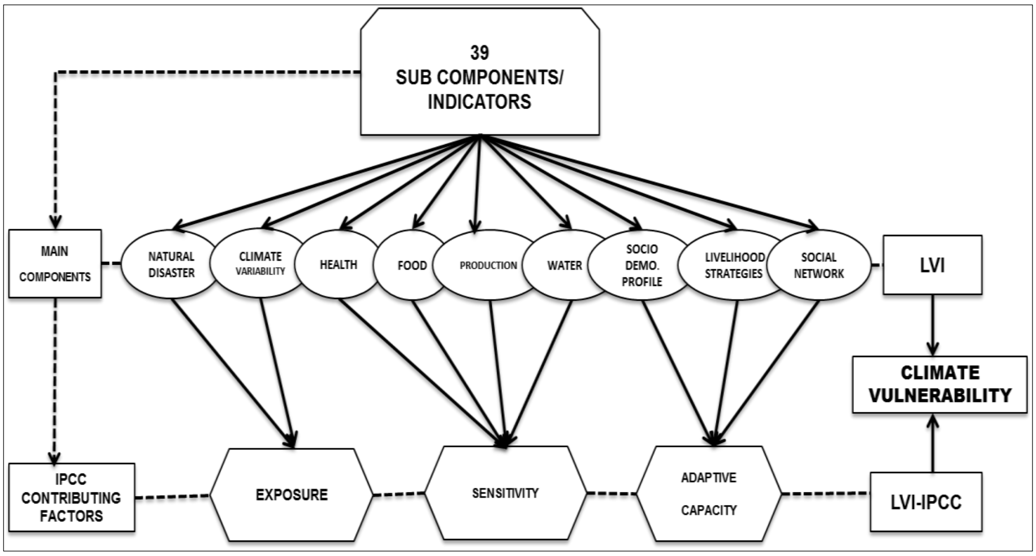


Figure 3.1: Grouping of major and sub components/indicators into LVI and LVI-IPCC

3.2 Materials and methods

3.2.1 Study areas

The study was conducted with smallholder households primarily engaged in horticultural crop production in two geographical contexts: Nsawam Adoagyiri and Keta Municipalities in the Eastern and Volta regions of Ghana respectively. The two municipalities are two of the main horticulture producing areas in Ghana. Nsawam Adoagyiri is an inland area, at the Forest Deciduous agro-ecological zone, while Keta is a coastal area found at the coastal savannah agro-ecological zone, allowing for some spatial comparative analysis. In addition, rural communities in Nsawam are subject to considerable climate variability, in terms of both decreasing precipitation and increasing temperature (Williams et al., 2017). Coastal communities on the other hand are prone to droughts and/or coastal inundation hence could be associated with experiencing climatic impacts (Shah et al., 2013; GSS, 2014a).

Smallholders dominate crop farming in both communities (about 80%). Production of fresh vegetables are strongly sensitive to the weather in both areas and use of irrigation in Ghana is increasing overall for seasonal fruit and vegetable crop production (NAB Council, 2014). Summary of physical, climatic and agricultural related characteristics for both study areas are described in Table 3.1.

Table 3.1: Physical, climatic and agricultural characteristics of study areas

Physical, climatic and agricultural characteristics	**Study areas**	
	Keta	**Nsawam**
Location	• Lies within longitude 0.30ºE and 1.05ºE and latitude 5.45ºN and 6.005ºN. It is about 160km east from the national capital	• Lies within longitude 0.07ºW and 0.27ºW and latitude 5.45ºN and 5.58ºN. It is about 23km south from the national capital
Relief	• Low-lying coastal plain	• Undulating plain
Climate	• Dry coastal equatorial climate with coastal savannah vegetation	• Wet semi-equatorial climate with mainly semi-deciduous forest vegetation (90%) and coastal savanna grassland (10%).
Mean annual rainfall range	• 800mm - 1000mm per annum	• 1250mm - 2000mm per annum
Mean temperature range	• 19ºC – 29ºC recorded in August and March respectively	• 26ºC – 30ºC recorded in August and April respectively
Rainfall pattern	• Bimodal: Two main peak periods between March -July and September – November	• Bimodal: Two main peak periods between May – June and September - October.
Major agricultural livelihood activities	• About 68% of population engaged in crop farming. The second most engaged agricultural activity is livestock rearing followed by fishing.	• About 60% of population engaged in crop farming. The second most engaged agricultural activity is livestock rearing followed by tree planting.
Key horticultural crops grown	• Crops cultivated include okra, tomato, pepper, onions, spring onions, carrots, shallots and watermelon.	• Crops cultivated include okra, tomatoes, pepper, onion, garden eggs cabbage, pineapple and pawpaw

Source: (GSS, 2014a) (GSS, 2014b)

3.2.2 Research design

Assessing vulnerability of a system should be pragmatically done by comparing different systems and identifying which components contributes more to vulnerability as well as pushes vulnerability levels (Panthi et al., 2016). A system may be the population, geographic region or human environment studied. Starting with a selection of climate vulnerability indicators extracted from literature (indicated as existing in Table 3.2), we engaged with about forty-three local stakeholders (subjectively by engaging smallholder farmers and experts at Ministry of Food and Agriculture (MoFA) including agricultural extension agents at both study areas) to select the final set of vulnerability indicators. This inclusive and participatory approach applied during the assessment process is acknowledged to support awareness creation and improvement in the quality and relevance of the assessment data (Raemaekers & Sowman, 2015; Tiani et al. 2015) addressing the challenge of indicator-based approach by reducing subjectivity in the selection process as earlier noted. The consultations resulted in the exclusion of some indicators commonly applied in the LVI framework (in literature), yet considered inappropriate in the Ghana smallholder horticulture context. For instance, existing indicators such as percentage of households with orphans; average Malaria Exposure and Prevention Index; average receive and give ratio; percentage of households that have not gone to their local government for assistance in the past 12 months; percentage of households that do not save crops; inverse of the average number of liters of water stored per household and percentage of households with an injury or death as a result of the most severe natural disaster in the past 6 years were considered not relevant in the local context studied and were subsequently removed. Other indicators were included (indicated "New" under status of indicator in Table 3.2) to translate relevant and applicable components and subcomponents. While applying the LVI approach, our study includes substantial modifications (indicated "Modified" under status of indicator in Table 3.2) towards better operationalisation of vulnerability in Ghana. The remaining indicators (indicated "Existing" under status of indicator in Table 3.2) were adopted directly from literature.

Table 3.2: Established LVI major and subcomponents for Keta and Nsawam Municipalities

Major component & Sub-component	Status of indicator in LVI	Functional relationship of subcomponent with vulnerability
Socio-demographic profile:		
Dependency ratio	Existing	The higher the number of dependents, the less capacity households can adapt. Higher percentages of socio-demographic profile indicators reflect less capacity of households to adapt and the higher the vulnerability.
% Female - headed households	Existing	
% Household head who has not attended school	Existing	
Livelihood strategies:		
%Households without member working outside community	Existing	Diversification of income sources increases adaptive capacity and decreases risk of losses. Therefore, higher values of indices reflect lower adaptive capacity hence lower vulnerability.
Average Agricultural Livelihood Diversification Index	Existing	
% Households with agriculture as only source of income	Existing	

% Households not rearing livestock	New	
Social network:		
% Households not having communication devices % Households not having access to government subsidy on production inputs % Households not associated with any Farmer Based Organization (FBO) Average borrow: lend ratio % Household not associated with any community social group	Modified New Modified Modified New	Access to information through communication devices improves individuals' awareness of impending hazard. The indicator was modified to inquire of those with access to 3 basic devices. In Ghana, FBOs and social groups are distinct from each other, but play significant roles within communities. Horticultural production in Ghana is capital intensive, therefore access to governments' subsidized input will enhance adaptive capacity of farmers. Social network indicators strengthen adaptive capacity of farmers but higher constraints of this lower vulnerability.
Health:		
Average time to health facility % Households with member having chronic illness % Households where a member missed work/school due to illness	Existing Existing Existing	The longer the time to travel to a health facility, the more families are ill or miss school/work, the more sensitive and less vulnerable. The indicators show how health impacts family and higher indices imply higher sensitivity
Food:		
% Households mainly dependent on family farm for food % Households that do not save planting materials Average number of months households struggle to get food Average Crop Diversity Index	Existing Modified Existing Existing	Limited ability to save planting materials from preceding harvests reflects sensitivity of the earlier season to unfavourable production conditions including climate. The higher the indicators for food, the more sensitive households are and the higher the vulnerability
Production:		
% Households that do not get information on improved production methods % Production output lost to post harvest losses % Production output lost to pests and diseases % Households' farm land under irrigation	New New New Modified	Production components emphasize on some production conditions and outcomes reflecting sensitivity of impacts of climate on horticultural producers/productivity. Horticultural crop production is sensitive to climate, which mostly impact negatively on horticultural crop productivity. In this context, higher indices reflect vulnerability as inadequate information on Good Agricultural Practices. A higher percentage of production losses implies higher sensitivity. The greater demand from more irrigated land,

		shows potential for water scarcity for crop production purposes hence the higher the vulnerability.
Water:		
% Households that reported water conflicts	Existing	Time to water source was changed to measure distance from farmland to the water source for the purpose of this study. This adjustment was to show how distance to available water source determines the number of households that primarily use irrigation (the longer the distance the more sensitivity). Overall, the higher percentages of indicators for water, the higher the sensitivity and more households are vulnerable
Average distance to water source	Modified	
% Households without consistent water supply	Existing	
% Households utilizing natural water source	Existing	
Natural disasters:		
Average number of flood/drought events reported in the past 5 years	Modified	Indicators were modified from initial 6 years memory recall of events to 5 years to improve on potential recall bias noted by Hahn, Riederer & Foster (2009). Mainly, higher index values reflect higher exposure and increased vulnerability
% Households that did not receive warning about expected natural disasters/events	Modified	
Climate variability		
Mean standard deviation of average monthly precipitation from 2007 to 2016	Existing	Higher variability implies higher exposure of all indicators under this component. According to Alexander et al. (2006), number of warm spells duration and very heavy precipitation are indices, which show the extent to which most extreme events are changing within a period and have significant impact on livelihoods. For horticultural production, changes in such extreme events challenge sustainable production with detrimental impacts on livelihoods (McCarthy et al., 2001; Deuter, 2008; Williams et al., 2017). Generally, the higher the frequency, the higher the exposure and vulnerability (Hahn, Riederer & Foster 2009; Shah et al., 2013; Panthi et al. 2016). The first three indicators were adapted from Hahn, Riederer & Foster (2009), the following three indicators were also adapted from Panthi et al. (2016) while the last two indicators are new indicators developed for the purposes of this study.
Mean standard deviation of monthly average Maximum Temperature (T_{max}) from 2007 to 2016	Existing	
Mean standard deviation of monthly average Minimum Temperature (T_{min}) from 2007 to 2016	Existing	
Average number of Consecutive Dry Days (CDD) from 2007 to 2016	Existing	
Average number of Consecutive Wet Days (CWD) from 2007 to 2016	Existing	
Average number of warm days from 2007 to 2016	Existing	
Average number of cold nights from 2007 to 2016	Existing	
Average number of warm spells duration from 2007 to	New	

2016	
Average number of very heavy precipitation from 2007 to 2016	New

Notes: With the exception of indicators for climate variability component, data for evaluation of the sub-components/indicators were obtained from respondents during the field survey. Climate variability indicators were computed from daily climate data from Ghana Meteorological Agency. Detailed description and explanation of the components and sub-components can be found in Appendix VI.

3.2.3 Data collection

Data collection for this study was conducted in three steps. It started with a reconnaissance visit to each of the municipalities in order to introduce the purpose of the research and seek approval to visit communities within the municipalities. During the visit, local stakeholders were engaged in a workshop for the selection of the final indicators used for the study as explained in section 2.4. Following the reconnaissance survey, we pretested the survey instrument (to improve clarity and applicability of the questions) followed by the main household survey. Data from primary and secondary sources were employed. Primary data was obtained using field survey conducted between October and November 2017 in both study areas in Ghana for original empirical data on all the major components and their indicators except climate variability component. Secondary data on climate from the nearest meteorological station in each municipality (daily precipitation, minimum and maximum temperatures between 2007 and 2016) received from the Ghana Meteorological Agency constituted data for climate variability component of the LVI. Mixed method approaches using structured questionnaire as well as participatory methods such as stakeholders' workshop, Key Informant Interviews (KIIs) and transects walks through study communities, was employed in the primary data collection process. We first selected four key fruit and vegetable cropping areas (named 'agricultural operational areas') affected by climate change and used a multiple stage sampling method to select communities and households. Without exhaustive access to population of smallholder households in identified areas, and in consultation with the Agricultural Extension Agents (AEAs) to ensure thorough representation of communities, we subsequently randomly selected three communities from each agricultural operational area making a total of 12 communities from each municipality. With consideration for availability and willingness of household heads to respond to survey, we randomly selected and interviewed approximately 20 households from each community. We surveyed a total number of 480 smallholder households (60 households in every 4 agricultural operational areas, in both municipalities). Culturally, even though males are mostly considered heads of households in Ghana, women were considered as heads and interviewed when widowed; single or the male partner was absent for six or more months per year (staying outside the community). Interviews were mainly conducted in Ghanaian local languages (Twi and Ewe) with local interpretations where required. Data was coded and analysis was done using SPSS 20.0.

3.2.4 Data analysis

3.2.4.1 Climate variability analysis

The climate variability component of the LVI was computed using daily temperature and precipitation. Indices were calculated using RClimdex software before being collated for standardization in the LVI. Temperature and precipitation indices were measured to reflect aspects of changing climate such as changes in intensity, frequency and/or duration of climatic events (Alexander et al., 2006). We computed absolute indices (e.g. mean annual rainfall; mean annual minimum and maximum temperatures), duration indices (e.g. warm spell duration, number of consecutive dry and wet days), and extreme percentile-based indices (e.g. number of cold nights and number of warm days and extremely wet days). This analysis allows evaluating the extent to which temperature and precipitation are changing under the climate variability component of the LVI. It was assumed that the higher the rate of change of those climate indicators, the higher households exposure to climate variability and extremes will be. Exposure to climate variability is assumed to be of equal amplitude within a municipality (relatively small spatial spread); hence vulnerability variations within a municipality are mainly as a result of variations in climate sensitivity and adaptive capacity.

3.2.4.2 Calculating LVI

The evaluation of the LVI relies on the equal weighting of major components (Hahn, Riederer & Foster, 2009). Since the subcomponents/indicators were measured on different units, the range of minimum to maximum value standardized them into a single index for comparability. This approach has been similarly applied under different contexts in resource-poor settings and considered accessible, simple and appropriate in the estimation of standardized indices and was adopted (Shah et al., 2013; Madhuri, Tewari & Bhowmick, 2014). Following standardization of all indicators, averaging the standardized scores of related indicators for each main component created the index for each major component. The scores were subsequently averaged using Equation 3.1. A combination of the weighted averages for all major components ensures equal contribution of the main components to the overall LVI (Sullivan, Meigh and Fediw, 2002). The applicable scale was 0 (least vulnerable) to 0.5 (most vulnerable).

$$LVI_r = \frac{w_{SDP}SDP_r + w_{LS}LS_r + w_{SN}SN_r + w_H H_r + w_F F_r + w_P P_r + w_W W_r + w_{ND}ND_r + w_{CV}CV_r}{w_{SDP} + w_{LS} + w_{SN} + w_H + w_F + w_P + w_W + w_{ND} + w_{CV}} \qquad \text{Eqn (3.1)}$$

where LVI_r is the Livelihood Vulnerability Index for municipal r This equals the average of the nine major components (Socio-Demographic Profile (SDP), Livelihood Strategies (LS), Social Networks (SN), Health (H), Food (F), Production (P), Water (W), Natural Disasters (ND) or Climate Variability (CV)), each weighted by their number of sub-components.

3.2.4.3 Calculating LVI-IPCC

Based on IPCC's definition, climate vulnerability was described as a function of a household's exposure, sensitivity and adaptive capacity to climate (Figure 3.1). Changing events under climate variability and natural disaster occurrences was used in the estimation of exposure in the study areas. Sensitivity was estimated by a municipality's current state of health, food, production and water status. Adaptive capacity was also estimated by the socio-demographic profile; types of livelihood strategies employed and the strength of social network of surveyed households in relation to the study districts. Factors corresponding to the previously standardized indicators and weighted LVI main components earlier estimated were applied to populate the LVI-IPCC measures as illustrated in Figure 3.1. Finally, climate vulnerability was calculated using estimations of the scores for the three contributing factors (exposure, sensitivity, and adaptive capacity) based on Equation 3.2 as applied by other studies (Hahn, Riederer and Foster 2009; Shah et al., 2013). The applicable scale for the LVI–IPCC was from -1 (least vulnerable) to +1 (most vulnerable).

$$LVI - IPCC = (Exposure - AdaptiveCapacity) * Sensitivity \quad \text{Eqn (3.2)}$$

3.3 Results

3.3.1 Livelihood Vulnerability Index (LVI)

Generally, the results of aggregate scores presented in Table 3.3 indicate that Keta had a higher LVI (0.395) than Nsawam (0.378). Overall, smallholder horticultural production in both municipalities shows a relatively higher vulnerability to climate variability but in contrast to smallholder horticultural producers in Nsawam, Keta may be more vulnerable to overall climate variability (Table 3.3). In distinguishing the different components of vulnerability, the LVI major components show Keta is more vulnerable in terms of health, food, production and natural disaster, while Nsawam is more vulnerable in socio-demographic profile, social network, livelihood strategies, water accessibility and climate variability. The highest levels of vulnerability (score>0.5) were exhibited in 11indicators/subcomponents for Keta 8 indicators/subcomponents for Nsawam (Table 3.3).

Table 3.3: LVI results for Keta and Nsawam Municipalities

Sub-component/ Unit	Keta		Nsawam		Max. value in study areas	Min. value in study areas
	Actual Value	Standa-rdized	Actual Value	Stand-ardized		
Socio-demographic profile		**0.129**		**0.154**		
Dependency ratio/ Ratio	0.911	0.182	0.844	0.169	5	0
% Female - headed	10.4	0.104	11.7	0.117	100	0

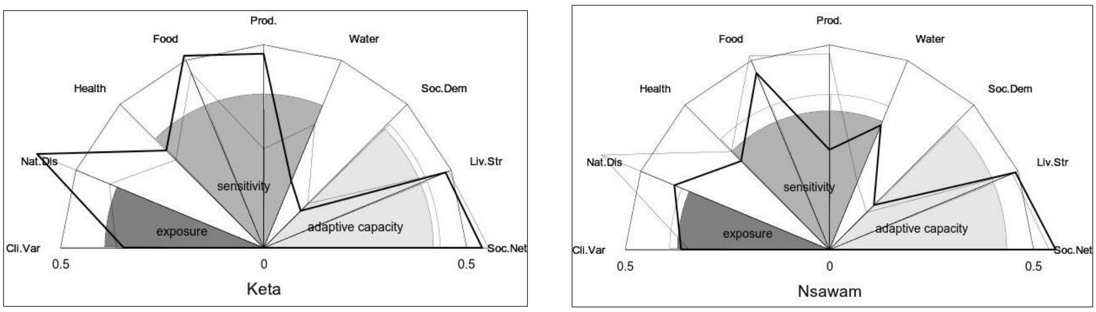
households/ %						
% Household head who has not attended school/ %	10	0.100	17.5	0.175	100	0
Livelihood Strategies		**0.485**		**0.493**		
%Households without member working outside community/ %	58.8	0.588	64.2	0.642	100	0
Average Agricultural Livelihood Diversification Index - 1/Number of livelihoods	0.505	0.261	0.522	0.287	1	0.33
% Households with agriculture as only source of income/ %	54.2	0.542	63.8	0.638	100	0
% Households not rearing livestock/ %	55	0.550	40.4	0.404	100	0
Social network		**0.538**		**0.554**		
% Households not having communication devices/ %	49.2	0.492	62.9	0.629	100	0
% Households not having access to government subsidy on production inputs/ %	21.3	0.213	46.3	0.463	100	0
% Households not associated with any Farmer Based Organization (FBO)/ %	57.9	0.579	44.2	0.442	100	0
Average borrow: lend ratio/ Ratio	0.975	0.488	0.935	0.468	2	0
% Household not associated with any community social group/ %	91.7	0.917	76.7	0.767	100	0
Health		**0.339**		**0.336**		
Average time to health facility/ Minutes	34.79	0.246	30.87	0.218	140	0.5
% Households with member having chronic illness/ %	45.1	0.451	47.6	0.476	100	0
% Households where a member missed work/school due to illness/ %	32.1	0.321	22.5	0.225	100	0
Food		**0.513**		**0.467**		
% Households mainly dependent on family farm for food/ %	92.5	0.925	89.2	0.892	100	0
% Households that do not save planting materials/ %	58.3	0.583	27.9	0.279	100	0
Average number of months households struggle to get food/ Months	4.9	0.355	3.73	0.248	12	1
Average Crop Diversity Index-1/number of crops	0.229	0.186	0.316	0.447	0.5	0.167
Production		**0.478**		**0.244**		
% Households that do not get information on improved	51.7	0.517	14.2	0.142	100	0

production methods/ %						
% Production output lost to post harvest losses/ %	10.84	0.155	12.18	0.174	100	0
% Production output lost to pests and diseases/ %	27.37	0.304	17.84	0.198	100	0
% Households' farm land under irrigation/ Percent	93.59	0.936	46.33	0.463	100	0
Water		**0.178**		**0.329**		
% Households that reported water conflicts/ %	2.1	0.021	18.8	0.188	100	0
Average distance to water source/Km	0.32	0.040	1.45	0.181	8	0
% Households without consistent water supply/ %	35	0.350	81.7	0.817	100	0
% Households utilizing natural water source/ %	30	0.300	13	0.130	100	0
Natural Disasters		**0.604**		**0.411**		
Average number of flood/drought events reported in the past 5 years/ Count	4.3	0.478	1.7	0.189	9	0
% Households that did not receive warning about expected natural disasters/events- %	72.9	0.729	63.3	0.633	100	0
Climate variability		**0.344**		**0.368**		
Mean standard deviation of average monthly precipitation from 2007 to 2016/mm	63.062	0.375	69.579	0.493	97.67	42.27
Mean standard deviation of monthly average maximum temperature (T_{max}) from 2007 to 2016/ ^oC	1.953	0.401	2.041	0.496	2.51	1.58
Mean standard deviation of monthly average minimum temperature (T_{min}) from 2007 to 2016/ ^oC	0.959	0.366	1.031	0.439	1.58	0.60
Average number of Consecutive Dry Days (CDD) from 2007 to 2016 / Days	48.60	0.346	40.80	0.244	99	22
Average number of Consecutive Wet Days (CWD) from 2007 to 2016 / Days	3.90	0.180	4.90	0.380	8	3
Average number of warm days from 2007 to 2016 / Days	12.832	0.376	6.205	0.166	32.60	0.94
Average number of cold nights from 2007 to 2016 / Days	7.224	0.556	5.980	0.412	11.20	2.24
Average number of warm spells duration from 2007 to 2016 / Days	4.20	0.200	1.20	0.006	21	0
Average number of very	15.50	0.292	19.60	0.633	24	12

heavy precipitation from 2007 to 2016 / Count		
LVI	**0.395**	**0.378**

3.3.2 IPCC-LVI results for Keta and Nsawam Municipalities

Results for the overall LVI-IPCC scores (using groupings of the subcomponents as shown in Figure 3.1) suggest that on a scale of - 1 to 1, horticultural smallholder producers in both Keta and Nsawam shared an almost similar degree of vulnerability though Keta households (-0.010) is marginally more vulnerable than Nsawam households (-0.021). This finding is also consistent with scores from the LVI as Keta was more vulnerable than Nsawam. In comparing the level of contribution from the three vulnerability-contributing factors, as depicted in Figure 2, Keta is the most exposed (0.391) and most sensitive (0.379) horticultural producing municipality to climate impacts compared to Nsawam's exposure (0.372) and sensitivity (0.339). This resulted mostly from exposure to natural disasters and high sensitivity to food availability (Fig. 2). In terms of adaptive capacity, Nsawam has less adaptive capacity (0.434) to climate vulnerability compared to Keta (0.418), which is mainly as a result of weak social network and livelihood strategies (Figure 3.2). Detailed results for corresponding indicators for the IPCC-LVI can be seen in Annex VI.



3.2a. Keta Municipality **3.2b. Nsawam Municipality**

Figure 3.2: Diagram showing the LVI major components and the vulnerability contributing factors of the IPCC (LVI-IPCC) in the two municipalities.

Note: 0 = least vulnerable/low contributing factor; 0.5 = most vulnerable/high contributing factor

Fig. 2a shows Keta is more vulnerable in terms of health, food, production and natural disaster, while Fig. 2b shows Nsawam is more vulnerable in socio-demographic profile, livelihood strategies, social network, water accessibility and climate variability. The highest levels of vulnerability (score>0.5) were exhibited for natural disasters (0.604) and food availability (0.512) for Keta and for social networking with scores of 0.554 and 0.5338 in Nsawam and Keta respectively

3.4 Discussion

3.4.1 Exposure

Findings from the main components and subcomponents (indicators) revealed that Keta is more exposed to natural disasters compared to Nsawam. Keta has a higher exposure value as a result of significant extreme climatic events. Coastal areas climatic exposures are often greater and considered hotspots of vulnerability (Wolters & Kuenzer, 2015). Our finding concurs with other studies where vulnerability of coastal and inlands were compared (Shah et al., 2013). Specifically, Keta has been more exposed to occurrence of natural disasters in last 5 years, while over the past decade, number of Consecutive Dry Days (CDD), average number of warm days, warm spells and cold nights all increased. Such extreme climatic events often relate with occurrences such as droughts in addition to coastal erosion. Most smallholder farmers are particularly exposed to natural disasters due to the lack of prior warning, which is a worrying situation. Frequent drying up of natural water bodies resulting in salt intrusion from seawater with subsequent effect on the quality of fruits obtained from fields and crops that suffer from such occurrences is prevalent in Keta. Although Nsawam is an inland area, it is also exposed to climatic variability and households mainly do not receive prior information about impending natural events. Increased climate variability, particularly dry spells with increasing temperatures, has negative impact on horticultural crop productivity (McCarthy et al., 2001). Untimely rains result in drought stress and/or high temperatures during crop development stages (flowering and fruit growth), that declines yield and causes physiological disorders in fruit and vegetable crops. Furthermore, increased rainfall variability together with rising temperatures reduces soil moisture availability amid high risk of crop failure (Rurinda et al., 2014). Since smallholder farmers in both municipalities mainly crop throughout the year with intermittent irrigation support whenever available, the exposure to natural disaster and climatic variation on crops and consequently on food security, is great and could further increase with projected future increase of climate variability. This is important for horticultural production in both areas as climate extremes coinciding with critical crop growth stages is detrimental and more likely through the production year.

3.4.2 Sensitivity

Accounting for health, food, production and water components in both municipalities, smallholder households in Keta are more sensitive to climate than Nsawam. Smallholders' in Keta are more sensitive to current health, food and largely more sensitive to production conditions while households in Nsawam are largely more sensitive to prevailing water conditions in the municipality. Higher sensitivity score for health status in the municipalities mainly arises from prevalence of illness. According to farmers, horticultural production is labour-intensive relative to other crops hence, health is particularly important as it relates to labour availability for crop production. Particularly, resource constrained smallholders' depend on family support to complement labour on family farms.

Indicators such as inability of households to save planting materials and low crop diversity impact negatively on the food component and consequently affect both municipalities' sensitivity. Availability of planting materials from preceding harvests could save cost of planting for subsequent production seasons. It could also be sold or bartered (as families mostly rely on family farm for food) to economically support other production activities or other family needs. Diversification of crops grown on the other hand, could reduce risk of production losses during periods of extreme climatic events as different crop-types respond differently to different climatic conditions (Malhotra, 2017). Dedicated education and promotion of those interventions to farmers could already reduce food vulnerability in Keta and Nsawam.

Nsawam is relatively less sensitive to production conditions. In contrast, production conditions in Keta heighten the vulnerability score. Water used for irrigation during dry spells result in reduced quality from increased salinity and increased risk of production losses through higher susceptibility to pest and disease affecting product quality and resulting in low market prices. While production losses is already attributed to pest and disease, their sensitivity to climate variability through limited effect of irrigation in Keta encourages the call for production and dissemination of improved techniques towards better climate variability management. Yet, farmers in Keta have limited access to such information while predominantly relying on irrigation. Active involvement of agricultural extension services in the municipality is therefore required.

Nsawam's sensitivity is affected by irrigation since most households cannot access consistent water supply. The distance of farmland to water sources is three times farther relatively to Keta, meanwhile that distance largely determines the cost and ability of farmers to irrigate. While farmlands in Keta commonly had traditional (hand-dug) wells on site, farmlands in Nsawam depended on nearest rivers and streams as source of water for irrigation. While irrigation directly minimizes impacts of climatic stresses such as droughts, smallholder horticultural producers in both municipalities are at increased risk of water unavailability due to dependence on natural water sources, which in addition are becoming more unpredictable and unreliable with changing climate. Alternative sourcing of water such as rainwater harvesting; or alternative water storage and management practices such as building ponds or digging wells/borehole (especially in Nsawam), or drip irrigation (especially in Keta) could decrease sensitivity and to some extent vulnerability of cropping systems during dry periods in both municipalities.

3.4.3 Adaptive capacity

It is critical to enhance the capacity of smallholder horticultural farmers to adapt to changing climate. The findings suggest that comparatively, Nsawam is less adaptive than Keta.

Indicators such as number of female-headed households, dependency ratio and number of household heads that have not attended school factor into relatively low socio-demographic profile in both municipalities. Education increases households' willingness to adopt new agricultural technologies to better cope with negative climate variability and has a positive impact on the farm productivity overall (Lin, 1991; Leichenko & O'Brien, 2002). With higher literacy rate and lower family dependency, adaptive capacity increase and farmers are more likely to positively cope/adapt to changing climate in both municipalities.

Livelihood strategies and social network had high vulnerability scores, which is critical as it reduces households' capacity in averting climatic risks. Not many farmers engage in livestock rearing, the second most important agricultural livelihood activity after crop farming in both areas A community is considered more vulnerable if there is too few options in terms of livelihood diversification (Antwi-Agyei et al., 2013). According to the farmers, horticulture production is an intensive production activity demanding relatively more resources and a lower capacity to diversify but they depend on their horticultural production as major livelihood and income source. This implies that farmers hardly can cope with short-term impact on their income. Livelihood stability for households in the study areas is therefore critical especially in the face of changing climate. Additional non-farm livelihoods are suggested to spread the risks from climate threats on farming households.

In both municipalities, the majority of smallholder horticultural producers do not possess basic communication devices (radio, television and mobile phone) with direct impact on social network scores, which strongly limit access to crop and weather-related information. It decreases the ability of farmers to plan for any impending climate risk. Additionally, most farmers in both municipalities are not actively associating with Farmer Based Organisations (FBOs) and other social groups at the local level further limiting access to crop and weather information. Smallholder farmers in Nsawam were better connected with FBOs and other communities showing a higher social capital than Keta. Social capital improves financial support, access to market, information accessibility as well as agricultural technical support and access to formal government structures (Eakin & Bojórquez-Tapia, 2008). Furthermore, building trust among such associations is important in positively influencing adoption rate of technologies or adaptation strategies through information dissemination and trials by proximity within the groups (Thomas et al., 2005).

Farmers in Keta have better access to government subsidies on production inputs, especially fertilizer. This may be related to a low-lying coastal plain with poor soil conditions (sandy) characterising Keta, and which is considered less conducive. Nevertheless, Nsawam has undulating land surfaces and farming equally puts soil conditions at risk of reduced fertility. Subsidized inputs generally enable farmers to reduce production costs, reducing financial burden and in effect, increasing adaptive capacity of households. Farmers in both areas acknowledged government support for their production activities through subsidizing inputs, yet this is very limited. Adaptive capacity of farmers would benefit from further governmental, non-governmental and other institutional support for a horticultural production, which is relatively capital-intensive.

3.4.4 Implications of findings

Vulnerability scores for the various components provide direction for recommendation into implementation of both collective and area-specific strategies that could be developed to cope/adapt to climate variability to reduce vulnerability. For instance, Nsawam could benefit from alternative water sources such as ponds, wells and boreholes to supplement irrigation while Keta requires water management practices such as drip irrigation to efficiently manage its available water. Overall, both municipalities need district-level project planning to consider providing alternative water sources such as harvesting rainwater at the governance level to effectively manage and supplement irrigation and as solution to water problems. Smallholder horticultural households in Nsawam further require government and other institutional support in relation to further subsidizing production inputs for enhanced productivity. At the farmer level, encouraging interactions and participation of smallholder farmers in FBOs and other community social groups is important in dealing with emergency situations, adapting to climate variability and handling crises due to changing climate in both municipalities. Farmers can also be introduced to agricultural insurance to reduce and guard against adverse climatic losses. Though this is not practiced among the horticultural producers and also not commonly applied in Ghana it could be considered as an important means of reducing climate sensitivity related risk and vulnerability during crop production. With fairly good socio-economic conditions in both municipalities, sensitization and education of smallholder farmers would further build adaptive capacity to cope with and adapt to changing climate in future. At the institutional level, microfinance schemes could be introduced to help farmers through livelihood diversification in terms of both agricultural and supplemental non-agricultural diversification options with the potential to reduce vulnerability in both municipalities. Both areas would benefit from climate disaster early warning systems and education programs to enhance adaptation planning. This includes improved dissemination and accessibility of reliable climate information such as seasonal forecasts to enhance preparedness against extreme weather events. At research level, further investigation into the identification of adaptation options suited to smallholder horticultural producers, particularly in terms of implementation profitability is recommended. The integration of an economic analysis into the vulnerability framework would provide empirical evidence in direct support of investment and development initiatives responding to a changing climate, in guiding policy recommendations to promote climate adaptation and in providing farmers with critical profitability estimation given their limited resources.

3.5 Conclusions

This study applied the Livelihood Vulnerability Index (LVI) and IPCC-LVI in the context of smallholder horticultural production in Ghana. Both LVI and IPCC-LVI indicate that smallholder farmers in Keta, a coastal area in Ghana, are more vulnerable to climate variability compared to smallholder farmers in Nsawam, an inland area. Overall, while Keta is more exposed and sensitive to climatic impacts, Nsawam has less adaptive capacity. High exposure was mainly attributed to occurrence of natural disaster and climate variability with limited prior warning. Inadequate family labour, low crop diversity, insufficient planting material or distance and limited water sources translate into high vulnerability scores for the health, food, production and water components in both municipalities. Weak social networking and unstable livelihoods resulted in lower adaptive capacity mainly for Nsawam. Cognizant of a range of options that would reduce sensitivity and/or increase adaptive capacity, identifying the most suitable for smallholder farmers, particularly in the light of limited financial resources, can certainly benefit from the dedicated integration of an economic assessment as part of the vulnerability assessment framework.

Overall, our study builds upon the LVI and IPCC LVI developed by Hahn, Riederer & Foster (2009) through the revision of some indicators (developing new and modifying indicators incorporated as credible local contextual factors) further reflecting multidimensional realities of vulnerability in Ghana, and critical for uptake at different localities. It presents a range of indicators, which can be used in other settings. The study on horticultural producers also contributes to the understanding of specific sector vulnerability, relying on a rigorous and replicable approach to studies in other geographical and sectoral settings. The study also contributes to addressing the critique of indicator-based approach studies, which is considered lacking due to subjectivity in the selection of indicators by literature. We employed literature review together with stakeholder validation in framing and designing indicators representing various components of the LVI to improve robustness of indicator selection. This additionally contributes to a consistently framed vulnerability assessment making it reflective of smallholder producers in Africa. Beside identification of vulnerable people and places, the study further provides adequate understanding, information and practical guidance to support decision-making on adaptation as expected of vulnerability assessments.

Chapter Synthesis

In fulfilling the first objective of this thesis, Chapter 2 assesses livelihood vulnerability of smallholder producers to climate variability in Ghana. The chapter illustrates how critical developed and modified indicators serve as credible local contextual factors reflecting the multidimensional realities of vulnerability in Ghana. This chapter is the first step for the vulnerability and adaptation assessment process (following the conceptual framework in Chapter 1). In the context of smallholder horticultural production in Ghana, the results illustrate that overall, smallholder farmers in the coastal area of Ghana (Keta) are more vulnerable to climate variability compared to farmers in the inland area (Nsawam). Indicator-based approach was used and the indicators constitute components of the Livelihood Vulnerability Index (LVI) adopted for the estimation of livelihood vulnerability of the smallholders. The chapter has shown that considering all subtle differences, farmer's vulnerability were subject to the major components of the LVI framework adopted (Keta was more vulnerable in relation to high exposure and high sensitivity to climate variability, while smallholders in Nsawam were also vulnerable due to their low adaptive capacity). Partly in support of some of the issues raised in the literature review (see Chapter 2), this chapter built upon the LVI approach that had been developed by Hahn et al. (2009) for assessing vulnerability. The revision was through highlighting the multidimensional realities of vulnerability in Ghana by developing new and modifying existing indicators. Also, the study particularly on horticultural producers supports need for understanding sector-specific vulnerability studies. Further, addressing the critique of indicator-based approaches, which lacked subjectivity in the selection of indicators mainly by literature, literature review together with stakeholder validations were employed in this regard.

Beside identification of vulnerable people and places, this chapter contributes to the scientific knowledge and literature on vulnerability assessment by showing broadened understanding, information, and practical guidance to support identification of adaptive responses. It provides implications for the need to identify suitable adaptation strategies for the smallholder farmers to reduce exposure, sensitivity and/or increase their adaptive capacity. As a context-specific study, the indicators identified highlighted the social, economic, institutional and environmental aspect of the farmer's vulnerability. These are considered important factors that impact the level of vulnerability within an area. In considering adaptation options as a result of the assessment, these factors further provide indication of factors constraining or promoting the pattern of adaptation. This chapter illustrates such discussions drawn from the fieldwork done with the horticultural farmers in Ghana.

The next phase of the thesis is to identify the suitable adaptation strategies for the smallholder farmers (i.e. Chapter 4 and Objective 2) to reduce exposure, sensitivity and/or increase adaptive capacity of farmers. Building on identified research need for vulnerability assessment to adequately inform decision-making on implementation of identified adaptation strategies, additional evaluation of the effectiveness of the most suitable practices (i.e. Chapter 5 and Objective 3) follows. In this regard, outcomes of knowing the vulnerable people and places presented in this chapter enable identification of the most appropriate response strategies. It again serves as first step in the assessment process (expressing vulnerability as a function of exposure, sensitivity and adaptive capacity) as outlined in the conceptual framework of this thesis in chapter 1.

