

**UNIVERSITY OF GHANA
COLLEGE OF BASIC AND APPLIED SCIENCES**

**VULNERABILITY AND ADAPTATION OF SMALLHOLDER
FARMERS TO CHANGES IN AGROECOSYSTEM SERVICES
AND CLIMATE IN SEMI-ARID REGIONS: THE CASE OF
NANDOM DISTRICT OF GHANA**

The image shows a large, faint watermark of the University of Ghana crest in the background. The crest is a shield-shaped emblem with a blue and gold color scheme. It features three golden wheat stalks at the top, a central golden cross with a diamond in the center, and two golden scrolls at the bottom. The shield is set against a light blue background.

ISHMAEL LENTE

**INSTITUTE FOR ENVIRONMENT AND SANITATION STUDIES
(IESS)**

JULY 2017

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COLLEGE OF BASIC AND APPLIED SCIENCES**

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AND CLIMATE IN SEMI-ARID REGIONS: THE CASE OF
NANDOM DISTRICT OF GHANA**

BY

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**THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF
GHANA, LEGON IN PARTIAL FULFILMENT OF THE
REQUIREMENT FOR THE AWARD OF PHD
ENVIRONMENTAL SCIENCE DEGREE**

**INSTITUTE FOR ENVIRONMENT AND SANITATION STUDIES
(IESS)**

JULY 2017

DECLARATION

I, Ishmael Lente, a student in the Environmental Science Programme, University of Ghana, Legon, hereby declare that this thesis is the result of my own research work carried out in Nandom District in the Upper West Region of Ghana. The analysis of all environmental samples was done at Ghana Atomic Energy Commission (GAEC), Department of Chemistry Laboratory and Ecological Laboratory of the University of Ghana under the watch of the Chief Technologist, Mr. Nash Owusu Bentil and Mr. Emmanuel Ansah, respectively. Prof. Christopher Gordon, Dr. Opoku Pabi and Dr. Daniel Nukpezah supervised the study.

Ishmael Lente, Doctoral Candidate

..... Date.....

3. Professor Christopher Gordon, Principal Supervisor

..... Date.....

4. Dr. Opoku Pabi, Supervisor

..... Date.....

5. Dr. Daniel Nukpezah, Supervisor

..... Date.....

ABSTRACT

Significant proportion of people in semi-arid regions depend on climate variables and agroecosystem services to sustain their livelihoods. These livelihoods are threatened by the deterioration of agroecosystem services and climate variability. Recently, many communities exhibit low levels of adaptive capacity due to maladaptation and the lack of understanding of the patterns of vulnerabilities. This study examined the scope and nature of vulnerability and adaptation strategies of smallholder households to recent changes in agroecosystem services and climate in semi-arid Upper West Region of Ghana, specifically in the Nandom District.

To achieve this goal, the study employed a participatory rural research design to collect and analyze the perceptions of smallholder farmers on vulnerability and adaptation options to the changes in agroecosystems and climate in the study area. Mixed methods involving qualitative and quantitative techniques were used to collect and analyze these data. The field work was undertaken between January 2016 and March, 2017 in four communities, namely, Billengangn, Gengenkpe, Naapaal and Ketuo using a questionnaire made up of semi-structured interviews with 194 households, focus group discussions with 125 farmers and key informant interviews with 10 relevant stakeholders drawn from government and non-government institutions. Soil and water samples were collected from selected farms, the Black Volta River, and selected boreholes and analyzed to assess the contribution of soil and water quality to livelihood strategies. Rainfall and temperature data spanning January 1984 to December 2014 were collected from the Ghana Meteorological Agency (GMet) to investigate the trends and variability. The livelihood vulnerability index (LVI) was employed to investigate the level of vulnerability of households in the study communities. A regression analysis

was performed to investigate the determinants of adaptation strategies of smallholder farmers.

The results of soil tests indicated that the soil was generally suitable for growth of crops in the study area. The levels of soil parameters ranged from marginal to adequate for crop production. The microbial analysis of the river water samples indicated high counts of total coliform and faecal coliforms. However, the results of the analysis of physico-chemical and trace metal parameters of river water samples with the exception of turbidity were within the TWQRs guidelines relating to domestic water use.

The results revealed that rainfall over the period showed much variability and did not show any visible trend with an average annual total rainfall of 981.2 mm. The analysis depicted that both annual mean minimum and maximum temperatures were increasing and the area was becoming warmer during the day and the night. The annual mean maximum and minimum temperatures were 34.7 °C and 22.1 °C.

Findings further showed that thirteen (13) key agroecosystem services underpinned the agricultural livelihoods of smallholder farmers in semi-arid Ghana. These included bushmeat, freshwater, fruits, soil fertility, fuelwood, fish, mushroom, non-timber forest products (NTFP), cropland, vegetation, leaves, honey, and animal products. These were perceived to have changed over the past 5 years, driven mainly by low rainfall, bush burning, and tree cutting. Access to climate information, acceptance of the current climate and agroecosystem services change and availability of agroecosystem services were significant determinants of adaptation strategies in the study area. The study has identified a number of issues which can help to improve the adaptability of smallholder farmers to changes in agroecosystem services and climate in this semi-arid region.

DEDICATION

This thesis is dedicated to my late Father, Mr. William Kofi Mabre, my Sister, Mrs Edith Uncle-Sam, and mother, Mad. Janet Adwoa Fordjour. Also to my wife, Mrs. Linda Delali Kpogli Lente and children, Mishael Nana Kofi Lente and Joel Anyorbukorni Lente, as well as Mr. Seth A. Larmie and Mr. Emmanuel Acquah.

ACKNOWLEDGEMENTS

In carrying out this thesis work, many people have assisted me in diverse ways and I owe them a lot of gratitude and appreciation. I wish therefore to express my warmest gratitude to my supervisors; Prof. Christopher Gordon, Dr. Opoku Pabi, and Dr. Daniel Nukpezah for their guidance and useful suggestions during every stage of this study.

This work was supported under the PhD Students Research Support Grant by the Adaptation at Scale in Semi-Arid Regions (ASSAR) project. The five-year ASSAR project is funded by International Development Research Centre (IDRC) and Department for International Development (DfID) through the University of Ghana, Legon. I wish to express special thanks to the above Institutions for the support.

I must sincerely thank the Institute for Environment and Sanitation Studies (IESS) of the University of Ghana, Legon for considering me to undertake this study and for the support.

Special thanks must go to Mr. Seth A. Larmie, the CEO of SAL Consult Limited for his support and encouragement as well as Mr Emmanuel Kofi Acquah, Nana Yaw Otu Ansah and all staff of SAL Consult Limited.

In addition, I thank Mrs. Linda Delali Kpogli Lente, my wife and my Sister Mrs. Edith Uncle-Sam. My gratitude goes to Mr. Amin Sulemana and Healthier Nana Ama for their support. To all others who contributed in one way or the other to make this work a reality. I am most grateful and God richly bless you.

GLORY BE TO GOD

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List of Abbreviations

ASSAR	Adaptation at Scale in Semi-Arid Regions
ASSAR-RDS	Adaptation at Scale in Semi-Arid Regions-Regional Diagnostic Study
CSIR	Council for Scientific and Industrial Research
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organization
FGD	Focus Group Discussion
GMet	Ghana Meteorological Agency
GPS	Global Positioning System
GSS	Ghana Statistical Service
KII	Key Informant Interviews
ICARDA	International Centre for Agricultural Research in Dry Areas
IPCC	Intergovernmental Panel on Climate Change
LVI	Livelihood Vulnerability Index
SSA	Sub-Saharan Africa
SPSS	Statistical Package for Social Sciences
TAMSAT	Tropical Application of Meteorological Satellite
THBC	Total Heterotrophic Bacteria Count
TWQRs	Target Water Quality Ranges
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
WB	World Bank
WHO	World Health Organization
WMO	World Meteorological Organization
WRC	Water Resources Commission
WRI	Water Research Institute

CHAPTER ONE: INTRODUCTION

1.1 Background

In semi-arid regions, communities and households face two key challenges related to the concept of “double exposure” (O’Brien & Leichenko, 2000; Leichenko & O’Brien, 2008). The first is the direct impact of climate change and extreme weather events and the second is the indirect effect of agroecosystem services change (Boon & Ahenkan, 2011; Bofo *et al.*, 2014; Egyir *et al.*, 2015; Bofo *et al.*, 2016).

According to Baird & Cann (2012), climate change refers to the continuous increases in average air temperatures and changing weather patterns including rainfall, humidity and wind resulting in drought for some areas and flooding for others. This may be attributed directly or indirectly to anthropogenic activities that increase the levels of carbon dioxide and other greenhouse gases in the atmosphere.

Globally, climate change or short-term fluctuations in weather conditions, pose the greatest threat to the livelihood systems of smallholder farmers in dryland environments like semi-arid regions (IPCC, 2007a). These threats have become widespread through the continuous alteration of agroecosystem services in these areas (Boon & Ahenkan, 2011; Egyir *et al.*, 2015). In most cases, smallholder households in Sub-Saharan Africa bear the greatest adverse impacts of these changes (Rurinda *et al.*, 2014; Adenle *et al.*, 2015; Adu-prah & Ko, 2015; Apurv *et al.*, 2015; Nyantakyi-Frimpong & Bezner-Kerr, 2015; Vignola *et al.*, 2015) due to over-dependence on climate variables and agroecosystem services. Semi-arid regions or dry sub-humid bands form one of the sub-classes of drylands in the world supporting hundreds of millions of farmers (Morten, 2007). Many farmers in semi-arid regions of Africa and Asia depend heavily on the

climate and agroecosystem services for their livelihoods and well-being (Boon & Ahenkan, 2011; Burkhard *et al.*, 2012; Smith & Sullivan, 2014; Egyir *et al.*, 2015; Notte *et al.*, 2017). As such these farmers are particularly vulnerable to climate-related impacts, especially changes in rainfall and temperature as well as agroecosystem services change. Agriculture within Africa and Asia is usually practised under smallholder farming systems, where the farmers' farmland holdings are relatively limited in size, not more than 2 hectares (Rurinda *et al.*, 2014; Vignola *et al.*, 2015). Farmlands constitute important entitlements that determine the endowments and wealth of the smallholder farmers. The cropland is the major asset of the farmers and serves as the source of food and income (Rurinda *et al.*, 2014).

Agriculture is largely the backbone of economies within Sub-Saharan Africa (SSA), providing employment and food for the growing population. However, it is noted to be dependent on climate variables and agroecosystem services (Boon & Ahenkan, 2011) and therefore, any change in these variables and services negatively effects food production systems and economies within these countries and the world at large. The changes in agroecosystem services have resulted in many negative transformations for smallholder farmers in Sub-Saharan Africa (Codjoe & Owusu, 2011; Sinare *et al.*, 2016). Harvey *et al.* (2014) supported this claim and noted that the poor smallholder farmers are those most vulnerable to the adverse impacts of climate change and variability.

Several studies carried out in semi-arid areas of northern Ghana indicated that smallholder farmers contribute immensely to food production (Morten, 2007; World Bank, 2007; Antwi-Agyei *et al.*, 2011; Antwi *et al.*, 2015; Nyantakyi-Frimpong & Bezner-Kerr, 2015). In addition, households lack social safety nets and possess low adaptive capacities to climate-related risks and shocks (Etwire *et al.*, 2013; Antwi *et al.*,

2015; ASSAR-RDS, 2015; Nyantakyi-Frimpong & Bezner-Kerr, 2015). Nyantakyi-Frimpong & Bezner-Kerr (2015) further observe that farmers in northern Ghana are restricted in the benefit of agroecosystem services besides their financial, political and social constraints. In a particular district, community or household, individuals experience varied impacts of climate change and related events due to differences in access to livelihood assets in respect of biophysical, socioeconomic and institutional factors (Nyantakyi-Frimpong & Bezner-Kerr, 2015). Several studies have assessed the impacts of climate change on smallholder farmers and attributed their vulnerability largely to socioeconomic factors such as access to credit and markets without due consideration of the contribution of agroecosystem services to enhancing the livelihood strategies and well-being in semi-arid areas (Boon & Ahenkan, 2011; Arnall & Kothari, 2015; Egyir *et al.*, 2015; Nyantakyi-Frimpong & Bezner-Kerr, 2015).

Despite these observations, most climate change literature have concentrated on scenario-based and sectoral impacts of climate change to the detriment of enhancing understanding of the main drivers that undermine adaptive capacities and exacerbate vulnerability of smallholder farmers at local communities (Nyantakyi-Frimpong & Bezner-Kerr, 2015). Many adaptation strategies are not widespread, hence farmers are unable to adopt most of the introduced strategies and available adaptation options (Conde *et al.*, 2007; Codjoe & Owusu, 2011). Adaptation is the process of adjusting and responding to actual or potential effects of climate change and variability so as to ameliorate the risks and take advantage of opportunities emanating from these changes (IPCC, 2007b). Recent changes in agroecosystem services has further limited the ability of farmers to adapt to climate change (De Fraiture *et al.*, 2007; Smith & Sullivan, 214; Egyir *et al.*, 2015). For instance, the reported low yield of cereals in semi-arid areas may be due to lack of pollinators and not necessarily climate change and variability or

the absence of improved seeds (Smith & Sullivan, 2014). Usually, climate change studies place little emphasis on the consequences of agroecosystem services change on the vulnerability and well-being of smallholder farmers.

In semi-arid areas of Ghana, smallholder agricultural production will be compromised because of the changes in agroecosystem services and climate change (Boafo *et al.*, 2014). Smallholder farmers depend solely upon agroecosystem services and rainfall for their farming activities (Antwi *et al.*, 2015). The two main agroecosystem services that influence agricultural livelihoods in dryland areas are soil fertility and water quality (Boon & Ahenkan, 2011; Egyir *et al.*, 2015). Studies suggest that the synergistic impacts of ongoing agroecosystem services change and climate change will pose several threats to smallholder farming households by decreasing their adaptive capacities and increasing exposure and sensitivity (Turner II *et al.*, 2003; Luers, 2005; Smit & Wandel, 2006; Smith & Sullivan, 2014; Egyir *et al.*, 2015).

Disaster risk assessment conducted by the Ghana National Disaster and Mobilization Organization (NADMO) and the United Nations Development Programme (UNDP) in 2015 classified the study District as drought prone with about thirty communities cited as being flood risk areas. Furthermore, due to the extent of climate variability and the underlying landscape vulnerability within different social groups, farmers in these areas are unable to predict the onset of the rainy season to assist in the planning of their farming activities and adopt appropriate adaptation strategies (Antwi-Agyei *et al.*, 2012).

1.2 Research Problem

In semi-arid regions, significant populations depend on agroecosystem services for sustaining their livelihoods (smallholder agricultural livelihoods) (Boon & Ahenkan, 2011; Smith & Sullivan, 2014). However, with the increasing adverse effects of climate change and variability on agroecosystem services (Swinton *et al.*, 2007; Zhang *et al.*, 2007; Power, 2010; Rockstrom *et al.*, 2010; IPCC, 2014; Egyir *et al.*, 2015; Sinare *et al.*, 2016), there will be negative livelihood transformations for smallholder agriculture and households in these areas (Boon & Ahenkan, 2011; Smith & Sullivan, 2014).

Largely, agricultural livelihoods and economies of the world, and particularly developing countries, depend heavily on the reliable flow and interactions of multiple agroecosystem services (MEA, 2005; Smith & Sullivan, 2014). Agroecosystem services form the foundation of agricultural livelihoods of semi-arid farmers, who are mostly smallholders (i.e. hold small plots of not more than 2 hectares, use family labour, low technology and low capitalization) (World Bank, 2007; FAO, 2010; Boon & Ahenkan, 2011).

Changes in agroecosystem services directly affect crop production and the extent of vulnerability and well-being of smallholder farming households in dryland regions (Conde *et al.*, 2007; De Fraiture *et al.*, 2007). Loss of these services greatly influences livelihood strategies and development (Costanza *et al.*, 1998; MEA, 2005; Boon & Ahenkan, 2011; Smith & Sullivan, 2014; Egyir *et al.*, 2015) under the changing climate. Notte *et al.* (2017) note that greater than two-thirds of the world's agroecosystem services is being degraded and altered leading to the reduction of future human well-being through scarcity of basic materials for a good life and low biological production. Consequently, good social relations for semi-arid farmers are compromised by a

situation described as environmental refugees where people, especially the youth (aged between 18 and 25 years) migrate to larger cities due to changes in agroecosystem services and lack of viable alternative livelihoods aside farming (Antwi-Agyei *et al.*, 2012; Etwire *et al.*, 2013).