CHAPTER 4

ADAPTING TO CHANGING CLIMATE THROUGH IMPROVING ADAPTIVE CAPACITY AT THE LOCAL LEVEL – THE CASE OF SMALLHOLDER HORTICULTURAL PRODUCERS IN GHANA

This chapter focuses on climate adaptation practices farmers use to reduce the negative impacts of climate variability. It shows how smallholder horticultural farmers in the two distinct producing areas of Ghana are responding to changing climate. Further, it explores trends in climate parameters, perceived changes and its effects on livelihoods. Constraints hampering the implementation of adaptation measures to enhance smallholder climate adaptation and reduce vulnerability are further explored. The chapter employs focus group discussions and questionnaire survey to achieve its aim.

Summary

The consequences of changing climate are often negatively impacting agricultural production, particularly vulnerable smallholder farmers. Smallholder systems heterogeneity requires local specific climate adaptation for reducing the negative impacts of changing climate in regions heavily relying on small farms agriculture. This study examined the trend in climate in Ghana, how smallholder horticultural farmers perceive this changing climate and how they are responding to its perceived effects. A survey of 480 resource-constrained horticultural producers was conducted in two municipalities of Ghana. Descriptive analysis and Weighted Average Index were employed to rank identified adaptation strategies and challenges. The results showed that farmers are already experiencing increasing temperature and declining rainfall patterns consistent with trends of observed climate changing in the last two decades. To reduce vulnerability and improve resilience of smallholders' production activities, a range of farmer driven soil, water and crop conservation measures and farm management practices are being adopted. The most important adaptation practices identified include fertilization, supplementary irrigation, crop rotation, intercropping and mixed farming. Enhancing households' climate adaptive capacity is dependent on factors such as improved access to financial resources, climate and production information, market accessibility, farm equipment, storage facilities and other institutional support. To facilitate effective and successful adaptation at the local level, government and institutional support are recommended to complement households' autonomous strategies for improved decision-making, adaptation plans and actions.

4.1 Introduction

Consequences of changing climate such as reduced availability of water resources, declining soil quality and increased frequency of pest and diseases have resulted in significant changes in conditions negatively affecting agricultural production (Enete & Amusa, 2016). Climate adaptation in agriculture is recognized as an essential intervention to reduce vulnerability and negative impacts from changing climate (Tambo & Abdoulaye, 2013). In the past few decades, the need for urgent actions to adapt to this changing climate and its impacts has become a subject of many climate related discussions globally, with emphasis on strengthening resilience and adaptive capacity to climate risks and natural disasters (Holzkämper, 2017). Even though climate adaptation is a global problem, the need for adaptation is considered higher among developing countries where vulnerability is presumably higher (Adger, 2003) and also in the interest of individual farmers who rely on the revenue generated from agricultural production (Holzkämper, 2017). This is especially the case in Africa since the population is highly dependent on rain fed agriculture (the most climate-sensitive sector) and particularly for smallholder farmers as they generally have limited adaptive capacity (Morton, 2007), hence they are considered among those who will suffer most from the impacts of climate change (Easterling et al., 2007). Agricultural production is a source of livelihood for many Africans especially the resource constrained in rural communities (Bryan et al., 2009). According to Douxchamps et al. (2016), given threats posed by climate change in the future, adapting to changing climate would improve food security status of households, reduce climate vulnerability and have a positive significant impact on land productivity ensuring sustained production.

Studies have shown that various adaptation strategies exist (Boko et al., 2007) and that farming systems in sub-Saharan Africa adapt in various ways to both short-term variations and longer-term changes in the physical, climatic and socio-economic environment (Challinor, Wheeler, & Garforth, 2007). However, the extent to which a system need to adapt is a function of its vulnerability to climate which is influenced by its level of exposure and sensitivity to the climate impacts (Elum et al., 2017). Furthermore, adaptation strategies are argued to be context specific and change over time, from location to location and for particular production systems (Smit and Wandel, 2006; Adger, 2003). Additionally, a study by Douxchamps et al., (2016) showed that there are no one-size-fits-all solutions and that for different smallholder farmers, different adaptation strategies would be plausible. Given threats posed by changing climate in the future with an estimated 250 million people in Africa projected to be exposed to greater risk of water stress by 2020 (IPCC, 2007) as well as high confidence of agricultural production and food security in many African countries being severely compromised by climate variability and change (Boko et al., 2007), adaptation in smallholder farming systems is necessary to enhance climate adaptation practices among farmers for sustainable livelihoods. In relation to this, understanding current effects and responses to climate variability and change in specific sectors and subsectors would enable identification of effective adaptation strategies.

With growing interest in adaptation studies, most research efforts on farmers' adaptation to climate variability and change, more generally have focused on major food crops such as cereals as well as root and tubers with introduction of numerous improved crop varieties which are resistant to droughts and/or early maturing varieties (Paavola, 2008). Development of similar crop varieties for other common subsectors such as horticultural crops is less developed (Malhotra, 2017) and adaptation of horticultural farmers to changing climate is under represented in literature (Williams et al., 2018a). Meanwhile, developing countries including African countries account for 98% of the production of fruit imports in developed countries and predominantly produced by smallholders (Sthapit et al., 2012). Horticultural production has the potential to grow further, as there is increased consumption of more fruits and vegetables globally rising from increasing interest in health conscious nutritional trends stemming steady demand for tropical fruits and vegetables (Sthapit et al., 2012). Small-scale producers of fruits and vegetables in Africa are however already faced with the impacts of changing climate. For instance, horticultural farmers in Uganda reported reduced yields and increased pest and disease outbreaks as a result of prolonged drought and hot temperature (Mugambwa, 2014). In Mozambique, tomato producers indicated significant impacts of climate stresses such as floods, extreme rainfall and temperatures on their livelihoods and crop growth (Vilissa, 2016). In Ghana, high rainfall variation coupled with increased temperatures were reported to lower tomato yields (Guodaar, 2015) while a study by Williams et al., (2017) revealed that climate variability impacts on the quality and quantity of pineapple production, highlighting the need for further research to explore adaptation options in response to challenging climatic conditions within the subsector.

Ghana like many African countries, have conducted numerous studies addressing climate adaptation strategies at different locations and within different farming systems (Westerhoff & Smit 2009; Codjoe & Owusu 2011; Antwi-Agyei 2012; and Asante & Amuakwa-Mensah 2015). The country is vulnerable to the impacts of climate variability and change with evidence attesting to exposures and sensitivities on different people and places (Bawakyillenuo, Yaro & Teye, 2014). Climatic variations resulting in increasing temperature, drought and flood events in the last four decades have also been reported (Asante & Amuakwa-Mensah, 2015). Cropping systems in Ghana are highly diverse and widespread (Srivastava et al., 2016) reflecting need for dynamic and context specific adaptations strategies applicable to the different cropping subsector systems and production areas, especially horticultural production where studies are limited for improved implementation potential. Given that, in the Ghanaian economy, horticultural production is a significant source of income for smallholder producers by providing households with employment opportunities at the farm level (Abdulai et al., 2017), it is important to enhance resilience to adverse climatic effects and for effective adaptation policies among smallholder horticultural households. Investigation into identification of adaptation options suited to smallholder horticultural producers has also been recently recommended (Williams et al., 2018b). In relation to this, our study aims at assessing how smallholder horticultural farmers in two distinct horticultural producing areas (Keta and Nsawam Adoagyiri municipalities of Ghana) are responding to changing climate. We further explore trends in climate parameters, perceived changes and its effects on livelihoods and finally assess constraints in implementing adaptation measures to enhance smallholder climate adaptation and reduce vulnerability.

4.2 Theoretical overview and definition of climate adaptation

Diverse responses to the effects of climate variability and change by farmers exist in the literature. Two fundamental categorizations of these responses have been recently reviewed by Vincent et al., (2013) and Holzkämper, (2017). According to Vincent et al., (2013), responses to past climate variability and change are divided into coping and adaptation; while coping is used to refer to short-term mechanisms to ensure survival, adaptation refers to longer-term shifts in behavior and practices, which reduces underlying vulnerability. Holzkämper (2017) also indicated that responses to climate variability could be distinguished into short-term incremental responses that farmers often choose autonomously in response to observed changes based on local knowledge and experiences, as well as long-term transformative responses that require strategic planning usually implemented at a larger spatial scale. While short-term responses help to improve management efficiency within existing technological, governance, and value systems, long-term responses involve alteration of the fundamental attributes of production systems to be considered transformative (Holzkämper, 2017). Vincent et al., (2013) specified that while adaptation addresses the reduction of negative effects of changing climate, determining whether or not observed strategies are examples of coping or adaptation is dependent on context of observation and scale of interest. Importantly, farmers in preparation for upcoming seasons are observed to use both coping and adaptation strategies noting both terms are used interchangeably in adaptation studies (Nelson et al., 2008). Further emphasizing the challenge of separating the two concepts, Brockhaus, Djoudi & Locatelli (2013) indicates that the definition of adaptation strategies is not definitively differentiated from coping strategies. Morton (2007) argued that coping strategies could become adaptations for households or whole communities in exceptional years.

IPCC defines adaptation as “adjustments made in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (IPCC, 2014). Climate adaptation is also seen as a means of strengthening resilience of individuals and systems to climate variability and change (Elum, Modise & Marr, 2017). Some authors argue that adaptation is progressive and that transformational adaptation happens when incremental adaptation is inadequate (Rickards and Howden, 2012). Smit & Wandel (2006)(Smit and Wandel, 2006)(Smit and Wandel, 2006)(Smit and Wandel, 2006)(Smit and Wandel, 2006) also view adaptation as anticipatory, concurrent or reactive based on timing in addition to degree of spontaneity be it autonomous or planned.

Multiple autonomous adaptation strategies adopted by different farming households across Africa have been identified (Deressa et al., 2009; Gbetibouo & Ringler, 2009; Below et al., 2010). Based on practices related to farm financial management, diversification of farm and off-farm activities, farm management and technology practice and knowledge management among others. Below et al. (2010) identified over one hundred adaptation practices used by farmers in Africa. Some measures such as increased water conservation and tree planting were peculiar to certain geographical regions (such as Southern Africa) and context (such as variation in temperature and precipitation) while others for instance adopting new crop varieties and livelihood diversification were observed across the whole continent (Tambo & Abdoulaye, 2013). According to Deressa, Hassan & Ringler, (2011), adaptation at farm-level involves two stages; perceiving change in climate, and which adaptation strategy to choose implying farmers perceptions are important for the uptake of available adaptation options. Research has revealed that farmers’ ability to adapt to changing climate depends on factors such as economic resources, infrastructure, access to information, social capital, agro-ecological settings and access to land (Bawakyillenuo, Yaro & Teye, 2014). From sustainable livelihood and resilience literature stance, ability of households to adapt to stressors such as climate variability, influences the extent to which they are vulnerable or can be harmed (Paavola, 2008). As climate adaptation has been used to tackle developmental support issues (Ziervogel & Parnell, 2014), tracing constraints limiting the uptake of adaptation measures by smallholder farmers would broaden understanding of climate adaptation and resilient agricultural development for sustained and improved production. With the myriad of existing adaptation measures this study therefore focused on varied autonomous adaptation strategies mostly used by smallholder farmers in two horticultural producing areas to show whether the two areas differ in the application of adaptation strategies. The interest of this paper however, is to explore how farmers' independently respond to the negative effects of past or current climatic variation. Consequently, for the context of our study (on climate vulnerability of agricultural production), we denote farmers' reaction to effects of climate variability as autonomous adaptation strategies adopted to reduce negative climatic effect on their production activities.

4.3 Methodology

4.3.1 Study areas

The study was conducted in two of the major horticultural producing areas in Ghana. These were Keta and Nsawam Adoagyiri Municipalities in the Volta and Eastern Regions of Ghana respectively. Keta is a coastal area within the coastal savannah agro-ecological zone while Nsawam is inland within the forest deciduous agro-ecological zone. Both municipalities were selected because they are both considered to be undergoing changing climate. Nsawam has been experiencing decreasing precipitation pattern with increasing temperature (Williams et al., 2017) whereas Keta, as a coastal community, is particularly sensitive to changing climate associated with temperature and precipitation (GSS, 2014a). Keta's total annual rainfall ranges from 800mm to 1000mm per annum and mean annual temperature ranges from 19^oC to 29^oC (GSS, 2014a). Nsawam on the other hand, receives a total annual rainfall of 1250 mm - 2000mm per annum with the mean annual temperature ranging from 26^oC to 30^oC (GSS, 2014b). Both municipalities are major horticultural crops producers, growing crops including okro, tomato, pepper, onions, spring onions, carrots, shallots cabbage, pineapple and watermelon.

4.3.2 Data collection

The study employed both primary and secondary sources of data. Primary data was collected through a survey of 480 smallholder horticultural households (240 from each municipality) conducted in October and November 2017. Multi-stage sampling approach was employed in the selection of study respondents. In consultation with local stakeholders, the initial stage was the purposive selection of four key agricultural operational areas within each municipality. In consultation with the Agricultural Extension Agents (AEAs) three communities were selected randomly within an operational area. In each community, approximately 20 household heads were selected randomly and interviewed (depending on availability and willingness of household heads to respond to survey). Two Focus Group Discussions (FGDs) were conducted in each municipality. The FGD was from a maximum of ten respondents purposively selected from members of cooperative farmers association with thorough knowledge and experiences on climate and horticulture production in Ghana. Hence, the survey consisted application of structured questionnaires and Focus Group Discussions (FGDs). The questionnaire interrogated climate variability exposure and perceived related impacts on respondents' livelihoods and household, level of respondents' application of a range of adaptation strategies and challenges in implementing those strategies based on their experiences of the past 10 years. The FGDs further explored perceptions about evidences of climate variability and households' adaptive capacity for in-depth information. Literature review combined with stakeholder consultations formed the basis of identification of adaptation strategies used by smallholder farmers in responding to climate related events (mainly droughts and floods). These were then complemented with two focus group discussions at the community level from each municipality with about ten farmer representatives. Secondary data on daily rainfall and mean temperature were collected from the Ghana Meteorological Agency (Gmet) for the closest meteorological station in each municipality (1996 to 2016).

4.3.3 Data analysis

We computed total annual rainfall and mean annual temperatures from the daily rainfall and temperature data collected for each municipality. A linear model was fitted to determine the trend of change over the 20-year period (1996-2016). Descriptive analysis was done using frequencies to describe farmers' perception about changing climate and impacts on their livelihoods. Responses and views from the FGDs were analyzed employing content analysis to complement information on changing climate and households' adaptive capacity. Using a likert scale, respondents ranked their frequency of utilization of selected adaptation strategies (0 for never to 4 for often) and their degree of importance of implementation (1 for low and 5 for high). Frequency (F) and importance (W) of each adaptation strategies serve to compute a Weighted Average Index (WAI). The same process was repeated for estimating households' challenges in responding to changing climate. A Weighted Average Index (WAI) was then estimated using Equation 4.1 as employed by other authors (Ndamani & Watanabe, 2015; Uddin, Bokelmann & Entsminger, 2014) to assess farmers important adaptation strategies and challenges to adaptation.

$$WAI = \frac{\Sigma FiWi}{\Sigma Fi} \qquad Equation(4.1)$$

Where F is the frequency of adaptation response/challenge, W is the weight of each score and i is the score. We employed a non-parametric Mann-Whitney U Test to identify the differences in relation to the selection of adaptation strategies and challenges between the two municipalities. The study regarded the first five adaptation strategies ranked as the most important measures utilized by the smallholder farmers and the first two challenges ranked highest as the most crucial challenges hindering farmers response to changing climate.

4.4 Results

4.4.1 Households perceptions and trends in climate

Observed total annual rainfall and mean annual temperature for the two study municipalities of Ghana for the period 1997 to 2016 are shown in Figure 4.1 and Figure 4.2 respectively. Total annual rainfall for the two municipalities ranged from 730 mm to 1560 mm (Figure 4.1). The wettest municipality was Nsawam, which recorded the highest rainfall of 1560mm in the year 2002. The least rainfall of 730mm during the study period was recorded in 2012 at Keta, the driest municipality. Both municipalities showed a decreasing rainfall trend of 5.4mm/year and 1.2mm/year trends for Keta and Nsawam respectively.

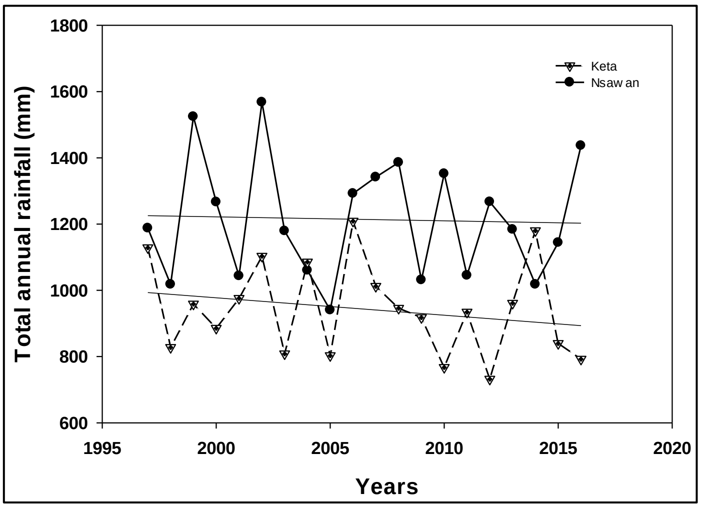


Figure 4.1 Total annual rainfall for the study areas

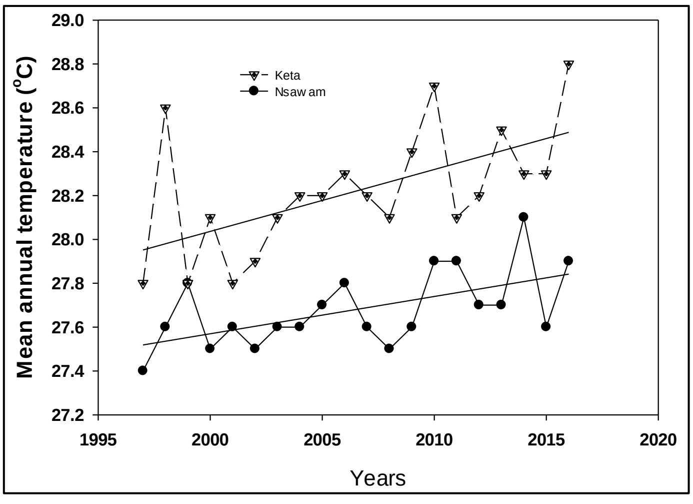


Figure 4.2 Mean annual temperature for the study areas

Mean annual temperature during the period 1997 to 2016 varied from 27.4°C to 28.8°C across the two municipalities (Figure 4.2). An increasing trend showing warming was observed in both study areas at a rate of 0.03 °C/year and 0.02 °C/year for Keta and Nsawam municipalities respectively. The lowest mean annual temperature was recorded in 1997 in Nsawam Adoagyiri municipality (27.4°C) and the highest mean annual temperature was recorded in 2016 in Keta municipality (28.8 °C).

Smallholder horticultural farmers also mainly experienced climatic changes in the past 10 years (Table 4.1). Almost all farmers in Keta (100.0%) and Nsawam (99.0%) perceived an increase in temperature. Majority of the farmers also perceived mainly a decrease in rainfall duration and quantity over the period. Few of the farmers perceived a moderate increase in rainfall duration (33.0%) especially for Nsawam. The perception of rainfall reduction is often related to the perceived increase in drought occurrence with 95.0% of responses in Keta and 93% in Nsawam agreeing to this. Perception of flooding in terms of volume and damage to farmlands was mostly mixed, with marginal majority perceiving decrease. Few of the farmers were indifferent (constant) about changes in flood occurrence. Two-thirds of respondents in Keta perceive that water sources for production activities has increased, unlike farmers in Nsawam who mostly perceived decrease. Generally, farmers perceived patterns of rainfall and temperature change shows farmers are conscious of the changing climate.

Table 4.1: Perception of changing climate parameters

	Degree of increase (%)									
Climate parameter	**Large increase**		**Moderate increase**		**Constant**		**Moderate decrease**		**Large decrease**	
	K	**N**	**K**	**N**	**K**	**N**	**K**	**N**	**K**	**N**
Temperature	65	62	35	37	0	0	0	1	0	0
Rainfall duration	0	5	4	11	0	2	50	61	46	22
Rainfall quantity	0	4	3	22	0	1	50	54	46	20
Drought	57	55	38	38	4	5	1	2	0	0
Flood volume	2	1	35	30	13	23	49	42	2	4
Flood damage to farmlands	2	2	30	37	17	20	59	36	2	4
Availability of water sources	18	0	51	12	7	28	19	54	6	6

K=Keta; N=Nsawam

4.4.2 Perceived impacts and response strategies of changing climate on farmers' livelihoods

4.4.2.1 Perceived impacts

Smallholder horticultural farmers' production activities mainly depend on climate. Changing climate impacts on their livelihoods and as shown in Figure 4.3, mostly affects the quality of horticultural farmer's produce, outputs, yield losses after harvesting and overall net revenue.

Majority of the farmers in both municipalities strongly agreed to climate having such impacts on their livelihoods. Focus Group Discussions with farmers' highlighted evidences of climate variability such as erratic rainfall pattern usually unpredictable and increasing temperature affecting various crop growth stages and resulting in yield losses and poor quality produce. This subsequently increases losses after harvesting reducing farmer's revenue. According to the farmers, shorter rainfall duration, droughts, coastal erosion and floods exacerbate such impacts. The FGDs further highlighted that horticultural farmers in both study areas are already experiencing the impacts from changing climate. According to the farmers, increasing temperature and variation in rainfall quantity and duration result in dehydration, leaf scorches, increase in pest and diseases, variation in fruit maturity and abnormal fruit set with occasional fruit set failure for most horticultural crops which negatively affects productivity. Even at maturity, farmers mentioned that water stress and high temperatures cause fruit cracking and sunburns with high post harvest losses. Such impacts were noted to affect farmers overall productivity.

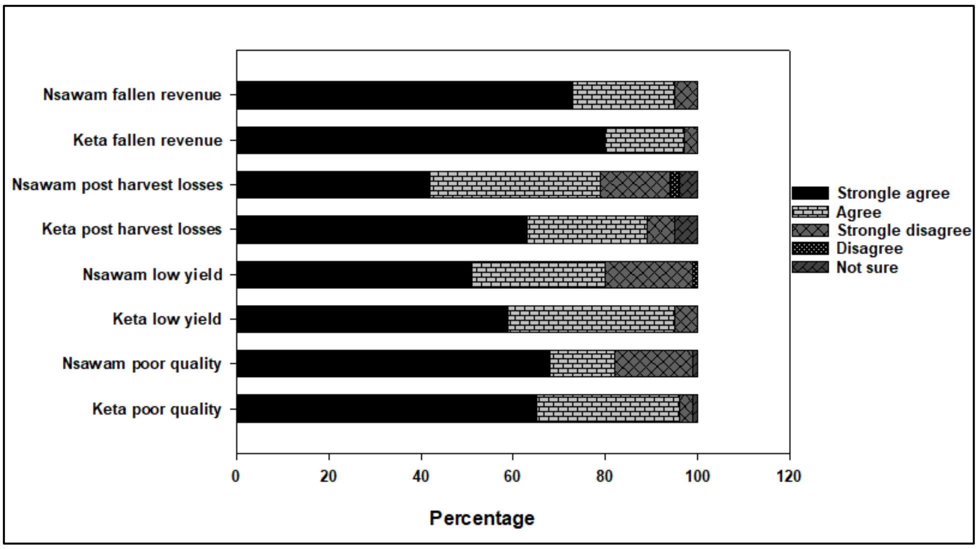


Figure 4.3: Famers' perception of climate impact on livelihood

4.4.2.2 Households' response strategies

The study identified and ranked adaptation practices employed by farming households to reduce their vulnerability to changes in climate and increase their resilience. These measures were based on households' local knowledge and perception of changing climate. Ranking results from strategies utilized by smallholder horticultural farmers in Keta municipality revealed that the first five most important adaptation practices at the local level included fertilization, supplementary irrigation, mixed cropping, crop rotation and intercropping (Figure 4.4) in descending order of importance. The ranking results for Nsawam's practices also showed fertilization as the first highest ranked and important adaptation practices. This was same for Keta. During discussions with farmers, it was mentioned that poor soil conditions at Keta (mostly sandy with low soil fertility) and continuous cropping on the same piece of land in Nsawam render soils infertile and resulted in both municipalities ranking fertilization as the most important adaptation strategy. Contrary to Keta, fertilization was followed by crop rotation, mixed cropping, supplementary irrigation and intercropping in descending order of importance. It was observed that farms in Keta mostly used underground water (boreholes) sources and traditional wells on farmlands for irrigation even though they suffered from high salinity during dry periods. Farmers in Nsawam during the FGDs explained that as much as irrigation is critical for horticultural production by conserving soil moisture and allowing for year-round production, most water sources within the municipality (small rivers and boreholes) lately dries up regularly causing water stress during crop growth hence their resort to crop rotation as second best practice. At Nsawam, rotating deep and shallow rooted crops were noted to improve soil stability and promote efficient use of soil moisture, which is highly preferable to irrigation. The least ranked and utilized practices for Keta were organic farming, crop insurance, Integrated Pest Management (IPM), livelihood diversification and animal production. Relating the least important practices in Keta to Nsawam, the same practices were also consistently ranked as the least important household practices in responding to changing climate. Other adaptation practices are shown in Figure 4.4. Decreasing farm size, use of improved varieties, adjustment in planting calendar, provision of windbreaks, increasing farm size, mulching shifting cultivation and seasonal migration are moderately implemented by households. These responses constitute crop, soil, water and farm management responses to changes such as increasing temperature, and rainfall variation including droughts and coastal flooding. Importantly, all the adaptation practices identified were autonomous and practiced at the local level. The farmers facilitated them personally by expending their own social capital and resources.

The Mann-Whitney U Test revealed no significant difference in the smallholder farmers ranking of the identified practices ($U=273$, $Z= -1.23$, p-value= 0.234). This indicates the same level of importance given to the adaptation strategies and is common to farmers from the two municipalities. The ranks did not differ significantly for the smallholder farmers' overall rankings across the two study areas.

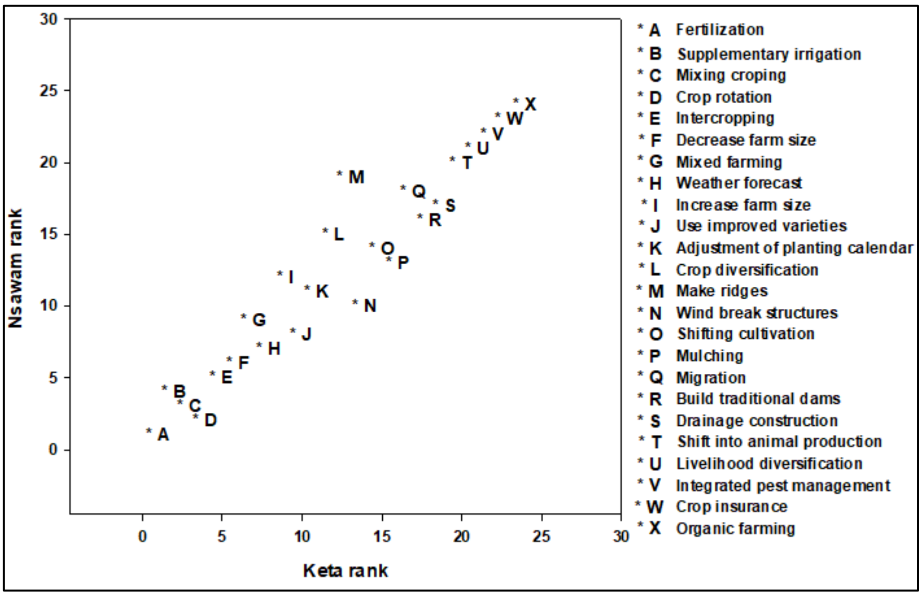


Figure 4.4: Adaptation strategies of households in Keta and Nsawam Adoagyiri municipalities

4.4.3 Households' challenges in responding to changing climate

Factors constraining the adaptive capacity of smallholder horticultural farmers in both study areas are summarized in Table 4.2. Using the Weighted Average Index (WAI), inadequate financial resources and high implementation cost, were ranked as the most critical challenges facing smallholder horticultural producers in adapting to changing climate in both study areas. Insufficient financial resources prevent farmers from adequately adapting to changing climate. In Keta for instance, farmers during discussions noted that because of poor soil conditions and high salinity of water for irrigation during water stress periods, fertilization which enhances nutrient availability for plant growth would need to be modified and regularly applied but requires more capital investment which they do not have the capacity to do. Also, high cost of acquiring some adaptation strategies, also deter farmers from implementing them. In Nsawam municipality, even though there exist other water sources, which could still be used during water stress periods, distance of farmlands to such water sources would require high capital investment for irrigation infrastructure of which farmers are limited.

With WAI of less than 2.0, land tenure and socio-cultural issues ranked as the least constraints hindering adaptation in both municipalities. Inadequate storage facilities and market accessibility, climate and production information, lack of farm equipment and institutional support were considered moderately constraining climate adaptation of smallholders'. In terms of differences in ranking, lack of farm equipment was ranked fifth in Nsawam while it ranked seventh in Keta. Access to climate information was fifth in Keta but sixth in Nsawam. Inadequate production information was also considered sixth in Keta but seventh in Nsawam. Overall, a Mann-Whitney U Test showed no significant difference in smallholder farmers' ranking of the challenges in responding to changing climate (Table 4.2) implying common challenges and same level of importance found across both municipalities.

Table 4.2: Factors constraining adaptive capacity of smallholder horticultural farmers

Constraints	Keta		Constraints	Nsawam	
	WAI	Rank		WAI	Rank
Inadequate financial resources	4.66	1	Inadequate financial resources	4.33	1
High implementation cost	4.23	2	High implementation cost	4.13	2
Inadequate storage facilities	3.96	3	Inadequate storage facilities	3.95	3
Inadequate access to market	3.90	4	Inadequate access to market	3.38	4
Lack of climate information	3.03	5	Lack of farm equipment	3.30	5
Inadequate production information	2.78	6	Lack of climate information	3.28	6
Lack of farm equipment	2.75	7	Inadequate production information	2.98	7
Poor institutional support	2.70	8	Poor institutional support	2.95	8
Poor extension services	2.60	9	Poor extension services	1.75	9
Land tenure issues	1.52	10	Land tenure issues	1.71	10
Socio-cultural issues	1.30	11	Socio-cultural issues	1.28	11
Mann-Whitney Test statistics					
Mann-Whitney U	58				
N	11				
Z	-0.164				
P-value	0.870				

4.5 Discussion

4.5.1 Climate and horticultural crop production

Smallholder horticultural farmers in the two study municipalities of Ghana have observed climatic changes with consequences on their production activities especially with regards to temperature and rainfall parameter changes. The predominant climate related factors for crop production are temperature and rainfall (Neenu, Biswas & Subba Rao, 2013). Trends in observed climate data were consistent with farmers' perception about changing climate indicating a rise in temperature and declining total rainfall over the study period. Such trends overtime would have detrimental effects on horticultural production in both municipalities corroborating the fact that risk in crop production increases as climate parameters become highly unreliable (Winkler et al., 2013).

Increasing temperature coupled with decreasing rainfall trend observed in both municipalities could further result in increased evapotranspiration and water stress affecting soil water and irrigation water availability. Additionally, water stress increases salt concentration in the soil affecting loss of water from plant cells (Pena & Hughes, 2007). Such conditions lead to increased water loss in plant cells and inhibition of processes such as photosynthesis and respiration thereby reducing productivity of most horticultural crops (Pena & Hughes, 2007; Abewoy, 2018). This is especially critical for households in Keta, which is a coastal area where elevated soil salinity during dry periods is already a general concern. Reports of reduction in crop growth, wilting and poor quality fruits were particular. However, even though farming situations for Nsawam Municipality (an in-land area) seem relatively more favorable (receives relatively higher rainfall, lower temperature and more fertile soils) than Keta, it is equally faced with increasing temperature trend and decreasing trend in total rainfall which could aggravate in future. This could challenge sustainable and increased production among smallholders. As a result, measures to sustain farmers' livelihoods in both municipalities are important as they are already faced with negative climatic impacts. While households are conscious about occurrence of climatic variation and changes, efforts on adaptation need to be enhanced to build resilient farming communities and minimize the adverse impacts of climate. Farmers consider horticultural production as a capital-intensive agricultural activity. Horticulture generally is in a development phase and requires initiatives for sustainable development (Malhotra, 2017). With climate variation having consequences on water availability and soil quality and subsequently influencing year-to-year agricultural production, there is need for improved adaptation actions. Adoption of effective adaptation practices would reduce vulnerability and improve resilience of households to adverse effects from climatic changes.

4.5.2 Households' adaptation responses

Agricultural crop production is primarily determined by factors such as soil moisture, temperature and soil fertility (Malhotra, 2017) which changing climate is expected to alter and subsequently influence productivity. Adoption of efficient and effective practices would therefore improve farmer's resilience to sustain and improve production. All practices identified in this study as adaptive responses utilized to respond to changing climate, reflect autonomous practices, which are independently farmer-led strategies (based on their experience, climate perception and local knowledge) and intended to reduce climate vulnerability and increase resilience of farmers. Practicing fertilization (both organic and inorganic), which enhances nutrient availability and improves soil fertility was the most important to horticultural household for both study municipalities. Changing climatic conditions reduces soil fertility, which resulted in fertilization being the most important adaptation measure to the farmers. As a soil conservation practice, fertilization has also been observed as an important practice across studies in other African countries such as Ethiopia (Abewoy, 2018), Senegal (Mertz et al., 2009) and other parts of Ghana (Fosu-Mensah, Vlek & MacCarthy, 2012). The top crop management practices that is, crop rotation, mixed cropping and intercropping identified are mainly to improve soil and water use efficiency, enhance nutrient uptake and buffer against losses in an unfavorable season.

Even though other farm production strategies such as crop diversification and changing planting date are common practices observed among other food crop producers in Africa (Belay et al., 2017; Ndamani & Watanabe, 2015; Farauta et al., 2011), market availability for crops produced is an important factor that informed farmers' choice of crops grown in a season together with irrigation facilities hence not promptly considered as critical adaptation measures for horticultural production. In cases of extreme variability at the beginning of the production season, farmers rather relied on weather forecast and this practice was observed to be improving in both municipalities. This is due to a mobile weather forecast services introduced by a telecommunication agency where regular forecast updates are sent directly to farmers on their mobile phones. With the interest shown by farmers on the usefulness of this service, improved awareness should be created for greater adoption. Other adaptation practices such as decreasing farm size, use of improved varieties, adjustment in planting calendar, provision of wind breaks, increasing farm size, mulching, shifting cultivation and seasonal migration were sometimes reportedly utilized in both municipalities to respond to climatic variation. These measures are mainly soil, water and crop conservation techniques as well as farm management practices that provide efficient use of natural resources and make farmers less sensitive to climatic changes. Unlike the horticultural producers context, these practices have been reported in findings of other studies as the highest ranked and utilized adaption strategy in food crop productions (Alam, Alam & Mushtaq, 2017; Belay et al. 2017; Ndamani & Watanabe 2015) concurring with the context specificity of adaptation studies in climate adaptation scholarship. Ridges and drainage construction, seasonal migration, building farm dams, crop diversification and shifting cultivation were seldom utilized to reduce impacts of climate variability especially excessive weather conditions such as instances of heavy rainfall. These practices are not proactively utilized as they are also considered capital, technology and other resources intensive. Technological adaptations for example are generally developed through research programs undertaken or government sponsored and also through Research and Development programs (Smit & Skinner, 2002) hence it is not surprising such practices are currently not common among horticultural smallholders and the rate of utilization is consistently low in both municipalities. This indicates the need for government programmes and policies as well as other institutional responses to adequately support smallholder farmers improve their responses to climate adaptation.

4.5.3 Enhancing households' adaptive capacity

Despite diverse climate adaptation measures existing in the study areas, it was revealed that horticultural smallholders' were constrained and limited in their capacity to practice the identified adaptation strategies to its full potential. Generally, smallholder farmers are financially constrained which farmers considered as a major limitation to their implementation potential. Limited financial resources together with high implementation cost amidst capital-intensive horticultural production among resource constrained smallholder farmers therefore are critical and associated with thwarting sustainable and increased production. To this end and at the local level, assessing the effectiveness of identified practices to guide and enhance farmers' decision making on likely options to invest in and implement given their limited resources is essential. Addai (2013), notes that farm businesses devote their resources toward the more pressing appropriate response to climate and market opportunities. Also, adaptation at the local level is considered as the result of individual decisions influenced by forces, particularly internal to the farm household, like risk of income loss (Smit & Skinner, 2002). Since adaptation comes with some costs and benefits, economic analysis which aims to understand and inform financial trade-offs in the efficient allocation of scarce resources amongst competing demands (Wise & Capon, 2016) would therefore improve decision support and enhance adaptation of smallholder production systems to changing climate. Additionally, support for improved access to sufficient financial resources through government subsidies and services to enable smallholder farmers' adequately obtain both production and adaptation facilities is needed. Furthermore, identifying more affordable and cost effective techniques for implementation could improve financial challenges faced by farmers. This resonates the need to economically assess adaptation strategies to guide decision making for implementation.

Besides financial capacity related challenges, inadequate storage facilities and limited market accessibility were major constraints in responding to climate variability. Horticultural crops are highly perishable and farmers during discussions noted that increasing their production outputs as a result of adapting to changing climate would subsequently result in high post harvest losses because of limited storage facilities and market accessibility. This implies that market accessibility and storage facilities could either trigger or hinder successful adaptation at the local level and needs to be improved. Other challenges identified such as inadequate climate and production information, farm equipment, institutional services including extension services, land tenure and sociocultural issues are in line with past studies in Africa where similar factors inhibited adaptation of smallholders to changing climate (Bryan et al., 2009; Deressa et al., 2009). Climate and production information as well as extension services increase awareness on vital adaptation information that would enhance households' production and climate adaptive capacity. Regular access to adequate climate information enables decision makers including farmers and even policy makers determine their intent, timing and direction for any climate adaptation plans and actions to be implemented as indicated by other scholars (Elum, Modise & Marr, 2017; Alam, Alam & Mushtaq 2017). Therefore up-to-date information should be improved for more informed decision-making on adaptation actions. Lack of farm equipment for example irrigation facilities is associated with limited technological development. Farm equipment was considered as a higher factor in Nsawam compared to Keta. Keta as a coastal area has a relatively higher water table. However, majority of irrigation water sources especially in Nsawam is from dug shallow (about 10 to15 meters deep) ponds and wells and with declining water tables hence reduced water accessibility. There is need for much deeper reach of underground water to maintain irrigation for production activities, which requires technological advancement. Lack of equipment to address this problem limits farmers from realizing the full potential from irrigation. Government intervention is required to support farmers to improve such measure at the local level. Finally, since adaptation strategies such as shifting cultivation and increasing farm size that requires more farmland were seldom practiced in both study areas, shortage of farmland and its associated land tenure and ownership agreement issues as well as other related sociocultural issues were considered least constraints in limiting climate adaptation in the study areas. This finding is contrary to studies in other contexts such as horticultural farmers in South Africa (Elum, Modise & Marr, 2017) and food crops in Northern Ghana (Ndamani & Watanabe, 2015) where such factors were considered crucial to climate adaptation.

4.6 Conclusion

This study presented climate adaptation strategies practiced at the local level using evidence from smallholder horticultural farmers in two municipalities of Ghana. The study revealed an increasing temperature and decreasing rainfall trends in the past two decades for observed climate data in the study areas. The observed data concurred with farmers' perceptions and experiences about climatic trends, which has consequences for production activities. As a market-oriented horticultural production activity, households' perceived impacts as poor quality produce, yield losses, post harvest losses and declined net revenue from climatic stress on their livelihoods. In the local context studied, the increasing temperature and decreasing rainfall trends guided the adoption of practices such as fertilization, supplementary irrigation, crop rotation, mixed cropping and intercropping as the most important and common adaptation strategies subsequently employed in response to the changing climate. Additionally, farmers also utilized a range of other soil, water and crop conservation measures as well as farm management practices in minimizing the effects of climate variability during production. With critical challenges related to finances, market, technological and institutional services identified to hinder adaptation, there is need for support to enhance implementation of adaptation strategies at the local level.

To enhance resilience of horticultural producers to climate variability and also sustain and improve production, it is important for smallholders' local level knowledge and actions to be augmented with government and other institutional support for effective and successful adaptation. Despite the various climate response strategies identified based on our findings, this study argues that climate adaptation with respect to market oriented and capital-intensive horticultural production and particularly resource constrained smallholder farmers need to be improved with adequate policy, institutional, technological and research support. This is based on the scholarship that agricultural adaptation is context specific and requires all climatic, economic, technological, social, and political forces for successful implementation. Particularly for smallholder farmers, we assert that improving their implementation potential is dependent on their economic resources for financial investment hence assessing the economic effectiveness of identified adaptation strategies is imperative for enhancing adaptation for vulnerable smallholder production systems. Hence research needs to explore the effectiveness of identified adaptation practices to support decision-making by relevant stakeholders (including farmers and policy makers) on efficient allocation of scarce resources. Specifically, economic analysis of strategies identified needs to be conducted to guide decision on adaptation actions. This is important to also enable identification of more affordable and cost effective techniques for implementation to improve financial challenges faced by farmers. Also, with a challenging climate, development of climate resilient horticultural crop varieties for adapting to conditions such as hot and dry environments and tolerance of salt could be emphasized in further research.

Chapter Synthesis

In light of perceived climatic changes observed by smallholders (e.g. increasing temperature and decreasing rainfall trends) the chapter critically identified local specific climate adaptation practices farmers use. The practices could be classified as a range of farmer driven soil, water and crop conservation measures and farm management practices. The implication of the identified practices is to guide various stakeholders in the planning and implementation of climate change adaptation. The chapter also revealed that farmers ranked practices differently based on factors such as soil conditions, soil water availability vis-à-vis total amount of rainfall received, either coastal or inland area, social capital and financial resources (socioeconomic context, geographic and climatic conditions). It further illustrates how the socioeconomic context, geographic and climatic conditions prevailing in a locality influences farmers level of importance assigned to adaptation practices. With regards to the framework adopted for the study, this chapter follows the climate vulnerability assessment process.

Challenges identified as hindering the implementation of response measures affected farmers directly as the results illustrated that farmers facilitated their own adaptive responses. This implied that, farmers been resource constrained, estimating the economic effectiveness of the identified practices as decision support on implementation of more affordable and cost effective strategies would be required to enhance smallholder production activities. Specifically, it contributes to scientific debates on the need of vulnerability assessments to support decision-making on adaptation implementation. Such effort builds on previous studies on enhancing climate adaptation and reducing potential challenges to adaptation (Ndamani and Watanabe, 2015; Shackleton et al., 2015) which emanates from the vulnerability assessment conducted. It also relates to the discourse of adaptation scholarship changing purposes to a vulnerability led approach as earlier noted in chapter 1. The findings therefore suggest the need to evaluate the economic effectiveness of the identified adaptation practices as reflected in the next stage of the framework adopted for this study (see Fig. 1.2; Chapter 1). Following the conceptual framing of the thesis, the next phase of the study evaluates the economic effectiveness of the adaptation practices using ex-ante cost benefit analysis.

CHAPTER 5

COST AND BENEFIT ANALYSIS OF ADOPTING CLIMATE ADAPTATION PRACTICES AMONG SMALLHOLDERS: THE CASE OF FIVE SELECTED PRACTICES IN GHANA

This chapter shows the economic effectiveness (through ex-ante in-depth empirical analysis of costs and benefits) of implementing the identified climate adaptation practices to guide informed planning and actions among stakeholders (Objective 3). Key expert interviews and questionnaire survey were employed for the data collection. The evaluation is done from private and public points of view and for the five most important climate adaptation strategies identified among the smallholder horticultural farmers in Chapter 4 (i.e. fertilization, supplementary irrigation, mixed cropping, crop rotation and intercropping). Risk dimension and non-monetary ancillary benefits associated with the implementation of the climate adaptation strategies is further explored.

Summary

Smallholder farmers mostly depend on agriculture for their sustenance yet the sector is threatened by changing climate. It is essential for smallholders to adapt to reduce their vulnerability. Estimating the economic effectiveness of climate adaptation practices would enhance planning and actions among stakeholders and consequently impact policy. This study conducted an ex-ante in-depth empirical analysis of the costs and benefits of implementing five climate adaptation strategies identified among smallholder horticultural farmers in Ghana. A total of 180 smallholder households who have implemented the identified practices in two horticultural crop-growing municipalities were surveyed. Profitability indicators, evaluation of environmental and social externalities were employed to comparatively estimate the cost-effectiveness of the practices. The results indicated that from private and public perspectives, implementing any of the five adaptation practices would yield positive benefits. However, considering the capital required, payback period for investments made and risks from implementation, two out of the five practices are particularly fitting choices for the smallholders. Institutional and policy support is desirable if all the practices are to be adopted. To broaden information on potential of climate adaptation vis-à-vis climatic effects with economic analysis, the study proposes integrating localized climate vulnerability and economic assessments for enhanced climate adaptation actions.

5.1 Introduction:

Adapting to changing climate is inevitable for developing countries particularly in sub-Saharan Africa (SSA) due to consistent low adaptive capacities throughout the continent. Yet adapting to climate risks and their amplification resulting from climate change is challenging because of the high dependence of populations on agriculture, the high sensitivity of this sector to climate, and the low adaptive capacity of most farming households (Millner and Dietz, 2015). For most economies in SSA, agriculture is the main source of income and food security. Consequences of changing climate such as reduced availability of water resources, declining soil quality and increased frequency of pest and diseases often impact negatively on the already vulnerable agricultural producers resulting in poor quality produce, yield losses and overall low net revenue (Williams et al., 2019). Phenomena that would increase the risk of soil erosion and vegetation damage such as frequent droughts, inconsistent torrential downpours and increasing temperature have been projected to challenge already vulnerable producers, predominantly smallholders (Below et al., 2010). In order to sustain and improve productivity despite the negative consequences of our changing climate, agricultural adaptation planning and actions supporting adoption by farmers are important. This requires considering uncertainty about impacts of future changes to maximize opportunities of planning for climate variability and adapting to climate change (Bhave et al., 2016).

Livelihood resilience to climate requires concerted efforts in committing time and resources to build meaningful adaptive capacity (Tongowona, 2017). Diverse strategies exist in responding to the effects of climate variability and change that also enhance sustainable livelihoods. However, efforts to adapt to existing and anticipated climate impacts are slowed by economic constraints calling for prioritization of options in terms of their cost-effectiveness (Cartwright et al., 2013). It is increasingly agreed that poverty alleviation and development are intrinsically linked to climate (Below et al., 2010; Below et al., 2015), hence climate adaptation is considered a developmental effort, of particular relevance for smallholder/rural farming communities. There is an opportunity to improve climate adaptation information to assist developmental planning of efficient strategies for sustainable and increased production. The regional aspect of the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) noted with high confidence that evolving national institutional frameworks across Africa cannot yet effectively coordinate adaptation initiatives (Niang et al., 2014a). This implies that at the local level, individuals, primarily farmers, are the main facilitators expending their own resources to cope and adapt to impacts of changing climate. Knowledge of the costs and benefits of implementing adaptation practices by farm households could be a defining factor for sensitization and scaling up and consequently support national planning (Tschakert, 2004). Given farmers (at individual local scales) and governments (at various administrative levels) limited resources, it is essential to provide guidance for efficient allocations among stakeholders and act on reducing their vulnerability.

Widespread adoption of climate practices also presents business opportunities pending sufficient analysis of related trade-offs (Schroth et al., 2015). Assessing the economic profitability of practices has the potential to enhance households' ability to adapt by concurrently increasing income and improving food security (Ng'ang'a et al., 2017a). Moreover, it determines the impact of those practices in terms of a time of return and livelihood levels achieved and maintained (Daigneault et al., 2016). Considering investment prioritization at multi-scale levels, Sain et al. (2017) noted that practising Cost-Benefit Analysis (CBA) has to take into account both private and public effects, through potential intervention, social and environmental values. Knowing that ecosystems (crop and soil biodiversity), human systems (e.g. water availability, health, social and political capital) as well as economic systems (costs, income and yield benefits) are interrelated and jointly affected by climate (OECD/FAO, 2016a), studies employing economic analysis, specifically CBA, often lack emphasis on the valuation of social and environmental impacts of practices (Sain et al., 2017; Ng'ang'a et al., 2017a; Cartwright et al., 2013). We recognize this challenge and explicitly attempt here to be inclusive of the full private and public potential of practices considered in order to enable investment prioritization.

Ghana like other SSA countries is experiencing the impacts and effects of climate variability and change. During the last two decades for example, Ghana has suffered from severe droughts and floods with increasing temperature in all agro-ecological zones, affecting key development areas such as food security, water resources management and economic growth (USAID, 2011). Average annual temperatures are projected to increase by 1.0°C-3.0°C, with changes in annual precipitation ranging from a 9% decrease to a 8% increase by mid-century and droughts are anticipated to become more frequent and more intense (Stanturf et al., 2011; USAID, 2011). The Government of Ghana (GoG) and other donor communities have begun recognizing vulnerability levels, and consequent adaptation priorities, so as to integrate this knowledge into development and sectoral planning targeting climate-related challenges (GoG, 2015; USAID, 2011). The agricultural sector provides livelihood for over 50% of the population, dominated by smallholder farmers who are particularly vulnerable to seasonal climate variability (Williams et al., 2017). According to the World Economic Forum (2014), up to 65% increase in projected losses due to changing climate could be averted, through cost-effective adaptation investment. Mainstreaming adaptation into sector-specific and local-level planning, through a number of considerate sub-sector measures, remain a central focus for government (GoG, 2015).

As an understudied sector (Williams et al., 2018a), horticultural production in developing countries presently accounts for 98% of the production of fruit imports in developed countries. This study provides an in-depth sector-specific assessment of the likely economic profitability of climate adaptation strategies for horticultural crop production in Ghana. Horticultural production presents growth potential in response to national, regional and global shifts towards diets richer in fruits and vegetables (Sthapit et al., 2012). Twenty-four potential adaptation practices available to horticultural producers have been recently identified (Williams et al., 2019). The strategies broadly constituted crop, soil, water and farm management responses to changes such as increasing temperature and rainfall variation, including droughts. Using evidence from smallholder producers in Ghana, this study aims to explore the following objectives: evaluating economic effectiveness – using CBA model - of the five most important climate adaptation strategies identified to respond to the changing climate in two smallholder horticultural growing municipalities (Keta and Nsawam); examining the value of external effects related to implementing these practices; assessing how specific outcomes from the study can inform and improve adaptation of smallholder production systems and policy decisions. This context-specific study is particularly expected to inform the capacity to adapt to changing climate through improved land use management, being a key priority area of the national strategies and plans on climate adaptation in Ghana.

5.2 Materials and methods

5.2.1 Climate adaptation practices

Adaptation is one of the important ways of reducing the impacts of climate variability and change (FAO, 2006). Apart from adapting to climate variability and change to improve the resilience of agricultural production, it is important for production practices to improve agricultural productivity (Zinyengere et al., 2013). This would ensure food security and meet demands of the growing population. The adaptation practices considered in this study are described in Table 5.1. All the practices reflect autonomous strategies that are used by smallholder horticultural farmers. They have been adopted based on farmers experience of the practice relevance to reduce climate vulnerability and improve crop productivity. Although the identified practices are associated with sustainable agriculture, they also increase the resilience of agricultural systems to climate impacts and have been repeatedly reported as climate adaptation strategies as well (Fadina and Barjolle, 2018; Kuwornu et al., 2013;(Kuwornu et al., 2013)(Kuwornu et al., 2013) Below et al., 2010; Easterling et al., 2007; Boko et al., 2007; FAO, 2006). Out of the twenty-four potential adaptation options identified by Williams et al. (2019), the following (see Table 5.1) were the first five most relevant strategies adopted by smallholder farmers and also considered for this study.

Table 5.1: Description of the climate adaptation practices considered

Climate Adaptation Practice	Description
Intercropping	• Introduction of a defined plant spacing system, including two or more crops in close proximity to one another, to efficiently use and maintain land, soil, water and other resources, as well as reduce proliferation of pests and diseases.
Mixed cropping	• Growing more than one crop concurrently on the same piece of land during a production season into a farm where monocropping was being practiced previously to avoid complete loss of products during seasons of variable climatic conditions.
Crop rotation	• Growing of crops in a defined sequence on a same piece of land, which involves a change in a crop each season/year. For instance, alternating deep and shallow rooted crops and or addition of a leguminous/cereal crop to vegetable/fruit crops in a sequence to improve soil fertility and soil water availability for crops.
Irrigation	• Improved irrigation efficiency through mechanization of irrigation systems, e.g. complementary use of sprinkler or water controller systems and water pumps, to improve efficiency particularly during dry periods in response to water limited availability (both surface and groundwater).
Fertilization	• Integration of organic manure and inorganic fertilizers to improve nutrient availability to crops as well as retain soil moisture to increase resilience to rainfall variability during a production season.

Source: Field survey 2018

5.2.2 Study sites

Data for this study was collected from two municipalities of Ghana, namely Keta and Nsawam Adoagyiri. Keta municipality is located in the Volta Region while Nsawam Adoagyiri is located in the Eastern Region, representing Coastal Savanna and Semi-deciduous forest agro-ecological zones respectively. Keta is about 160 km east from the national capital Accra and lies within longitudes of 0.30°E and 1.05°E and latitudes of 5.45°N and 6.01N (GSS, 2014a). Nsawam is about 23 km south of Accra and lies within longitudes of 0.07°W and 0.27°W and latitudes of 5.45°N and 5.58°N (GSS, 2014b). Both municipalities experience bi-modal rainfall patterns with major and minor growing seasons, which comprise major horticultural producing areas in Ghana. Annual rainfall for Keta is about 800–1000 mm per annum and for Nsawam 1250–2000 mm. Both study sites experience dry periods during a production year, ranging from 3 to 6 months and during which low rainfall affects crop production (Williams et al., 2017). Mean annual temperature in Keta lies within 19–29 °C and 26–30 °C in Nsawam.

Observed trends in total annual rainfall over the past two decades depict a decreasing rainfall of 5.4 mm/year for Keta and of 1.2 mm/year for Nsawam. In addition, mean annual temperature warms at a rate of 0.03 °C/year for Keta and 0.02 °C/year for Nsawam (Williams et al., 2019). Consequently, vulnerabilities of both municipalities are further stressed by this changing climatic exposure, when considering continued sensitivities and low adaptive capacities (Williams et al., 2018b). Okra, pepper, tomato, onion, shallot, pineapple, carrot, watermelon, pawpaw, garden egg and cabbage are the main crops cultivated in both municipalities. Table 5.2 illustrates those major crops, adaptation practices with local known effect, and the corresponding farm sizes associated.

Table 5.2: Major affected crops and farm size of each adaptation practice in study locations

Climate adaptation practice	**Keta Municipality**		**Nsawam Municipality**	
	Crops affected by adaptation practice	**Farm size (ha)**	**Crops affected by adaptation practice**	**Farm size (ha)**
Intercropping	Okra, pepper, tomato and shallot	1.20 ± 0.32	Okra, pepper, tomato and garden egg	2.40 ± 0.40
Mixed cropping	Pepper, tomato, shallot and onion	1.20 ± 0.20	Okra, pepper, tomato, and onion	2.40 ± 0.40
Crop rotation	Okra, tomato, shallot, onion and beans	1.60 ± 0.40	Okra, tomato, onion, garden egg, beans, and maize	1.60 ± 0.40
Irrigation	Pepper, tomato, onion, and carrot	2.40 ± 0.32	Okra, pepper, onion, and carrot	2.80 ± 0.40
Fertilization	Okra, pepper, tomato, shallot and onion	1.60 ± 0.20	Okra, pepper, onion and garden egg	2.00 ± 0.20

Source: Field survey 2018

5.2.3 Research design and data collection

Both primary and secondary data sources were used in this study. Primary data was collected with structured questionnaires through a survey of farmers and key experts conducted between July and August 2018. Prior to the main data collection, participatory validation workshop to validate and affirm the appropriateness and usefulness of the selected practices to reflect the study areas were conducted in both municipalities. A total of 43 representative stakeholders including farmers, agriculture extension agents and other experts from the Ministry of Food and Agriculture (MoFA) from the respective study sites were engaged in the workshop. Afterwards, a primary sampling frame of 480 farm households implementing the practices and obtained from an earlier study on vulnerability assessment conducted in both study sites was used in the sampling process (Williams et al., 2018b). Using stratified random sampling technique within the five selected practices; a sample of 180 farm households was selected for this study. Ninety farmers who applied at least one of the selected practices were identified and interviewed in each municipality. Information collected from the primary data included the demographic profile of the farmers, general information about adaptation practice, physical productivity and yield change from implementing a practice, cost of installation and maintenance of a practice and prices of inputs and farm products related to a practice. Semi-structured questionnaires were used to collect information from six experts on the external effects (externalities) relevant to the implementation of the adaptation practices. The experts were selected from the Ministry of Food and Agriculture and academic institution based on their background and experience with the five adaptation practices considered for the consequences observed/expected in terms of externalities. Information obtained included adaptation practices external feedback, values of the change in externalities with the corresponding estimation of the monetary value of each externality. Secondary data was sourced from existing international scientific and local/national literature.

5.2.4 Cost benefit analysis

Ex-ante Cost and Benefit Analysis (CBA) was employed to estimate the economic profitability of selected climate adaptation practices. CBA is a sustainable decision-making tool that informs the implementation of financially more effective and equitable projects (USAID, 2016). CBAs are generally used to assess profitability of alternative investments (Ray, 1990). It is however acknowledged that uncertainty over climate, impacts the efficiency of adaptation responses (Cartwright et al., 2013), which challenges the accuracy of estimations from CBA especially at the local level. In overcoming this challenge, it is important to note that all practices considered in this study are considered ‘no regret’ options. The explicit implication is that the options considered are expected to result in social and/or economic benefits now and build future resilience irrespective of climate changing or not (De Bruin et al., 2009). A probabilistic CBA approach was employed for this study unlike a conventional CBA approach (also known as deterministic CBA) where single averages or mode values of economic variables are commonly used (Brent, 1996). Thus, the measurement of variability and uncertainty was incorporated in the computation of economic assessment indicators to avoid underestimating risk during adoption (Sain et al., 2017). Additionally, the temporal effect of adaptation was factored in the analysis to avoid confounding inefficiencies from long-term application of practices. The analysis contained herein was therefore based on differences in the flow of benefits and costs for climate adaptation practices' life cycle, period starting from the adoption of a certain practice and ending when the practice is no longer considered effective (see Appendix VII for each practices life cycle). At the end of an application's life cycle, a practice is stopped or renewed. In the latter, likely improvements/changes to the system is made. Given the relatively short time frame of life cycle, the impact of changing climate was not included in the assessment. However, influences of climate vulnerabilities were captured in the selection of the practice (Williams et al., 2019).

Two economic profitability indicators were evaluated namely, the Net Present Value (NPV) and the Internal Rate of Return (IRR). NPV is the incremental flow of net benefits produced by compared alternatives over a practice life cycle while IRR is the discount rate that makes the present value of the flow of future net benefits exactly equal to the initial investment (that equates NPV to zero) (Juhász, 2011). NPV shows how much wealth has been accumulated practicing an adaptation practice during its entire life cycle. IRR allows for comparison under different scenarios with a range of values to assess a practice's possible profitability. The study used a discount rate of 27.5%, which is equivalent to the interest rate applicable to farmers when a formal loan is taken from the bank (BoG, 2018). A practice is considered profitable if the IRR is greater than the discount rate, hence the higher the IRR the more economically feasible a practice is. The NPV and IRR were calculated based on values (such as benefits flow, costs of machinery, inputs, services, labour) from the household survey. The probabilistic CBA approach used in the study allowed the generation of the cumulative distribution function of the IRR from the existing alternatives given the probability that the adaptation practices adopted by the farmers are profitable (Anderson and Dillon, 1992). This was derived from the probability distribution of random variables using @Risk software to undertake Monte Carlo Simulation (Palisade Corporation, 2013).

5.2.5 CBA model specification

The unit of analysis for this study was per hectare basis at the farm-level and from the point of view of the farmers who adopt the practices (termed private profitability). However, the value of the impact of other external benefits resulting from implementing a practice such as a change in biodiversity, soil erosion control, increased water availability as well as other social impacts were separately evaluated (termed public profitability/externalities). Values for the externalities were included in the CBA estimation with details of its composition discussed in Section 2.6.

Private profitability estimation was set in two farm scenarios; not practicing the adaptation options considered (doing Other Practice - OP) and implementing at least one of the adaptation options (with Adaptation Practice - AP). Equation 1 indicates a flow of net benefits of replacing OP by an AP per hectare, which was used in the evaluation of private profitability. Taking the life cycle of the adaptation practices into consideration, the flow of incremental costs was taken from the flow of incremental gross benefits per hectare as done in other studies (Sain et al., 2017; Ng'ang'a et al., 2017a) and shown in Equation 5.1. Incremental gross benefits were estimated by multiplying product price by the incremental crop yield.

$$\Delta NetBenefits_t^{AP} = \sum_{t=1}^{T} \frac{1}{(1+r)^t} \left[\sum_{d=1} P_{dt} * \Delta Y_{dt}^{AP-OP} - \sum_{d=1} \Delta C_{dt}^{AP-OP}\right] \quad \text{Eq. 5.1}$$

Where P_{dt} = Price of commodity "d" in time t;

ΔY_{dt}^{AP-OP} = Annual change in yield for "d" for AP compared to OP;

ΔC_{dt}^{AP-OP}= Annual change in the cost of implementing an AP compared to OP;

r = Discount rate

5.2.5.1 Variables used in the modeling - Benefit

An assumption made in the CBA modeling was that all the practices considered were potentially assumed to positively improve soil fertility, improve crop water availability and reduce soil erosion among others. Such effects were believed to implicitly result in improved crop yield. Therefore in modeling the effect of climate adaptation practice on crop yield, a physical response pattern of yield in response to AP was assumed. It followed a linear plateau preceding a lag from installation and commencement of yield response, known as a Liebig Production Function (Beattie and Taylor, 1993) and depicted in Figure 5.1.

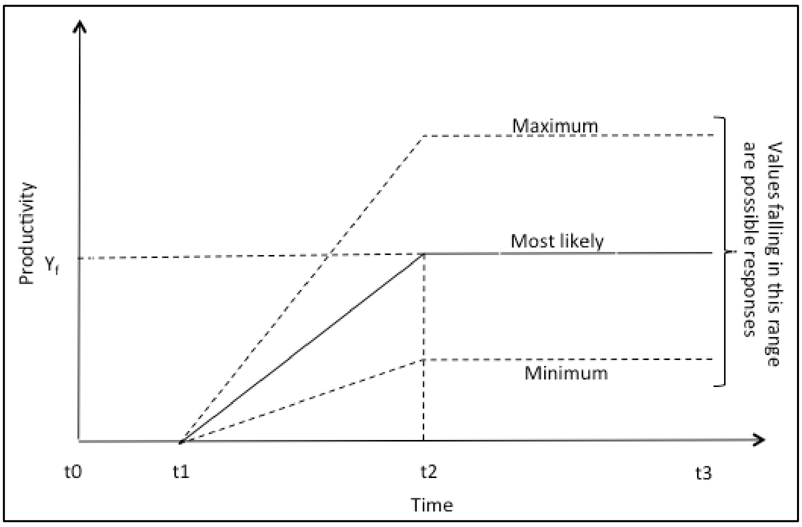


Figure 5.1: Linear response function of yield in response to implementing an adaptation practice
Adapted from Beattie and Taylor (1993)

Stages in the characterization of the Liebig Production Function include initial implementation (t_0) to start of increase in yield response (t_1), from t_1 until physical response reaches maximum production (t_2) then from t_2 when a linear plateau is attained until end of the practice life cycle (T). Y_f represents the most likely or estimated value of the final increase in yield related to the implementation of AP. Minimum and maximum values could be estimated to represent triangular distribution and depict variability in yield responses. Relative to the law of the minimum, the Liebig Production Function has been commonly applied in biological process modeling in other studies (Sain et al., 2017; Ng'ang'a et al., 2017a; Ng'ang'a et al., 2017b).

Data obtained from the survey was used in modeling the physical response curve from the implementation of the adaptation practices. In this study, yield response from the annual crops studied showed that practices take a relatively shorter time (between one and two years) to be realized over a life cycle range of six and thirteen years (see Appendix VII). Yield before implementation of an adaptation practice (Y_o); estimated final/most likely yield after implementation of a practice (Y_f); possible minimum yield from a practice (Y_{min}) and possible maximum yield from a practice (Y_{max}) were all computed from the survey data. Market prices for the crops under study were also collected from the field survey. Together with the yield responses for both OP and AP, evaluation of private benefits from implementing a practice was conducted and incorporated in the CBA estimation.

5.2.5.2 Variables used in the modeling - Cost

In the CBA estimation, three major types of costs were evaluated and incorporated. These included installation, maintenance and operational costs. Installation costs are once-off outlays expended by farmers to cover expenses at the assumption of implementation of a practice. Farmers to ensure an adopted practice is sustained throughout its life cycle annually disburse maintenance costs. Operational costs are also costs incurred as a result of introducing a practice and specific to products/activities relevant to a practice (such as harvesting cost for specific product activities). Even though operational costs may not necessarily be incurred annually, because annual crops were covered for this study, all operational costs were computed yearly. All three types of costs covered more broadly the costs of equipment and machinery, inputs, services and labour. Prices of inputs and outputs computed into the CBA were assumed to be constant.

5.2.5.3 Categorization of the cost and benefit variables

A probabilistic CBA entails classification of all variables used in the CBA estimation as either non-random or random. Non-random variables usually have values evaluated at the average/mean or mode as variables had minimum variation across farm households regardless of options considered. Random variables on the other hand, constitute values evaluated across a range of possible values through cumulative distribution frequency, as a representative of variation among farm households. Non-random variables considered in this study included the discount rate, life cycle for practices and market prices for crops. The life cycle of a practice and the market price for crops was based on the nature of the practice under consideration and the study site respectively. Random variables for the study included the cost structure (installation, maintenance and operational costs) as well as crop yield responses. Due to the degree of uncertainty about the true values of cost and yield values resulting from differences in farming systems and technologies applied across farms, capturing these variables as random distribution was not plausible. Moreover, these variables determine the impact of implementing an adaptation practice and their estimations should be representative and as succinct as possible. Uncertainty associated with crop yield responses was estimated by assuming that yield followed a triangular probability distribution as described earlier (Figure 5.1) (Also refer to data in Appendix VII). The shape of the probability distribution of the cost structures were automatically determined with @Risk software based on the survey data to generate best fit distribution (See Appendix VII) (Palisade Corporation, 2013).

5.2.6 Environmental and social externalities

Benefits associated with an implementation of climate adaptation practices are not exclusive to economic profitability, improved and sustained productivity but also indirectly provide external benefits. For instance, evidence shows that adopting improved irrigation efficiency ensures improved soil moisture that surges water availability for crop production during dry production periods (Ndhleve et al., 2017; Nangia and Oweis, 2016). Diversifying crop rotations, mixed cropping and intercropping maintain ecosystem services by changing biodiversity and prevents a build-up of pest and disease infestations (Hassen et al., 2017; Himanen et al., 2016; Tiemann et al., 2015). Additionally, improving soil quality through integrating organic resources is reported to enhance the resilience of cropping systems to climatic impacts and mitigation of greenhouse gas (GHG) emissions derived from inorganic fertilizers (Roobroeck et al., 2015; Fairhurst, 2012). While such externalities or public benefits may not primarily be the focus of a CBA approach, they are considered important factors in achieving a holistic CBA benefit estimation.

The study evaluated on-farm externalities associated with the five climate adaptation practices studied in the two localities. With varied external effects resulting from adopting the practices, experts selected five main externalities considered applicable and pertinent in the study areas (Table 5.3). In computing and evaluating the economic benefits from the externalities, the contingent valuation method was employed. This involves using a weighted amount of change in the externality as a result of the introduction of a practice and shadow price of the external effect (Sain et al., 2017). Shadow price estimation involved a market proxy reflecting the willingness of society to pay for an externality (Lera-López et al., 2014; Ray, 1990) as applied in other studies (Sain et al., 2017; Ng'ang'a et al., 2017a). Information for computation of external effects was provided after consultations with key experts and officers from academic and agriculture institutions and literature during the fieldwork.

Table 5.3: External effects related to selected climate adaptation practices

Climate adaptation practice	**Externality**				
	Improved water quality	**Reduced soil erosion**	**Improved crop biodiversity**	**Improved soil biodiversity**	**Social impact**
Intercropping	No significant impact	Enhances water infiltration and slow run-off water	Medium increase in plant species per unit area	No significant impact	Medium increase in farm labour employment
Mixed cropping	No significant impact	Enhances water infiltration and slow run-off water	Medium increase in plant species per unit area	No significant impact	Medium increase in farm labour employment
Crop rotation	No significant	Enhances water	Medium increase in	Increase soil fertility	Medium increase in

	impact	infiltration and slow run-off water	plant species per unit area		farm labour employment
Irrigation	Increases soil moisture availability	No significant impact	Medium increase in plant species per unit area	No significant impact	No significant impact
Fertilization	Increases soil moisture availability	Enhances water infiltration and slow run-off water	Medium increase in plant species per unit area	Increases soil fertility	No significant impact

Source: Field survey 2018

5.2.6.1 Estimation of the external effects

We could not estimate the external impact of the practices of all identified externalities particularly those indicating ‘no significant impact’ (Table 3). This is because, although there could be some potential impact related to these externalities, due to the limited impact noted by experts and corresponding lack of data to enable estimations, all non-significant impacts were not evaluated. Details of the valuation are discussed below.

Improved water availability

The two study areas experience dry periods ranging between 3 and 6 months in a production year. During critical growth stage, this affects crop productivity hence water availability plays an important role in smallholder production activities. Experts were asked to estimate the volume of water (in m^3) that could be made available per hectare in a period of one year by an adaptation practice over farmer’s other practices. This was estimated as a percentage of the amount of run-off water per year as provided by experts. Employing the contingent valuation method, the value of water was estimated at an average of US$0.52 m^{-3}. The product of the change in water available per unit per year and the shadow price constituted the value of improved water availability from a considered practice.

Controlled soil erosion

Soil erosion is reported to be depleting topsoil resource base and contributing to the loss of soil nutrients (Fairhurst, 2012). Crop and soil management practices are noted to reduce erosion through decreased run-off avoiding crust formation and improving soil porosity and infiltration rates (Nearing, 2013; Fairhurst, 2012). In its valuation, experts estimated the amount of soil erosion reduced per hectare of land in a year resulting from the adoption of adapted practice compared to a non-adapted other practice. The value was assumed to be related to the amount of contaminants (in kg) such as agro-chemical loss applied as a result of the negative effects associated with soil erosion. The price of agro-chemicals was multiplied with the percentage change of losses to obtain the value of change in crop rotation.

Improved crop biodiversity

According to literature, attempts have been made in Eastern Africa and Southern America to employ farm level land-use scores to quantify a change in crop biodiversity (Henry et al., 2009; Pagiola et al., 2007). Food crops were assigned lower scores while forestry vegetation/primary forests were assigned high scores because forests provide diverse crop biodiversity benefits (within an index range of 0-1.6 from both studies). Due to comparable data limitation in West Africa and Ghana, under a similar principle, experts estimated the percentage change in the number of crop plants from the land-use change over farmers other practices. A willingness-to-pay method was further used to estimate the price per unit change to derive the value of crop biodiversity. The experts estimated this average price at US$10.

Improved soil biodiversity

Change in soil biodiversity was related to soil fertility and assumed to be the amount of nitrogen fixed per hectare per year by leguminous crops and other decomposing organic manure affected by a climate adaptation practice. This represented changes in soil fertility due to the implementation of a climate adaptation practice over farmers' other practices. The amount of kilogram of nitrogen fixed per hectare per type of leguminous crop was obtained from the literature (Ng'ang'a et al., 2017a). Experts estimated the amount of change resulting from an adaptation practice, leading to an average price per kilogram of nitrogen gained of US$0.43 (equivalent to the market price of a kilogram of nitrogen fertilizer). Soil fertility benefit per hectare was valued as the product of a change in nitrogen gained and the shadow price.

Social impact

Social impact stemmed in this study from a potential increase in employment resulting from the implementation of a climate adaptation practice compared to a non-adapted practice. Change in labour utilization was obtained from the survey data from installation, maintenance and operation activities. A price of US$6.29 (average cost of labour at study sites) was used to multiply the change in labour per practice per hectare to get the value of social benefits

5.3 Results

5.3.1 Cost flow

Results from the study show that except for irrigation, all the adaptation practices had relatively low installation cost in both study areas (Figure 5.2). Cost of implementing irrigation in Nsawam (US$ 4,620) is close to twice that of Keta (US$ 2,010). Beside irrigation, Keta had the highest implementation cost for intercropping (US$ 470) and crop rotation (US$ 126), while Nsawam had the highest cost for fertilization (US$613) and mixed cropping (US$ 120) (Figure 5.2).

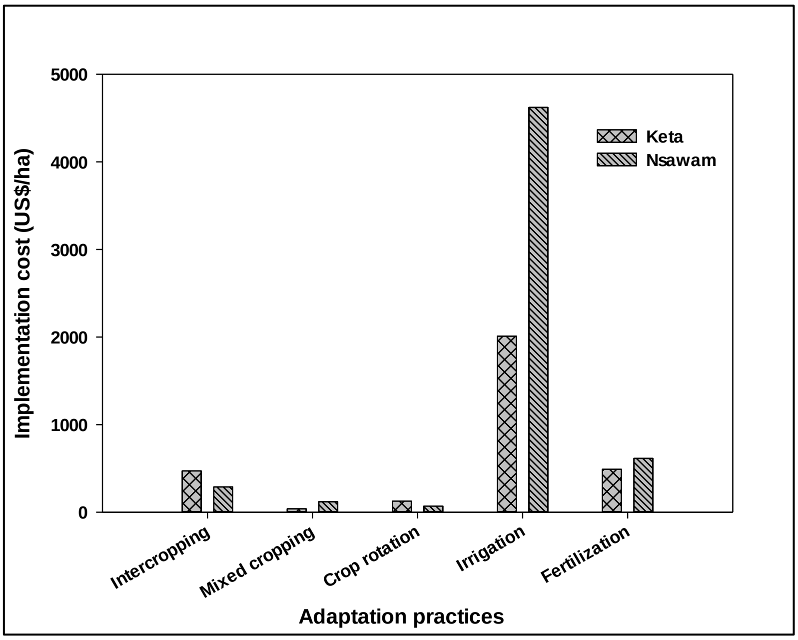


Figure 5.2: Implementation cost of the climate adaption practices

Regarding maintenance, the results show that Keta's costs were the highest for irrigation (US$ 605) and medium for mixed cropping (US$ 179) and intercropping (US$ 245) practices (Figure 5.3). Nsawam on the other hand, has medium maintenance cost for intercropping (US$ 309) and fertilization (US$ 308) while low cost for crop rotation (US$ 104.90), mixed cropping (US$ 95) and irrigation (US$ 145) practices.

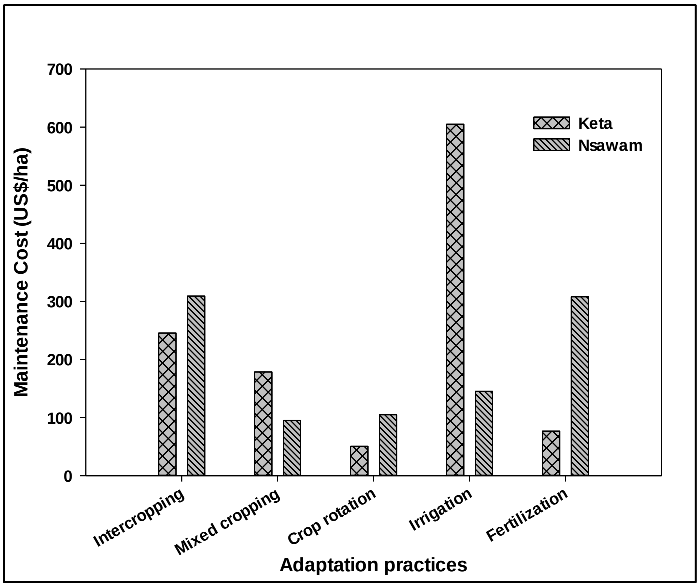


Figure 5.3: Maintenance cost of the climate adaptation practices

In terms of operational cost, Nsawam had the highest cost of operating mixed cropping (US$ 623), fertilization (US$ 531) and crop rotation (US$ 550) with medium cost for intercropping

(US$ 397) practices and irrigation (US$ 483) (Figure 5.4). Keta also had the highest operational cost for adopting crop rotation (US$ 585) and irrigation (US$ 513) practices and medium cost for intercropping (US$ 306) mixed cropping (US$ 456) and fertilization (US$ 404).