In addition, there is a shift in the rain season towards later rainfall while rainfall projections also vary considerably for various regions including semi-arid (Ghana Climate Change Report, 2015; Kankam-Yeboah *et al.*, 2013; ASSAR-RDS, 2015). Available agroecosystem services, including forest products and non-timber forest products, soil and surface water supply are being threatened by rising temperature, extreme rainfall variability, pollution from agricultural activities and climate-related extreme events (Rockstrom *et al.*, 2010; Boon & Ahenkan, 2011; Egyir *et al.*, 2015).

Climate change and extreme weather events such as drought, floods, prolonged dry spells, inter-decadal, interannual rainfall variability have devastated agroecosystem services and food production systems (Antwi-Agyei *et al.*, 2012; Antwi *et al.*, 2015; ASSAR-RDS, 2015). Semi-arid areas have been the most affected areas where rain-fed agriculture is most sensitive and vulnerable to extreme weather events (ASSAR-RDS, 2015) as is the case of semi-arid Ghana (Etwire *et al.*, 2013; ASSAR-RDS, 2015).

Sub-Saharan Africa (SSA) and Asia have experienced the worst of the extreme weather events; meanwhile, these regions are projected to witness further severe food shortages because of the changing climate (IPCC, 2007a; 2014). Consequently, smallholder farmers have over the years tried on their own to adapt to these global processes (i.e. agroecosystem services change and climate change) by the adoption of both indigenous (traditional) and introduced strategies (Maddison, 2006; Antwi-Agyei *et al.*, 2012; Etwire *et al.*, 2013) to improve their well-being. However, the current adaptation

options available to farmers are not widespread to improve their agricultural livelihoods and well-being and may be due to the growing evidence of agroecosystem services deterioration (ASSAR-RDS, 2015).

In Ghana, and the Upper West Region, Antwi-Agyei *et al.* (2012), Etwire *et al.* (2013), Antwi *et al.* (2015), and Nyantakyi-Frimpong & Bezner-Kerr (2015) among others report that farmers in northern Ghana can no longer predict the onset of the rainy season, hence are unable to plan their farming activities. This situation has led to farmers extending farming onto flood prone lands and increasingly marginal lands thereby making them more vulnerable to extreme weather events.

Furthermore, household-level primary data on the nature of vulnerability of households to changes in agroecosystem services and climate change and variability in semi-arid Ghana is inadequate. Hence, the adaptation strategies of these farmers and their households have not been effective in reducing the actual or potential negative impacts of climate change and improve the adaptive capacities of smallholder farmers. (Boafo *et al.*, 2014; Nyantakyi-Frimpong & Bezner-Kerr, 2015). The level of vulnerability depends upon availability and utilization of agroecosystem services (soil fertility, freshwater, food, bushmeat, medicinal plants, and fuelwood) that underpin the livelihoods strategies of these farmers (Boon & Ahenkan, 2011; Smith & Sullivan, 2014) as well as climate variables (Boafo *et al.*, 2014; Boafo *et al.*, 2016).

In addition, studies show that responses and adaptation strategies to climate threats are not well understood and inadequate in addressing the vulnerabilities of smallholder farmers and their households (Etwire *et al.*, 2013; ASSAR-RDS, 2015; Nyantakyi-Frimpong & Bezner-Kerr, 2015). This is because most of these strategies are not developed from empirical household-level data from the local communities. Moreover,

in developing adaptation strategies for farmers, often little or no attention is paid to the role of agroecosystem services to increasing adaptive capacities at the local scale (Boon & Ahenkan, 2011; Smith & Sullivan, 2014; Nyantakyi-Frimpong & Bezner-Kerr, 2015).

1.3 Research Questions

The main research question: ‘How are smallholder farmers’ vulnerabilities and adaptation strategies shifting due to changing agroecosystem services and climate in semi-arid areas in the Upper West Region of Ghana?’ and is answered by addressing the following specific questions:

1. How does soil and water quality contribute to livelihood strategies of smallholder farmers in the study communities?
2. How do smallholder farmers perceive rainfall and temperature trends and variability in study communities and the effects on their livelihood strategies?
3. How do smallholder farmers perceive trends in the availability, utilization and changes in agroecosystem services in the study communities?
4. What is the level of vulnerability of smallholder farmers to recent agroecosystem services change and climate variability in the study communities?
5. How do smallholder farmers perceive adaptation options and knowledge sources on adaptation available for managing agroecosystem services and climate change?

1.4 Objectives of the Study

The overarching goal is to examine the scope and nature of vulnerability and adaptation strategies of smallholder farming households to changes in agroecosystem services and climate in semi-arid areas of the Upper West Region of Ghana.

The specific objectives of the study are to:

1. Assess the contribution of soil and water quality to livelihood strategies of the study communities.
2. Examine rainfall and temperature trends and variability and how these are perceived by the study communities in their selection of livelihood strategies.
3. Investigate smallholder farmer perceptions on trends in the availability, utilization and changes in agroecosystem services in study communities.
4. Assess the level of vulnerability of smallholder farmers stemming from recent changes in agroecosystem services and climate variability.
5. Investigate how smallholder farmers perceive adaptation strategies and knowledge sources on adaptation available for managing agroecosystem services and climate change.

1.5 Justification of the Study

Semi-arid regions are marked by rain-fed agriculture and smallholder livelihood systems that depend heavily on reliable flow of agroecosystem services. According to Rockstrom *et al.* (2003), about 80 percent of the agricultural land worldwide is under rain-fed agriculture with generally low crop yield levels and high on-farm water and

soil health losses. Meanwhile, climate change and variability continue to affect the availability, quality and use of agroecosystem services.

The IPCC in its Fifth Assessment Report, AR5 (IPCC, 2014), highlights the following key messages for Africa's changing climate:

- Africa's climate is already changing and the impacts are already being felt;
- Further climate change is inevitable in the coming decades;
- Climate change poses challenges to growth and development in Africa;
- Adaptation will bring immediate benefits and reduce the impacts of climate change in Africa;
- Adaptation is fundamentally about risk management;
- Adaptation experience in Africa is growing;
- Some low-carbon development options may be less costly in the long run and could offer new economic opportunities for Africa;
- Africa stands to benefit from integrated climate adaptation approaches; and
- International cooperation is vital to avert dangerous climate change and African governments can promote ambitious global action.

According to the report (AR5), enhancing understanding of the constraints and bottlenecks to adaptation and transformational change are critical knowledge gaps. Many climate studies in northern Ghana point out limits of adaptation at the household and community levels, yet the dynamic interactions between agroecosystem services, socioeconomic, and socio-political barriers remain poorly understood (Antwi-Agyei *et al.*, 2012; Etwire *et al.*, 2013; Nyantakyi-Frimpong & Bezner-Kerr, 2015). Social vulnerability analysis approaches alone have not improved the understanding of the

dynamics of smallholder vulnerability in the context of biophysical and relational factors that drive vulnerability and contribute to bridging this knowledge gap.

Over the past five decades, semi-arid areas, especially, in West Africa are exposed to prolonged dry spells, drought and devastating floods (Rockstrom *et al.*, 2003, 2010; Agrawal, 2008; Rockstrom *et al.*, 2010; Codjoe & Owusu, 2011; Antwi-Agyei *et al.*, 2012; Komba & Muchapondwa, 2012; IPCC, 2014). The combined impacts of agroecosystem services deterioration and climate change continue to lower adaptive capacities and resilience of several local communities and make them more vulnerable (IPCC, 2007a, 2014).

The impacts of climate change are observed through the occurrences of extreme weather events (Phillipo, Bushesha, & Mvena, 2015) that have affected crop production. These incidences have led to changes in the already limited agroecosystem services, especially soil fertility and freshwater supply and quality that form the base of the livelihoods strategies households in local communities (Boon & Ahenkan, 2011; Smith & Sullivan, 2014; Egyir *et al.*, 2015).

To address these risks and stresses, information on the patterns of vulnerability and adaptation strategies of smallholder farming households to agroecosystem services and climate change need to be acquired and better understood for policy decision-making; This will enable effective integration of outcomes into local and national policies and plans. Greater integration of climate and agroecosystem service information would help to prioritize other resources, strengthen institutional capacities and support responsive strategies for effective implementation of adaptation frameworks (Phillipo, Bushesha, & Mvena, 2015) at the local level.

There have been several studies conducted on climate change and smallholder farmers in Ghana, particularly in the Upper West Region (Antwi-Agyei *et al.*, 2011; Antwi *et al.*, 2014; Antwi *et al.*, 2015; Nyantakyi-Frimpong & Bezner-Kerr, 2015), which indicate that adaptation strategies whether indigenous or introduced are not robust and farmers are unable to adapt for improving crop production. Therefore, research is strongly needed to explore the patterns of vulnerability to agroecosystem service and climate changes to improve the adaptation strategies of smallholder farmers in semi-arid areas of West Africa and Ghana. Etwire *et al.* (2013) in a study conducted in the three regions of northern Ghana to assess vulnerability of smallholder farmers to climate change, conclude that the Upper West Region was most sensitive and vulnerable to climatic risks as a result of the region's lack of access to food and water resources.

There is also the need to explore and understand the agroecosystem services that support crop production and underpin the livelihood strategies of smallholder farmers in local communities. The sharply increasing pressure and demand placed on agroecosystem services in Sub-Saharan Africa, particularly northern Ghana because of the ongoing climate change and variability requires adaptation planning across scales.

In addition, research is required to providing understanding of the factors that hinder adoption of adaptation strategies among smallholder farmers within the agricultural landscapes in arid and semi-arid areas. Only a few studies analyzed vulnerability of smallholder farmers using the agroecosystem services concept (Smith & Sullivan, 2014). Understanding the impacts arising from agroecosystem services change and the patterns of vulnerability is required to identify feasible and practical adaptation strategies for different groups of smallholder farmers within households in local communities.

This study enhances awareness and understanding of vulnerability, adaptation options, and adaptive capacity of local communities to the impact of recent changes in agroecosystem services and climate, whilst providing relevant household-level baseline data for developing and implementing appropriate and resilient interventions by policy-makers and other stakeholder groups.

1.6 Organization of the Thesis

The thesis consists of six chapters. Chapter 1 is the introduction and entails background, problem statement, research questions, objectives and the justification of the study. Chapter 2 consists of definition of terms, the literature review and research conceptual framework as well as limitations of the study, followed by Chapter 3, which comprises the materials and methods. Chapter 4 presents the results obtained from the research, whilst Chapter 5 provides the discussions of the results based on the objectives of the study. This discusses the results on soil and water quality analysis, rainfall and temperature trends and variability in study communities, smallholder perceptions on trends in the availability, utilization and changes in agroecosystem services, analysis of the level of smallholder farmer vulnerability to agroecosystem services and climate variability, adaptation strategies of smallholder farmers and the knowledge sources on adaptation available for managing recent changes in agroecosystem and climate. Finally, Chapter 6 presents the conclusions and the recommendations of the research findings.

CHAPTER TWO: REVIEW OF LITERATURE

2.1 Definition of Terms

Smallholder Farmers

Smallholder farmers include farmers who possess or own relatively smaller (not more than 2 hectares) farmlands or plots for the cultivation of mainly subsistence crops, depending largely on household or family hands or labour (Morton, 2007; World Bank, 2007). Smallholder farming systems are those characterized by small farmlands, low technology, no mechanization and low investments. Smallholder farming describes rural producers mostly existing in developing countries and for whom the farm forms their principal or only source of income.

Livelihood

Livelihood is the totality of the means by which households make a living from their engagement and lifetime activities (Chambers & Conway, 1992; Antwi-Agyei *et al.*, 2012). It is usually the means of securing the basic necessities of life such as food, water, fuelwood, shelter and clothing.

Shocks

Shocks refer to the sudden events that impact on livelihood security (Cooper *et al.*, 2008). These events include, for example, a fire that destroy grazing pasture and crops, outbreak of diseases such as Cerebrospinal Meningitis (CSM), floods, theft of livestock and communal conflicts.

Stresses

Stresses refer to long-term patterns of events that sabotage normal livelihood efforts and adversely affect the survival of each member of the household (IPCC, 2001; Adger, 2006; Smith & Wendel, 2006). Stresses include a steady decline in quality and quantity of agroecosystem services, climate change, seasonal variability, frequent cholera incidences and political instability.

Coping Strategies

These are the short-term responses households develop to specific shocks to contain challenging conditions until things normalize (Yohe & Tol, 2002; Dinar *et al.*, 2008; Campbell *et al.*, 2011; Engle, 2011). For instance, active members of the households may cope with drought or flood by migrating to other cities to work to remit their families back home.

Adaptive Strategies

These are long-term and permanent changes in strategy or behaviour and practices in response to continuing stresses (Fraser, 2007). Households respond to agroecosystem services change or climate change by altering their cropping systems or adopting new innovations and practices. Farmers may respond to the changing climate by establishing irrigation systems for dry season farming. Adaptive strategies are generally enabled by availability and access to assets such as fertile soils and forest products and the extent of adaptive capacities (Antwi-Agyei *et al.*, 2012).

2.2 Climate Change and Climate Variability

Climate change is the significant and persistent change in the mean state of the climate system as attributed to direct or indirect anthropogenic activities that emit greenhouse gases at high concentrations which alter the composition of the global atmosphere observed over long period of time, usually thirty years and above (IPCC, 2007a). The continuous increase in average global air temperature and changing weather patterns have resulted in extreme events such as drought and flooding in several areas of the world (Baird & Cann, 2012). Anthropogenic activities that result in excessive production of greenhouse gases such as Carbon (IV) Oxide, Methane, Ozone, Chlorofluorocarbons, Nitrous Oxide, and Water vapour as well as natural processes cause climate change (IPCC, 2001).

Climate variability is an associated term that represents the temporary fluctuations of the weather that can occur without interference from human activities (Kalame *et al.*, 2009; Hameso, 2015). Climate change and climate variability are considered as climate change in most climate change literature in reference to the IPCC's definition.

Globally, climate change and variability poses the greatest threat to the livelihood systems of smallholder farmers in dryland environments (; IPCC, 2007b; FAO, 2010). In Africa, climate change and variability affect agriculture through shifts in rainfall trends and extreme weather events such as drought, floods and prolonged dry spells (Frazer *et al.*, 2011). These climate events are pushing land systems to cross biophysical thresholds causing long-term drop in agricultural productivity, particularly in semi-arid regions. Reeds (2008) argued that drylands in SSA are vulnerable to climate change due to great uncertainty of climate change, which do not permit prediction of expected changes. These authors opined that research must focus on improving livelihood

security in drylands, particularly semi-arid areas. Asia and SSA (IPCC, 2014) are predicted to be hit by severe food shortage because most of the populations live in drylands that experience extreme weather events. The impacts of climate change on livelihoods of the population in SSA are already known, but there is limited information on effective ways to respond and adapt to these changes (ASSAR-RDS, 2015).

In West Africa, the impacts of climate change and variability are visible, especially in semi-arid areas that host variety of biophysical environments intertwined with highly diverse socioeconomic, demographic and land use characteristics (ASSAR-RDS, 2015). Evidence of climate change is seen in temperature that has increased by 1 °C on average across the region over the past 50 years. Rainfall is highly variable and subject to uncertainty in the direction and magnitude of changes across the West African Region. Evidence from Burkina Faso and Ghana (Kalame *et al.*, 2009) indicate that climate change adversely impacts on livelihoods. These authors noted that drought and high interannual rainfall variability contribute strongly to underdevelopment in West Africa and result in the observed high levels of poverty.

Ghana's Third National Communication to UNFCCC (Climate Change Report, 2015) confirmed that various sectors of Ghana's economy were being affected by climate risks and events such as increasing temperature, unpredicted rainfall, and floods. These impacts are expected to pose threat to livelihoods related sectors such as agriculture, forests, health, and water resources.