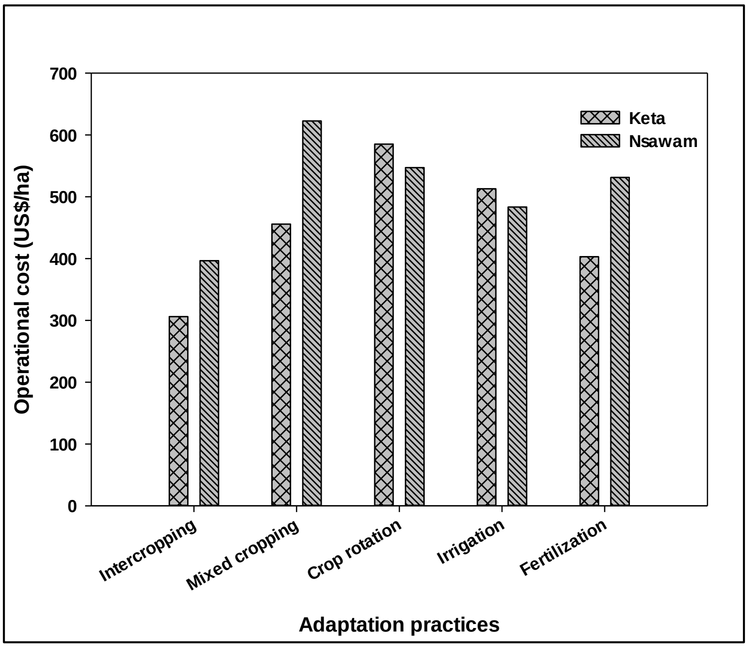


Figure 5.4: Operational cost of the climate adaptation practices

5.3.2 Private profitability of adopting practices

All climate adaptation practices studied were profitable over their life cycles. They had positive NPV and IRR greater than the discount rate applied in the analysis (27.5%) (Table 5.4). NPV sums up the value of enhanced yield and reduced labour minus cost flow values. Details of estimated values of enhanced yield per crop per practice are included in Appendix VII. The NPV for all the practices in Keta ranged between US$ 438 and 1682 and IRR from 34 to 157%. The payback period was from 2 for mixed cropping and crop rotation to 6 years for irrigation. Nsawam had an NPV ranging from US$ 176 to 1935 and an IRR ranging from 29 to 160% with a payback period ranging from 2 to 7 years. The indication is that if any of the five climate adaptation practices studied were to be adopted there should be positive economic returns for the farmer. Fertilization and irrigation in both municipalities had relatively lower profitability (Table 5.4). The IRR in both cases were marginally higher than the discount rate. It would take for instance a period of 6 and 7 years in Keta and Nsawam respectively for farmers to realize an increased income from adopting irrigation after pay back of the initial investment. Fertilization in Keta also requires a significant time of 5 years to pay back the initial investment. The rest of the practices require 2 to 3 years to make an impact in terms of economic returns except intercropping in Keta that require 4 years payback (Table 5.4).

Table 5.4: Estimated private profitability indicators of adopting climate adaptation practices

Adaptation Practice	Keta			Nsawam		
	Probability distribution average		Payback period	Probability distribution average		Payback period
	NPV	IRR	PP	NPV	IRR	PP
Intercropping	487	54	4	862	78	3
Mixed cropping	1682	157	2	1698	117	2
Crop rotation	1535	123	2	1935	160	2
Irrigation	544	34	6	176	29	7
Fertilization	438	35	5	259	31	3

Source: Field survey 2018

The probability distribution of the IRR for the adaptation practices is summarized in Table 5.5. This further represents the profitability risk associated with implementing an adaptation practice. The respective distribution graph for each cumulative distribution function is presented in Appendix VII. The results show that when intercropping, mixed cropping and crop rotation are adopted; it presents a minimal financial risk to the farmer in a given year within the practice's life cycle (Table 5.5). On average, a farmer receives profitable returns and the financial risks to the farmer would be minimal. However, adopting irrigation and fertilization shows a significant level of risk in both municipalities (Table 5.5)

Table 5.5: Summary of average IRR probability distribution as a result of the different climate adaptation practices

Adaptation Practice	Summary probability distribution of IRR results	
	Keta	Nsawam
Intercropping	The practice is profitable to the farmer with more than 90% probability that the estimated cost of capital will be between 27.5% and 74%. There is a 5% probability of getting an IRR above 74%. There is low risk (2%) of getting an IRR below the discount rate applied (27.5).	The practice is profitable to the farmer with about 94% probability of the estimated cost of capital being between 27.5% and 104%. There is a 5% probability of getting an IRR above 104%. There is no significant probability of getting an IRR below the discount rate applied (27.5).
Mixed cropping	The practice is highly profitable to the farmer with about 95% probability of getting an IRR between 27.5% and 214%. There is a 5% probability of getting an IRR distribution above 214%.	The practice is highly profitable to the farmer. A high probability (95%) exists of getting an IRR between 27.5% and 158%. There exist 5% probability of getting an IRR above 158%. Only 0.3% likelihood of getting an IRR

	There is no significant probability of getting an IRR below the discount rate applied (27.5%) hence no risk of farmer losing money.	below 27.5% exists which represents no risk of farmers losing money from this practice.
Crop rotation	From an economic point of view, this practice is highly profitable to the farmer since there is 95% probability of getting an IRR above 27.5% with no significant risk of going below this.	The practice is highly profitable to farmers with a 95% probability of getting IRR above 27.5% and even 5% probability of getting above 225%. No significant risk of getting lower than 27.5% IRR exists.
Irrigation	About 84% of the average IRR will be between 27.5% and 47%. A 5% probability exists of getting a value above this. The results however, show a likelihood of farmers losing money, as there is close to 16% probability of getting an IRR below the discount rate.	About 60% of the distribution of the IRR falls between 27.5 and 39% with a 5% probability of getting above this value. However, investment in this practice poses a significant risk to farmers at Nsawam as there is a 35% probability of getting an IRR below the discount rate, and making a deficit.
Fertilization	Implementing this practice in Keta municipality shows some risk of farmers' losing money, as there exists a 13% probability of getting an IRR below the discount rate. The rest of the distribution however shows an average of 82% probability of getting an IRR between 27.5% and 48%. 5% of the distribution lies above the 27.5% value.	The distribution shows an average of 68% probability of getting an IRR between 27.5% and 44%. However, from an economic point of view, there is a significant probability (27%) of getting an IRR below the 27.5% value and quite a risky practice.

Source: Field survey 2018

5.3.3 Environmental and social externalities

Adoption of the climate adaptation practices resulted in further external benefits (externalities) related to environmental and social benefits as earlier depicted in Table 5.3. Estimated average values of benefits associated with the externalities from Monte Carlo Simulation are shown in Table 5.6. According to the results, improved water availability, as a result of adoption of the five practices, had the highest benefit across all practices in both municipalities with an average value of US$ 24 ha^{-1} $year^{-1}$ in both Keta and Nsawam. This was followed by social impact ensuing from an increased demand for labour. The average benefit was US$ 17 and 18 ha^{-1} $year^{-1}$ for Keta and Nsawam respectively. Average benefits from better management of soil erosion as a result of adopting the five practices was US$ 5 ha^{-1} $year^{-1}$ for Keta and US$ 3 ha^{-1} $year^{-1}$ for Nsawam. The benefit associated with improved soil fertility (soil biodiversity) is US$ 5 and 4 on average ha^{-1} $year^{-1}$. Increased crop biodiversity are the same in both municipalities at US$ 2 ha^{-1} $year^{-1}$. Improved water availability was mainly from irrigation and fertilization practices while social impact mainly came from mixed cropping. Improved biodiversity and soil erosion was almost evenly distributed across the practices (Further details can be found in the Annex).

Table 5.6: Simulated estimation of external benefits

Externality	Mean (US$ ha^{-1})		Minimum (US$ ha^{-1})		Maximum (US$ ha^{-1})	
	Keta	**Nsawam**	**Keta**	**Nsawam**	**Keta**	**Nsawam**
Improved water	24	24	22	22	26	26
Crop biodiversity	2	2	2	2	2	2
Soil biodiversity	5	4	4	3	6	5
Reduced soil erosion	5	3	4	3	6	3
Social Impact	17	18	16	17	19	20

Source: Field survey 2018

5.3.4 Pubic profitability of climate adaptation practices

Social net benefits arising from the inclusion of the externality values into the CBA estimation are presented in Table 5.7. Social Net Present Values (SNPV) sums the private NPV and the externality benefits related to the implementation of the climate adaptation practices. For the five practices, the SNPV range is between US$ 486 and 2,513 in Keta municipality and US$ 304 and 2,907 in Nsawam municipality (Table 5.7). The respective Social Internal Rate of Return (SIRR) ranges between 36 and 363% for Keta and between 30 and 282% for Nsawam municipality (Table 5.7). Importantly, values for the public profitability indicators (SNPV and SIRR) are higher than values obtained for the private profitability indicators (NPV and IRR) indicating a positive impact of implementation of the adaptation practices on society and the environment. For instance, average labour increase by 8 and 11 man-days in Keta and Nsawam respectively, can directly be seen as improved labour and employment conditions and a public profit of US$50 in Keta and US$72 per hectare in Nsawam (Table 5.8).

Table 5.7: Estimated indicators of public profitability of adopting climate adaptation practices

Adaptation Practice	Social Net Present Value (SNPV)		Social Internal Rate of Return (SIRR)	
	Keta	**Nsawam**	**Keta**	**Nsawam**
Intercropping	603	1,012	61	90
Mixed cropping	2,513	2,907	363	282
Crop rotation	1,936	1,989	122	166

Irrigation	747	379	37	30
Fertilization	486	304	36	31

Source: Field survey 2018

Table 5.8: Estimated impact on labour due to adoption of climate adaptation practices

Adaptation Practice	Labour (man-days)		Labour value (US$)	
	Keta	Nsawam	Keta	Nsawam
Intercropping	+ 4	+ 6	+ 25	+ 38
Mixed cropping	+ 34	+ 50	+ 214	+ 315
Crop rotation	+ 2	+ 1	+ 13	+ 6
Irrigation	0	0	0	0
Fertilization	0	0	0	0

Source: Field survey 2018

5.4 Discussion

5.4.1 Economic effectiveness of adopting climate adaptation practices

All five practices studied are economically effective with positive NPVs (profitable), which makes them worthy for farmers to invest in and implement. However, their prioritization is not definite. In a more pragmatic context, it is important to acknowledge that farmers consider the efficient allocation of their resources, in consideration of a larger number of alternatives and constraints. Therefore, consideration of the time benefits take to be realized after adoption of a practice (the Payback Period) becomes highly valuable information. Any payback period longer than two years is problematic for a smallholder farmer, whose subsistence/livelihood can be affected by a seasonal/annual time scale. Practices that realize benefits after a year or two from implementation would likely be preferred by smallholder farmers as least affecting their sustenance. Mixed cropping and crop rotation only present payback period of two years in both municipalities, all other realizing benefits after two years. Mixed cropping and crop rotation had a high IRR and a low implementation cost. They require less implementation costs and decrease the amount of inputs used, hence potentially further increase profit. Also realizing a low risk of deficit, both practices are expected to produce economic returns within their life cycles. Mixed cropping and crop rotation therefore appear as choices most suited for direct adoption by horticultural smallholder farmers in Keta and Nsawam municipalities. Mixed cropping would be the strongest choice for Keta and crop rotation for Nsawam.

Implementation of intercropping can also be of interest to the smallholder farmers in relation to the IRR and risk distribution but has a higher payback period of 4 and 3 years for Keta and Nsawam respectively. This relates to the fact that intercropping was one of the practices with the highest implementation and maintenance costs. Relatively, irrigation and fertilization require large capital for investment (for equipment and machinery) and maintenance (for accessing limited fresh water for irrigation and organic fertilizer) in both municipalities. Both practices also require significant amount of time (between 3 and 7 years) to repay initial investment and impact positively famer's income. Furthermore, distribution of the profitability indicators presents significant risks in the two practices' ability to consistently maximize expected net benefits within its life cycle. These practices may therefore not be readily adopted and/or upscaled for use by smallholder producers due to its resource and cost requirements. Subsequently, this would affect enhancing implementation of climate adaption actions at the local level by smallholders. In horticultural production, climatic variability is a major factor impacting crop development process and affecting the quantity and quality of outputs produced (Malhotra, 2017; Deuter, 2008), leading to significant reduction in crop revenue. Conversely, horticultural producers are interested in practices such as intercropping, irrigation and fertilization which offer increased resilience to climate variability through improved crop water availability, increased soil health (moisture retention and temperature regulation) and increased nutrient availability during crop production (Williams et al., 2018b). Given the higher risk of failure, long payback period and limited value of those practices for smallholder horticultural farmers, their adoption needs external institutional and policy support. To ensure food security, sustaining horticultural production and reducing sensitivity to climate vulnerability, adapting is becoming more pressing. While a few practices are directly available and attractive to smallholder farmers, providing enabling conditions for those and for the uptake of less attractive options in the private sphere is paramount. Irrigation, fertilization and intercropping are such risky practices with long pay back period, yet greatly attractive on the public/social sphere (e.g. employment, environmental sustainability) and may be achieved through public sector necessary support and actions. Direct interventions and regulatory measures including reducing the interest rate on credit; improved access to production inputs and credit; subsidization of prices for implementation equipment and machinery; short-term livelihood diversification options; risk insurance; institutionalizing water pricing and secured land use tenure, should be provided to mobilize local capacity for implementing such practices.

5.4.2 External impacts of implementing climate adaptation practices

Creating a system that is more climate resilient through improved adaptation actions also facilitate substantial ancillary effects (Chambwera et al., 2014). Thus, adaptation actions yield benefits other than direct financial benefits. Number of studies have argued for the explicit consideration of externality values as a factor in decision-making and selection of climate adaption investment (Viguie and Hallegatte, 2012; Kubal et al., 2009). Beside the aggregate CBA calculations in this paper, computed/assessed values for respective externalities showed that all climate adaptation practices had an impact on the connected environment and society. There were improved ecosystem services through biodiversity conservation, notably from adoption of any of the five practices. Irrigation and fertilization improve water availability and proficient use of water through efficient water management and retentive nature of the soil fertility practice adopted. The inclusion of inorganic manure increases soil organic matter. Practices such as intercropping, crop rotation and mixed cropping controls soil erosion by preventing excess nutrients and chemicals from leaching away (Hassen et al., 2017; Tiemann et al., 2015). It also requires the use of additional labour, which positively translates into additional employment opportunities for individuals, especially in local vulnerable groups (i.e. the youth and the women). These effects consequently have a positive impact on the Social Net Present Value (SNPV) and Social Internal Rate of Return (SIRR) of all the practices.

Changing climate is expected to decrease both surface and groundwater availability and reduce soil moisture resulting in an increased evapotranspiration and decreased crop water availability (Ndhleve et al., 2017; Nangia and Oweis, 2016). Water management practices should be considered as an important adaptation strategy that smallholder farmers would have to adopt. Moreover, improved water availability had the highest benefit and impact as an externality mainly from irrigation and fertilization practices. These two practices however had the greatest risk of being unprofitable economically for farmers' uptake challenging increasing adoption and upscale. Nonetheless, they are worth investing into where enhancing development or adapting to drought conditions is the priority. Climate-related challenges such as droughts, floods and increasing temperature have been recognized in both studied municipalities (Williams et al., 2018a). Efforts on development and sectorial planning by the Government of Ghana (GoG) and other development agencies/planners emphasize mainstreaming vulnerability and adaptation knowledge (GoG, 2015; USAID, 2011). Since fertilization and irrigation practices can help to adapt to the climate-related challenges already identified, the inclusion of their externality benefits thus strengthens a case for public support. In addition to the other three economically feasible climate adaptation practices, targeted and dedicated institutional and policy support from the broader society would make irrigation and fertilization more attractive to external investment, which in turn would improve both on-farm and the public good (enhanced ecosystem services).

5.4.3 Consequences of the economics of adaptation practices for planning and actions

Acknowledging that access to relevant knowledge and information is key to the ability of farmers to adapt to climate variability (Challinor et al., 2007), the major factors considered when making investment decisions and possibly upscaling a practice, is profitability. In

Ghana for instance, benefits from a practice is an important factor in influencing households' adoption of best-bet agricultural practices (Akudugu et al., 2012). In policy planning and decision-making particularly, the major concerns are whether a practice would be providing private (individuals) and public (community) benefits (Sain et al., 2017). Even though this study only investigates cases limited to Ghana and horticulture, results give insights into decisions requiring multi-criteria considerations, including economic, social and environment. It informs on the costs and benefits associated with a practice (showing that not implementation of all the five practices is costly); the relevance of time; the definition of risk associated with adoption; the external and social benefits resulting from adoption and the role of various actors (private or public). For example, initial capital requirement for irrigation is enormous in both municipalities, mostly due to the long distances covered from farm to fresh water sources. However, due to increasing salinity in the coastal area such as Keta, maintaining irrigation after investment costs twice as much as Nsawam. In the case of fertilization, limited access to organic manure in Nsawam significantly increases the cost of maintaining fertilization. The refined assessment of payback periods, externality benefits and actors' involvement for the considered practices, allow for more accurate understanding of the potential of each practice and guide the selection of the best bet practices to adopt in consideration of private or public sphere. This subsequently provides critical information that would also improve planning of climate adaptation actions. In the local context of Keta and Nsawam municipalities and as a means of providing evidence-based information for decision-making and policy support, this study provides private and public economic justification and evidence that can be used as basis for upscaling and providing extra support for implementation of the practices identified. Alternatively, results from the CBA could inform potential development agencies/planners/donors who would like to invest in climate adaption or resilient horticultural production in the studied municipalities and Ghana, and beyond where a strong private versus public contrast shows.

Debates about the impact of local level CBAs on global and national policy decisions exist. This largely arises from uncertainties linked to downscaling climate change at local level, its impacts and consequences for global and national adaptation (Ziervogel et al., 2008). Costs and benefits analysis is argued to be location-specific and requires localized impacts and detailed geographical knowledge of climate vulnerability and impacts, which result from relatively high uncertain climate projections (Refsgaard et al., 2013). Despite such challenges, the advantage of numerical segregation resulting from the local use of CBA is offering efficient investment-planning information in the face of climate change (Chambwera et al., 2014; Reid et al., 2013). Given acknowledged limitations, such approach could form the basis for later replication towards up scaled information at national, regional or global scales. For instance, a World Bank's unique two-track approach of parallel comparison of national and global adaptation costs revealed that local costs for strengthening infrastructure against windstorms, precipitation, and flooding were about 10 to 20% higher compared to disaggregated global estimates (World Bank, 2010). This was due to the ability of country-level studies to consider at least some socially contingent impacts. Another study has also shown evidence of under-investment in adaptation when considering global estimates only of the need for adaptation funds (Das, 2009). This reflects the necessity for local level physical attributes to be explicitly accounted for when assessing adaptation funding. Such necessity has otherwise been highlighted as a pre-requisite to enhance climate adaptations and to reduce vulnerability (Antwi-Agyei et al., 2015). The challenge of climatic uncertainty could be managed through localized vulnerability assessments that can in turn closely inform and guide adaptation practices recommended from CBA estimations. From another perspective, most local level adaptation strategies currently follow 'no-regret' conditions (Niang et al., 2014a) (as in this study) so that economic and social benefits are minimal realization under a future least possible conducive situation. Open disclosure and full understanding of limitations of the methodological approach employed is critical, and is required to transparently guide the use of local level CBA which could play a role in informing national decision making (Scrieciu et al., 2013).

5.5 Conclusion

This study evaluated the value of explicitly using costs and benefits analysis in the adoption considerations of five climate adaptation practices in two horticultural growing municipalities in Ghana. Private and public profitability and risk were analyzed. The study suggests that any of the five-climate adaptation strategies yield positive benefits and are economically profitable. The adaptation practices if adopted would also favor positive environmental and social impacts. While mixed cropping and crop rotation were low-cost practices, intercropping, irrigation and mixed cropping require relatively high investment costs. Cost of implementing irrigation was the highest among the practices studied. In Nsawam municipality, cost of capital required to implement irrigation was twice as much as in Keta, while in Keta cost of maintaining irrigation was twice as much as in Nsawam. Concurrently, while mixed cropping and crop rotation required two years to pay back investment costs on average, the other three practices required more than three years and presented highest risks of failure if adopted. Promoting intercropping, irrigation and fertilization in Keta and Nsawam municipalities therefore needs to be cautiously considered and likely requires targeted and dedicated external institutional and policy stakeholders' support.

The study also clearly advanced risk dimension and non-monetary ancillary benefits associated with the implementation of the climate adaptation strategies. These advanced considerations need to be included in economic analyses of adaptation options in order to ensure robust economic evaluation. It also supports decision-making on selection of the adaptation options and guide efficient allocation of scarce resources. Market prices were assumed to be constant in this analysis, and future studies could benefit from considering the market's dynamics. Limited data and climate uncertainties remain major challenges for economic assessment at local level, and need to be acknowledged and accounted for to best inform selection of climate adaptation strategies. It is important to note that economic analysis provides information on appropriate investment decisions alone. To support practical decision-making on the efficacy of practices in relation to food security and climatic adaptation, vulnerability assessment needs to constantly precede economic assessment. Such a holistic approach will provide a strong focus and broaden information on prioritization in the selection of most appropriate climate adaptation alternatives depending on the nature of climatic stressors than the associated economic costs and benefits. This would further enhance planning and actions especially at the local level for subsequent higher uptake if required.

Chapter Synthesis

It had been shown in the previous chapters the essence why smallholders need to adapt to reduce their vulnerability as part of the assessment process. However, due to farmers' limited financial resources, this chapter has shown the economic effectiveness (through ex-ante in-depth empirical analysis of costs and benefits) of implementing the identified climate adaptation practices to guide informed planning and actions among stakeholders (Objective 3). This could consequently impact policy on climate adaptation. The chapter has revealed that, enhancing adoption of identified adaptation measures among resource-constrained smallholders requires prioritized selection of the measures. It was acknowledged that, even though economic analysis provides information on appropriate investment decisions alone, this chapter particularly advanced such discussions. It included the risk dimension and non-monetary ancillary benefits associated with the implementation of the climate adaptation strategies. Such efforts broaden decision support on practical selection of the adaptation options and guide efficient allocation of scarce resources publicly. Additionally, the chapter revealed that, promoting climate adaptation practices among smallholders require targeted and dedicated external institutional and policy support. This is related to the fact that the implementation of appropriate practices comes with a number of challenges such as inadequate financial resources, high implementation cost among others (Chapter 4). For instance, the implementation of some of the identified strategies requires significant financial investments but given the financial and developmental challenges confronting smallholders, external efforts will be needed to address such barrier to ensure successful implementation of adaptation measures. Various stakeholders need to carefully consider these in the design and implementation of climate change adaptation actions. How differential vulnerability shape what adaptation options are affordable and to whom is mentioned. For instance it is made clear that in Nsawam municipality, cost of capital required to implement a practice like irrigation was twice as much as in Keta mostly due to the long distances covered from farm to fresh water sources. In Keta, cost of maintaining irrigation was also twice as much as in Nsawam due to increasing salinity in the coastal area of Keta hence requiring more capital to access water to maintain irrigation after investment. In the case of fertilization, limited access to organic manure in Nsawam significantly increases the cost of maintaining fertilization. These dynamics show relational forms of vulnerability

The results contribute to scientific debate that adaptation actions yield other benefits even in event of a constant climate. Thus it corroborates findings of studies that have argued for consideration of externality values as a factor to consider in decision-making and selection of climate adaption investment (Viguie and Hallegatte, 2012; Kubal et al., 2009). Findings from this chapter further fostered the idea of using insights from the preceding chapters to posit for advancement of local vulnerability assessment framing specifically for smallholders to be presented in Chapter 6. At this stage, it is important to emphasize that, considering an approach that holistically select the most appropriate climate adaptation alternatives depending on the nature of climatic stressors with related economic cost and benefit is pertinent. To provide information on potential of climatic effects, climate adaptation and evaluation of the strategies in the light of limited financial resources of targeted stakeholders, a proposal for the integration of economic assessment as part of the vulnerability assessment process is suggested.

With regard to achievement of the overall thesis aim, this chapter's contribution provides empirical evidence to deepen understanding of climate adaptation assessment process. It forms part of the vulnerability and adaptation assessment process earlier described in chapter 1. To improve decision-making on adaptation, it shows how effective practices adopted by smallholder farmers are as they attempt to implement appropriate strategies. This is also necessary to inform adaptation and policy planning. A proposal for the integration of economic assessment as part of the vulnerability assessment process is given and explored in the next chapter.

CHAPTER 6

ADVANCING LOCAL VULNERABILITY ASSESSMENT FRAMING TO ENHANCE CLIMATE ADAPTATION PLANNING AND ACTIONS: INSIGHTS FROM SMALLHOLDER PRODUCTION SYSTEM IN GHANA

Building on the results of the preceding empirical chapters (Chapters 3-5), this chapter contributes to a better understanding of linking adaptation and vulnerability assessments. It explains the role of adaptation after a vulnerability assessment and the need to integrate it. The chapter highlights the usefulness of the assessment process for adequate adaptation planning and decision-making. It then examines how does the explicit consideration would facilitate adaptation planning and action. The chapter shows whether evaluation of effectiveness of adaptation strategies provide valuable information for adoption to enhance preparedness to potential climatic impacts.

Summary

Studies on vulnerability have widely contributed to building its understanding through development of methods and frameworks for its analysis (Refer to Chapter 2). Vulnerability science has however been criticized in recent years for its limited use in decision-making and consequent poor adoption of adaptation strategies. To ensure preparedness for the increasingly extreme and uncertain climate, there is need to strengthen vulnerability assessment practice and enhance its relevance for decision support to improve adaptation planning and actions. Certain improvement can result from a wider awareness of changing climate, and an explicit assessment of adaptation options under such changes. Integrating identification and evaluation of adaptation strategies as routine components would lead to such improvement. This study described the operationalization of localized vulnerability assessment, explicitly integrating adaptation alternatives, as demonstrated by three studies conducted with smallholder farmers in Ghana. Lessons from the studies are used to show the design of such integration, as well as demonstrate its value added in terms of vulnerability assessment information. The adaptable design is built upon utility of existing frameworks and methods, tailored to guide climate adaptation. Further exploration of a systems' adaptive capacity is however essential for ensuring continuous identification and evaluation of adapted alternatives and ensure successful adaptation in practice.

6.1 Introduction

Climate related events including floods, droughts and sea level rise are among visible events that emphasize human and ecosystems vulnerability to climate variability and change. According to the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC-AR5), there is inadequate preparedness among developing countries in responding to climatic impacts. Within the agriculture sector, impacts such as unstable food production or inadequate water supply are affecting production activities with consequences for human livelihoods and well being (IPCC, 2014a). Consequently, how vulnerability research is featured within policy discussions plays a decisive role in identifying relevant and useful vulnerability indicators and as such, influences adaptation actions. Scholars have argued that, to improve the preparedness and responses to climate adaptation, the science of vulnerability should evolve and further include climate change and variability, in order to better serve climate driven adaptation discussions (Williams et al., 2018a; Donatti et al., 2018; Mimura et al., 2014). Vulnerability, resilience and adaptation are three fundamental concepts arising in climate change adaptation discussions (Preston et al., 2011). In over two decades, vulnerability assessment has become a common tool in improving understanding of climate change effects (Archer et al., 2017). Yet it had limited success in guiding decision making regarding investments and policy development, including the vulnerable agricultural sector (Preston, 2012; Singh, Deshpande and Basu, 2017; Williams et al., 2018a).

As an evolving field, vulnerability science is characterized by substantial heterogeneity in frameworks, concepts and operationalization's within the research community (Williams et al., 2018a). Approaches stem from different topical and disciplinary foci such as schools of thought on physical exposure to climatic events and their outcomes (e.g. drought or flood hazards) as well as differential access to resources (e.g. social structures) (Sumner and Mallett, 2013). Plethora of research approaches positively demonstrates efforts to make vulnerability concept more meaningful and useful. Nonetheless, this diversity is also critiqued as it results in inconsistent definition and operationalization of the assessment practice (Hinkel, 2011). According to Preston et al. (2011), stakeholders involved in the assessment process, influence objectives, frameworks and methods, as well as better translate outcomes into action. This suggests that, besides the examination of the scientific assessment practice or the values assessed, enhancing climate adaptation planning and actions relies strongly on the participants involved in the vulnerability assessment process. Building more inclusive methods of understanding the nature and magnitude of vulnerability, require the inclusion of specific and suited objectives to better support adaptation decisions.

The process of undertaking assessments can contribute to better understanding the community and its environmental needs with respect to capacity-building and/or the identification of adaptation actions for vulnerability reduction (Adger et al., 2004). While the concept of adaptation is linked with the concept of vulnerability, both concepts have not been adequately related practically (Donatti et al., 2018). A large body of research and generations of first-hand, tried and tested climate adaptation responses exist which can be used to better inform policies on local, regional, national or global scales (Tambo and Abdoulaye, 2013; Tambo, 2016; Below et al., 2010; Deressa et al., 2009). Yet, studies with the primary objective being to support decision making often considers the context of adaptation partially (Preston et al., 2011). Those assessments usually improve awareness of sources of vulnerability and needs (including options) for adaptation. They are however critiqued for lack financial and human resources information, limited integration of and coordination with governance, absence of key adaptation leaders and advocates and monitoring of adaptation effectiveness (IPCC, 2014a), later hindering decision making (Hansen et al., 2003; IPCC, 2014). This limits adoption and action of adaptation interventions, which often target direct climate change impacts (Bennett et al., 2016).

This study therefore builds upon the debate of integrating climate into vulnerability assessment, through the explicit consideration over time of adaptation alternatives, which promote synergies for development and vulnerability reduction. It contributes to the better understanding of linking and using adaptation into vulnerability assessments and consequently enhancing usefulness of the assessment for adequate adaptation planning and decision-making. It explains the role adaptation assessment plays after a vulnerability assessment and how to integrate it. Thus, how does this explicit consideration facilitate adaptation planning and action process? Does evaluation of effectiveness of adaptation strategies provide valuable information for adoption to enhance preparedness to potential climatic impacts? Within the agricultural sector, applied conceptual vulnerability assessment framing include Sustainable Livelihoods, Social Protection, Hazard and Human Ecology, Political Economy, Entitlement or Resource Endowment, Poverty and Development Studies (Williams et al., 2018a). Other scholars have applied frameworks in empirical vulnerability assessment across South America (Sietz et al., 2012), Africa (Jamshidi et al., 2018; Antwi-Agyei et al., 2013) and other developing countries (Panthi et al., 2016; Gbetibouo and Ringler, 2009). This study refers specifically to local level assessments of smallholder agricultural systems, which has been inconsistently explored in past studies. We put forward a vision of vulnerability assessment re-design through the experimented steps of vulnerability assessment relying on the explicit integration of identification of adaptation alternatives and their potential to reduce vulnerability, and explore the role this integration plays into the vulnerability assessment.

6.2 Transitioning towards an integrated vulnerability assessment

6.2.1 Outcomes from vulnerability assessments

Even though identification of vulnerable people and places has been the primary outcome of most vulnerability assessments, there are some discontentment about this alone being a sufficient goal (Preston et al., 2011; Ford et al., 2018). Earlier vulnerability assessments also had narrow focus like isolating natural and biophysical elements of a system (Ribot, 1995). Quite recent advances have considered combined biophysical and socioeconomic effects (Malakar & Mishra, 2016- Dube). Some studies have also integrated climate variability and change assessments into the vulnerability assessment. For instance, Yohe et al. (2006) integrated climate change projections with other socioeconomic metrics to map interactions between biophysical and socio-political aspects of vulnerability. Berry et al. (2006) integrated output from a ecosystem and natural resources model with an adaptive capacity index. Preston and Jones (2008) combined biophysical, socioeconomic, and natural resources management indicators to map catchment vulnerability. Preston et al. (2009) integrated top-down regional-scale assessments of vulnerability with bottom-up local scale assessments. Another study integrated mapping of local scale biophysical conditions and behaviors with national markets and globalization to assess agricultural vulnerability (Acosta-Michlik and Victoria Espaldon, 2008). Despite such advances, Preston (2012) highlights that there is a cultural divide between research and policy communities, where the former sees its role as providing information to the latter yet the issue of assessments enhancing decision support is not adequately tackled . An integrated approach combining vulnerability and adaptation assessments within local context bridge some of that gap. It would improve the understanding of the adaptation as a factor of vulnerability, and support prioritization and information for decision making towards implementation. It is indeed important for decision-makers to understand not only risks and adaptation options but in which extent those adaptation options reduce vulnerability, and whether additional policy or public actions would provide adoption incentive with private and public benefits. It supports the hugely influential study by Barry Smit et al (2000), which encourages researchers to tease out a broader view of adaptation with conceptual considerations such as how adaptation occurs, where and by whom adaptation decisions are made and how adaptation choices are evaluated during the actual process of adaptation.

Adaptation planning is related to the context specific nature of adaptation, differences in resource availability, values, needs, and perceptions among and within a system (Mimura et al., 2014). Thus, for future vulnerability research to provide a more significant impact, transition to linking practice to decision-making is essential. In so doing, we advance a novel approach furthering the generalized understanding of current or future exposure, sensitivity, and/or adaptive capacity and priorities. Focus is given to the urgency of adaptation action and put into practice through vulnerability assessments in cases of limited resources. Usually, vulnerability assessments only provide limited insights regarding possible interventions as a result of an apparent division between assessment and deployment practices (Preston, 2012; Singh, Deshpande and Basu, 2017; Williams et al., 2018a). Considering in unison, vulnerability assessment, identification of adaptation measures and evaluation of such measures, would provide better understanding of the system, move towards prioritization and aid the selection of measures for implementation. Subsequently, this would promote collaborative discussions between academics and non-academics as well as offer insights into a learning process by jointly contributing to the assessment process (Preston, 2012).

6.2.2 Proposed reframing of vulnerability assessment

Vulnerability assessment is expected to provide relevant knowledge in a manner that enables decision-makers to become more empowered and capable of leading decision-making activities (Delaney et al., 2014). With recent discontents of vulnerability research earlier highlighted, it is clear that not all expected benefits particularly decision support could be obtained if assessment objectives are not linked more directly towards providing information tailored to facilitate the decision-making. Integrating adaptation into vulnerability assessment uncovers adaptation initiatives through their lifetime, for better understanding of more efficient implementation and development strategies and processes. A first step is a methodological development offering a reframing which embeds local level conditions (regarding a system of interest), advance its understanding and contribute to its specific adaptation process. We propose to build from existing frameworks and recommend complementary concepts, which capture and support the dynamics of vulnerability and adaptation.

A proposal for redesigning vulnerability assessment framework arises from the acknowledgment that assessment outcome and its process is valuable components in decision making on possible responses to vulnerability. One major concern for the proposed framework is the possibility of integrating the concepts of vulnerability and adaptation in a comprehensive framework. As explained by O'Brien et al. (2007), if the knowledge to integrate consists of disparate models of causality, then the integration process cannot be simply a matter of building a shared language or been wary of not only establishing better communication. Further to this, integration occurs when different disciplines use a common framework and interact to better understand the system in question. This implies that it is possible to develop a shared conceptualization of the problem. In this study, by an integrated assessment of vulnerability and adaptation, it means a conceptual and analytical approach that enables the representation and evaluation of adaptation options/alternatives after a vulnerability assessment, as a factor of reduction of vulnerability. At the fundamental level, this thesis posits that it is possible to integrate both vulnerability and adaptation using a comprehensive assessment process but it must be cautiously done to improve understanding of how to link their operationalization. Approaches to produce the required outcome need to be explicit on definitions adopted and its operationalization. It is therefore important to recognize the usefulness of the concepts within different contexts. Already, literature on adaptation is closely related to different framings of vulnerability identified in the international discourse (Preston, 2012; Tschakert 2013) which shows a potential framework that would promote adaptation and reduce risk. In this regard, the framework presented is to enhance discussions on how to link vulnerability and adaptation concepts. From this perspective, the interpretation of vulnerability given in the earlier section were manifestations of different discourses and framings of the climate change problem. Although studies would occasionally be explicit about the interpretation and framing adopted, for vulnerability studies, the role of framing emphasizes the way in which the process of specifying adaptation, specifically through the use of particular assessment methods, affects the choice of actions including policy interventions (Bisaro et al., 2010). Adoption of a widely recognized framework that is integrative in nature and concepts and links to the social and biophysical dimensions of environmental change developed by Turner et al. (2003) and Scoones (1998) is adopted for this study in developing decision-oriented approaches to adaptation.

The proposed framework (Figure 6.1) is drawn from Turner et al. (2003) vulnerability framework together with Scoones (1998) Sustainable Livelihood Framework to understand vulnerability and adaptation of smallholder farming to changing climate. Turner et al. (2003) developed a classic approach to express vulnerability known as Expanded Vulnerability that directly considers coupled human–environment systems by exploring the synergy between human and biophysical subsystems. The Sustainable Livelihood Framework (SLF) recognizes that more attention must be paid to the various factors and processes which either constrain or enhance poor people’s ability to make a living in an economically, ecologically, and socially sustainable manner (Scoones, 1998). According to Scoones (1998), livelihood is sustainable when it can cope with and recover from stresses and shocks, maintain or enhance it while not undermining the natural resource base. Sustainable livelihood approach allows to express linkages between people’s livelihood strategies, their asset status, and their way of using available resources, and is therefore a useful approach for understanding and promoting sustainable development at the local level (Krantz, 2001).

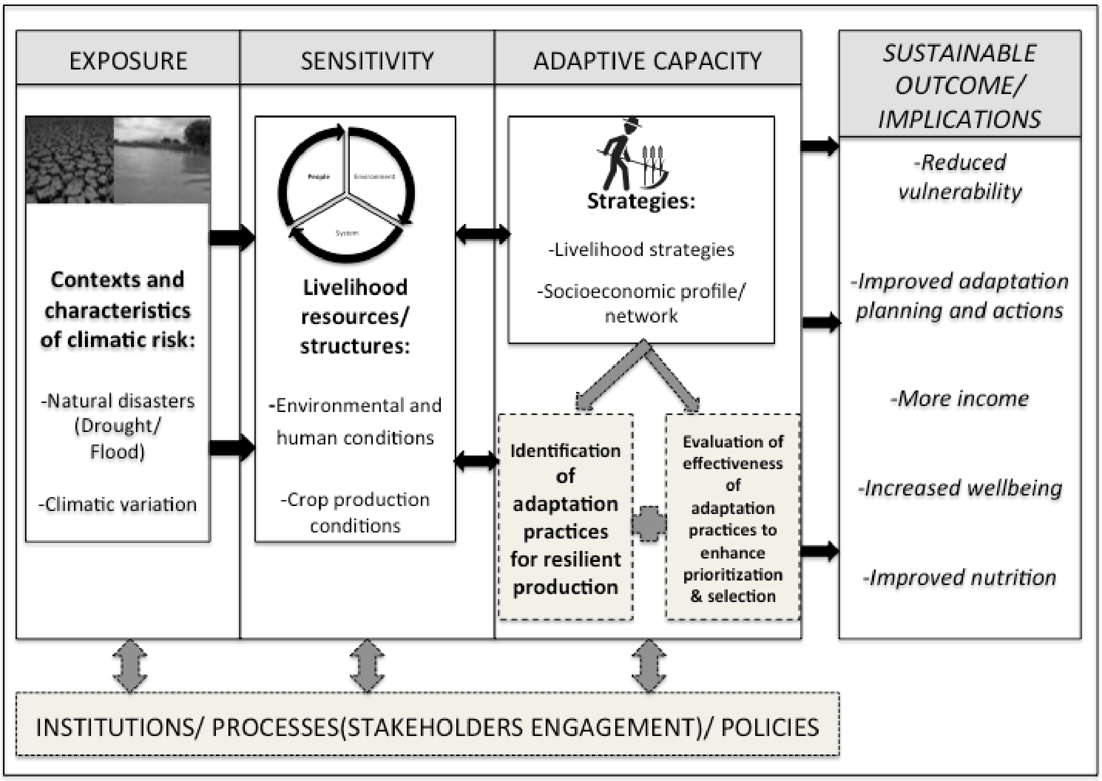


Figure 6.1: Proposed redesigning of framework for assessing vulnerability and adaptation. ***Building from Turner et al. (2003) and Scoones (1998)***

The proposed framework is divided into the three major constructs of the IPCC framework: exposure, sensitivity and adaptive capacity as defined in Chapter 1. Exposure considers the frequency, magnitude and duration to which the system is subject to climate-related hazards such as drought. Climate variability and extremes have long been important in many decision-making contexts. Climate-related risks are now evolving over time due to both climate change and development (IPCC, 2014a). Information from the past and present weather extremes, natural disasters, weather patterns and long-term climate trends help to understand local adaptive mechanisms (Preston, 2012). The sensitivity of a system is determined by the extent to which environmental and human characteristics are affected by exposures. Finally, the adaptive capacity of a system refers to the system's ability to cope and adapt to the impact. An elaboration of smallholders' adaptive capacity is made particularly on capacity to manage extremes or explore alternative livelihood opportunities. Adaptation planning and implementation are then dependent on how adaptation strategies are framed in particular contexts (Mimura et al., 2014).