It has been predicted that mean temperatures may rise by 3.8 % (1.02 °C) in 2040, and slightly increase by 5.6 % (1.5 °C) in 2060, and then by 6.9 % (1.8 °C) thereafter. Average monthly maximum temperature is predicted to rise by 2040 and 2060 by 1.2 °C and 2.1 °C, respectively as presented in the graphs in **Appendix 1**.

The climate change report (2015) further observed from rain gauge data spanning a period of twenty (20) years across the ecological regions that rainfall had become more variable. For the rate of change, the southern zones recorded 333 %, whereas the mid zones had 112 %, and 431 % for northern parts. Decadal rainfall change was negative for the middle part at -2.8%, but positive for southern (13 %) and northern (3.3 %). The changes are more intense towards the north than the south for both temperature and rainfall. Based on the historical rainfall patterns (1980-2010), rainfall across the country has been projected to decrease by 2.9 % in the near future (2040). This will be followed by a slight increase in the mid future (2060) by 1.1 % and later decrease in the far future (2080) by 1.7%. This observation is a reflection of the uncertainty associated with rainfall (see **Appendix 1 for Graphs**).

In Ghana, other studies point out that reduction in rainfall in the main agricultural zones has resulted in crop failure during both the minor and major seasons (Egyir *et al.*, 2015; Owusu & Waylen, 2012). Climate change and variability have increased the uncertainty of sustainability of the main traditional socioeconomic activities (i.e. crop production) of households in semi-arid areas of northern Ghana (; Maddison, 2006; Antwi-Agyei *et al.*, 2012). These impacts will further increase hunger and poverty because of pressure on agroecosystem services that underpin agriculture in these areas (Cooper *et al.*, 2008; Kalame *et al.*, 2009). Consequently, these changing patterns of rainfall and temperature affect crop production, water availability, and agroecosystem service processes and functioning (IPCC, 2007a) as a whole (Nazari, *et al.*, 2015).

In addition, Nyantakyi-Frimpong & Bezner-Kerr (2015) reported on analysis of rainfall and temperature variables in the Upper West Region that there was wide temporal variability in rainfall over a 30-year period. These authors noted that the region recorded very low rainfall levels between 1981 and 1988 with the worst case in 1986

at 523.7 mm. The analysis reveals that the years between 1995 and 1997 recorded a sharp increase in rainfall. According to Nyantakyi-Frimpong & Bezner-Kerr (2015), the mean annual rainfall for the period 1953 and 2012 was 1036 mm with the peak amount at 1500 mm in 1963. Their findings further revealed that the start of the farming season delayed and only started either in the middle of April or May instead of February or March between 1980 and 1990. They also observed that the mean annual temperature was 33.7 °C for the period 1982 to 2012.

2.3 Vulnerability to Climate Change

Vulnerability refers to “the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress/stressor” (Turner II *et al.*, 2003, p.8074). Vulnerability to climate change is the extent to which a system is likely to experience harm due to exposure to climatic risk, stress or hazard. It depends on the duration and magnitude of the climate variation to which the system is exposed, its sensitivity and adaptive capacity (IPCC, 2001). Exposure depends on the nature, duration and magnitude of the exposed unit to climate change whereas sensitivity is the degree to which the exposed unit is affected, either negatively or positively by climate-related stresses or risks (Brooks, 2003). On the other hand, adaptive capacity is the capability of a system or exposed unit to respond or adjust to climate change to moderate actual or potential effects emanating from exposure and to cope with the harm and take advantage of any opportunity therein (McCarthy *et al.*, 2001; Adger, 2006).

Vulnerability involves different disciplines with several conceptual approaches in its analysis and these give rise to issues of interpretation. Vulnerability to climate change can be treated based on two interpretations as opined by O'Brien *et al.* (2004). First,

vulnerability as a starting point, where the state of the exposed unit is attributed to biophysical, socioeconomic, socio-political factors but amplified by climate change, and second, vulnerability as an end point, where there is inability of the system to cope with changes. The end point considers vulnerability as a fallout of climate change impacts without adaptation (Gbetibouo & Ringler, 2009).

Though vulnerability is subject to several interpretations, a number of studies agree that it is the most essential concept of human condition and well-being since both the rich and the poor could be vulnerable to climate change (Ghana's third national climate change report, 2015; Hameso, 2015). It is also important because climate risks are inevitable whilst some communities or sectors are more vulnerable than others, as are smallholder farmers. Vulnerability to climate change is found to be moderated by household characteristics such as family size, farm size, level of education, access to credit, social safety nets, crop yield, other capital resources of local communities (Antwi-Agyei *et al.*, 2012; Etwire *et al.*, 2013). In this context, all smallholder farmers within the same space may be exposed to climate change but those less endowed with assets would be more sensitive to the impacts and be more vulnerable (Rurinda *et al.*, 2014; Nyantakyi-Frimpong & Bezner-Kerr, 2015). For example, Etwire *et al.* (2013) reported from a study conducted in northern Ghana that vulnerability to climate change was linked to large family size, no education, inadequate access to information and resources such as land and credit. Besides, the climate change report (2015) reported medium to extreme climate change risks to drought, floods, migration, unpredictable rainfall, and increasing temperature among respondents within Guinea and Sudan Savannah zones.

It is evident that no one conceptualization of vulnerability is best for community assessment due to differentiated impacts of climate change stemming from the diversity

of societies, resources, and economies (Hahn *et al.*, 2009). Many vulnerability studies have been based on entitlements models that comprise concepts such as human ecology, expanded entitlements, and political economy (Bohle *et al.*, 1994), natural hazard or biophysical models such as the risk-hazard and pressure-and-release (Blaikie, Cannon & Wisner, 1994; Turner *et al.*, 2010; Fussel, 2007), and recently the integrated approaches (Eakin, 2006).

Bohle *et al.* (1994) opined that climate change will directly affect human ecology and resource endowments, especially for those in the tropics and semi-arid areas and result in low crop yields, increased flood hazards, and further land degradation. Strategies for responding to vulnerability must therefore reduce exposure to potentially harmful perturbations, increase ability to cope with stresses, shocks or crises and strengthen processes of recovery based on a sound understanding of the dynamics and relations that prescribe vulnerability for specific groups in the present and the future (Luers *et al.*, 2003; Luers, 2005; Smit & Wandel, 2006).

Bohle *et al.* (1994) contends that individuals and groups are vulnerable to climatic stresses and unable to cope with food entitlement decline because of endowment with environmentally degraded resources located in respect of the human ecology crises. Bohle *et al.* (1994) also observed that besides livelihoods, groups, and individuals such as widowed, divorced or separated women, malnourished children, the infirm, persons with disabilities (PWDs), and the elderly are most vulnerable to climate change impacts. These individuals or groups may be vulnerable to food entitlement because of poor resource or asset base within the human ecological space of vulnerability.

2.4 Adaptation and Adaptive Capacity

Adaptation is said to have originated from the natural sciences, specifically, evolutionary biology (Futuyama, 1979; Winterhalder, 1980; Kitano, 2002). It mainly refers to the development of physiological and morphological traits and characteristics by an organism to cope with changes in the environment in order to survive and reproduce. Individual organisms develop adaptive features to ensure that each one survives in its environment in the event of unfavourable conditions (what is known as survivor of the fittest).

Anthropologist and cultural ecologist, Julian Steward, is reported to be one of the earliest to apply adaptation to human systems (Smit & Wandel, 2006). He used the term “cultural adaptation” to describe adjustment of “culture core” to the natural environment through subsistence activities. Brook (2003, p.8) describes adaptation as “adjustments in a system’s attribute and characteristics to improve its ability to cope with external stress”. Adaptation is a concept that has been with societies and cultures and have allowed humanity and other organisms to survive to date. However, climate change and deterioration of the biophysical environments presents a new paradigm shift in terms of context for adaptation and poses several threats to societies, especially smallholder farmers within semi-arid regions. Since the beginning of the 1990s, many research studies have defined adaptation in various ways (Smit & Wandel, 2006). Several authors of climate change literature have described the concept of adaptation of smallholder farming communities and households to climate stresses and extreme weather events in different ways. For instance, Smit *et al.* (2000, p.225) defined adaptation as “adjustments in ecological-socio-economic systems in response to actual or potential climatic stress, their effects or impacts”. Adaptation to climate change

refers to the adjustment and response in natural or human systems to actual or potential risk, shock or stress from changing climatic conditions and their effects in a manner that moderates harm or capitalize on beneficial opportunities from climate change' (Etwire *et al.*, 2013; IPCC 2007b).