Turner et al. (2003) suggested the inclusion of elements advancing sustainability as a process leveraging both quantitative and qualitative data, and methods capable to derive and analyze this data. Most useful to the contribution to knowledge on sustainable adaptation actions is to use novel methods to derive and analyze information. That is, 'developing structures for linking vulnerability analyses to decision making as well as focusing on the salience, credibility, and legitimacy of information produced. Proposal for integration of explicit identification and evaluation of effectiveness of adaptation strategies into the framework is suggested. Such routines would enhance stakeholders' decision in prioritization and selection of adaptation responses for locally relevant implementation. To avoid maladaptation, the identification and assessment (costs, benefits and/or efficacy) of each potential adaptation measure is highly encouraged. Sustainable livelihood analysis involves local community and letting their knowledge, perceptions and interests be heard, making possible to grasp the decision-making roles of each, even the poorest, in shaping their own livelihoods. This is vital for the design of support activities that build on the strengths of the community, particularly the poor households, through participatory engagement, and gain local relevance to account for. This makes participatory stakeholder engagement of local perspectives an integral part of the framework (Figure 6.1). The proposed framework connects information arising from diverse methodologies such as indicator, cluster and mapping approaches, as well as participatory tools. The framework emphasizes the interdependent relationship between vulnerability and efficient and effective adaptation development. Besides the three main constructs, the framework requires active participation with external institutions, policy making and governing bodies, which play an influencing role in managing the systems' resources and further management in the face of climatic risks. This would ensure a sustainable system overall with facilitation of reduced vulnerability, through enhanced adaptation, well-being and productivity.

6.3 The context: Integrated assessment of smallholder agricultural systems in practice

This study presents the practice of our integrated vulnerability assessment, through operationalization of critical elements of this framework, through three case studies conducted. The first study assessed current vulnerability particularly focused on understudied smallholder horticultural farmers in two municipalities of Ghana. The two localities represented a coastal area and an inland with differing climatic and growing conditions as well as vulnerabilities to allow for comparison of the outcomes and the adaptive responses. The adaptive responses in both study areas were subsequently identified in the second study. The third study evaluated the costs and benefits for adoption of the responses identified. Due to limited and inconsistent access to data, future vulnerability could not be assessed. The studies show how each of the approaches depends on each other to impact their respective outcomes holistically. Below are descriptions of the three studies conducted to present the operationalization of an integrated approach for improving adaptation of smallholder production systems to climate variability in Ghana. Generally, the case studies illustrate characteristics of vulnerability to multiple stressors that affect interventions to increase resilience, highlight some challenges for adaptation planning, contribution of external interventions to support adaptation actions and draws attention on how adaptation choices could be evaluated.

6.3.1 Local climate vulnerability assessment

The study on present day vulnerability applied the Livelihood Vulnerability Index (LVI) and IPCC-LVI developed by Hahn et al. (2009) to understand the nature of climate vulnerability among smallholder horticultural farming households. Indicators were developed through a survey at the household level for LVI major components including socio-demographic profiles, livelihood strategies, social networking, health, food, production, water, natural disasters, and climate variability (Williams et al., 2018b). Indicators were subjectively selected through participatory engagement with relevant stakeholders as well as theoretically engaging with relevant literature. Estimated indicators were aggregated in a composite index and differences among the study locations were compared. The steps followed in the assessment process were an initial reconnaissance visit for familiarization, pretesting of survey instruments for applicability and main household survey. Additionally, secondary data on daily precipitation, minimum and maximum temperatures comprised the climate variability component of the LVI. Exposure included climate variability and natural disaster occurrences. Sensitivity included state of health, food, production and water status. Adaptive capacity encompassed socio-demographic profiles, types of livelihood strategies and the strength of social network of households. Factors corresponding to the standardized LVI indicators and main components were applied to populate the IPCC-LVI (Williams et al., 2018b).

In operationalizing vulnerability as a function of exposure, sensitivity and adaptive capacity, the study provided insight that to the same stressors, the system being studied exhibited different degrees of vulnerability The coastal area (facing the challenge of being the most exposed and sensitive) compared to the inland (having low adaptive capacity) had a generally higher level of vulnerability. As a vulnerability assessment study, household's ability to adjust and manage climatic extremes damages and sorts out what alternative opportunities including developing alternative livelihoods, accessing government subsidies on production inputs and social network emerged. The study extended understanding on how social network impacts on communication. Social networking represented households actively associating with Farmer-Based Organizations and other social groups for improved access to crop and weather related information, promoting interactions among households and developing capacities in averting climatic risks. The study extended the goal of vulnerability not to only produce current vulnerability but also provide adequate understanding, information, and practical guidance into the nature of the vulnerability for implementation of both collective and context-specific measures appropriate for critical conditions and future research guidance. For instance, while the inland area in the case study could benefit from alternative water sources such as ponds, wells, and boreholes to supplement irrigation, the coastal area required drip irrigation to efficiently manage its available water resources. Project planning to effectively manage and supplement irrigation as solution to water problem is however required in both areas. Compared to other localized vulnerability studies, the study also improved robustness in indicator selection by utilizing both theoretical and relevant subjective approaches in finalizing the indicators applied in the study. This resulted in the modification and development of some indicators other than fully adopting the existing ones.

6.3.2 Identification of relevant adaptation responses through local engagement

The second study drew upon the data collected in the first case study (Williams et al., 2019). Climate adaptation measures were explored to reduce climate vulnerability. Relevant adaptation measures suited to the local circumstances, stressors and production systems were identified as part of the assessment process. The methodology followed in the data collection was mainly consistent with the one described in the first study. Perceptions about evidences of climate variability, impacts on farmers' livelihoods and households' adaptive capacities for in-depth information were further established. Literature review combined with stakeholder consultations formed the basis of identification of adaptation strategies used by smallholder farmers in responding to climate related events. These were then complemented with two focus group discussions at the community level from each municipality with about ten farmer representatives. This was followed by a structured questionnaire that interrogated the level of respondents' application of a range of adaptation strategies and challenges in implementing the strategies based on farmers' experiences over the past decade (Williams et al., 2019).

The study identified diverse adaptation strategies specific to the local circumstances of smallholder farmers focusing on horticultural producers and relevant to reducing vulnerabilities identified. This concurs with the notion that there is no-one-size-fit-all approach to climate adaptation. While measures identified would differ given different location, community, conditions, or a stand-alone study, building this identification efforts into the vulnerability assessment provides valuable information on drivers of vulnerability and the measures which can help reduce it. Asking farmers to select measures they consider most important to reduce their vulnerability and increase their resilience, builds households' local knowledge into the assessment, acknowledges community perceptions of our changing climate and leads to adaptation measures of relevance. This resulted in the selection of fertilization, supplementary irrigation, mixed cropping, crop rotation and intercropping as the most important adaptation practices adopted at the local level in both study municipalities out of twenty-four strategies otherwise identified. Uptake, as a consequence of the identification of these strategies was however unclear. While the study documented limiting factors to farmers' capacity to practice the identified adaptation strategies to its full potential, it discussed the potential of positively influencing decision-making and increase adaptation planning and actions. Important aspects considered are that, smallholders are financially constrained, implementation cost is considered high yet horticultural production is also capital-intensive. We assert that improving implementation potential of smallholders is dependent on their economic resources for financial investment. Assessing the effectiveness of identified practices to guide and enhance decision-making on likely options to invest in and implement given limited resources is emphasized. Its importance is to prioritize strategies in relation to the costs, benefits and effectiveness of the adaptation measures as adoption of adaptation measures comes with some costs and benefits. It is apparent to know to identify cost effective measures to enhance efficient allocation of farmers' limited resources.

6.3.3 Exploring effectiveness of climate adaptation responses

The third study conducted an economic analysis of the climate adaptation measures identified. This aimed at ensuring that adaptation planning and actions are improved through explicit financial aspect of implementation and returns overtime. The first five most important strategies adopted by smallholder farmers were considered for the economic analysis. Farmers who applied at least one of the selected practices were identified and interviewed using structured questionnaires in each of the study municipality. Information investigated included productivity from implementing a practice, prices of farm products and inputs as well as costs of implementing and maintaining a practice. This information was complemented with secondary information on the ancillary effects (externalities) and change in value of externality of adopting a practice on society and the environment from literature and key experts (Williams et al. in review). Different from a stand-alone approach that would have prioritized adaptation strategies not directly connected to a specified contextual vulnerability, this study advanced understanding of improving adaptation planning of smallholder production systems. Thus, after the vulnerability assessment and identification of resilient measures, it became essential to ensure such outcomes support decision-making for prioritization of adaptation options. Decision-making around the management of vulnerability involves determining why one plausible management strategy is preferable to an alternative and the manner in which it should be implemented (Clark and Clark, 2002). Inclusion of economic analysis advances ways of doing this through providing a multi-criteria approach useful to suggest economic effectiveness of each strategy, timeliness of paying back investment made, risk associated with each adoption, environmental and social benefits from a practice and highlights the need for other stakeholders' support in the implementation process considering farmers limited financial resources.

The study revealed that adoption of each of the different adaptation practices indeed comes with other co-benefits other than financial benefits, which can support decision-making on its adoption. These included improved water availability, reduced soil erosion, improved biodiversity and other social impacts. The risk of climate change to human systems including agriculture is increased by loss of biodiversity, which supports ecosystem services (Oppenheimer et al., 2014). Adapting to changing climate provides co-benefit of improving biodiversity with implications of reduced risk of climate change and better interactions between humans and the environment (land and water resources) for increased resilience. The study further provides understanding and recognition of the role of extra institutional and policy support. As much as adaptation practices evaluated in the study were economically feasible to implement, it was recognized that some of the practices presented some level of risk during its implementation that required further institutional and policy support to cautiously adopt it. The need for direct interventions and regulatory measures from stakeholders within external institutions and governments to improve local capacities for actions is emphasized.

6.4 Discussion

The above studies underscore the novel aspects of an integrated approach used in the vulnerability research with the inclusion and linkage of vulnerability assessment with adaptation and its evaluation. This strengthens the vulnerability practice and enhances its relevance for decision support to improve adaptation planning and actions. It further engages with some critiques of vulnerability research recently highlighted in literature by filling in some knowledge gaps understanding smallholders' vulnerability to climate variability and change. The integrated approach contributes to address critical questions such as how an assessment leads to identification of vulnerability reduction measures; how the identification of those measures improves the implementation of adaptation planning and action compared to stand-alone vulnerability assessments. We therefore discuss the main arguments under the questions drawing from the studies described above and discuss some potential challenges associated with this integrated approach.

6.4.1 Potential strengths and contributions of the proposed framework

The vulnerability assessment process revealed how important it is for a practice to provide information on whom and where vulnerable smallholders and communities studied are. In consequence, community relevant adaptation strategies can be identified. We argue that an assessment process should not only lead to identification of vulnerable people/places (traditionally the case) but should also provide relevant alternatives to reduce vulnerabilities. Compared to a conventional approach, the first and second studies offer insights into this. While the multidimensional realities of vulnerability in Ghana resulted in the adoption/modification/development of reflective indicators (mainly through improved stakeholder and theoretical engagement) to successfully identify present-day vulnerability, the framework also allowed identification of relevant adaptation alternatives. Although the smallholder farmers were exposed to similar hazards (e.g. floods, droughts, climate variability indices), various degrees of differential vulnerabilities could still be exhibited, in accordance to geographic location, household characteristics and local knowledge or perceptions of changing climate. For instance, farmers located in the coastal area, with limited access to assets and social networking and who perceive increasing temperature and declining rainfall quality and quantity, were the most vulnerable. Albeit, inland farmers exhibit low adaptive capacity resulting from high family dependencies, limited access to government subsidies, household's health issues, limited social networking and perceiving high climatic impacts on livelihoods. Such basic understanding of farmer's context guides exposure, sensitivity and adaptive capacity analysis towards more tangible and more relevant responses. Thus, linking adaptation responses to the assessment practice facilitate motivations for the specific adaptation responses suggested in reducing vulnerability.

Although over twenty adaptation responses were identified to reduce vulnerability of the smallholders, the extent of its effectiveness to facilitate actions on adoption was not known. While the strategies were suggestive for the socioeconomic and local context of the system studied, there was no information about how effective the measures were at facilitating planning and actions. This is partially addressed through the integration of cost effectiveness of a measure as part of the vulnerability assessment. It enables financially relevant prioritization of explored measures throughout their implementation and their lifecycle/time returns. This approach concurs with the AR5 of the IPCC, acknowledging that adaptation decision making is informed by evaluating feasibility of strategies, which may include cost effectiveness (such as cost benefit analyses) (Mimura et al., 2014). In our example, if any of the five strategies were to be adopted it would yield positive benefits and would be economically profitable. However, two out of the five strategies analyzed were low-cost practices while the other three required high investment costs and longer pay back periods and presented highest risks of failure. Where vulnerability and adaptation are integrated in an associated and interdependent relationship as we suggest, it allows constructing vulnerability in consideration of the applicability and success expectation of locally relevant adaptation measures. The resulting characterization of measures, with their affordability and efficiency in terms of vulnerability better informs decision-making for adaptation planning and actions.

Another key highlight of taking an integrated approach to vulnerability is to cross-inform institutional and stakeholders' best fitted roles and responsibilities towards adaptation planning and action. In our example, it was noted that, some of the adaptation strategies could be considered, granting dedicated external institutional and policy stakeholders' support were obtained. While the traditional vulnerability assessment process can reveal weaknesses in institutional supports that limit farmer's adaptive capacity, an integrated approach offers characteristic measures designing private (farmers) or public (governing body) entities to be better suited at affecting efficient adaptation. Typically, while a low-cost implementation, fast return, and low risk practice will be particularly attractive to farmers (private uptake), a higher-cost implementation, slow return, high risk practice could still present high adaptation value but must be explicitly supported by governing bodies. Additionally, the integrated approach including the economic analysis addresses concerns, such as recently expressed by Ford et al. (2018) where vulnerability research is critiqued for operating in disciplinary silos. As much as climatic (social) and non-climatic (biophysical) factors are considered in the studies overall, this approach contributes better understanding of vulnerability and adaptation from a multidisciplinary (social, biophysical and economic) base as well as qualitative and quantitative focus for the knowledge generation.

6.4.2 Potential weaknesses and limitations of the proposed framework of integrating vulnerability and adaptation approach

Despite the strengths of an improved framing in enhancing decision support from vulnerability reduction, operationalization comes with limitations to acknowledge. Our example studies were conducted using traditional social survey-based studies at the local level that required significant amount of time and funds. Meanwhile, accessing secondary data for similar analysis which could result in understanding future vulnerability is often challenging due to unavailable, inconsistent or incomplete data (Williams et al., 2018a). According to Preston (2012), if vulnerability assessment is to assist in making decisions regarding where investments should be made to reduce current and future vulnerability, assessments must attempt to reflect future states. This would enable development of future scenarios to represent plausible, yet uncertain future trajectories transfer in some extent into the vulnerability output. Although future climate change is of utmost importance, climate variability is already felt and immediate effect for smallholder farming communities justifies adaptation efforts (Lindoso et al., 2014). However, application of longitudinal research approach, which refers to a series of repeated measures over two or more points in time, focused on the same characteristics and observational unit in order to track development, processes, and interactions individually and collectively through time, can be practiced (Fawcett et al., 2017). It would capture the multi-dimensional aspects of change and allow for a better understanding of context, continuities, idiosyncrasies, key events, and the speed, quality, and types of change that take place (Fawcett et al., 2017).

Adopting an integrated approach requires collaboration across disciplines to provide a strong understanding of vulnerability and of the adaptation explored under livelihoods and risks respectively. Understanding the economic implication of adopting an adaptation practice, in relation to concurrent change in vulnerability would require yet another discipline. Informing decision-making, by use of a transdisciplinary approach, which incorporates different ways of informing vulnerability research with complementary knowledge (e.g., indigenous/local knowledge) and engaging in how this knowledge is used, is making a step further into embracing this multidisciplinary approach. Regardless of the ability of the proposed framing to be applicable on diverse methodological approaches, each existing method comes with some pros and cons that need to be addressed contextually on a case-by-case basis. Irrespective of the methodological approach applied, constraints related to subjectivity and sociopolitical hindrances to decision making will be present. While developing a transdisciplinary approach would be a way to overcome this challenge, ensuring linkages with levels of governance, as well as the collaboration and participation of a broad range of stakeholders in the assessment process will help by enabling a social learning process and facilitating uptake of assessment outputs. This however requires high level of coordination between political and administrative levels, so that institutions can play a driving role in maximizing cooperation, coordinating and promoting prioritized adaptation actions.

Finally, one could argue the necessity of integrating adaptation planning into vulnerability assessment, where considering the adaptation output only could suffice. It has been identified with high confidence that factors such as the rate of climate change, rate of economic development, demographic change, ecosystem alteration, and technological innovation representing biophysical, institutional, financial, social, and cultural factors, influence the planning and implementation of adaptation options and potentially could reduce their effectiveness (Klein et al., 2014). As a comprehensive approach to framing vulnerability and adaptation, the human and environmental conditions within a system are identified for any perceived deficiencies in accessing resources highlighted for recommendation in handling where/if applicable. Independently of significant implications of additional knowledge on human, social, environmental or financial capital requirement provided by the integrated approach, the framing necessarily needs to be definitive of its objectives in the light of their ability or shortcoming to addressing particular issues at hand.

6.5 Conclusions

This study is directed towards responding to the demand for research on vulnerability and adaptation to improve decision support. To do this, it offers an integrated approach linking adaptation analysis as a routine component of vulnerability assessment in our case particularly targeted at smallholder production systems, highly subject to climatic and non-climatic stresses. The study builds on the utility of existing framing and methods, towards a more robust process with a greater focus on understanding and guiding adaptation planning and actions within the context of a smallholder production system. We targeted two existing frameworks to explicitly articulate the assessment of smallholder vulnerability through the integration of adaptation alternatives, from identification to costs and benefits over their life cycle, including risks and ancillary benefits, into the process of vulnerability assessment. Such multi criteria approach is expected to better inform the selection of relevant adaptation options, through a better understanding of their consequences in terms of vulnerability. Given limited resources of many smallholder farmers, the reflection on their vulnerability looking at their social and environmental conditions, practical opportunities as well as considering the importance, effectiveness, co-benefits and sustainability of considered adaptation strategies ensures better informed prioritization and measurable evidence to draft policy in response to adaptation planning and actions in a changing climate.

While conducting vulnerability and adaptation research separately provides useful outcomes, adaptation remains a costly process, which could be reduced by refining prior integration. A framework that comprehensively combines adaptation within vulnerability assessment by understanding of context-specific vulnerabilities as a result of moving from current to adapted systems is essential. This perspective and the consequent increased capacity to prioritise adaptation options are expected to minimize maladaptation. We therefore argue that, prioritization of adaptation strategies should be based on the results of vulnerability assessments, to effectively promote adaptation planning and actions and ultimately to reduce vulnerabilities. The integrated framework proposed largely includes stakeholders at various stages of the assessment, partly making the process participatory. Making value for decision a major outcome of the vulnerability assessment is likely to result in a broader impact (sustainable production outcomes), a greater implication from vulnerability research (identification of vulnerable people and improved conceptualization of vulnerability) as well as facilitate appropriate and informed planning and actions on adaptation (through adopting effective options). It also reveals the interconnectedness between vulnerability, impacts and adaptation scholarship. The framework proposed provides guidance for the conceptualization of a system-specific study (here smallholder farmers), which can be widely applicable to various other contexts. We however suggest that identification of adaptation options and assessing their effectiveness should arise in part at least from the exploration of opportunities, which expand a system's adaptive capacity.

Chapter Synthesis

This chapter explored the need to strengthen vulnerability practice and enhance its relevance for decision support to improve adaptation planning and actions as widely called for in literature. The chapter utilizes lessons learnt from the preceding chapters of this thesis on vulnerability and adaption of smallholders to establish a framework for vulnerability and adaptation assessment conceptually (Objective 4). Methodologically and conceptually, vulnerability and adaption remain insufficiently integrated at the assessment level. However methodological linkage between the two concepts for more successful operational engagement is limited but needed to build better adaptive capacity to hazards under changing climate. The chapter explicitly extends the debate on enhancing the methodological and operational compatibility between the two concepts and informing the decision-making process on adaptation (as shown in the literature review in Chapter 2). People's ability to reduce risks is typically determined by dynamic livelihood decisions that depend on household resources and their allocation to generate benefits and pursue a meaningful life. Operationalisation of adaptation options applied to particular systems like smallholder production system where vulnerability assessment is not combined with adaptation evaluation limits the exploration of the system's vulnerability. In this thesis, this limit has been exemplified in the integration of the Livelihood Vulnerability Index and adaptation processes at the local level in Ghana. It is important to note that, smallholders particularly in Africa operate their farms as entrepreneurs, thereby, raising their own capital and making decisions as well as taking both risks and profits. This explains that, actions to cope with, respond to or prepare for specific hazards (e.g. drought, floods) with dynamic decision-making processes and adaptation pathways that involve deliberations over decisions, critical thresholds and inevitable trade-offs are important especially for this livelihood group. The increasing awareness of potential climatic impacts particularly on smallholders' production system then leads to the consequent need to advance adaptation actions considering them are resource-constrained and vulnerable (reflecting on their social and environmental conditions and capabilities). This chapter explains the proposal for redesigning vulnerability assessment framework that arises from acknowledging that assessment outcome and its process are valuable components in decision making on possible responses to vulnerability.

Within the framework, evaluation of adaptation strategies was suggested to be a routine component of an assessment practice. Thus, conducting vulnerability and adaptation research separately provides useful outcomes. However, since adaptation is a costly process, the chapter proposes a framing that comprehensively combines the two advances particularly for smallholder producers who are the main facilitators of responses taken but are resource constrained. Outcomes of this process are relevant also for other development organizations and policy makers. It suggests that selection of adaptation options should basically be based on the interdependent relationship with identified vulnerability. A framework shown here emerged from lessons drawn from Turner et al. (2003) and Scoones (1998). It emphasizes the importance of understanding and applying concepts such as subjectivity, socioeconomic process and knowledge on adaptation to the analysis of vulnerability and adaptation

The framework is promoted to inform decision-making through the IPCC concept of exposure, sensitivity and adaptive capacity when assessing vulnerability in the context of smallholder producers. The process underscores that the critical factors of the framework are related to the exposure of a system to a hazard or stressor, the susceptibility of the system exposed, and its adaptive capacity. The framework proposed in this chapter recognizes the need to enhance understanding of context-specific (smallholders) vulnerabilities in relation to careful decision-making in selection of responses through prioritization. Overall, the framework adds knowledge to discussions on how to frame and link vulnerability and adaptation concepts. It emphasises the importance of understanding the context in which vulnerability is experienced. This reflects 'contextual vulnerability' and draws attention to the factors that make some people or groups disproportionately vulnerable to shocks and stressors. It further improves understanding on how multiple, interacting stressors be it social, natural, financial, institutional or human factors (expressed in the components of the LVI adopted for this study) influence this context. Thus the framework can be used to assess vulnerability interventions in the context of both climatic and non-climatic stressors, and to identify efforts that influence the effectiveness of different types of interventions aimed at reducing vulnerability. Considering the importance, effectiveness, co-benefits as well as sustainability of relevant adaptation strategies will ensure prioritization of cost-effective options among smallholders in Ghana and more widely. Ultimately, this will inform policy in response to adaptation planning and actions in a changing climate. The chapter further acknowledges that operationalization of the framework may be constrained by factors such as significant required amount of time and funds, need for multidisciplinary collaboration and ability of the framework to provide the required scientific enquiry. More future research is needed in this area to test the wider applicability of the proposed framework

CHAPTER 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This is the concluding chapter of the thesis. It summarizes the key findings of the study and explores the implications of how vulnerability assessment of smallholder agricultural systems could be enhanced to enable effective climate adaptation planning and actions at the local level in Ghana and beyond. It then highlights the limitation of the study and provides recommendations for policy, further research and private actions.

7.1 Introduction

The aim of this thesis was to explore how vulnerability assessment of smallholder agricultural systems could be enhanced to enable effective climate adaptation planning and actions at the local level using smallholder horticultural production systems in Ghana as a relevant demonstration case. It adapted an interdisciplinary mixed method approach to assess climate vulnerability and adaptation and economically evaluate the effectiveness of proposed adaptation strategies. Both primary and secondary data sources that combine field surveys, in-depth interviews, focus group discussions and field observations were employed in this research. These provided both qualitative and quantitative inputs for analysis. The analysis involved theoretical insights from livelihood analysis (Sustainable Livelihood Framework) with an appraisal method (Cost Benefit Analysis) that best provides analysis on gains and losses arising from investment in adaptation options as analytical frameworks. The analysis provided understanding of the concept of climate vulnerability for improvement of adaptation in smallholder production systems. The approach to vulnerability assessment adopted extended linkage to climate adaptation to suggest a decision-relevant framework for vulnerability and adaptation studies. Application of this approach was through results from a field survey in Ghana. The research provides contribution to knowledge in the advancement of integrated framework for assessment of vulnerability to support local relevant adaptation decision-making. This thesis used evidence from smallholder horticultural production systems in two municipalities (Keta and Nsawam) of Ghana as case studies to: a) assess livelihood vulnerability of smallholder producers to climate variability in Ghana; b) determine smallholder producers' adaptive responses that reduce the vulnerability of crop production in Ghana; c) evaluate the economic effectiveness of adopting the most important adaptation practices identified for decision support on climate adaptation and d) establish an improved framework for assessing climate vulnerability and adaptation for improvement of smallholders' planning and actions on climate adaptation. Vulnerability and adaptation assessment practice approach commenced with a systematic review followed by empirical studies that addressed the objectives.

7.2 Summary of findings

- **Livelihood vulnerability of smallholder producers to climate variability**

Indicators for components of Livelihood Vulnerability Index (LVI) and IPCC-LVI including socio-demographic profiles, livelihood strategies, social networking, health, food, production, water, natural disasters, and climate variability were sought through field survey to estimate the livelihood vulnerability of smallholders. These components reflect the role of both climatic and non-climatic stressors and their relative importance in assessing smallholders' vulnerability. Within the context of this study, both the climatic and non-climatic factors considered indicated high exposure in the coastal area (Keta) that was attributable to occurrence of natural disaster and climate variability with limited structures for prior warning. Weak social networking and unstable livelihoods resulted in lower adaptive capacity mainly for the inland area (Nsawam). The results reveal smallholder farmers at different locations show varied vulnerabilities in relation to exposure and sensitivity to climate variability and low adaptive capacity. High vulnerability scores resulted from indicators such as inadequate family labor, low crop diversity, insufficient planting material and limited water sources. Relativity of indices to systems studied that is used in current indicator based approach is highlighted. On the basis of this, an enhanced and complemented way to construct a reasonable indicator system was done to build upon the LVI approach that had been developed by Hahn et al. (2009) for assessing vulnerability. The revision was through developing new and modifying existing indicators as credible local contextual factors. This reflects multidimensional realities of vulnerability and the range of indicators revised in this study could be used in other settings and geographic conditions.

The significance of engagement of greater diversity of stakeholders as participants throughout the assessment process to make it a social learning process is underscored. The study approach addresses the critique of indicator-based approaches in other studies, which lacks subjectivity in the selection of indicators (mainly done by literature). Literature review together with stakeholder engagements for validation that was employed for the framing and designing of indicators in this thesis improve robustness of indicator selection. Such engagement maintained throughout an assessment process serves as a learning process for the stakeholders. Due to the dearth of studies identified for thematic and sub-sector specific assessment efforts (especially for subsectors such as livestock and horticulture) in literature, this study on context specific assessments for horticultural producers supports this need for understanding sector-specific vulnerability studies. Subsequently, the findings thereof showed broadened understanding, information, and practical guidance to support identification of adaptive responses that would reduce exposure, sensitivity and/or increase adaptive capacity of farmers. A profound influence of the outcomes of knowing the vulnerable people and places motivates and helps in the identification of the most suitable adaptation strategies for smallholder farmers.

- **Identification of adaptation practices to reduce climate vulnerability**

Local specific climate adaptation practices farmers use to reduce the negative impacts of changing climate is highlighted in this study (Chapter 4). Increasing temperature and decreasing rainfall trends had been observed in the past two decades in the two municipalities studied. The thesis revealed that farmers had perceived and experienced similar perspectives about the climatic trends. These affect farmers livelihood and results in effects such as poor quality produce, yield losses, post harvest losses and declined net revenue on their livelihoods. The findings from the study reveal that climatic trends, local knowledge and perspectives guide the adoption of autonomous adaptation strategies to reduce vulnerability and improve resilience to production activities in a local context. More specifically, the socioeconomic context, geographic and climatic conditions prevailing in a locality (e.g. soil conditions, soil water availability vis-à-vis total amount of rainfall received, coastal or inland area, social capital and financial resources) is considered important in the identification of adaptation practices. Attempts in this study showed this knowledge was applicable in the identification of adaptive responses. Thus the importance of the five top most strategies across the study municipalities were ranked differently for each location. For instance, while fertilization was the first highest ranked and important adaptation practice in both areas, the remaining four practices were ranked differently for each municipality.

The adaptation practices identified could be classified as a range of farmer driven soil, water and crop conservation measures and farm management practices. For horticultural production, these include fertilization, supplementary irrigation, mixed cropping, crop rotation and intercropping. Other practices such as decreasing farm size, use of improved varieties, adjustment in planting calendar, provision of windbreaks, increasing farm size, mulching shifting cultivation and seasonal migration are moderately implemented by households. Findings illustrate that farmers facilitate their own adaptive responses, which results in challenges in adopting the practices. It is apparent that enhancing households' climate adaptive capacity is dependent on factors related to finances, market, technological and other government and institutional support to complement farmers' efforts. If resource constrained smallholder farmers' resilience and productivity has to improve, conditions for the identified factors needs to be improved. From this, I assert that improving the implementation potential of smallholders is dependent on their economic resources for financial investment. This argument leads to the point that assessing the economic effectiveness of identified adaptation strategies is imperative for enhancing adaptation planning and actions for resource constrained stakeholders. Due to the limited resourcefulness of farmers, it is pivotal to further explore the economic effectiveness of identified adaptation practices as decision support on implementation of more affordable and cost effective strategies.

- **Evaluation of effectiveness of adopting climate adaptation practices**

This study demonstrates that evaluating effectiveness of identified climate adaptation practices could guide informed planning and actions among stakeholders and consequently impact policy on climate adaptation. It is depicted that while implementation of adaptation practices could yield positive financial benefits (privately) and also favor positive environmental and social impacts (publicly), conducting thorough in-depth empirical evaluation of effectiveness of a practice would reveal not only low-cost practices but also bring to the fore other factors that provides better and detailed information for decision support. It further highlights the role of governance and institutional support in climate adaptation. For instance, as economic evaluation of the five most important climate adaptation strategies identified in this study revealed positive private and social benefits making it highly feasible for adoption, further in-depth analysis (risk dimension and non-monetary ancillary benefits associated with the implementation of an adaptation strategy) showed that only two of the five practices would be suitable for private adoption. The remaining three practices required relatively higher investment costs and more than three years pay back, along with higher risks of failure posed if adopted. The implication of this is that, promotion of some practices requires targeted and dedicated external institutional and policy support. It underscores the critical role the public (governance and institutions) should play to enhance climate adaption actions.

The findings further reveal auxiliary benefits (environmental and social) from the adoption of adaptation practices, which is expected to provide meaningful information and motivation for public decision to support climate adaptation actions. In attempt to improve adaptation planning, actions and policy impact of resource constrained stakeholders, the importance is understanding how economic analysis provides information on appropriate investment decisions alone. However, detailed evaluation of the effectiveness of a practice as conducted in this study broadens information used for decision support in guiding efficient allocation of the scarce resources and also brings in public support. It is important to note at this point that the cost flow for adoption of a practice is location specific. For instance, in considering high cost of implementing irrigation, the cost of implementation was twice as much, in one municipality compared to the other while the cost of maintenance was also twice as much in one location compared to the other. This was due to unavailability and/or proximity of area to implementation equipment, geographic condition of location resulting in high demand for water in maintaining for instance irrigation and the type of irrigation being practiced in a locality. This reflects the socio demographic context, geographic and climatic conditions prevailing in a locality, which further explains differences in ranking of the practices observed in Chapter 4. The view so far on a holistic selection of the most appropriate climate adaptation alternatives strongly depends on the nature of vulnerability stressors, identification of relevant adaptive responses and evaluation of effectiveness of identified options based on appropriate stakeholder engagement process to facilitate planning and actions. Particularly in the light of limited financial resources of targeted stakeholders, proposal for a vulnerability assessment framework that integrates economic assessment as part of the assessment practice is extended. This proposal is anchored in preceding chapter developments, but posit for the advancement of local vulnerability assessment framing, specifically for smallholders communities.

- **Proposal for an improved framework for climate vulnerability and adaptation of smallholders**

As a starting point to respond to vulnerability and adaptation research, this study was built on the utility of existing framing and methods but making it a more robust process. The argument for an improved framework is that considering scarce resources available for smallholders and/or other stakeholders, reflection on their vulnerability looking at their social and environmental conditions and capabilities as well as considering the importance, effectiveness, co-benefits and sustainability of relevant adaptation strategies to reduce vulnerabilities will ensure prioritization of cost-effective options. Subsequently this would inform policy in response to adaptation planning and actions in a changing climate. Even though conducting vulnerability and adaptation research separately provides useful outcomes, because adaptation is a costly process, a framework that comprehensively combines the two advances enhances understanding of context-specific vulnerabilities. This is in relation to careful decision-making in selection of responses through prioritization. A novel aspect of the proposed framework highlights the subjective inclusion of relevant stakeholders at various stages of the assessment making it partly a participatory process to enable a social learning process and ownership of assessment outcomes. Identification and evaluation of adaptation strategies are suggested to be a routine component of a vulnerability assessment practice and conducted synergistically instead of in parallel. Linking vulnerability assessment outputs with adaptation measures highlights the relevance of assessments to end-users. Selection of adaptation options should basically be based on the interdependent relationship with identified vulnerability.

It is acknowledged that diverse conceptualization and methods in conducting assessments with no consensus in defining and operationalizing the vulnerability assessment process makes it a complex scholarship. Applicability of proposed framework for smallholder production systems however avoids ambiguity in understanding the system assessed and helps contextual selection of methods relevant for the assessment process. This allows flexibility in application of existing methods of assessing vulnerability and effectiveness of adaptation strategies. The operationalization of the framework may come with some limitations such as significant amount of time and funds required if the traditional social survey-based approach is used, need for multidisciplinary collaboration and ability of the framework to provide the required scientific enquiry. Accessing secondary data for similar analysis is suggested as a complement to primary data collection though this could also be challenging, as required data is usually unavailable, inconsistent or incomplete. Identification of the human and environmental conditions within a system would address any perceived deficiencies in accessing resources to ensure the objective of related scientific enquiry is achieved. For successful adaptation of the proposed framework in future applications it is pivotal to explore opportunities to expand a system's adaptive capacity.

7.3 Implications of findings

This study assessed vulnerability of smallholder horticultural producers at the local level and in the process, identified and assessed adaptive responses to reduce farmers' vulnerability. The research provides improved understanding into area-sector specific (horticulture in Ghana) adaption to changing climate. The focus of smallholder climate vulnerability research is increasingly moving towards human-environment coupling system hence this thesis attempted to also move towards similar comprehensive approach. It highlighted interaction between multiple stressors including interactions and participation of smallholder farmers in Farmer Based Organizations (FBOs) and other community social groups, access to finance, dissemination and accessibility to reliable climate information, increased consecutive dry days, flood and drought events among others that impact pathways for the adaptive capacities of the study communities. The study also emphasized the role of governments and institutions in climate adaptation implementation process where resource constrained smallholders require their support. This is through direct intervention and regulatory measures such as reducing the interest rate on credit; improving access to production inputs and credit; subsidization of prices for adaptation implementation equipment and machinery to facilitate adaptation initiatives. Such inputs could promote climate adaptation and be mainstreamed into agricultural development strategies and plans for development of horticultural industry in Ghana.

This study showed that livelihood analysis is applicable in suggesting pathways to reduce the vulnerability of farming communities once proxy indicators for assessments are comprehensively selected. This contributes to improved understanding and theoretical knowledge on livelihood vulnerability of smallholder production systems that could be applicable to other local areas across Africa. With the dearth of studies on evaluation of effectiveness of adaptation responses as critical aspect of vulnerability assessment literature, economically, the study provides further insights into accessible and affordable practices to private stakeholders (i.e. farmers) and longer-term evidence for public decision support (e.g. development organisations, government and policymakers). It allows to better target investments in planning and acting on adaptation for development initiatives in responding to a changing climate. This could also facilitate adoption, which is critical for increasing crop productivity and subsequently enhance food security in the face of climate change. Further production levels of nutrient-rich crops required for healthy human nutrition would be increased to account for increased consumer demands globally.

Furthermore, drawing upon the results of the thesis, improved conceptual framing within the context of livelihood vulnerability of smallholders could in addition to elements of vulnerability (exposure, sensitivity and adaptive capacity) also draw upon measures of adaptive responses, decision support tools for adaptation planning (like cost and benefit analysis) and existing institutional processes for potential improvement in adaptation actions. The framework highlights the relationship between vulnerability and climatic and other socioeconomic indicators such as family dependency ratio, education, social capital and access to infrastructure as identified within the context of study (Appendix VIa). The framework also emphasizes on the engagement with concepts such as sociopolitical and institutional processes, subjectivity, poverty reduction, socio-natural stressors and knowledge during its application to show the relational aspects of vulnerability and adaptation. This contributes to complement current studies and debates in climate vulnerability and adaptation but also has wider significance in enabling resource constrained and vulnerable smallholders enhance their current conditions into more desirable and resilient futures.

7.4 Limitations of the study

Conclusions from the thesis are broadly based within the context of smallholder horticultural production systems within Africa/Ghana. However, in terms of the study approach and assumptions made, there were some limitations. Firstly, time and limited resources affected the scope and focus of this thesis in a number of ways. These included limiting the number of practices economically evaluated to five even though over twenty practices were identified. While the five top most important strategies identified by farmers were evaluated, a detailed picture of the adaptation potential of more practices would have been known given further time and resources. Traditional survey methods adopted were costly and time consuming. Two municipalities were also studied because of constraints with inadequate secondary data availability to support the primary data. It is however important to note that in view of the study aim, the two municipalities were technically adequate representation to have societal, theoretical and political significance and impact. Data constraints (both climatic and socioeconomic at the local level) also hindered projections and assessment of future vulnerability limiting the thesis to current vulnerability analysis. Even though current vulnerability assessed gave detailed information critical for future research guidance, future vulnerability assessment could have given temporal scales of vulnerability with implications for understanding the dynamism of vulnerability over time. It is also acknowledged that, direct quotes from respondents were not given in the empirical chapters. It is however important to stress that, responses from the qualitative approaches employed such as during the workshops, Focus Group Discussions and key informant interviews provided key in-depth knowledge and understanding that improved the research design and enhanced discussions to enrich implications of the empirical chapters given. Appendix VIII gives some few direct perspectives provided by farmers as reference Finally, as much as the thesis deems it fit and relevant, the application of IPCC's 4th Assessment Report definition of the term 'vulnerability' due to the context of study, period study was conceptualised, means and also in facilitating appropriate responses for the context of this study, it is acknowledged that the scholarship keeps evolving with the release of the 5th Assessment Report. The 5th AR brings in a different perspective to the meaning of the term (refer to details in Chapter 1) but is considered beyond the scope and relevance of this present study. Once it becomes more popular in coming years, future studies under vulnerability, adaptation and environmental change are encouraged to broadly engage with it.

7.5 Concluding remarks

Smallholder horticultural production systems in Ghana are vulnerable to climate variability and change. Livelihood Vulnerability Index (LVI) was modified to assess farmers' livelihood vulnerability. Adaptation options identified along the process were economically analyzed to facilitate adaptation planning and actions. Findings and discussions raised in this thesis contribute to improving the livelihood and food production systems' security and adaptive capacity of farmers while informing policy development. General recommendations appropriate to enhance adaptation based on the study findings include:

At the private level

- Efforts should target enhancing farmers capacity to adopt practices that are cost effective, contribute to sustainable production while also responding to changing climate.
- Education and shared knowledge and understanding on interactions and participation of smallholder farmers in Farmer Based Organisations (FBOs) and other community social groups (social capital) should be encouraged for handling emergency situations and adapting to climate variability among farmers. This would further enhance farmer capacity to stimulate adoption of sustainable and productive practices.

At governance and institutional level (including governments, policy-based and development agencies):

- It has been established that governance and institutional support are paramount for adaptation to be successful. Policy and development agencies should be well engaged to focus on promoting and encouraging autonomous adaptation efforts being practiced by smallholder producers across the study locations, Ghana and Africa at large.
- Financial support, incentives and subsidies should be given to farmers for the adoption of measures that have high adoption costs at the private level but are relevant to reduce climate vulnerability with social and environmental benefits publicly (such as improve ecosystem, employment, soil fertility) for achieving sustainable productivity growth. Thus farmers should be supported with practices that are beneficial both privately and publicly. For example irrigation, which increases water availability for improved crop production also has great potential at socially creating employment opportunities and environmentally contributing to on-farm biodiversity so needs to be promoted.
- Various structures are needed to create good policy environment for adaptation needs of smallholders to be promoted, formulated and/or incorporated into existing and prospective development programmes across scale to improve responses to climate variability and reduce vulnerability. Needs to be considered include improved credit facilities; access to and dissemination of reliable climatic and agronomic information; capacity building opportunities for farmers to plan and organize farm operations effectively; agricultural insurance scheme for farmers; improved access to input and output markets; equipping vulnerable farmers with livelihood diversification support; institutional strengthening and other infrastructural developments that would further

inform and facilitate planning and actions on the uptake of adaptive strategies to minimize adverse climatic impacts.

At the research/knowledge level

Notwithstanding the contribution of this research to climate vulnerability and adaptation theory and practice, further investigations would improve such study and extend its methodological approaches and applicability. Future research could:

- Test and see further elaborations on ways to operationalise the proposed framework. Wider applicability of the proposed framework within other subsectors and within other areas in Ghana or other locations within Africa particularly where limited studies were identified in the literature review (Eastern and Central African countries). The framework could guide further contextual and relational questioning and methods relevant to contribute extra knowledge and policy impact to vulnerability and adaptation discourse.
- Explore opportunities to expand a system's adaptive capacity after the identification of adaptation options and assessing their effectiveness to ensure successful adaptation. This could be achieved through studying other institutional, financial, demographic change and socioeconomic proxy indicators identified to potentially influence and reduce effectiveness of adaptation options.
- Investigate the explicit role of policy and other institutions in climate adaptation related to smallholders. As has been shown in this thesis, autonomous efforts by farmers are unlikely to be sufficient to create a sustainable, productive and resilient production system if support and the enabling conditions are not provided hence further exploring how policy makers and institutions could promote this is paramount to guide interventions more efficiently.
- Explore longitudinal research approaches or search data sources that could account for temporal changes that occur to a population or system overtime as such changes may play an important role in shaping households' decision-making process. More future research is needed in this area to investigate further the dynamism and multidimensionality of vulnerability and adaptation process.

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APPENDICES

Appendix I: Research questionnaire (Vulnerability and adaptation assessment)

A. Respondents Profile

1. Name of respondent: ………………………… Contact phone No: …………………………
2. Age of respondent: ....Years
3. Sex of respondent: [ ] 1=Female 2=Male
4. Marital status of respondent: [ ] 1 = Single 2 = Married 3 = Divorced/Separated 4 = Widowed
5. Highest level of formal educational of respondent: [ ] 1 = None 2 = Basic (Primary/JHS/Middle) 3 = Secondary (Secondary/vocational) 4 = Tertiary (Training college/Polytechnic/University)
6. Years of farming experience of respondent: ……………… Years
7. Origin of respondent [ ]: 1 = Native 2 = Settler/Migrant 3 = Other (specify)…………………………………….
8. If non-native, when and why did you move into this community? a: …………Years; b. Why:…………………………………...
9. What is the total number of your dependents: …………………………….
10. Indicate details of your household constitution:

Dependent	Relationship to dependent	Sex	Age (years)	Level of education	Is he/she having a chronic illness?
a.					
b.					
c.					
d.					
e.					
f.					
g					

B. Livelihood strategies:

11. What are the major types of horticultural crops you cultivate? Indicate below:

	Vegetables/ Fruit	**Area cultivated (Acres)**	**% Sold**	**% Consumed**	**% Contribution to household income**
a.					
b.					
c.					
d.					
e.					

12. What is the major crop you cultivate? …………………………………
13. What other livelihood activities are you engaged in? (Contribution to household income)

Livelihood activity	% Contribution to household income
a.	
b.	

c.	
d.	

Farming (other food crops), petty trading, salaried (formal) work, artisan, etc

14. Does any member of your household work outside this community? [ ] 1 = Yes 2 = No

15. Are members of your household engaged in any off – farm income generating activity? [ ]
1 = Yes 2 = No

16. If yes, provide the following details:

Activity	Number of males	Number of females
a.		
b.		
c.		
d.		
e.		
f.		

C. Assessment of assets

17. Which of these assets do your household own? [ ]/ [ ]/ [ ]/ [ ]/ [ ]/ [ ]/ [ ]/ [ ]
1= Radio 2 = T.V 3 = Mobile phone 4= Bicycle 5= Tricycle 6= Motorbike 7= Car
8= Others (specify)………………………..

18. Do you get information on improved production methods and systems [ ] 1 = Yes 2 = No

19. How often do you use the communication gadgets to access information on weather/production methods and activities [ ] 1 = Very often 2 = Not often 3 = Sometimes 4 = Not at all

20. What is the total size of your farm? (Average since 5 years ago): ....acres

21. How did you acquire land for farming? [ ] 1 = Inherited 2 = Bought 3 = Lease
4 = Own 5 = Sharecropping 6 =Hiring 7= Other **(**specify**)**…………….

22. Do you have livestock/poultry? [ ] 1 = Yes 2 = No

23. If yes, indicate the types and numbers:

Animal (livestock/poultry)	**Current number**	**Number sold in 2016**	**Value per animal (GHS)**
Cattle			
Goat			
Sheep			
Pig			
Chicken			
Guinea fowl			
Turkey			
Duck			
Other (specify):			

24. Do you have access to plough? [ ] 1 = Yes 2 = No

25. Do you have access to good road network? [ ] 1 = Yes 2 = No

26. Does your household keep seeds/planting material to cultivate in the next season? [ ]
1 = Yes 2 = No
27. Do you rely on food from your own farm for the household? [ ] 1 = Yes 2 = No
28. If no, where and how do you supplement this? ………………………………………………………………………….
29. Does your household have adequate food throughout the year from own production and/or purchases? [ ] 1 = Yes 2 = No
30. If no, how many months in a year does this household experience food shortage? …………………months
31. Do you have a health facility in this community? [ ] 1 = Yes 2 = No
32. How long (minutes) does it take to get to a health facility? …… on foot /……….. by car
33. Has any member of your household been sick that they had to miss work/school in the past 6 months? [ ] 1 = Yes 2 = No
34. Are your agricultural products exported? [ ] 1 = Yes 2 = No
35. Do you have access to ready markets for your produce? [ ] 1 = Yes 2 = No
36. If yes, how long (minutes) do you have to travel to the market? ……on foot /………by car
37. Do you lose some of your products before reaching the market? [ ] 1 = Yes 2 = No
38. What percentage of your total output do you lose as a result of post harvest losses?................
39. Do you lose some of your products as a result of pests and disease attack? [ ] 1 = Yes 2 = No
40. What percentage of your total output do you lose as a result of pests and disease attack?..........................
41. Do you have irrigation system on your farm? [ ] 1 = Yes 2 = No
42. If yes, what type of irrigation system? [ ] 1= Manual 2 = Mechanised
43. What is the main source of water for irrigation? [ ] 1=Stand pipe 2= Bore hole 3=Tube well 4=River, sea, lake, lagoon, spring 5= dam 6 = traditional well 7= others (specify)…………………………
44. How long (minutes) and far (km) does it take to get to the water source? ……minutes ; ………km
45. Has water availability been a problem? [ ] 1 = Yes 2 = No
46. In the past, have you heard about any conflicts over water in this community? [ ] 1 = Yes 2 = No
47. Do you pay for using irrigation facility? [ ] 1 = Yes 2 = No
48. If yes, how much GHS/year …………………………………………………
49. What percentage of your farm land is under irrigation?......................................
50. What is the main source of water for drinking and for household chores? [ ] 1=Stand pipe 2= Bore hole 3=Tube well
4=River, sea, lake, lagoon, spring 5= dam 6 = traditional well 7= Sachet water 8 =Bottled water 7= other…………….

D. Availability and access to credit

51. Do you have access to credit for your agricultural activities? [ ] 1 = Yes 2 = No

52. If yes, from which source multiple response [ ]/ [ ]/ [ ]/ [ ]/ [ ]/ [ ]/ [ ]/ [ ]]/ [ ]
1 = Family/friend support 2 = Trade credit 3 = Susu 4 = Local money lenders 5 = Reinvestment 6 = Personal savings 7 = Bank loan 8= NGOs/Church 9=Other (specify)………………………..

53. Has your household received remittances/assistance from family or friends within the past 12 months? [ ] 1 = Yes 2 = No.

54. If yes specify the type of help received? ……………………………………………….

55. Did you borrow any money from relatives/friends in the past 12 months? [ ] 1 = Yes 2 = No

56. If yes specify the amount you borrowed [GHS ……..], how much you repaid [GHS ……] and in how many months [……..months]

57. What did you use it for?...

58. Did you borrow any money from formal credit sources in the past 12 months? [ ] 1 = Yes 2 = No

59. If yes specify the amount you borrowed [GHS …], how much you repaid [GHS …………] and in how many months [……….months]

60. What did you use it for?...

61. Did you lend any money to relatives/friends in the past 12 months? [ ] 1 = Yes 2 = No

62. If yes specify the amount you lend out [GHS…..], how much was repaid [GHS …..] and in how many months [……..... months]

63. Do you have access to any subsidies during production? [ ] 1 = Yes 2 = No

64. If yes, mention the subsidies …………………………………………………………...........

E. Social network

65. Are you a member of a Farmer Based Association (FBO)? [ ] 1 = Yes 2 = No

66. Are you a member of any social organisation? [ ] 1 = Yes 2 = No

67. Have you ever received any support from any Research and Development Institution (s) [ ] 1 = Yes 2 = No

68. Have you ever received any support from governmental or non-governmental organisations? [ ] 1 = Yes 2 = No

69. Have you received any support from the organisations/institutions above in coping with climate-related issues in the past? [ ] 1 = Yes 2 = No

70. If yes to any of the questions from 65-69, please indicate the following:

Name of association /cooperative /institution	Form of assistance	Status of organization *(3=active 2=less active 1=inactive)*
a. FBO		
b. FBO		
c. CBO		
d. MoFA		
e. NGO		
f. NGO		
g. CSIR		

h. Research		
i. Government institution		

1=Capacity building 2=Provision of inputs 3=Irrigation 4=Improved varieties of seeds/planting materials 5=Market 6=Credit 7=Climate information 8=Information on improved production methods and systems 9= Group farming 10=other(specify…………………………)

71. Do you have access to information on seasonal forecasts for your farming activities? [ ]
1 = Yes 2 = No

72. If yes, what are your main sources of information? [ ]/ [ ]/ [ ]/ [ ]/ [ ]/ [ ]/ [ ]/ [ ]
1 = Weather forecast from Newspaper/ Television/ Radio 2 = Friends/family 3 = Agricultural Extension Agent (AEA) 4 = Personal Observation 5 = Indigenous knowledge 6= Other (*Specify*)……………………..

73. Do you have access to/contact with Agricultural Extension Agents (AEA) [ ] 1 = Yes 2 = No

74. If yes how often? a) Weekly b) Monthly c) Quarterly d) Every six months e) Annually

75. Have you received any extension services from other farmers in the past 12 months? [ ]
1 = Yes 2 = No

76. If yes, what services? [ ]/ [ ]/ [ ]/ [ ]/ [ ]/ [ ]/ [ ]/ [ ] / [ ]
1=Capacity building 2=Provision of inputs 3=Irrigation 4=Improved varieties of seeds/planting materials 5=Market 6=Credit 7=Climate information 8=Information on improved production methods and systems 9=other (specify………..…)

77. Have you received any formal agricultural extension services in the past 12 months? [ ]
1 = Yes 2 = No

78. If yes, what services: [ ]/ [ ]/ [ ]/ [ ]/ [ ]/ [ ]/ [ ]/ [ ] / [ ]
1=Capacity building 2=Provision of inputs 3=Irrigation 4=Improved varieties of seeds/planting materials 5=Market 6=Credit 7=Climate information 8=Information on improved production methods and systems 9=other (specify.…..……)

79. Do you get information on improved production methods and systems [ ] 1 = Yes 2 = No

D. Climate variability exposure and impacts

80. Comparing your experiences now with about ten (10) years ago, what kinds of changes have you observed about the following parameters?

	Large increase	**Moderate increase**	**Constant**	**Moderate decrease**	**Large decrease**
a. Rainfall i. Quantity ii. Duration					
b. Wind storm i. Frequency ii. Force (violent)					
c. Water Sources i. Number ii. Abundance					

iii. Quality					
d. Temperature					
e. Drought					
f. Flood i. Volume ii. Damage to farmlands					
g. Seasonal calendar					
h. Incidences of soil erosion					

81. Comparing your recent experiences with about ten (10) years ago, would you say that your income from farming has been affected as a result of impacts from climate variability? *Tick as appropriate where SA mean strongly agree, A (agree), D (disagree), and SD (strongly disagree):*

	Household income from production has been affected as a result of:	**SA**	**A**	**D**	**SD**	**Not sure**
a.	Poor quality of produce					
b.	Low yield/quantity harvested					
c.	High post harvest losses					
d.	Fallen net revenues from crops					

82. Did you receive any warning about the flood or drought before it happened? [ ] 1= Yes 2 = No

83. Have you received training to deal with the changes in rainfall and temperature patterns for your farming activity in the past 5 years? [ ] 1 = Yes 2 = No

84. If yes, who organized this? ……………………………………………………………

E. Adaptation

85. Indicate which of the following adaptation strategies you utilize in coping with the challenges of climate variability in your production activities

	Adaptation Strategies	**Frequency of utilization**			
		Never	**Always**	**Sometimes**	**Rarely**
a.	Water conservation practices such as mulching				
b.	Practice crop rotation				
c.	Practice mixed farming				
d.	Adoption of organic farming				
e.	Building of traditional dam to store water for dry period				
f.	Increase production farm size to ensure improved yield				
g.	Reduce farm size to minimise chances of loss				
h.	Use of soil conservation practices				

	such as bush fallowing				
i.	Use of Integrated Pest Management (IPM) practices				
j.	Planting of improved seed/planting material varieties (drought resistant/tolerant varieties)				
k.	Use of weather and meteorological reports to guide farming				
l.	Increase fertilizer use to improve yield				
m.	Construction of channels to drain off excess water				
n.	Use of wind break structures				
o.	Adjustment of planting calendar				
p.	Crop insurance				
q.	Making ridges across farm				
r.	Movement into non-farm occupations				
s.	Movement into animal production				
t.	Temporary/permanent migration				
u.	Crop diversification				
v.	Others (specify):				

86. Ranking of top five (5) adaptation strategies used based on contribution to sustaining productivity in spite of climate variability (use list from question 84 above) (Rank position 1-5)

Adaptation strategies	**Rank**	**Climatic challenges used for**
a.		
b.		
c.		
d.		
e.		

Climatic challenges: 1 = Drought 2= Flooding 3= Increasing temperature 4 = Erratic rainfall 5 = Windstorms

6 =Unpredictable season 7 =Coastal erosion 8= Other (Specify)………………………………………………

87. Please indicate the degree of importance of the following challenges from implementing the adaptation strategies highlighted above? *(Least important=1; Somewhat important =2; Important = 3; Very important = 4; Crucial = 5*)

	Constraint	**1**	**2**	**3**	**4**	**5**
a.	Inadequate financial resources					
b.	Poor access to climate information					
c.	Inadequate information about effectives of adaptation strategies					
d.	Inadequate institutional support					

e.	Complex land tenure systems and gender issues					
f.	High cost of implementation					
g.	Socio-cultural barriers					
h.	Inadequate storage facilities					
i.	Lack of reliable/ready market					
j.	Lack of appropriate farm machinery /implement					
k.	Inadequate access to extension and advisory service					
l.	Others (specify):					

88. In your view, what changes will affect your farm/crops in the future (like 10 years)?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

89. Would you like to add any other information?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

The end: Thank you for your cooperation

Appendix II: Interview guide for Focus Group Discussion (FGD)

1. FGD composition:

		Number of years stayed in community				Farm size (number)	
Gender	Total	< 5	5 – 15	15 - 25	> 25	</= 5 ac	> 5 ac
Male							
Female							

2. Have you noticed any changes in the climate in your lifetime or in that of your parents or grandparents (10-60 years)? [*Probe to determine nature of change*]
   a) Changes in rainfall
   b) Changes in soil conditions
   c) Changes in sunlight intensity
   d) Incidence of drought
   e) Incidence of floods
   f) Change in season length or characteristics
   g) Other

3. If yes for any climate variable above, how long have you noticed these changes?..................
4. How have you managed these changes to your farm/crops in the past five (5) years? [*Is your production sensitive to climate change and in what form?*]
5. Can you rank the intensity of these changes?
   a) High
   b) Moderate
   c) Low
6. How many drought situations have this community experienced since 2005
7. How many flood situations have this community experienced since 2005
8. Describe your water sources both for household chores and for irrigation as well as state of these sources. *[Stand pipe, bore hole, tube well, river, sea, lake, lagoon, spring, dam, traditional well, dam, others (specify)…………………………………………….]*
9. Is there a market in this community?
10. Describe the road network in this community. [*Farm and market accessibility*]
11. Indicate your extent of agreement or disagreement with the statements below by ticking the appropriate option as SA (strongly agree), A (agree), D (disagree), SD (strongly disagree) and U (uncertain):

	Statements	**SA**	**A**	**D**	**SD**	**U**
1	Change in rainfall has had impact on our water sources and availability for farming					
2	The challenges faced in our farming operations as a result of climate variation has decreased our vulnerability					

3	Resulting food security and water problems from unstable climate has no direct impact on our health					
4	Incidences of heat and water-borne illnesses in most of our households have increased in the recent years as climate change challenges heighten					
5	Incidences of poor nutrition or starvation in most households has nothing whatsoever to do with the heightened problem of climate change challenges					
7	Our livelihoods are threatened as a result of continuous decline in production due to unpredictability of seasons/agricultural calendar					
8	The unpredictability of rainfall and prolonged drought have in no way affected our farming activities					

12. Apart from horticultural production, what other livelihood activities are people engaged in this community [*Including both farming and non-farming activities*]
13. How are your production activities vulnerable to climate?
14. Describe the main costs incurred during production per acre of land
15. Describe technology and equipment you use and also need during production
16. Describe land tenure system in this community
17. How do you get information about weather/climate and on improved production methods and systems [*Formal training, education and sensitization*]
18. What pests and diseases affects your cops
19. How do you treat pests and diseases during production
20. How do cope with changes in the weather pattern? [*Adaptation strategies*]
21. Ranking of adaptation strategies based on contribution in securing food sustained production in spite of climate variability [*Use list identified in Question 20*]

Adaptation strategy	Rank

22. What prevents you from implementing identified adaptation strategies?
23. Are there any beliefs or social/cultural norms that prevent the community from taking certain decisions to respond to changes in the weather?
24. Please list (and describe) the five most important things that you think could help this community to reduce its vulnerability to climate variability.
25. Suggest two policy measures for enhancing your ability to adapt to changing climate [*Kinds of intervention to help improve solutions to adapt to climate variability and threats in your environment*]

Appendix III: Research questionnaire (Cost and benefit of identified climate adaptation strategies)

A. Respondents Profile

1. Name of respondent: ………………………… Contact phone No: …………………………
2. Age of respondent: ....Years
3. Gender of respondent: [ ] 1=Female 2=Male
4. Marital status of respondent: [ ] 1 = Single 2 = Married 3 = Divorced/Separated 4 = Widowed
5. Highest level of formal education of respondent: [ ] 1= None 2=Basic(Primary/JHS/Middle) 3 = Secondary (Secondary/vocational) 4 = Tertiary (Training college/Polytechnic/University)
6. Years of farming experience of respondent: ……………… Years
7. What is the total size of your farm? ....acres
8. How did you acquire land for farming? [ ] ; [ ] ; [ ] ; [ ] ; [ ] ; [ ] ; [ ] ; [ ] 1 = Inherited 2 = Bought 3 = Lease 4 = Own 5 = Sharecropping 6 =Hiring 7= Other (specify)…………….
9. Indicate the area of the farm covered by the following farm lands:

	Inherited	Bought	Lease	Own	Share cropping	Hiring	Other
Size (acres)							

B. General information about adaptation practice (Choose one: Intercropping; Mixed Cropping; Crop Rotation; Irrigation and Fertilization)

10. Name of practice:……………………………………………………………………..
11. How long have you practiced the above named practice in your farm? ……………… Years
12. What is the lifetime of the above-mentioned practice (i.e., since when the practice starts and reaches the end of a cycle so that the cycle starts all over again)? …………………. Years
13. What is the total size of your farm covered by this practice? …………………. Acres
14. List the main crops affected by this practice

Table 1: Details of crops affected by practice

Crop affected by practice	Size of farm/ acres	Season of production (1=major; 2=minor; 3=both; 4=other, specify………..)	Number of cultivations per year
a.			
b.			
c.			
d.			

15. Please indicate the harvesting periods for each of the output crops

Table 2: Crop harvesting times for adaptation practice

Crop affected by practice	**Planting month**	**First and second crop harvest**	**Time *(months)***
a.		How long after planting is the first	

		harvest?	
		How long after planting is the last harvest?	
b.		How long after planting is the first harvest?	
		How long after planting is the last harvest?	
c.		How long after planting is the first harvest?	
		How long after planting is the last harvest?	
d.		How long after planting is the first harvest?	
		How long after planting is the last harvest?	

Note: for some crops, there will be just one harvest.

C. Physical productivity and expected yield:

16. What has been the trend in productivity from three years back when farmers' practice ended (BAU-without practice) and three years into commencement of the adaptation practice (with practice). This is to tell us about the yield of each crop in the past few years in the plot?

Table 3: Estimated changes in productivity

Crop affectedby practice	Units (i.e.bags, kg etc)	Yield - Business As Usual (BAU)			Yield – With adaptation practice		
		Year ( )	Year ( )	Year ( )	Year ( )	Year ( )	Year ( )
a.							
b.							
c.							
d.							

Note: The start year may change in this table because here we want to capture trend in productivity before the introduction of the practice under consideration and after introduction of the practice

17. What was the price trend for the yield in Ques. 16 (Table 3)

Table 4: Estimated changes in prices

Crop affected by practice	Price per unit - Business As Usual (BAU)			Price per unit – With adaptation practice		
	Year ( )	Year ( )	Year ( )	Year ( )	Year ( )	Year ( )
a.						
b.						
c.						
d.						

18. Indicate the period of the lifetime of the adaptation practice when yield is affected by the practice.

Table 5: Lifetime of the adaptation practice when the crop yield/activity is affected by the practice

Activity	Crops

	a	b	c	d
Practice life cycle (Refer to Ques. 12)				
Period (years) when physical response start to increase in response to implementing practice				
Period (years) when physical response reaches maximum productivity response as a result of implementing the practice (after which productivity response remain constant until the end of the lifetime				

19. For each of the affected crops, could you please tell us the maximum yield per unit area after introduction of the adaptation practice and without the practice? This information can be obtained (as an approximation) from key resource person

Table 6: Crop yield with and without practice

Crops affected by practice	Unit per acre (*Same as Ques. 16*)	Business As Usual		With adaptation practice	
		Minimum yield	Maximum yield	Minimum yield	Maximum yield
a.					
b.					
c.					
d.					

NB: The unit (bowls, bags, mini-sack, fertilizer bag, etc.)

20. What are the minimum and maximum prices for the estimated yield in Ques. 19?

Table 7: Pricing and price variability

Crops affected by practice	Unit per acre (*Same as Ques. 19*)	Business As Usual		With adaptation practice	
		Minimum Price *(GHS/ unit)*	Maximum Price *(GHS/ unit)*	Minimum Price *(GHS/ unit)*	Maximum Price *(GHS/ unit)*
a.					
b.					
c.					
d.					

21. What are the reasons for changes in yield with and without the adaptation practice and frequency of occurrence?

Table 8: Reasons for changes in yield

Changes in yield	Business As Usual	With adaptation practice
What is the reason for the difference between the expected minimum and maximum yields?		
How often are the minimum yields?		
How often are the maximum		

yields?		

D. Cost Structure: As in physical productivity case, information about the cost structure under the farmer without practice is relevant. In this case, the same information about the production structure and its cost is collected for each of the crop affected by the practice described.

22. **Installation/Implementation & Maintenance Costs:** Please fill in Table 9 with information about the units and unit prices associated with the machinery, inputs, services and labor required for implementation and maintenance for production with adaptation practice for the production of each of the output crops.

Table 9: Units and prices for implementation and maintenance costs

Items/Operation	Unit	Price/unit (GHS)	Number of times done/ applied per season
Machinery/Equipment			
i.	Number		N. A.
ii.			N. A.
iii.			N. A.
iv.			N. A.
Inputs			
i. Seeds crop ‘a’			N. A.
ii. Seeds crop ‘b’			N. A.
iii. Seeds crop ‘c’			N. A.
iv. Seeds crop ‘d’			N. A.
v. Fertilizer ‘I’	Bag		N. A.
vi. Fertilizer ‘II’			N. A.
vii. Fungicide			N. A.
viii. Insecticide			N. A.
ix. Herbicide			N. A.
x. Manure/ Mulch			N. A.
xi.			N. A.
xii.			N. A.
Services			
i. Tractor for ploughing			N. A.
ii. Equipment for chemical application			N. A.
iii.			N. A.
iv.			N. A.
Labour/Mandays			
i. Land preparation	Mandays		
ii. Planting	Mandays		
iii. Weeding	Mandays		
iv. Fertilizer application	Mandays		
v. Fungicide application	Mandays		
vi. Insecticide application	Mandays		
vii. Herbicide application	Mandays		
viii. Manuring	Mandays		
ix. Machinery operation	Mandays		
x. Equipment operation	Mandays		
xi.	Mandays		
xii.	Mandays		

N. A. = Not applicable

23. **Installation/Implementation costs**: Please fill in Table 10 with information about the quantities for machinery, inputs, services and labor required for implementation for production of each of the output crops with or without an adaptation practice.

Table 10: Implementation/Installation cost

Items/operation	**Crops without practice (Quantity of item use or application in units per year)**				**Crops with practice (Quantity of item use or application in units per year)**			
	a.	**b.**	**c.**	**d.**	**a.**	**b.**	**c.**	**d.**
Machinery/Equipment								
i.								
ii.								
iii.								
iv.								
Inputs								
i. Seeds								
ii. Fertilizer 'I'								
iii. Fertilizer 'II'								
iv. Fungicide								
v. Insecticide								
vi. Herbicide								
vii. Manure/ Mulch								
viii.								
ix.								
x.								
Services (Basically from hiring)								
i. Tractor for ploughing								
ii. Equipment for chemical application								
iii.								
iv.								
Labour/Mandays								
i. Land preparation								
ii. Planting								
iii. Weeding								
iv. Fertilizer application								
v. Fungicide application								
vi. Insecticide application								
vii. Herbicide application								
viii. Manuring								
ix. Machinery operation								
x. Equipment operation								
xi.								
xii.								

24. **Maintenance costs:** Please fill in Table 11 with information about the quantities for machinery, inputs, services and labor required for maintenance of production for each of the output crops with or without an adaptation practice. *(Maintenance activities are carried out*

periodically and are necessary to keep a farming practice working properly over the entire lifetime. For example: Replacing damaged irrigation hoses, weeding stonewalls) (YEAR 2-T)

Table 11: Maintenance cost

Items/operation	**Crops without practice (Quantity of item use or application in units per season)**				**Crops with practice (Quantity of item use or application in units per season)**			
	a.	**b.**	**c.**	**d.**	**a.**	**b.**	**c.**	**d.**
Machinery/Equipment								
i. Knapsack								
ii.								
iii.								
iv.								
Inputs								
i. Fertilizer								
ii. Herbicide								
iii. Fungicide								
iv. Insecticide								
v.								
vi.								
vii.								
viii.								
Services (Basically from hiring)								
i. Equipment for chemical application								
ii.								
iii.								
Labour/Mandays								
i. Weeding								
ii. Fertilizer application								
iii. Herbicide application								
iv. Fungicide application								
v. Insecticide application								
vi.								
vii.								
viii.								

25. **Operational/Harvest**: Please fill in Table 12 with information about the units and unit prices associated with the operational inputs, services and labor required for the operational activities needed for production with adaptation practice for each of the output crops. (Harvest costs are costs that occur at the end of the life cycle or planting season, often associated with harvesting. These costs are different from the "maintenance costs" because they occur only at the end of the growing cycle, or harvest time).

Table 12: Units and prices for operational cost

Items/Operation	a.	b.	c.	d.

	Unit	Price per Unit/ GHS	Unit	Price per Unit/ GHS	Unit	Price per Unit/ GHS	Unit	Price per Unit/ GHS
Operational inputs/Harvesting equipment (crates, sacks, baskets, knives etc)								
i. Measure for outputs								
ii. Knives								
iii. Pan								
iv.								
v.								
vi								
Operational services (From hiring)								
i. Transport to farm gate								
ii. Transport to market								
iii.								
iv.								
Operational labour (Mandays)								
i. Harvesting								
ii. Cleaning								
iii. Sorting								
iv. Packaging								
v. Loading								
vi.								
vii.								
viii.								

26. **Operational/Harvesting costs:** Please fill in Table 13 with information about the quantities for operational inputs, services and labor required as operational costs of production for each of the output crops with or without an adaptation practice.

Table 13: Annual operational cost

Items/operation	Crops without practice (Quantity of item use or application in units per year)				Crops with practice (Quantity of item use or application in units per year)			
	a.	b.	c.	d.	a.	b.	c.	d.
Operational inputs/Harvesting equipment (crates, sacks, baskets, knives etc)								
i. Measure for outputs								
ii. Knives								
iii. Pan								
iv.								
Operational services (From hiring)								
i. Transport to farm gate								
ii. Transport to market								
iii.								
iv.								
Operational labour (Mandays)								
i. Harvesting								
ii. Cleaning								

iii. Sorting								
iv. Packaging								
v. Loading								
vi.								
vii.								
viii.								

27. Please indicate the period (years) when the activities/output of the affected crops start to incur operational cost and when the operation cost stops (please fill in Table 14).

Table 14: Period in the lifetime of a practice when operation cost starts and ends

Activity	Crops			
	a	b	c	d
Practice life cycle (Refer to Ques. 12)				
Period (year) when operation cost initiate/starts (years)				
Period when operation cost ends (years)				

E. **External effects:** Besides the expected benefits that come from implementing the adaptation strategies (such as higher yields) you may find that introducing the practice might have come with some additional, unexpected effects on the farming system and the farm environment. This constitutes external effects resulting from implementing the adaptation practice discussed so far. This may be in the form of **reduction of carbon emission (for improved air quality), nitrogen fixation, social benefits, enhancing the quality of the environment/natural beauty, improved water availability, reduced soil erosion, increased soil biodiversity, increased crop biodiversity or any other, please specify**.

28. What are the externalities you know are as a result of practicing the adaptation strategy being discussed?

Table 15: Identification of externalities

External Effect (EE)	Name
EE 1	
EE 2	
EE 3	
EE 4	

29. Please indicate the period (years) in the lifetime of the adaptation practice when the External Effect (EE) starts due to implementing the practice and when it reaches its maximum.

Table 16: Response to EE

EE Response parameters	Value
EE 1:	
Practice life cycle (See question 3)	
Period when response from EE1 starts	
Period when response from EE1 reaches maximum	
EE 2:	

Practice life cycle (See question 3)	
Period when response from EE 2 starts	
Period when response from EE 2 reaches maximum	
EE 3:	
Practice life cycle (See question 3)	
Period when response from EE3 starts	
Period when response from EE3 reaches maximum	
EE 4:	
Practice life cycle (See question 3)	
Period when response from EE4 starts	
Period when response from EE4 reaches maximum	

The end: Thank you for your cooperation

Appendix IV: Key expert survey guide (Cost and benefit of climate adaptation strategies

1. Please indicate if the adaptation strategies have an impact on the identified externalities. (Indicate Low Impact; High Impact and No Impact)

Practice/ Externality	On-farm biodivers ity	Soil biodivers ity	Carbon sequestra tion	Soil erosion	Water availabili ty	Social capital	Politica l Capital
Irrigation							
Fertilization							
Crop rotation							
Intercropping							
Mixed cropping							

2. I would like you to assess the value of the external effects for four of the adaptation practices with high externality impact. That is, estimate the *"Rate of change and actual values*" per hectare per year for the maximum effect of four relevant externalities coming out from four of the adaptation practices For example, indicate if crop rotation improves water availability by 10% and by10m^3 (actual value) per ha per year. Also "***Valuate in GHS***," which is the estimated monetary value. In other words, how much a farmer would be willing to pay for this effect.

A. Practice Name: ____Please choose one: *Intercropping; Mixed Cropping; Crop Rotation; Supplementary irrigation and Fertilization*

No.	**External Effect**	**Unit**	**Response value resulting from adaptation practice per ha**		**Willingness to pay/ Valuation (GHS)**
			Rate of change in value (%)	**Actual value of change per unit**	
1.					
2.					
3.					
4.					

Note the unit for each external effect: *On farm biodiversity = number of species of plants/animal per ha; soil biodiversity = Kg Nitrogen fixed per ha per year; carbon sequestration = tonnes* CO_2 *sequestrated per ha; water availability =* m^3 *water per ha; soil erosion = kg of contaminants per ha;*

social capital = number of social interactions; political capital = number of political interactions with external entities/institutions

B. Practice Name: ____Please choose one: *Intercropping; Mixed Cropping; Crop Rotation; Supplementary irrigation and Fertilization*					
No.	**External Effect**	**Unit**	**Response value resulting from adaptation practice per ha**		**Willingness to pay/ Valuation (GHS)**
			Rate of change in value (%)	**Actual value of change per unit**	
1.					
2.					
3.					
4.					

Note the unit for each external effect: *On farm biodiversity = number of species of plants/animal per ha; soil biodiversity = Kg Nitrogen fixed per ha per year; carbon sequestration = tonnes CO_2 sequestrated per ha; water availability = m^3 water per ha; soil erosion = kg of contaminants per ha; social capital = number of social interactions; political capital = number of political interactions with external entities/institutions*

C. Practice Name: ____ Please choose one: *Intercropping; Mixed Cropping; Crop Rotation; Supplementary irrigation and Fertilization*					
No.	**External Effect**	**Unit**	**Response value resulting from adaptation practice per ha**		**Willingness to pay/ Valuation (GHS)**
			Rate of change in value (%)	**Actual value of change per unit**	
1.					
2.					
3.					
4.					

Note the unit for each external effect: *On farm biodiversity = number of species of plants/animal per ha; soil biodiversity = Kg Nitrogen fixed per ha per year; carbon sequestration = tonnes CO_2 sequestrated per ha; water availability = m^3 water per ha; soil erosion = kg of contaminants per ha; social capital = number of social interactions; political capital = number of political interactions with external entities/institutions*

D. Practice Name: ____Please choose one: *Intercropping; Mixed Cropping; Crop Rotation; Supplementary irrigation and Fertilization*				
No.	**External Effect**	**Unit**	**Response value resulting from**	**Willingness**

			adaptation practice per ha		to pay/
			Rate of change in value (%)	Actual value of change per unit	Valuation (GHS)
1.					
2.					
3.					
4.					