Smit & Wandel (2006) opined that adaptation is directly associated with vulnerability and adaptive capacity. They consider adaptation as manifestations of adaptive capacity and means of reducing exposure and sensitivity of a system to a stress, shock or risk. Adaptations of a system are specific illustrations of the underlying adaptive capacity. The ability of a community to adapt is driven by factors such as managerial capability, access to credit, technological, and information resources, infrastructure, institutional arrangements, political will and social networks among others.

Adaptive capacity refers to the ability of an exposed unit to adjust to climate change to overcome the potential hazards and take advantage of the opportunities and cope with the risks, shocks and stresses (McCarthy *et al.*, 2001). People possess enhanced adaptive capacity if they are able to modify their attributes in order to cope better with changes emanating from external factors.

Adaptation can take place at the individual, household or community level or beyond to ameliorate anticipated negative effects of climate change. Autonomous adaptation can also take place at household or farm level where both government and non-government institutions provide anticipatory or planned adaptation (Maddison, 2007). Anticipatory or reactive adaptation is the action, process or outcome in the household, community, group or sector in terms of timing relative to risk, whereas planned adaptation is the result of an intent of a policy based on research or information that

conditions have changed or are about to change which requires actions to curtail damage (Fankhauser *et al.*, 1999; Smit *et al.*, 2000; Smit & Wandel, 2006).

Adaptation is a common phenomenon among smallholder farming communities in dryland regions of the world (Vogel, 2005; Antwi-Agyei *et al.*, 2012). Many of these communities have adapted to the changing climate and its variability for so long and do not consider climate change as a major challenge in relation to other stresses (Nyantakyi-Frimpong & Bezner-Kerr, 2015). However, changes in agroecosystem services in semi-arid areas of West Africa and Ghana add a new dimension to the existing stress (Boon & Ahenkan, 2011; Egyir *et al.*, 2015). Adaptation in this context is the adjustment by smallholder farmers to reduce the impacts from the changes in agroecosystem services, climate and weather-related events and to take advantage of opportunities and cope with the associated damage. Adaptation develops the adaptive capacity and reduce vulnerability to these changes (Parry *et al.*, 2007). Adaptation has several benefits for smallholder farmers (IPCC, 2014) in terms of increased crop yield, improved household incomes, enhanced agroecosystem services provisioning, and reduced vulnerability to climatic risks (IFAD, 2013). Additionally, adaptation is beneficial to policy design, planning and decision making at international, regional, national, and local levels (Huq & Reid, 2004; Moser & Ekstrom, 2010).

Empirical studies on adaptation from semi-arid Ghana, particularly in the northern part of the country conclude that smallholder farmers have low adaptive capacities to deal with the changing climatic conditions such as drought and floods (Antwi-Agyei *et al.*, 2012; ASSAR-RDS, 2015). Historically, these farmers have adopted many coping strategies to overcome the harsh environments. Recently, however, the unpredictable climate pattern inhibits adoption of either planned or anticipatory adaptation strategies of communities (Etwire *et al.*, 2013; ASSAR-RDS, 2015). There is limited

understanding of the patterns of their vulnerability and adaptation options which is attributed to both changing climatic conditions and recent changes in agroecosystem services (Egyir *et al.*, 2015).

Furthermore, Gbetibouo (2009) and Maddison (2006) observed that without adaptation, climate change and climate-related events will cripple the agricultural sector but with adaptation, vulnerability is reduced significantly. This is because, adaptation moderates potential damage and takes advantage of opportunities associated with these changes and enable smallholder farmers to cope with consequences (IPCC, 2014). The adaptation measures of smallholder farmers are mainly anticipatory or reactive rather than actual ones (Etwire *et al.*, 2013).

Studies have identified several adaptation strategies to climate change and related risks. However, most of these are ineffective and not being used by smallholder farmers due to some unknown reasons. Adaptation strategies for smallholder farmers in semi-arid regions have remained the traditional ones that include terraces, small dams (dugouts), bonding or ridging among others (Etwire *et al.*, 2013; Rurinda *et al.*, 2014; Nyantakyi-Frimpong & Bezner-Kerr, 2015). These strategies are mainly landscape management strategies used to slow down surface runoff and prevent flood as well as mulching to conserve soil water and maintain moisture of cropland.

Deressa *et al.* (2009) in a study of farmer's choice of adaptation methods in Ethiopia cited adaptation strategies among smallholder farmers to include the use of different crop varieties, tree planting, soil conservation, early and late planting and irrigation. Their study further identified lack of information on adaptation methods and financial constraints as bottlenecks to successful adaptation to climate change and related events.

In Tanzania, Komba & Muchapondwa (2012) identified actual adaptation options of smallholder farmers to include use of short season crops, drought resistant crops, irrigation and tree planting. A doctoral thesis by Hameso (2015) identified adaptation strategies among smallholder farmers in Sidama, Ethiopia as consumption of wild food, migration, consumption of food stock, sale of firewood, fewer meals per day, sale of assets, sale of livestock, and engaging in daily work.

In a study undertaken in northern Ghana, Etwire *et al.* (2013) reported that adaptation strategies adapted by smallholder farmers were mainly crops and livestock related strategies. Other indigenous practices were also soil related strategies that involved landscape modifications such as bonding, and creating drainage channels. The third group, called cultural practice related strategies included mulching and non-burning of crop residues. The literature review on climate change and variability suggest that many communities exhibit low levels of adaptive capacity due recent agroecosystem services deterioration and more variable climatic factors.

2.5 Agroecosystem Services Change

Ecosystem services are the natural benefits of the landscape flowing to human society and agricultural production (Millennium Ecosystem Assessment, 2005; Smith & Sullivan, 2014). Generally, ecosystem goods and services are referred to as ecosystem services. According to the MEA (2005), provisioning ecosystem services include, food, freshwater, fibre and fuelwood. These services are linked directly to the constituents of human well-being (Notte *et al.*, 2017), thus human security, basic material for good life, health, good social relations and freedom of choice and action (MEA, 2005).

Agroecosystem services are highly managed agricultural ecosystem services that provide rural society with food, forage, bioenergy, and medicinal materials that are essential to human well-being (Swinton *et al.*, 2007; Power, 2010; Notte *et al.*, 2017). According to Dawson & Martin (2015), agroecosystem service refers to ecosystem services within semi-arid agricultural landscapes that underpin the livelihoods of local communities (Xu & Mage, 2001; Freitas, Schutz, & Oliveira, 2007; Zhang *et al.*, 2007; Muller & Burkhard, 2012). However, these services have recently come under threat from climatic and non-climatic stresses (Boon & Ahenkan, 2011; Smith & Sullivan, 2014; Egyir *et al.*, 2015). About two-thirds of agroecosystem services is being degraded and modified posing a major threat to future human well-being (Swinton *et al.*, 2007; Power, 2010; Notte *et al.*, 2017).

A larger percentage of the world's poor who live in semi-arid regions depend on multiple agroecosystem services to sustain their livelihoods (WRI *et al.*, 2005), where agriculture is the major livelihood activity (Rockstrom *et al.*, 2003). Attempts to improve food production have in most cases compromised agroecosystem services that underpin the livelihoods of rural people. Changes in the supply and function of these services have exposed local communities to multiple stresses, risks and shocks (Smith & Sullivan, 2014). There is an intimate link between ecological sensitivities and social vulnerability across all hot spots, particularly in semi-arid regions, due to the over-dependence of livelihoods on agroecosystem services (Rockstrom *et al.*, 2003; MEA, 2005; Smith & Sullivan, 2014).

Studies show that climate-related events such as drought and floods are pushing semi-arid natural capital assets to cross-biophysical thresholds causing long-term drop in agricultural productivity thereby exposing the people to further risks of low crop yield and poverty (Egyir *et al.*, 2015). Thompson & Scoones (2009) in their climatic risk

studies carried out in dry sub-humid areas of Ghana, recommended further research to better understand how the changes in agroecosystem services and institutional drivers are affecting the well-being of smallholder farmers in semi-arid areas of Ghana. Frazer (2011) argued that household's access to different resources such as soil fertility, water regulation and provision, and social relations at the local scale provides greater capacity to adapt to a challenge. Productivity can be maintained if households have access to agroecosystem services without any external support in times of climate stresses or shocks.

2.5.1 Soil Quality and fertility

Crop production depends upon soil for plant growth and yield. Three key factors determine plant nutrition, thus, amount of available nutrients in the soil, environmental factors that affect nutrient availability, and plant nutrient uptake (Estefan *et al.*, 2013). Studies indicate that soil organic matter for instance will decrease under climate change and variability because the soil will be a major source of atmospheric carbon. Climate change and its related events such as increasing temperature and variable rainfall patterns pose serious threat to soil properties and processes, particularly in semi-arid areas (Brevik, 2013). According to Johansen *et al.* (2012), smallholder farmers in rain-fed agriculture consider the soil as a very important resource for crop growth and food production. But as cropping intensifies there is a general decline in the physical, chemical and biological properties of soil which limits crop yield. This is primarily caused by declining soil organic matter from accelerated oxidation through tillage and exacerbated by the continuous burning of crop residues that limit return of land surface biomass to the soil.

In addition, the inability of smallholder farmers to adopt cropping systems based on minimum tillage, crop residue retention, and appropriate crop rotations have resulted in the decline of soil quality in their fields. Soil fertility represents the inherent capacity of the soil to supply plant nutrients in adequate amounts, forms, and in soluble proportions required for maximum plant growth.

Crop production in semi-arid regions heavily depends on two key agroecosystem services; soil fertility and water quality (Rockstrom *et al.*, 2003). Soil is a non-renewable agroecosystem service that forms the basis of agricultural livelihoods and well-being of human beings and livestock (Estefan *et al.*, 2013). In addition to food production, soil provides solid foundation for material well-being of smallholder farmers through the provision of security (secure resources access as fertile soil is regarded as an entitlement for high biological production), basic materials for good life (sufficient nutritious food and shelter due to high biological production), health (high nutrition level and access to clean water due to high biological production and water provisioning), good social relations (ability to increase crop yield and avoid out-migration and be able to help others), and freedom of choice and action (ability to achieve goals by improved crop yield without limitations) (MEA, 2005; Gough, McGregor & Camfield, 2007; McGregor, 2006). This is because fertile soil as an agroecosystem services generally links the above components of human well-being to sustain the livelihoods of semi-arid people (MEA, 2005; White, 2010). Material well-being refers to what people do to achieve their goals (McGregor, 2006). Soil is a resource that offers farmers in semi-arid regions opportunity to achieve all five components of human well-being, improve adaptive capacity (MEA, 2005), and reduce vulnerability of smallholder farmers.

Mary & Majule (2009) found that low soil fertility is caused by both poor farming practices and extreme climate and weather-related events including drought, erratic rainfall, prolonged dry spells and high temperatures. Low rainfall contributes to loss of soil water, whereas increasing temperatures lead to rapid decomposition of organic matter that hold the essential elements required by crops (Antwi-Agyei *et al.*, 2012).

Soils vary greatly throughout the world and have inherent weaknesses, primary deficiencies in nutrients that are essential to growing crops. Even when adequately supplied in the early stages of land cultivation, the nutrient-supplying capacity invariably diminishes with time. The mineral nutrients essential for plant growth are the primary macronutrients; carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K) which are required by crops in larger amounts and therefore are most deficient in most farm soils. The secondary macronutrients like calcium (Ca), sulphur (S), magnesium (Mg) as well as the micronutrients such as boron (B), chlorine (Cl), manganese (Mn), iron (Fe), zinc (Zn), copper (Cu) and molybdenum (Mo) are equally essential for optimum crop growth and development.

However, most soils are deficient in nitrogen (N), which is transient in nature and plants require a lot of it. In many cases, phosphorus (P) is just critical because soil chemical reactions reduce the effectiveness of P fertilizers. The soils of the Sub-Saharan Africa are generally well supplied with potassium (K), and usually do not need fertilization, especially for low-yielding rain-fed crops (Estefan *et al.*, 2013).

Soil depletion and degradation is a major drawback to crop production in Ghana, especially, in semi-arid areas. Continuous cropping without nutrient replenishment through fertilizer application and proper soil management practices is common among smallholder farmers in dryland and semi-arid areas in Northern Ghana (Antwi-Agyei

et al., 2012). Sanchez (2002) reported the rate of soil nutrient loss in Sub-Saharan Africa as 22 kg, 2.5 kg and 15 kg per hectare of cropped land per year for N, P and K, respectively (Cited in Okebalama, 2014). There are reports that both macronutrients and micronutrients are deficient in most semi-arid areas (Pinto *et al.*, 2012; Etwire *et al.*, 2013; Okebalama, 2014; Boafo *et al.*, 2016).

The quality and fertility of an agricultural soil are indicated by physical and chemical parameters such as pH, organic matter, organic carbon, electrical conductivity (EC), nitrogen (N), phosphorus (P), potassium (K) and trace metals (Cr, Fe, Mn, Cu, Zn, Cd, Pb, Ni, Co, and As), particle size, and Bulk density. The concentration levels of each of these parameters have implications for soil water, aeration, soil aggregate formation, nutrient reserves, moisture retention, biological activity, and nutrient availability to plants ((FAO, 1980; Soltanpour, 1985; Matar *et al.*, 1988; Johnson & Fixen, 1990; Martins & Lindsay, 1990; Estefan *et al.*, 2013). **Table 1** shows pH value ranges in typical soils.

Table 1: Description of pH value range in soils.

pH Range	Description	Indications	Associated Conditions
Below 5.0	Strongly Acidic	Soil is deficient in Ca and/or Mg and requires liming.	Poor crop growth because of low cation exchange capacity, possible Al ³⁺ toxicity and probable P deficiency
5.0-6.5	Moderately to Slightly Acidic	Soil is without lime and should be closely monitored.	Satisfactory for most crops
6.5-7.5	Neutral	Ideal range for crop production	Soil cation exchange capacity is near 100 % base saturation
7.5-8.5	Moderately Alkaline	Free lime (CaCO ₃) exists in soil	Usually excellent filtration and percolation of water because of high Ca content on clays. Both P and micronutrients are less available
Above 8.5	Strongly Alkaline	An indication of sodic soil	Poor physical conditions;- infiltration and percolation of soil water is low and may result in root deterioration and organic matter dissolution

(Source: Estefan *et al.*, 2013)

2.5.2 Quality of Water Resources

The physical impacts of climate change on biophysical systems such as water resources and livelihoods are visible in many parts of the world (IPCC, 2007b). The IPCC estimates that by 2020, between 75 and 250 million people in developing countries, most of them in Africa would lack access to water due to water stress (UNEP-PROVIA, 2013).

Africa has significant water resources that include large lakes such as the Volta, Chad, rivers, streams, ocean, and groundwater that when properly managed can support her socio-economic growth. However, climate change and variability, and population explosions as well as resource deterioration are expected to have adverse effects on water availability, accessibility, and demand in Africa and add to the cost of managing water resources (Tingju & Ringer, 2010). According to Onuoha (2010), more than 600 lakes in Africa are declining rapidly owing to the combined impact of climate change and resource overuse. For instance, Lake Chad lost over 50 % of its water between 1973 and 2002.

Studies show that the impacts of climate change in Africa would be greatly felt through water resources stresses (IPCC, 2007b). Climate change will create uncertainties, alter hydrology, weather factors, and cause the occurrence of more extreme events. This will put further pressure on water resources and sensitive sectors such as agriculture, livestock, and fisheries that depend mainly on water. In Africa, most households depend on these sectors for their socio-economic development.

Increases in flood and drought events coupled with reduction in mean precipitation would impact water resources, and adversely affect agriculture and human health. This could come from sewage contamination during flood events (IPCC, 2007b). In Sub-

Saharan Africa, where evidence of long-term declines in water availability exist, climate change may make it more difficult to access improved water needed for healthy livelihoods and well-being.