Note the unit for each external effect: *On farm biodiversity = number of species of plants/animal per ha; soil biodiversity = Kg Nitrogen fixed per ha per year; carbon sequestration = tonnes CO_2 sequestrated per ha; water availability = m^3 water per ha; soil erosion = kg of contaminants per ha; social capital = number of social interactions; political capital = number of political interactions with external entities/institutions*

External effect	Unit	Description
Water Availability	(m3 water/Ha)	The quantity of water available per hectare in cubic meters (m^3), or the % changes over baseline.
Soil Erosion	(Kg contaminant/Ha)	Assuming that the amount of contaminants in the soil increases erosion, assess the amount of soil contaminant (inorganic fertilizers, pesticides) per hectare measured in kilograms (or percentage change over baseline)
Soil Biodiversity	(kg N2 fixed/ha/yr)	Assuming that nitrogen is an indicator of soil health and quality, assess the amount of fixed Nitrogen (Kg) in one hectare of soil per year (or %change over baseline).
On-farm Biodiversity	(% change # species)	The change in the number of species of plants and animals found on-farm (including cultivated crops; raised animals; forages; wild plants, animals, grasses, etc.) (or %change over baseline)
Carbon sequestration	(t CO2/Ha)	Assuming that increased Carbon Dioxide (CO_2) sequestration improves air quality, assess the amount of Carbon Dioxide (CO_2) sequestered in terms of tons of CO_2 per hectare, or % change over baseline
Social Capital	(# of social interactions / yr.)	Participation in local groups (farmer, community, etc.) that facilitates engagement and sharing of skills or knowledge with outside groups (government, NGO, development partners, regional/national farmer groups, etc.). Assuming that creating links to share knowledge and information is intrinsically valuable, assess "social capital" using the annual number of interactions with outside entities, or % change over baseline year.
Political Capital	(# interactions with outside entities/ yr.)	This relate to factors of political nature that affect adaptation practice either positively or negatively.

Appendix Va: Reference list of final studies reviewed

No	Reference	Author (s)	Title of publication
1.	Angula and Kaundjua, 2016)	Angula, M.N. and Kaundjua, M.B.	The changing climate and human vulnerability in north-central Namibia
2.	Antwi-Agyei *et al.*, 2013	Antwi-Agyei, P., Dougill, A.J., Fraser, E.D.G. and Stringer, L.C.	Characterising the nature of household vulnerability to climate variability: Empirical evidence from two regions of Ghana
3.	Asare-Kyei *et al.*, 2017	Asare-Kyei, D., Renaud, F.G., Kloos, J., Walz, Y. and Rhyner, J.	Development and validation of risk profiles of West African rural communities facing multiple natural hazards
4.	Bele, Sonwa and Tiani, 2014	Bele, M.Y., Sonwa, D.J. and Tiani, A.M.	Local Communities Vulnerability to Climate Change and Adaptation Strategies in Bukavu in DR Congo
5.	Cooper and Wheeler, 2017	Cooper, S.J. and Wheeler, T.	Rural household vulnerability to climate risk in Uganda
6.	Choptiany *et al.*, 2017	Choptiany, J.M.H., Phillips, S., Graeub, B.E., Colozza, D., Settle, W., Herren, B., and Batello, C.	SHARP: integrating a traditional survey with participatory self-evaluation and learning for climate change resilience assessment
7.	Dasgupta and Baschieri, 2010	Dasgupta, A. and Baschieri, A.	Vulnerability to climate change in Rural Ghana: Mainstreaming climate change in poverty-refuction strategies
8.	Derbile and File, 2016)	Derbile, E.K., File and D.J.M	Community risk assessment of rainfall variability under rain-fed agriculture: the potential role of local knowledge in Ghana
9.	Derbile, File and Dongzagla, 2016	Derbile, E.K., File, D.J.M. and Dongzagla, A.	The double tragedy of agriculture vulnerability to climate variability in Africa: How vulnerable is smallholder agriculture to rainfall variability in Ghana?
10.	Deressa, Hassan and Ringler, 2009	Deressa, T.T., Hassan, R.M. and Ringler, C	Assessing household vulnerability to climate change
11.	Dumenu and Obeng, 2016	Dumenu, W.K. and Obeng, E.A.	Climate change and rural communities in Ghana: Social vulnerability, impacts, adaptations and policy implications
12.	Effah, 2014	Effah, E.	Assessment of vulnerability of assets and livelihoods to climate variability for adaptation planning in a coastal community in Ghana
13.	Etwire *et al.*, 2013	Etwire, P.M., Al-Hassan, R.M., Kuwornu, J.K.M. and Osei-Owusu, Y.	Application of Livelihood Vulnerability Index in Assessing Vulnerability to Climate Change and Variability in Northern Ghana
14.	Hahn, Riederer and Foster, 2009	Hahn, M.B., Riederer, A.M. and Foster, S.O.	The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change-A case study in Mozambique
15.	Grothmann *et al.*, 2017	Grothmann, T., Petzold, M., Ndaki, P., Kakembo, V., Siebenhüner, B.,, Kleyer, M., Yanda, P. and Ndou, N.	Vulnerability assessment in African villages under conditions of land use and climate change: Case studies from Mkomazi and Keiskamma

16.	Hotz, 2010	Hotz, H.	Local-scale Vulnerability and Adaptive Capacity to Climate Variability and Change: a Case Study from Northern Central Namibia
17.	Jakpa, 2015	Jakpa, J.T.	Smallholder famers' vulnerability to floods in the Tolon District, Ghana
18.	Mapfumo *et al.*, 2013)	Mapfumo, P., Adjei-Nsiah, S., Mtambanengwe, F., Chikowo, R. and Giller, K.E.	Participatory action research (PAR) as an entry point for supporting climate change adaptation by smallholder farmers in Africa
19.	Molefe and Masundire, 2016	Molefe, C. and Masundire, H.	Climate change vulnerability and risk analysis in the Bobiriwa Sub-District, Botswana: Towards improving livelihood adaptation to climate
20.	Kienberger, 2012	Kienberger, S.	Spatial modelling of social and economic vulnerability to floods at the district level in Búzi, Mozambique
21.	Ng'ang'a *et al.*, 2012	Ng'ang'a SK, Maute F, Notenbaert A, Herrero M, Moyo S.	Coping strategies and vulnerability to climate change of households in Mozambique
22.	Nkondze, Masuku and Manyatsi, 2013	Nkondze, M.S., Masuku, M.B. and Manyatsi, A.	Factors Affecting Households Vulnerability to Climate Change in Swaziland: A Case of Mpolonjeni Area Development Programme (ADP)
23.	Notenbaert *et al.*, 2013	Notenbaert, A, Karanja, S.N., Herrero, M., Felisberto, M. and Moyo, S.	Derivation of a household-level vulnerability index for empirically testing measures of adaptive capacity and vulnerability
24.	Okpara, Stringer and Dougill, 2017	Okpara, U.T., Stringer, L.C. and Dougill, A.J.	Using a novel climate–water conflict vulnerability index to capture double exposures in Lake Chad
25.	Oluoko-odingo, 2011	Oluoko-odingo, A.A.	Vulnerability and Adaptation to Food Insecurity and Poverty in Kenya
26.	Pavageau, Butterfield and Tiani, 2013	Pavageau, C., Butterfield, R. and Tiani, A.M.	Current vulnerability in the Virunga landscape, Rwanda
27.	Raemaekers and Sowman, 2015	Raemaekers, M. and Sowman, S.	Community-level socio-ecological vulnerability assessments in the Benguela Current Large Marine Ecosystem
28.	Rurinda *et al.*, 2014	Rurinda, J., Mapfumo, P., van Wijk, M. T., Mtambanengwe, F., Rufino, M. C., Chikowo, R. and Giller, K. E.	Sources of vulnerability to a variable and changing climate among smallholder households in Zimbabwe: A participatory analysis
29.	Sallu, Twyman and Stringer, 2010	Sallu, S.M., Twyman, C. and Stringer, L.C.	Resilient or vulnerable livelihoods? Assessing livelihood dynamics and trajectories in rural Botswana
30.	Sorey, 2011	Sorey, G.	Climate change and vulnerability Impact assessment study of the agricultural adaptability in Tanzania
31.	Tesso, Emana and Ketema, 2012	Tesso, G., Emana, B., and Ketema, M.	Analysis of vulnerability and resilience to climate change induced shocks in North Shewa, Ethiopia
32.	Tiani *et al.*, 2015	Tiani, A. M., Besa, M.C., Devisscher, T., Pavageau, C., Butterfield, R., Bharwani, S. and Bele, M.Y.	Assessing current social vulnerability to climate change: A participatory methodology

33.	Umoh *et al.*, 2014	Umoh, G.S., Udoh, E.J., Solomon, V.A., Edet, G. E., Okoro, G. I., Uwem, C.A., Bassey, N. E. and Akpan, O.D.	Analysis of upland farm households' vulnerability to climate variability in the Niger Delta, Nigeria
34.	van Vliet, 2010	van Vliet, N.	Participatory Vulnerability Assessment in the Context of Conservation and Development Projects: A Case Study of Local Communities in Southwest Cameroon
35.	Vilissa, 2016	Vilissa, D.J.	Vulnerability of horticulture producers to climate variability
36.	Westerhoff and Smit, 2009	Westerhoff, L. and Smit, B.	The rains are disappointing us: Dynamic vulnerability and adaptation to multiple stressors in the Afram Plains, Ghana

Appendix Vb: Summary of conceptual definitions of vulnerability, hazards and variables for characterizing vulnerability of reviewed studies

Representative studies	Conceptual definition of vulnerability indicated in studies	Nature of main climate hazard/threat considered	Variables used in characterizing vulnerability
Grothmann et al. 2017	Amount of Agricultural Production (AP) and availability of different Alternative Income Source (AIS)	Drought	Amount of AP (ratio of agricultural outputs to inputs) and availability of AIS. Potential vulnerability determinants are found in the resource system, resource units, the governance system within the village, the users of the resources in the village, the social, economic and political setting, the related ecosystems, and the interactions between these factors
Cooper & Wheeler 2017	Was divided into internal and external aspects. The internal aspects comprised innate features of an exposure unit which was a household and the external aspect was the magnitude of exposure and the externalities which affect sensitivity	Drought, inter/intra seasonal dry spells, rainfall variability	Proxies for demographic and socio-economic characteristics (such as age, gender, education, household size, agricultural extension contacts, livestock ownership) were selected to represent intrinsic attributes of sensitivity. Selected external attributes were represented by land ownership, employment in a non-farm livelihood (any income-generating activity which was not crop or livestock production), participation in agricultural extension (extension farmers) and livestock ownership, all hypothesized to influence adaptive capacity
Asare-Kyei et al. 2017	Vulnerability was characterized by exposure, susceptibility and the capacity of coupled Socio-Ecological System to cope and adapt to the impacts of either a	Drought, floods	Hydro-climatic hazards and stressors such as floods and/or heavy rainfall events, slow onset events such as droughts, late onset of the rainy season but also more gradual changes such as changes in variability or averages of rainfall were variables for characterizing exposure. Socio-economic drivers and stressors included population

	single hazard or the combined effects of multiple hazards.		affected by floods, population affected by droughts, average area of affected cropland, average number of affected livestock, number of people killed by floods, economic value of properties (houses, personal effects etc.) destroyed by floods or fires and/or occasioned by prolonged drought
Okpara, Stringer & Dougill 2017	Theoretical non-observable phenomenon relating propensity of a system, subsystem or component to experience harm	Climate-water conflict	Seven indicating baskets were considered relevant to operationalising vulnerability. That is, exposure to (1) climate variability and (2) water conflict; sensitivity to (3) lake water variability and (4) physical/natural assets; and adaptive capacity captured by (5) socio-demographic profile, (6) livelihood income strategies and (7) social/political networks. Some indicators were water accessibility, conflict sensitivity, lake water variability, physical and natural assets
Derbile, File & Dongzagla 2016	Vulnerability was conceptualised in the context of susceptibility of agriculture to climate change and climate variability.	Drought, heavy precipitation	Key variables considered were state of defenselessness arising from a low capacity to cope and/or adapt without damaging loss, households experiences and perceptions of exposure to risks, shocks and stress. It was described as comprising two sides; the external side that comprise the exposure to risks, shocks and stress which an individual or household experiences and the internal side showing a state of defenselessness.
Dumenu & Obeng 2016	The degree to which a system is susceptible to the effects of climate change owing to interplay of social, economic and demographic factors, describing the existing state (capacity) of rural communities that predispose them to climate change impacts.	Not specific	Indicators contributing to the high vulnerability level of the study zones were used and included demographic, social and economic factors such as household size, literacy level, diversified sources of income, climate sensitive occupation, access to climate information, dependence on forest resources
Westerhoff & Smit 2009	Vulnerability reflect the dynamic interaction of biophysical conditions (including climate change) and socioeconomic conditions with manifestations at scales from global to local.	Not specific (indicated future climatic changes)	People's exposures and sensitivities to external conditions were influenced by their occupancy and livelihood characteristics consisting of households' social, economic, cultural and political conditions (physical capital, social capital, water scarcity, migration, credit) and the nature and degree to which these were affected by external stresses (climate)
Raemaekers & Sowman 2015	Not explicitly defined for study	Not specific (indicated climate)	Relevant changes that affect the fishery system and local livelihoods' threats or stressors related to the environment; socio-economic

			circumstances and the management/governance arrangements such as historical overview of events, changes and impacts of environmental stressors, geographical location, post-harvest activities were considered.
Choptiany et al. 2017	Capacity of social, economic and environmental systems to cope with a hazardous event, trend or disturbance.	Not specific (Climate change and variability)	Farming resources/practices/knowledge, sources of water, non-farm income generating activities, exposure to hazards were resilience indicators, resources, practices and knowledge used in characterizing vulnerability.
van Vliet 2010	Not explicitly defined for study	Not specific (Climate)	Multiple stimuli such as political, cultural, economic, institutional and technical forces; socio-economic situation, access to roads, markets, education, and health facilities, household members, primary sources of income, current farming activities, recent changes affecting livelihood strategies, perceptions of local environment, and strategies for meeting short-term development aspirations were variables considered in vulnerability characterization.
Oluoko-odingo 2011	Not explicitly defined for study	Drought, floods	Information on climate and food security was the main vulnerability variables considered. These include months of drought, socioeconomic variables such as households' total production, farm size, land cultivated, years of farm operation, distance to the nearest market and proximity of households to various infrastructural sources like schools, banks, markets, fuel, and water.
Bele, Sonwa & Tiani 2014	The interplay between social capital and nature	Not specific (changing climate)	Factors such as poverty and number of conflicts were the top two factors that were identified listed as the most important factors amplifying vulnerability. Additional variables were lack of climate information, lack of access to credit, lack of infrastructure, lack of access to sufficient farm input and limited access to markets.
Pavageau, Butterfield & Tiani 2013	Not explicitly defined for study	Not specific (mentioned climate)	Changes in conflicts, political and social factors, exploitation of natural resources and livelihoods were highlighted and used by the study for vulnerability characterization. Climate impacts on famine, overexploitation of natural resources and livelihoods and the high number of refugees were also noted to have a toll on the environment, historical climate and hazards
Mapfumo et al. 2013	Not explicitly defined for study	Not specific (changing climate)	Major variables considered were declining soil fertility, land tenure system, crop nutrient deficiencies and yield changes.
Tesso, Emana & Ketema 2012	Difference between adaptive capacity of a household and its	Not specific (indicated climate)	Climate data, responses to indicators for socioeconomic and natural factors such as household characteristics, landholding, crops and

	sensitivity and exposure to climate induced hazards		livestock production, disaster occurrence, perception level (on precipitation, temperature, soil moisture, air moisture and wind direction), adaptation strategies pursued, level of resilience were considered.
Deressa, Hassan & Ringler 2009	Probability of a household falling below a consumption level due to climate shocks and as expected poverty	Drought, floods, hailstorm	Variables considered were incidence of climate and other shocks in the past years, access to food aid, social capital, access to credit, land tenure system, machinery ownership, livestock production, rain fed and irrigated agriculture and perceptions of changing climate
Angula & Kaundjua 2016	Not explicitly defined for study	Drought, flood	Vulnerability was characterized mainly by the occurrence and intensity of natural disasters, impact of climate related natural disasters on livelihoods, population displacement and movements as well as human health.
Derbile & File 2016	Exposure to risks and hazards and capacity for adaptation.	Rainfall variability	Variables considered were mainly climate related and included decreasing and irregular rainfall, level of local climate knowledge and individuals' experiences with changing climate
Kienberger 2012	Expected probability of harmful consequences and losses resulting from interaction between natural and anthropogenic hazards	Floods	Set of spatial indicators constituting vulnerability units and characterizing an area considered were land cover/land use, road network, location of schools, hospitals in addition to individuals' perception and experiences with changing climate.
Molefe & Masundire 2016	Not explicitly defined	Rainfall variability, drought, flood	Vulnerability variables considered were mostly socioeconomic indicators such as education, quality of products, market accessibility, changes in plant and animal diseases, knowledge of climatic changes.
Sorey 2011	Impacts of climate change on humans and their livelihoods	Not specific (indicated climate)	Indices on past climate parameters to show hydrologic events such as Monthly Average Precipitation, Yearly Average Precipitation, Absolute Deviation from Average Precipitation Estimated Monthly Average Temperature and its impacts on humans and livelihoods were variables considered.
Effah 2014	Function of both magnitude and scope of perturbation and the system it influences	Floods	Vulnerability of Community Assets and livelihood to flood were illustrated in the washing away of top soil making soil infertile, destruction of crops by flood, animals killed and carried away by water during flood, exposure of livelihoods to water and community's perception about changes and causes of climate variability
Umoh et al. 2014	Risk of present and future	Not specific (climate	Factors considered to predispose households to being vulnerable

	climatic variations and responses to improve resilience to future risks.	variability)	were irrigation water availability, drought, changes in agricultural productivity and production, labour availability, land tenure, food storage and processing, income and conflicts.
Tiani et al. 2015	A function of exposure, sensitivity and adaptive capacity of a system	Drought, flood, strong winds	How identified hazards (drought, flood, winds) in relation to past trends and current conditions affects various actors, livelihood activities and resources in the study areas indicated different dimensions of vulnerability in the study.
Hotz 2010	Not explicitly defined for study	Not specific (climate change and variability)	Variables for vulnerability included social factors such as household's living conditions, perceptions of weather and climate, land and water management for example land allocation or conflicts over water (water point committee).
Jakpa 2015	It is a function of exposure, sensitivity and adaptive capacity of a system to create total household's vulnerability (IPCC 2007)	Flood	Location of farms was the principal determinant of flood vulnerability in the study. Other socioeconomic and climate factors considered were connected to livelihood asset indicators such as access to information, credit, number of farms owned, dependency ratio and membership of Farmer Based Organisations (FBO) as well as standard deviation of change in average monthly temperature and precipitation, flood occurrence in the past decade, injuries incurred by household members as a result of floods, farm land degraded by flood events in the past ten years and crops damaged due to floods
Sallu, Twyman & Stringer 2010	Not explicitly defined for study	Drought	Variables such as Landsat images and aerial count data records on diurnal and seasonal temperature variations, low average annual rainfall as well as social and political factors such as access to diversity of assets and support from formal and informal institutions were considered.
Notenbaert et al. 2013	Exposure to climate change impacts and variability of households in the same village to be equal, sensitivity to the impacts and capacity to cope with those impacts.	Not specific (climate variability)	Social factors were employed and these were livelihood strategies, livelihood ownership, livestock feeding techniques and management, welfare outcomes (income, food consumption and health), market, household composition, herd dynamics and species.
Nkondze, Masuku & Manyatsi 2013	Impact of diseases (HIV and AIDS) and shocks (erratic weather patterns and poverty) and a household's ability to withstand	Not specific (climate change)	Livelihood capital assets: natural assets such as land, soil and water; physical assets such as livestock and equipment; financial assets such as savings, salaries, remittances or pensions; human capital assets such as farm labour, gender composition and dependants and social assets such as information, community support, extended families

			and formal or informal social welfare support characterized vulnerability.
Ng'ang'a et al. 2012	Not explicitly defined for study	Not specific (climate variability)	Socioeconomic variables were used in characterizing vulnerability. These were livestock holdings and management, off-farm income activities and earning, household characteristics, households' demographic, households' livelihood, livestock ownership and other standard cattle-related activities, household composition, livelihood strategies, and livestock assets; herd dynamics and species and vulnerability context as main concerns facing the households.
Dasgupta & Baschieri 2010	Not explicitly defined for study	Drought	Assets such as labour, non-labour productive assets (like land, radio, vehicles) human capital, household relations demographic characteristics of household members, their reported health status, education, employment, housing and income from wages, agricultural production and presence of infrastructure, schools among others were seen as important productive assets for rural Households and could either be used or sold in order to buffer short-term climatic shocks so their specific changes characterized vulnerability. The more assets people have, the less vulnerable they are, and the greater the erosion of people's assets, the greater their insecurity'
Etwire et al. 2013	Not explicitly defined for study	Flood, drought	Local context subcomponents under socio demographic profile, livelihood strategies, social network, health, access to food, water and natural disasters constituted estimation of vulnerability of area studied.
Hahn, Riederer & Foster 2009	Capacity of social, economic and environmental systems to cope with a hazardous event, trend or disturbance	Flood, drought, (also climate variability)	Multiple indicators constituting natural disasters, social and economic characteristics to assess exposure to natural disasters and climate variability, social and economic characteristics of households that affect their adaptive capacity, and current health, food, and water resource characteristics that determine their sensitivity to climate change impacts.
Antwi-Agyei et al. 2013a	Capacity of a system to cope with environmental disturbance	Drought	Vulnerability was characterized by identification of multiple indicators that highlight household livelihood vulnerability and links to different assets such as human, financial, natural, physical and social capitals.
Rurinda et al. 2014	Not explicitly defined for study	Not specific (climate variability)	Vulnerability was characterised by perceptions about changing climate parameters, perceptions of climate variability, onset of rains,

			temperature changes, drought occurrence and seasonal dry spells as well as components of farming systems affected by a hazard, cropping patterns, types and amounts of fertilizer use, crop yields.
Vilissa 2016	Not explicitly defined for study	Not specific (climate variability)	Households socioeconomic consequences to changing climate, timing, frequency and intensity of weather variability, livelihood impact of climatic stresses and agricultural production challenges at each stage of production (during sowing, transplanting, flowering and harvesting) characterized vulnerability.

Appendix Vc: Summary of outcomes and implications of vulnerability assessments from reviewed studies

Reference(s)	Key outcome of assessment	Recommendations given for future vulnerability research	Challenges mentioned as constraining response to vulnerability	Mention of adaptation/coping measures after assessment
Angula and Kaundjua, 2016)	Examined factors contributing to farmers vulnerability to impacts of climate change discussing various aspects of human vulnerability	Further research to develop scenario based on past historical climate variability and future projection to climate change as well as use a comprehensive approach to contextualize vulnerability assessment at local and household levels.	Unemployment, high adult and elderly population as well as high dependency on agricultural livelihood systems.	Existing coping strategies identified included reduction of agricultural activities, supplementary agricultural based livelihood, migration, and use of crop variety that is resistant to drought .
Antwi-Agyei *et al.*, 2013	Developed and applied Livelihood Vulnerability Index (LVI) at community and household levels to explore the nature of climate vulnerability	Recommendation for future vulnerability research was not given	Not mentioned	Not mentioned
Asare-Kyei *et al.*, 2017	Conducted risk assessment for multiple hazards and assessed risk perspective of Socio-Ecological Systems by quantifying indicators of vulnerability	Recommendation for future vulnerability research was not given	Not mentioned	Not mentioned

Bele, Sonwa and Tiani, 2014	Mainly developed appropriate responses to climate change vulnerability	Recommendation given for strengthening assessment of social and economic vulnerability to involve process identifying priorities for adaptation	Capacity to respond affected by poverty, armed conflicts, weak economies, low literacy rate, weak institutional support, lack of technology and information, limited marketing, farm input and low management capacities	Range of adaptation measures specified included diversification of crops and income sources, planting different crop varieties, changing planting and harvesting dates to correspond to the changing pattern of precipitation, crop irrigation and strengthening nonfarm income activities.
Cooper and Wheeler, 2017	Evaluated the vulnerability of farmers to climate risk	Need for future research capture dynamism of vulnerability	Inequality between wealthier and poorer farmers	Mentioned general adaptation measures practiced such as Employment in a non-farm livelihood (any income-generating activity which was not crop or livestock production), planting earlier, planting short-maturing varieties and/or strategic planning, directly through purchasing food, asking neighbours for food, subsisting on stored food, or indirectly by generating income and/or the liquidation of asset
Choptiany *et al.*, 2017	Measured resilience of a farm system to climate variability and change	Tool for vulnerability called 'SHARP' developed was commended for more application in vulnerability assessments	Geographical differences across communities limiting capacity to adapt	Not mentioned
Dasgupta and Baschieri, 2010	Evaluated the extent to which standard money metric measure of poverty contributes to climate change vulnerability and mainstreaming it to poverty reduction strategies.	More research needed for development of measures of vulnerability to climate change. Also, assessment for vulnerability was suggested too be integral part of poverty assessment and development of poverty reduction strategies	Not mentioned	Not mentioned
Derbile and File, 2016)	Explored potential of Community Risk Assessment (CRA) using perspectives of climate related	Recommendation for future vulnerability research was not given	Not mentioned	Not mentioned

	risks among local population.			
Derbile, File and Dongzagla, 2016	Explored how vulnerability of smallholders can be differentiated, risk factors farmers encounter and how they affect production	Recommendation for future vulnerability research was not given	Not mentioned	Not mentioned
Deressa, Hassan and Ringler, 2009	Analyzed probability of farmers falling below a given consumption level due to climate shock	Recommendation for future vulnerability research was not given	Not mentioned	Identified coping strategies used by households such as use of drought tolerant varieties, crop and livestock diversification, mixing crop and livestock production and membership of credit groups
Dumenu and Obeng, 2016	Assessed social vulnerability to climate change, climate change impacts and identified locally evolved adaptation strategies	Recommendation for future vulnerability research was not given	Not mentioned	Provided adaptation strategies practiced such as promoting non-farm economic activities alongside climate change resilient forms of agriculture, less expensive irrigation facilities, establishment of rural information hubs and use of mobile telecommunication services
Effah, 2014	Assessed vulnerability of studied community to drought and estimated adaptive capacity of community to drought	Recommendation for future vulnerability research was not given	Not mentioned	Study proposed some adaptation strategies to reduce vulnerability such as infrastructure provision (e.g. storage facilities, protecting harbors and landing sites) to improve fish market and quality, capacity building training programs, diversification and alternate sources of livelihoods
Etwire *et al.*, 2013	Assessed level of vulnerability of agricultural communities	Recommendation for future vulnerability research was not given	Lack of information about pending national disasters, fluctuations in rainfall, illiteracy, large family size, and inadequate access to foo and water resources affect households response to vulnerability	Not mentioned
Hahn, Riederer and	Developed LVI to estimate climate change vulnerability of	Developed the LVI but suggested for pragmatic	Not mentioned	Not mentioned

Foster, 2009	some districts in Mozambique involved in agricultural livelihoods	approach to be used to monitor vulnerability programme resources by introducing scenarios into the LVI model for baseline comparison while including refinement of social network subcomponent to move more accurately and evaluate social bonds.		
Grothmann *et al.*, 2017	Described identifying which factors determine vulnerability and how it can be addressed using Socio-Ecological Systems (SES) Framework	Suggested for more comparative research on local level and development of typologies similar in vulnerability assessments	Poor governance affecting conflicts between resource users as well as access to information and education constrains response to vulnerability	Not mentioned
Hotz, 2010	Analyzed how adaptive capacity is built by agrosilvopastoralists by analyzing vulnerability	Recommended for back up of assessments with adaptation projects as well as need for empirically downscaled climate change models to provide more clarity to local communities concerning future climate.	Not mentioned	Not mentioned
Jakpa, 2015	Assessed spatial-temporal variations of flood events by identifying triggering factors and adaptive capacity of smallholders	Recommended for a detailed assessment for flood vulnerability with wider understanding of physical elements.	High poverty level among smallholders limit their adaptive capacity	Not mentioned
Mapfumo *et al.*, 2013)	Explored state of resilience among smallholder farming	Recommendation for future vulnerability research was not given	Capacity to respond to vulnerability constrained by lack of access to information, improved technologies and poor support mechanisms to promote assimilation of new	Not mentioned

			knowledge	
Molefe and Masundire, 2016	Developed common understanding among various stakeholders of main hazards and issues of vulnerability in a SESs landscape	Recommendation for future vulnerability research was not given	Shortcomings in governance as well as structural inequalities, livelihood options and employment opportunities, poverty, high levels of HIV/AIDS	Used the assessment to build on some adaptive measures such as irrigating using underground water, supplementary feeding, water harvesting and livelihood diversification
Kienberger, 2012	Provided integrated spatial modeling of different dimensions of vulnerability, exploring factors of vulnerability and integrated expert knowledge for adaptation strategies	Recommended for the integration of knowledge and experiences from the ground into spatial modeling of vulnerability at subnational levels and also provide useful tool for mapping approaches for identifying needs and constraints to reduce vulnerability.	Not mentioned	Not mentioned
Ng'ang'a *et al.*, 2012	Identified factors that influence the nature and degree of peoples vulnerability to climate change at the household level by developing a vulnerability index with coping mechanisms identified	Recommended for more in-depth studies into the coping capacity of households using bottom-up assessment approaches employing primary data to enhance understanding of vulnerability and its underlying processes.	animal loss due to theft, insecurity/violence/fighting, lack of adequate food, crop failure and loss of access to land. lack of buyers for animals that households wished to sell; loss of house due to natural disaster, high input prices and conflict over water. Figure	Identified some local coping strategies such reducing the number of livestock, preventive health care for livestock, preventive health care for people, reduced mobility, reducing investments, saving, storing foods, introduction of irrigation and increasing water storage facilities. Increasing diversification by growing a variety of crops on the same plot or on different plots of land.
Nkondze, Masuku and Manyatsi, 2013	Investigated household vulnerability to climate change and factors affecting vulnerability of the households	Suggested need to conduct studies that will involve the use of panel data to reflect main impacts from due to climate change and in order to capture the impacts of climate change on households	Not mentioned	Not mentioned

Notenbaert *et al.*, 2013	Analysed vulnerability and coping strategies to climatic stress	Recommendation for future vulnerability research was not given	Not mentioned	Not mentioned
Okpara, Stringer and Dougill, 2017	Compared vulnerability of farming, fishing and pastoral livelihoods	Recommended for further refinement of vulnerability indicator frameworks	Not mentioned	Not mentioned
Oluoko-odingo, 2011	Showed linkages between food insecurity and poverty and how they relate to livelihoods and vulnerability discussing source of vulnerability	Recommended need for multidisciplinary approach to studying climate vulnerability to involve all livelihoods and land use.	Lack of land redistribution affecting access to land	Not mentioned
Pavageau, Butterfield and Tiani, 2013	Provided information about various vulnerability dimensions	Recommendation for future vulnerability research was not given	Not mentioned	Not mentioned
Raemaekers and Sowman, 2015	Identified threats to livelihoods, exposure and assessed vulnerability in relation to climate change and identify vulnerability of groups and coping strategies	Recommendation for future vulnerability research was not given	Not mentioned	Summary of coping strategies were given after assessment such as better organization at local level (i.e. cooperatives) and improvement of infrastructure and facilities including post-harvest facilities
Rurinda *et al.*, 2014	Investigated nature and sources of vulnerability of smallholders to climate variability and change	Recommendation for future vulnerability research was not given	Households limited access to resources	Identified some local coping strategies such as staggering planting dates, diversifying cropping cultivar, managing soil fertility, strengthening social safety nets,
Sallu, Twyman and Stringer, 2010	Assessed resilience and vulnerability of livelihoods.	Recommendation for future vulnerability research was not given	Not mentioned	Not mentioned
Sorey, 2011	Investigated how hydrology and climate influences vulnerability and adaptation of livelihoods	Suggested future assessments to consider different methods to implement adaptation strategies as a prerequisite to ensure secure future.	Not mentioned	Mentioned current adaptation and resilience strategies such as livelihood diversification, increasing soil fertility and plant drought resistant crops
Tesso,	Quantitatively determined the	Recommendation for future	Social factors (low literacy	Not mentioned

Emana and Ketema, 2012	magnitudes and patterns of rural households vulnerability to climate change	vulnerability research was not given	level and lack of awareness on hazard related issues).	
Tiani *et al.*, 2015	Used participatory method to assess vulnerability of study communities	Suggested studies of future vulnerability to and impact to be based on scenario analysis to help identify possible adaptation options under different possible future conditions	Not mentioned	Not mentioned
Umoh *et al.*, 2014	Analysed household vulnerability to climate variability	Recommendation for future vulnerability research was not given	Non availability of irrigation facilities, insufficient labour, lack of food storage, low income and inadequate means of transportation	Not mentioned
van Vliet, 2010	Identified sources of social vulnerability as perceived by local communities	Recommendation for future vulnerability research was not given	uncertainty of prices and production, the absence of savings facilities, and a gender imbalance in access to income. From a conservation perspective, the major risk is the shift of pressure on natural resources from inside the protected area to the border, with increased deforestation and destruction of key habitats	Not mentioned
Vilissa, 2016	Estimated vulnerability of a system by describing exposure, sensitivity and adaptive capacity	Recommendation for future vulnerability research was not given	Lack of access to reliable information, insufficient technology, low extension services, inability to access credit services and market barriers prevents response to vulnerability	Various adaptation measures were mentioned such as cleaning secondary and tertiary canals, opening field drainages, use of seed varieties tolerant of higher temperatures, use of mulching, sowing either under shady trees or along river beds, increasing water supply building drip irrigation systems, breeding new varieties, conservation agriculture, introduction of

				Integrated Pest Management (IPM) and biological control and introduction of agroforestry techniques
Westerhoff and Smit, 2009	Contributed to understanding and conceptualization of vulnerability in climate change contributing to practical efforts of enhancing adaptive capacity	Recommendation for future vulnerability research was not given	Not mentioned	Related study to adaptation strategies practiced such as use of family networks (migration) alternative non-traditional livelihood activities (e.g., charcoal production, hairdressing, etc.), reduction in household expenditure, changes in household organization (to compensate for lost labour), rainwater collection, use of hand-dug reservoir and increased dependence on social food networks.

Appendix VIa: Established LVI major components and sub-components for Keta and Nsawam Districts, Ghana

Major component & Sub-component	Explanation of sub-component	Status of sub-component	Descriptive remarks and relationship with vulnerability
Socio-demographic profile:			
• Dependency ratio	Ratio of the age of population below 15years and over 65years to the population between 19years and 64years of age.	Existing	All indicators under socio-demographic profile are already existing and adapted from Hahn, Riederer & Foster (2009). The higher the number of dependents, the less capacity households can adapt. Women usually have less capacity to adapt. Education also improves awareness and ability to manage the changing climate during production. Therefore higher percentages of socio-demographic profile indicators reflect less capacity of households to adapt and the higher the vulnerability.
• % Female - headed households	Percentage of households where the main adult is female. If a male head has been away from home for more than 6 months, the female is considered as the head of the household.	Existing	
• % Household head who has not attended school	Percentage of households where the head reported not attended school before	Existing	
Livelihood strategies:			
• %Households without member working outside community	Percentage of households that did not have a member who works outside the community for their primary work	Existing	Already existing indicators under livelihood strategies components were adapted from Hahn, Riederer & Foster (2009). This was extended to include livestock rearing (developed for the purposes of this study) to emphasize the relevance of the activity as the second most important livelihood and source of income after farming in both districts (GSS, 2014a)(GSS, 2014b). Diversification of income sources increases adaptive capacity and decreases risk of losses. Therefore, higher values of indices reflect lower adaptive capacity hence lower vulnerability.
• Average Agricultural • Livelihood Diversification Index	Inverse of (the number of agricultural livelihood activities +1) reported by a household,	Existing	
• % Households with agriculture as only source of income	Percentage of households depending on agriculture livelihood as only source of income.	Existing	
• % Households not rearing livestock	Percentage of households not keeping livestock for sales	New	

Social network:			
• % Households not having communication devices	Percentage of households that did not have access to mobile phone, radio and television.	Modified	Existing indicators under social network component within the LVI was either modified or a new one developed for the purposes of this study. Access to information through communication devices improves individuals' awareness of impending hazard. The indicator was modified to inquire those with access to 3 basic devices. In Ghana, FBOs and social groups are distinct from each other but play significant roles within communities hence as adapted from Panthi et al. (2016) in terms of cooperative/group groups were separate to emphasize their contributions. Ratio of a household money borrowing and lending adapted by Hahn, Riederer & Foster (2009) was modified to capture for a production season as a more refined measure and clarify limitation of exchange of non-monetary goods Hahn, Riederer & Foster (2009). Horticultural production in Ghana is capital intensive therefore access to governments' subsidized input will enhance adaptive capacity of farmers. Social network indicators strengthen adaptive capacity of farmers but higher constraints of this lower vulnerability.
• % Households not having access to government subsidy on production inputs	Percentage of households not having access to subsidized production inputs (fertilizer)	New	
• % Households not associated with any Farmer Based Organization (FBO)	Percentage of households who are not members of any FBO in their community	Modified	
• Average borrow: lend ratio	Ratio of a household borrowing money in the last production season to a household lending money in the last production season	Modified	
• % Household not associated with any community social group	Percentage of households who are not members of any social/welfare group in their community	New	
Health:			
• Average time to health facility	Average time households take to get to the nearest health facility (minutes)	Existing	All indicators for health component of LVI are already existing and adapted

• % Households with member having chronic illness • % Households where a member missed work/school due to illness	Percentage of households that subjectively reported at least a member with chronic disease. Percentage of households that reported at least a member who had to miss school/work in the last 2 weeks due to illness.	Existing Existing	from Hahn, Riederer & Foster (2009). The longer the time to a health facility, the more families are ill or miss school/work, the more sensitive and less vulnerability (Hahn, Riederer & Foster, 2009; Panthi et al., 2016). The indicators show how health impacts family and higher indices imply higher sensitivity
Food:			
• % Households mainly dependent on family farm for food • % Households that do not save planting materials • Average number of months households struggle to get food • Average Crop Diversity Index	Percentage of households that get their food primarily from their personal farms Percentage of households that do not save planting materials from their preceding harvest. Average number of months households struggle to feed their family. The inverse of (the number of crops grown by a household +1).	Existing Modified Existing Existing	Apart from modification of the indicator 'households saving planting materials' for the purpose of this study, all indicators under food component of the LVI are already existing and adapted from Hahn, Riederer & Foster (2009). Limited ability to save planting materials from preceding harvests reflects sensitivity of the earlier season to unfavourable production conditions including climate. The higher the indicators for food, the more sensitive households are and the higher the vulnerability (Hahn, Riederer & Foster, 2009; Shah et al., 2013).
Production:			
• % Households that do not get information on improved production methods • % Production output lost to post harvest losses • % Production output lost to pests and diseases	Percentage of households that do not receive information about improved production methods (including pest and disease control) Percentage of produce that respondents loose as a result of post harvest losses (quantity determined subjectively by respondents) Percentage of produce that respondents loose as a result of pest and disease attack (quantity determined subjectively	New New New	Indicators categorized under production were added as a new major component to the LVI developed for the purposes of this study. They are to emphasize on some production conditions and outcomes reflecting sensitivity of impacts of climate on horticultural producers/productivity. Horticultural crop production is

	by respondents)		sensitive to climate, which mostly impact negatively on horticultural crop productivity (McCarthy et al., 2001). In this context, higher indices reflect vulnerability as inadequate information on Good Agricultural Practices and higher percentages of production losses implies higher sensitivity.
• % Households' farm land under irrigation	Percentage of households' farm land with primary irrigation source for production	Modified	The greater demand from more irrigated land, shows potential for water scarcity for crop production purposes hence the higher the vulnerability. This indicator was adapted but modified from (Gbetibouo & Ringler 2009; Madhuri, Tewari & Bhowmick 2014)
Water:			
• % Households that reported water conflicts	Percentage of households that reported water conflicts in their community.	Existing	All indicators under water component of the LVI were adapted from Hahn, Riederer & Foster (2009). However time to water source was changed to measure distance from farmland to the water source for the purpose of this study. This adjustment was to show how distance to available water source determines the number of households that primarily uses irrigation (the longer the distance the more sensitivity). Overall, the higher percentages of indicators for water, the higher the sensitivity and more households are vulnerable
• Average distance to water source	Average distance (km) it takes from primary water source to farm lands	Modified	
• % Households without consistent water supply	Percentage of households reporting constant unavailability of water	Existing	
• % Households utilizing natural water source	Percentage of households that reported they depend on natural water sources such as rivers, lakes, wells, springs etc apart from public water system	Existing	
Natural disasters:			
• Average number of flood/drought events	Total number of floods and droughts subjectively reported by households in the past 5 years.	Modified	Even though indicators under natural disaster and climate variability

reported in the past 5 years			component was originally developed by Hahn, Riederer & Foster (2009), separation of natural disaster component from climate variability component as done in this study was adapted from Panthi et al. (2016). Indicators were modified from initial 6 years memory recall of events to 5 years to improve on potential recall bias noted by Hahn, Riederer & Foster (2009). Mainly, higher index values reflect higher exposure and increased vulnerability
• % Households that did not receive warning about expected natural disasters/events	Percentage of households that do not receive prior warning /information about the floods and droughts before occurrence in the past 5 years	Modified	
Climate variability:			
• Mean standard deviation of average monthly precipitation from 2007 to 2016	Averaged standard deviation of the monthly precipitation between 1998 and 2003 for each study district	Existing	Again, indicators under natural disaster and climate variability component was originally developed by Hahn, Riederer & Foster (2009) but separation of climate variability component as shown in this study was adapted from Panthi et al. (2016). Higher variability implies higher exposure of all indicators under this component. The first three indicators were adapted from Hahn, Riederer & Foster (2009), the following three indicators were also adapted from Panthi et al. (2016) while the last two indicators are new indicators developed for the purposes of this study. According to Alexander et al. (2006), number of warm spells duration and very heavy precipitation are indices, which show the extent which most extremes events are changing within a period and have significant impact on livelihoods. For
• Mean standard deviation of monthly average Maximum Temperature (T_{max}) from 2007 to 2016	Averaged standard deviation of the average monthly T_{max} between 2007 and 2016 for each study district.	Existing	
• Mean standard deviation of monthly average Minimum Temperature (T_{min}) from 2007 to 2016	Averaged standard deviation of the average monthly T_{min} between 2007 and 2016 for each study district.	Existing	
• Average number of Consecutive Dry Days (CDD) from 2007 to 2016	Average number of consecutive (3 days) dry spells between 2007 and 2016 for each district	Existing	
• Average number of Consecutive Wet Days (CWD) from 2007 to 2016	Average number of consecutive (3 days) wet spells between 2007 and 2016 for each district	Existing	

• Average number of warm days from 2007 to 2016	Average number of warm days (Tmax is greater than 90th percentile) between 2007 and 2016 for each district	Existing	horticultural production, changes in such extreme events challenges sustainable production and detrimental impacts on livelihoods (McCarthy et al., 2001; Deuter, 2008; Williams et al., 2017). Generally, the higher the frequency, the higher the exposure and vulnerability (Hahn, Riederer & Foster 2009; Shah et al., 2013; Panthi et al. 2016)
• Average number of cold nights from 2007 to 2016	Average number of cold nights (Tmin is less than 10th percentile) between 2007 and 2016 for each district	Existing	
• Average number of warm spells duration from 2007 to 2016	Average number of days with at least 6 consecutive days when Tmax is greater than 90th percentile between 2007 and 2016 for each district	New	
• Average number of very heavy precipitation from 2007 to 2016	Average annual total precipitation when rainfall is greater than 99th percentile between 2007 and 2016 for each district	New	

Notes: Modification of indicators was subjectively done with key stakeholders in study districts. Some of the indicators originally developed by Hahn, Riederer & Foster (2009) were omitted as they were considered less relevant to horticultural production and/or to the Ghana context studied. With the exception of indicators for climate variability component, data for evaluation of the sub-components were obtained from respondents during the field survey. Climate variability indicators were computed from daily climate data from Ghana Meteorological Agency.

Indicator selection for the various components as earlier noted was based on both review of literature (theory) and local stakeholders' judgment. This process resulted in modifying, introducing and maintaining some indicators of various components used in the original LVI and considered as more relevant to the context under study (Supplementary Table 1). For instance, indicators such as percent of households with orphans; average Malaria Exposure and Prevention Index; average receive and give ratio; percent of households that have not gone to their local government for assistance in the past 12 months; percent of households that do not save crops; inverse of the average number of liters of water stored per household and percent of households with an injury or death as a result of the most severe natural disaster in the past 6 years were considered not relevant in the local context studied and were removed. Details of additions and modifications of major and sub-components are summarized and described in Supplementary Table 1. Average agricultural livelihood diversification index and average crop diversity index sub-components where increase in share value is considered to reduce vulnerability (Hahn, Riederer & Foster, 2009), an inverse of the index was instead estimated to allow for consistency whereby, greater vulnerability is assigned to households with lower number of crop species or agricultural livelihoods.

Appendix VIb: LVI results for Keta and Nsawam Districts, Ghana

Major component	**Sub-component**	**Units**	**Keta**		**Nsawam**		**Maximum value in both districts**	**Minimum value in both districts**	**Major component index for Keta**	**Major component index for Nsawam**
			Actual Value	**Standardized**	**Actual Value**	**Standardized**				
Socio-	Dependency ratio	Ratio	0.911	0.182	0.844	0.169	5	0	Socio-	Socio-

demographic profile	% Female - headed households	Percent	10.4	0.104	11.7	0.117	100	0	demographic profile index = 0.129	demographic profile index = 0.154
	% Household head who has not attended school	Percent	10	0.100	17.5	0.175	100	0		
Livelihood Strategies	%Households without member working outside community	Percent	58.8	0.588	64.2	0.642	100	0	Livelihood Strategies Index = 0.485	Livelihood Strategies Index = 0.493
	Average Agricultural Livelihood Diversification Index	1/Number of livelihoods	0.505	0.261	0.522	0.287	1	0.33		
	% Households with agriculture as only source of income	Percent	54.2	0.542	63.8	0.638	100	0		
	% Households not rearing livestock	Percent	55	0.550	40.4	0.404	100	0		
Social network	% Households not having communication devices	Percent	49.2	0.492	62.9	0.629	100	0	Social network index = 0.538	Social network index = 0.554
	% Households not having access to government subsidy on production inputs	Percent	21.3	0.213	46.3	0.463	100	0		
	% Households not associated with any Farmer Based Organization (FBO)	Percent	57.9	0.579	44.2	0.442	100	0		
	Average borrow: lend ratio	Ratio	0.975	0.488	0.935	0.468	2	0		
	% Household not associated with any community social group	Percent	91.7	0.917	76.7	0.767	100	0		
Health	Average time to health facility	Minutes	34.79	0.246	30.87	0.218	140	0.5	Health index = 0.339	Health index = 0.306
	% Households with	Percent	45.1	0.451	47.6	0.476	100	0		

	member having chronic illness									
	% Households where a member missed work/school due to illness	Percent	32.1	0.321	22.5	0.225	100	0		
Food	% Households mainly dependent on family farm for food	Percent	92.5	0.925	89.2	0.892	100	0	Food Index = 0.512	Food Index = 0.467
	% Households that do not save planting materials	Percent	58.3	0.583	27.9	0.279	100	0		
	Average number of months households struggle to get food	Months	4.9	0.355	3.73	0.248	12	1		
	Average Crop Diversity Index	1/number of crops	0.229	0.186	0.316	0.447	0.5	0.167		
Production	% Households that do not get information on improved production methods	Percent	51.7	0.517	14.2	0.142	100	0	Production Index = 0.478	Production Index = 0.244
	% Production output lost to post harvest losses	Percent	10.84	0.155	12.18	0.174	100	0		
	% Production output lost to pests and diseases	Percent	27.37	0.304	17.84	0.198	100	0		
	% Households' farm land under irrigation	Percent	93.59	0.936	46.33	0.463	100	0		
Water	% Households that reported water conflicts	Percent	2.1	0.021	18.8	0.188	100	0	Water index = 0.178	Water index = 0.329
	Average distance to water source	Km	0.32	0.040	1.45	0.181	8	0		
	% Households without consistent water supply	Percent	35	0.350	81.7	0.817	100	0		

	% Households utilizing natural water source	Percent	30	0.300	13	0.130	100	0		
Natural disasters	Average number of flood/drought events reported in the past 5 years	Count	4.3	0.478	1.7	0.189	9	0	Natural disasters Index = 0.604	Natural disasters Index = 0.411
	% Households that did not receive warning about expected natural disasters/events	Percent	72.9	0.729	63.3	0.633	100	0		
Climate variability	Mean standard deviation of average monthly precipitation from 2007 to 2016	Millimeters	63.062	0.375	69.579	0.493	97.67	42.27	Climate variability Index = 0.344	Climate variability Index = 0.363
	Mean standard deviation of monthly average Maximum Temperature (T_{max}) from 2007 to 2016	Celsius	1.953	0.401	2.041	0.496	2.51	1.58		
	Mean standard deviation of monthly average Minimum Temperature (T_{min}) from 2007 to 2016	Celsius	0.959	0.366	1.031	0.439	1.58	0.60		
	Average number of Consecutive Dry Days (CDD) from 2007 to 2016	Days	48.60	0.346	40.80	0.244	99	22		
	Average number of Consecutive Wet Days (CWD) from 2007 to 2016	Days	3.90	0.180	4.90	0.380	8	3		
	Average number of warm days from 2007 to 2016	Days	12.832	0.376	6.205	0.166	32.60	0.94		
	Average number of	Days	7.224	0.556	5.980	0.412	11.20	2.24		

cold nights from 2002 to 2011									
Average number of warm spells duration from 2002 to 2011	Days	4.20	0.200	1.20	0.006	21	0		
Average number of very heavy precipitation from 2002 to 2011	Count	15.50	0.292	19.60	0.633	24	12		
							Livelihood Vulnerability Index N=480	**0.395**	**0.378**

Appendix VIc: Results of IPCC-LVI contributing factors for Keta and Nsawam Districts

Major components	**Major component scores**		**IPCC factors**	**IPCC contributing factor scores**	
	Keta	Nsawam		Keta	Nsawam
Climate variability	0.344	0.363	Exposure	0.391	0.372
Natural disasters	0.604	0.411			
Health	0.339	0.306	Sensitivity	0.379	0.339
Food	0.512	0.467			
Production	0.478	0.244			
Water	0.178	0.329			
Socio-demographic profile	0.129	0.154	Adaptive capacity	0.418	0.434
Livelihood Strategies	0.485	0.493			
Social network	0.538	0.554			
LVI	**0.395**	**0.378**			
LVI-IPCC				**-0.010**	**-0.021**

Appendix VIIa: Distribution of cost structure and parameter values

Adaptation Practice	Installation costs (US$/ha)		Maintenance costs (US$/ha)	
	Keta	Nsawam	Keta	Nsawam
Intercropping	Lognormal (494, 584)	Lognomal (305, 364)	Uniform (205, 287)	Uniform (267, 352)
Mixed cropping	Lognormal (56, 122)	Lognomal (140, 206)	Uniform (147, 210)	Uniform (55, 136)
Crop rotation	Lognormal (133, 180)	Lognomal (106, 140)	Uniform (63, 189)	Uniform (78, 133)
Irrigation	Lognormal (2146, 2738)	Lognomal (4860, 6200)	Uniform (384, 819)	Uniform (141, 438)
Fertilization	Lognormal (513, 615)	Lognomal (639, 786)	Uniform (42, 109)	Uniform (308, 550)

Appendix VIIb: Distribution of price structure and parameter values

Commodity	Price per unit (GHS/kg)	
	Keta	Nsawam
Okra	Uniform (2.05, 2.43)	Uniform (1.49, 1.78)
Pepper	Uniform (9.61, 11.42)	Uniform (9.59, 11.34)
Tomato	Uniform (3.51, 4.22)	Uniform (4.40, 5.27)
Onion	Uniform (3.74, 4.49)	Uniform (5.58, 6.71)
Carrot	Uniform (3.00, 3.64)	Uniform (3.02, 3.63)
Beans	Uniform (4.37, 5.23)	Uniform (4.35, 5.24)
Shallot	Uniform (3.32, 3.97)	-
Garden egg	-	Uniform (9.49, 11.34)
Maize	-	Uniform (1.46, 1.75)

Appendix VIIc: Values of initial yield (Y_0), estimated minimum, maximum and most likely final yield (Y_f) under the climate adaptation practices for the different crops studied.

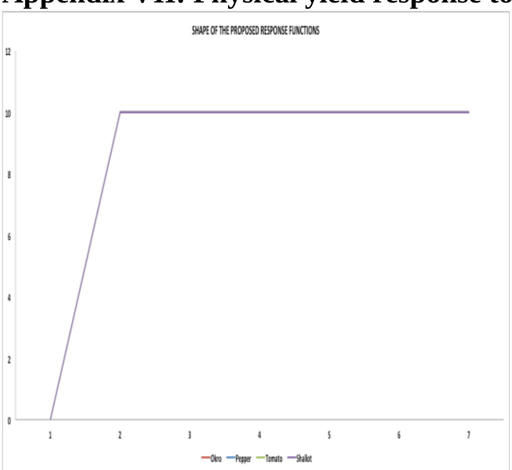
Crop	Keta					Nsawam				
	Y_0 (Kg/ha)	Y_f (Kg/ha)	% Change	Y_{min} (Kg/ha)	Y_{max} (Kg/ha)	Y_0 (Kg/ha)	Y_f (Kg/ha)	% Change	Y_{min} (Kg/ha)	Y_{max} (Kg/ha)
Intercropping										
Okra	1200	1700	42	1587.2	1814.7	1400	2000	43	1872.2	2138.7
Pepper	1000	1150	15	1054.6	1225.6	950	1050	11	983.14	1129.96
Tomato	975	1170	20	1076.9	1253.8	910	1300	43	1195.95	1385.04
Shallot	800	1168.8	46	1074.4	1253.8	-	-	-	-	-
Garden egg	-	-	-	-	-	675	877.5	30	817.61	940.45
Mixed cropping										
Pepper	0	950	-	884.36	1012.47	0	775	-	723.61	839.07
Tomato	3250	1170	-64	1094.23	1258.28	2860	1040	-63	960.78	1122.14
Shallot	0	962.5	-	893	1028.1	-	-	-	-	-
Onion	0	1003.75	-	936.22	1072.74	0	1095	-	1009.77	1164.42
Okra	-	-	-	-	-	0	900	-	838.64	960.07
Crop rotation										
Okra	900	1500	67	1387.39	1610.62	1000	1400	40	1310.33	1483.22
Tomato	1050	1170	11	1081.08	1268.47	1200	1330	11	1237.76	1433.74

Onion	823	1095	33	1022.07	1183.52	912.5	1186.3	30	1098.11	1265.91
Shallot	894	1031.25	15	963.7	1105.99	-	-	-	-	-
Beans	0	687.5	-	641.663	733.974	0	312.5	-	290.859	334.051
Garden egg	-	-	-	-	-	810	945	17	871.73	1011.59
Maize	-	-	-	-	-	0	625	-	576.128	668.671
Irrigation										
Pepper	800	1050	31	970.4	1119.14	750	1025	37	950.19	1093.55
Tomato	910	1430	57	1321.47	1532.03	-	-	-	-	-
Onion	910	1430	60	1330.58	1581.03	730	1460	100	1359.32	1550.54
Carrot	720	1530	113	1421.26	1640.00	1080	1350	25	1252.25	1442.7
Okra	-	-	-	-	-	800	1200	50	1109.87	1283.27
Fertilization										
Okra	800	2100	163	1960.98	2272.54	900	1800	100	1681.82	1914.22
Onion	730	1277.5	75	1179.15	1370.66	1003.75	2007.5	100	1859.84	2141.46
Pepper	1050	1200	14	1120.89	1291.99	1200	1500	25	1395.73	1619.58
Shallot	825	1237.5	50	1151.31	1335.18	-	-	-	-	-
Tomato	910	1375	51	1284.65	1470.37	-	-	-	-	-
Garden egg	-	-	-	-	-	945	1282.5	36	1197.89	1374.7

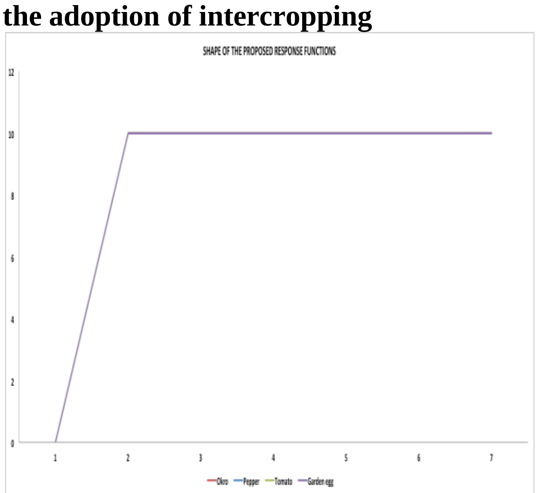
Appendix VIId: Summary of estimated changes in value of externalities for the climate adaptation practices per hectare per year

Externality	Intercropping		Mixed cropping		Crop rotation		Irrigation		Fertilization	
	Keta	Nsawam	Keta	Nsawam	Keta	Nsawam	Keta	Nsawam	Keta	Nsawam
Improved water	n. a	n. a	n. a	n. a	n. a	n. a	44.2	44.2	3.4	3.4
Crop biodiversity	1.6	1.6	1.6	1.6	1.6	1.6	2.1	2.1	2.1	2.1
Soil biodiversity	n. a	n. a	n. a	n. a	3.8	4.0	n. a	n. a	3.8	4
Soil erosion	3.8	0.3	3.8	3.1	5.7	4.7	n. a	n. a	3.8	3.1
Social Impact	5.3	5.8	45.3	48.4	2.7	1.0	n. a	n. a	n. a	n. a

Appendix VII: Physical yield response to the adoption of intercropping

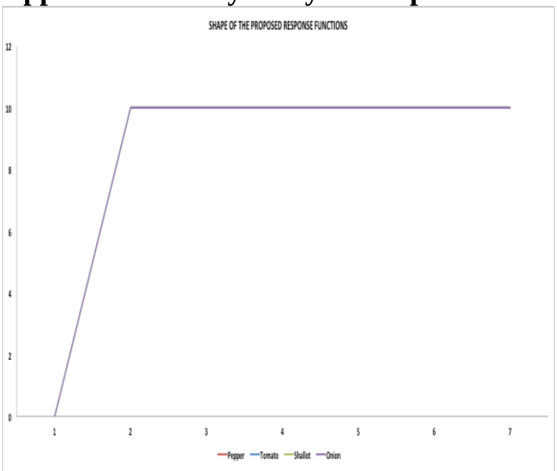


e: In Keta Municipality

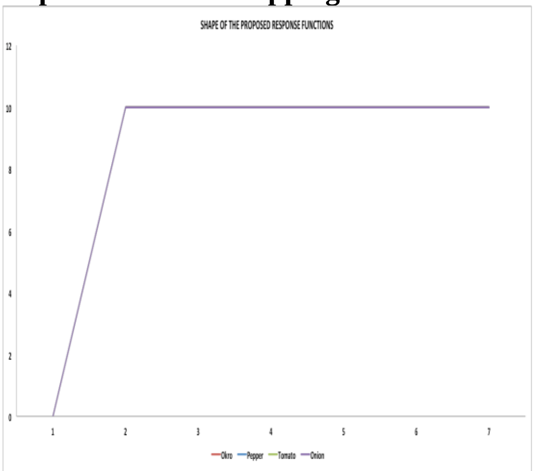


f: In Nsawam Municipality

Appendix VII: Physical yield response to the adoption of mixed cropping

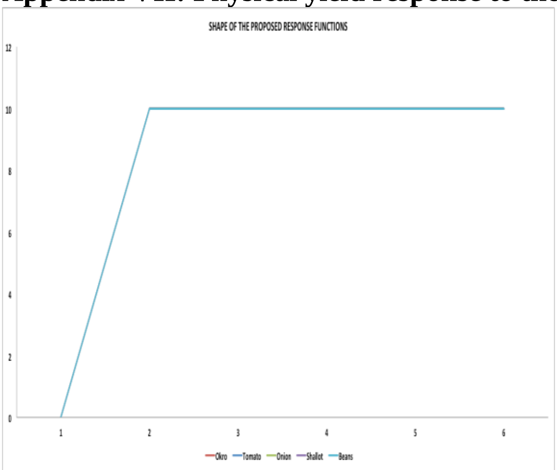


g: In Keta Municipality

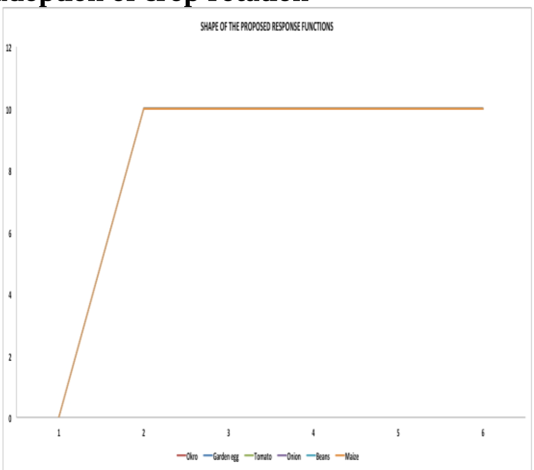


h: In Nsawam Municipality

Appendix VII: Physical yield response to the adoption of crop rotation

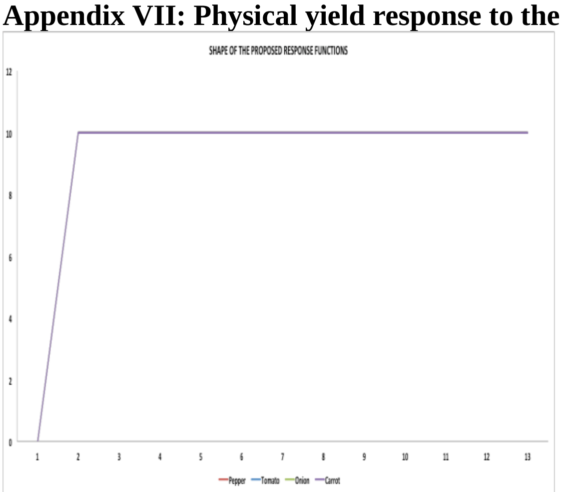


i: In Keta Municipality

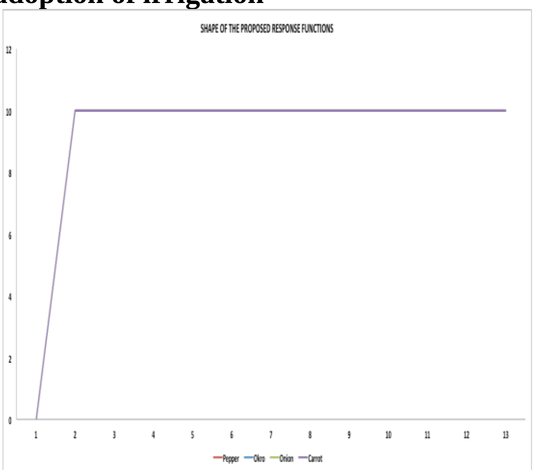


j: In Nsawam Municipality

Appendix VII: Physical yield response to the adoption of irrigation

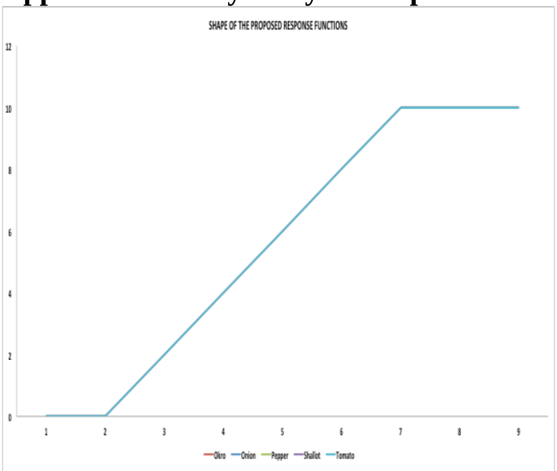


k: In Keta Municipality

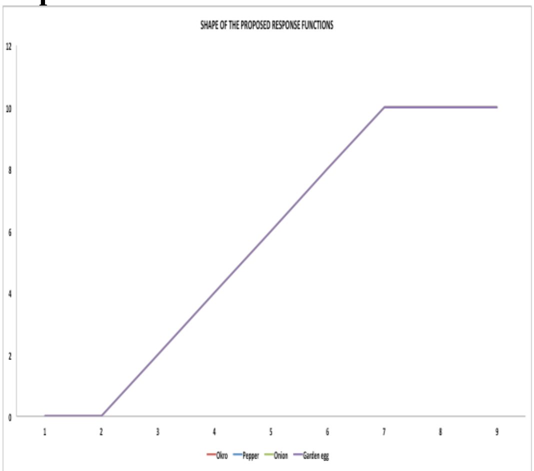


l: In Nsawam Municipality

Appendix VII: Physical yield response to the adoption of fertilization

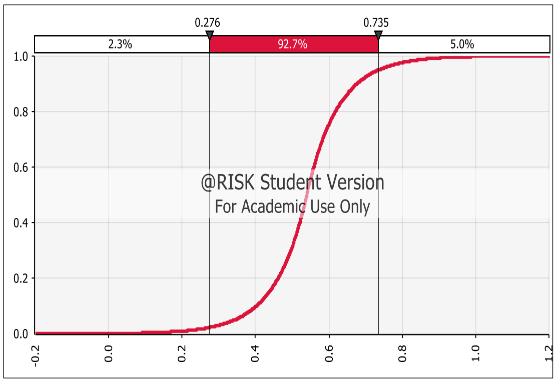


m: In Keta Municipality

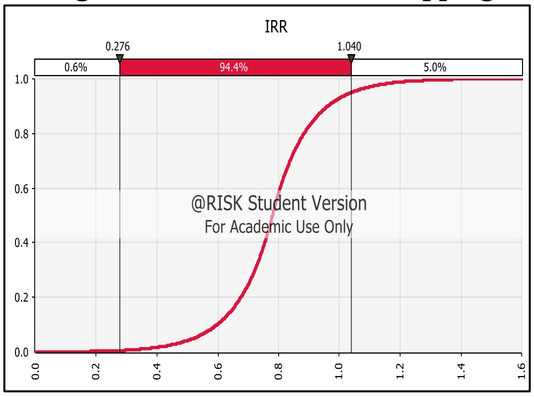


n: In Nsawam Municipality

Appendix VII: Cumulative distribution of the average value of IRR for intercropping

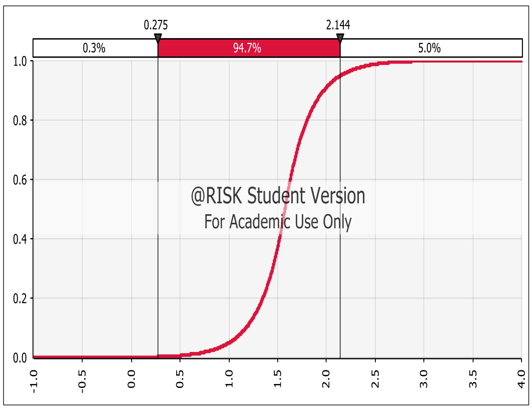


o: In Keta Municipality

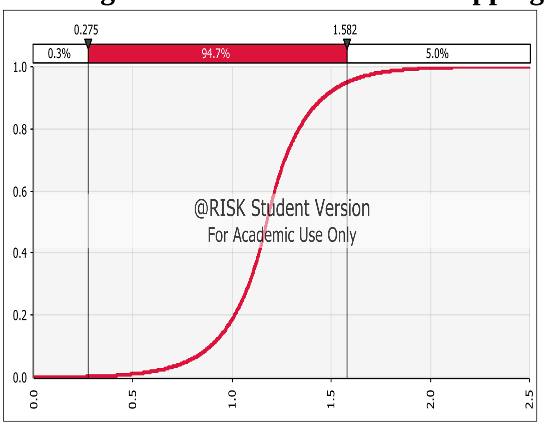


p: In Nsawam Municipality

Appendix VII: Cumulative distribution of the average value of IRR for mixed cropping

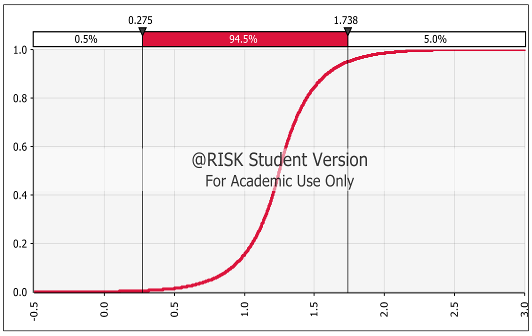


q: In Keta Municipality

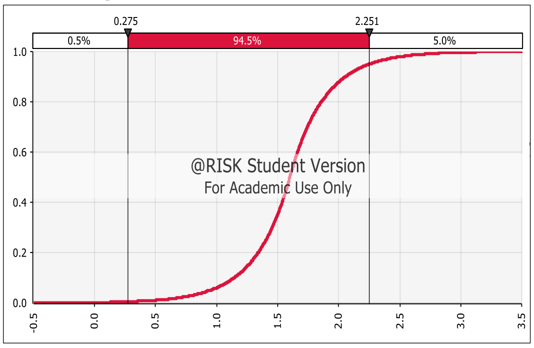


r: In Nsawam Municipality

Appendix VII: Cumulative distribution of the average value of IRR for crop rotation

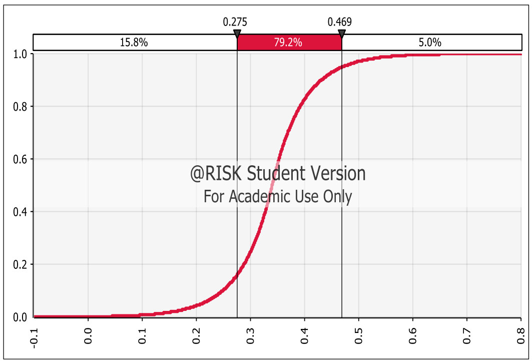


s: In Keta Municipality

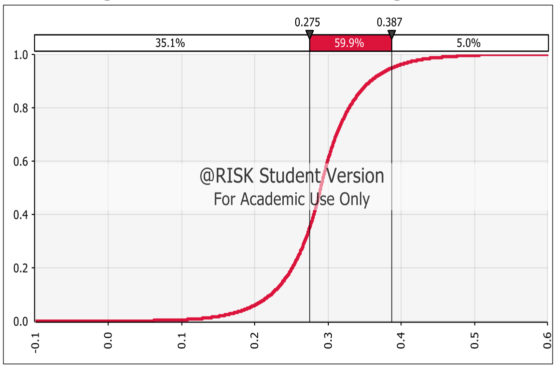


t: In Nsawam Municipality

Appendix VII: Cumulative distribution of the average value of IRR for irrigation

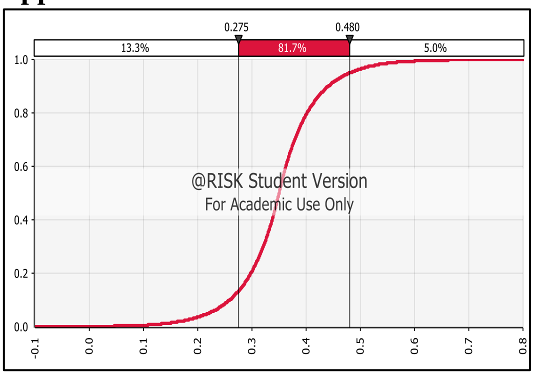


u: In Keta Municipality

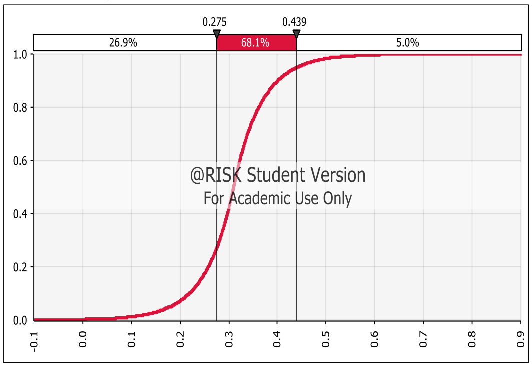


v: In Nsawam Municipality

Appendix VII: Cumulative distribution of the average value of IRR for fertilization



w: In Keta Municipality



x: In Nsawam Municipality

Appendix VIII: Some quotes on farmer's perspectives on climate variability and its effects at the study municipalities

- According to a farmer from Nsawam Municipality, "*cabbage does not fold at the expected time because of delayed rainfall season affecting the size of fruit harvested at the end of the season" -* a farmer from Nsawam

- "*Water has been drying up to the extent that since 2016 I build two or three traditional wells every year. I have also shifted from growing okro, which cannot withstand the changing weather to carrot* "– a farmer from Keta municipality

- "*I can't sit at home without food so I go to the seashore help fishmongers and they will pay me some money and small quantity of fish. I survive on this with my two grandchildren till the rains set in*" – a farmer from Keta municipality

- A farmer at Keta Municipality exclaimed, "*the closeness of the area to the sea and the changes in weather has increased the salinity of the underground irrigation water*".

- "*I have been keeping records of the amount of rainfall in the area since 1989 and per my observations, in the past 6 years the rainfall pattern has changed making it difficult to predict rainfall. The amount of rainfall has also reduced*" – a farmer from Nsawam Municipality

- "*The weather is very hot and that affects the growth of tomatoes. It reduces the yield and increase perishability after harvest*" - a farmer from Nsawam Municipality

- "*Rainfall and temperature changes have a great impact on my production activities. A combination of both conditions during the growing season impacts negatively on production levels and increases the perishability of the crop. This in effect results in high post harvest losses*" - a farmer from Keta Municipality

- "*Pests and diseases are abundant in the soil and they destroy my crops especially during hot temperature conditions*" a farmer from Keta Municipality.

- "*Due to inadequate access to information on good production activities, we sometimes abuse chemical usage. We require training on good agricultural practices*" - a farmer from Nsawam Municipality

- "*I am aware that deforestation contributes to climate change but the situation is worsening in our communities as urbanization and estate developers keep pulling down trees. This has resulted in faster drying up of water bodies used for irrigation*" - a farmer from Nsawam Municipality

- "*Since 2005, the amount of rainfall received has drastically reduced and affecting production activities*" - a farmer from Keta Municipality

- "*The frequency of droughts has increased significantly in the last 10years. We used to have drought once in every 5 or 10 but now it's almost every other year thus affecting planning especially on crop choice*" a farmer from Nsawam Municipality

Appendix IX – Socio-demographic/economic characteristics of farmers

Socio-Variable of farmers	Keta		Nsawam	
	Frequency	**Percentage (%)**	**Frequency**	**Percentage (%)**
		Age (years)		
20 - 29	21	8.8	14	5.8
30 - 39	66	27.5	61	25.4
49 - 49	60	25.0	83	34.6
50 - 59	61	25.4	40	16.7

> 60	32	13.3	42	17.5
Gender				
Male	215	89.6	212	88.3
Female	25	10.4	28	11.7
Educational level				
None	24	10.0	42	17.5
Basic	156	65.0	167	69.6
Secondary	47	19.6	24	10.0
Tertiary	13	5.4	7	2.9
Farm land size (ha)				
< 2.0	76	31.7	38	15.8
2.0 – 5.0	112	46.7	122	50.8
> 5.0	52	21.6	80	33.4
Years of farming experience				
< 10	52	21.7	37	15.4
10 – 20	92	38.3	98	40.8
> 20	96	40.0	105	43.8
Number of dependents				
0 - 4	131	54.6	115	47.9
5 - 9	104	43.3	122	50.8
> 10	5	2.1	3	1.3
Engagement in off-farm activity				
Yes	110	45.8	87	36.3
No	130	54.2	153	63.7
Source of farm land				
Inherited	96	40.0	44	18.3
Bought	0	0.0	5	2.1
Lease	12	5.0	29	12.1
Sharecropping	6	2.5	24	10.0
Hiring	126	52.5	138	57.5
Access to information on improved production methods				
Yes	100	41.7	205	85.4
No	140	58.3	35	14.6
Access to market				
Yes	170	70.8	213	88.7
No	70	29.2	27	11.3
Access to good road network				
Yes	154	64.2	43	17.9
No	86	35.8	197	82.1
Access to government subsidy				
Yes	189	78.8	129	53.7
No	51	21.2	111	46.3
Membership of Farmer Based Organization				
Yes	101	42.1	134	55.8
No	139	57.9	106	44.2
Membership of community social group				
Yes	26	10.8	46	19.2
No	214	89.2	194	80.8
Received Non-Governmental Organization support				
Yes	119	49.6	146	60.8
No	121	50.4	94	39.2
Access to information prior to flood/drought event				
Yes	65	27.1	88	36.7
No	175	72.9	152	63.3

Appendix X – Field survey & data collection in pictures (*Photo credit: Portia Adade Williams*)

Appendix VIIIIa: Participatory stakeholder engagements at the two study areas

Appendix VIIIIb: Data collection (Focus Group Discussions)


Appendix VIIIIc: Data collection (Questionnaire administration)


Appendix VIIIId: Data collection (Key Informant Interviews - with a community opinion leader [left] and a community chief [right])


Appendix VIIIIe: Data collection (Field observation)


Appendix VIIIIf: Data collection (Transect walks)