In Ghana, the Volta River Basin covers about 70 % of the surface of the country and is shared by five other West Africa countries which include; Mali, Burkina Faso, Cote d'Ivoire, Togo and Benin. The Black Volta River Basin that transverse the study area of this research, which Ghana shares with Burkina Faso and Cote d'Ivoire has a total drainage area of about 149,015 km² with only 38,107 km² lying in Ghana. The main tributaries of the Black Volta River Basin are Benchi, Chuko, Laboni, Gbalon, Pale, Kamba and Tain rivers (Kankam-Yeboah *et al.*, 2004).

The crucial roles of water in food production in Ghana cannot be overemphasized because about 80 % of agriculture is rain-fed and depend upon rainfall to meet evapotranspiration demand and maintain soil moisture (Antwi-Agyei *et al.*, 2012). In many parts of semi-arid Ghana, where precipitation is already limited, water stress had further made crop production vulnerable to climate change impacts (Codjoe *et al.*, 2012). Evidence of floods, droughts, warmer temperatures, decline precipitation, bushfires, over use of fertilizers, and water pollution from changes in crop production in semi-arid and sub-humid regions of Ghana have been reported (Codjoe & Owusu, 2011). In its Fourth Assessment Report, AR5, the IPCC noted that climate change impacts on surface and groundwater supplies may adversely affect livelihood strategies in dry sub-humid areas (IPCC, 2007b). Water provisioning service is essential for smallholder farmers' well-being and crop production in semi-arid regions (ASSAR-RDS, 2015).

Freshwater supply as an agroecosystem service within an agricultural landscape is greatly influenced by water quality. Water quality indicators of concern for domestic use include physical, chemical, ions, trace metals, and microbiological. These parameters are pH, EC, TDS, TSS, BOD, Alkalinity, Turbidity, Salinity, Colour, Nitrate, Potassium, Sodium, Calcium, Magnesium, Fluoride, Chloride, Sulphate, Chromium, Iron, Manganese, Copper, Zinc, Lead, Nickel, Cadmium, and Arsenic. The WHO (2011) established guideline values for some physical and chemicals parameters in drinking water based on whether they are of health significance or not. These guidelines recommended that water should be aesthetically acceptable to consumers to avoid the usage of unsafe water. In this view, the appearance, taste, odour and other physical properties of drinking water must be acceptable to consumers at all times.

The Water Resources Commission (WRC) of Ghana through the water research institute (WRI) of the Council for Scientific and Industrial Research (CSIR) established the raw water quality guidelines for the purposes of monitoring and ensuring the proper use of raw water. The Ghana raw water quality criteria and guidelines is called the Target Water Quality Ranges (TWQRs) and is referred to as “no effect range” (WRC, 2003, p. 2). The volumes 1 and 4 (B) deals with the domestic water use and agricultural water use for irrigation, respectively.

2.5.3 Conclusions on Literature Review

The review of literature indicates that significant populations of people in semi-arid regions depend heavily on climate variables and agroecosystem services to sustain their livelihoods (IPCC, 2014; ASSAR-RDS, 2015; Nyantakyi-Frimpong & Bezner-Kerr, 2015). It is evident that many communities, particularly in Sub-Saharan Africa exhibit low levels of adaptive capacity due to growing evidence of agroecosystem services

deterioration and increasing vulnerabilities of smallholder farmers. Climate change is expected to pose the greatest threat to populations in harsh environments where natural resources are overexploited.

Climate projections indicate that Ghana will experience warmer periods and by 2060, average temperature may rise from 1.0 °C to 3.0 °C, whilst by 2090 from 1.5 °C to 5.2 °C (Ghana Climate Change Report, 2015). The predicted percentage of warming will be highest in the northern regions in relation to the southern parts. Analysis of climate data indicate upsurge in temperature and more recorded warmer days and nights. It is also predicted that about sixty percent days may be warmer by 2060. Most projections indicate declining cold days and nights.

Rainfall will continue to be uncertain and difficult to predict. Projections of mean annual rainfall from different models predict wide range of changes. About half of the models predict increases while the other half project decreases. The proportion of total annual rainfall that falls in heavy events tends towards an increase in the ensemble projections. Projected changes in 1 and 5-day rainfall maxima trend towards increases, but projection ranges between both increase and decrease in all seasons.

According to the Third Ghana Communication to the UNFCCC, Climate Change Report (2105), agriculture is dominated by smallholder farmers who are sensitive to climate variables, particularly rainfall. Irrigation systems are non-existent for most of these farmers.

In addition, Ghana will be adversely affected by climate change and variability through alteration of the agro-ecology and natural resources deterioration. The magnitude of climate change impact is determined by the extent of vulnerability and the level of adaptive capacity of smallholder farmers. Some adaptation efforts are in place to

safeguard the environment and human life, and improve agriculture. However, low adaptive capacities of households have led to maladaptation in most communities.

Though Ghana is projected to be severely affected by climate change and variability, household-level case studies required to highlight the factors contributing to the level of vulnerability of livelihoods and ineffective adaptation are inadequate. This knowledge gap hinders understanding of the barriers and enablers of adaptation to climate change and variability in Ghana, particularly semi-arid areas. There is therefore the strong need for a specific study to explore the scope and nature of vulnerability and adaptations of smallholder farmers to recent changes in agroecosystem services and climate. This thesis employs an exploratory and descriptive research design through participatory rural appraisal methods to assess the level of vulnerability of households to changes in agroecosystem services and climate in semi-arid Ghana. Biophysical factors including rainfall, temperature, and soil and water quality as well as household primary data on socioeconomic and socio-political indicators were aggregated into vulnerability assessment of the study communities.

2.6 Conceptual framework

The aim of this study was to explore and understand the scope and nature of vulnerability and adaptive strategies of smallholder farmers to changing agroecosystems and climate in semi-arid areas of the Upper West Region of Ghana. In the study area, households contend with extreme natural resource depletion challenges, including poor soil fertility, pests, crop diseases, and lack of access to agricultural inputs. Added to these challenges are the effect of changes in agroecosystem and climate, manifesting in the form of prolonged droughts, floods, scarcity of fuelwood, water shortage among others (Armah, 2011; Boafo *et al.*, 2014; Boafo *et al.*, 2016). The

concepts and theories of vulnerability, adaptation, and agroecosystem services were employed to guide this research.

The conceptual framework for the vulnerability analysis is adopted from Turner II *et al.* (2003). The framework explains the connections between the drivers of change and the vulnerability context in relation to responses and the extent of impact of key ecosystem services change and climate change on the agricultural livelihoods and well-being of smallholder households in semi-arid areas of West Africa. The concept contends that vulnerability of the smallholder household arises mainly because of changes in biophysical and socioeconomic factors as well as socio-political (institutional) factors, internal and external to the smallholder farmer (Chambers, 1994; Turner II *et al.*, 2003; Arnell, 2004; Eakin & Luers, 2006; Fussel, 2007, 2009;). The biophysical drivers are mostly natural and anthropogenic climate change and variability that include floods, droughts and fires on one hand and ecosystems change or changes in natural capital such as agroecosystem services on the other hand. The socioeconomic drivers most often consist of policy, demography, land tenure systems and economic (local markets) factors. The socio-political or institutional factors comprise governance structures and arrangements that affect the smallholder farmer livelihoods (Eakin & Luers, 2006; Fussel, 2007, 2009).

The extent of impact on households from changes in agroecosystem services and climate in semi-arid areas is dependent on the vulnerability level of smallholder farmers, which is proportional to exposure level, sensitivity, and adaptive capacity as presented in the conceptual framework below (**Figure 1**).

The level of exposure is dependent upon the frequency, intensity, and duration of the hazard or risk posed by a driver in this case agroecosystem services change, natural and

anthropogenic climate change and variability (IPCC, 2007a; Mbow *et al.*, 2008). Sensitivity of smallholder farmers in dryland areas also depend on the cropping and livestock systems, socioeconomic, socio-political as well as human and ecological conditions (Luers, 2005). The third factor of vulnerability is the adaptive capacity, which assesses the traditional and introduced adaptation options, strategies and patterns of responses for improving the well-being of the smallholder farmer. To reduce vulnerability to agroecosystems and climate change and enhance adaptive capacity, smallholder farmers usually employ traditional or indigenous adaptation options (Etwire *et al.*, 2013; Antwi *et al.*, 2015; Nyantakyi-Frimpong & Bezner-Kerr, 2015). However, these traditional strategies have mainly been short-term solutions that have proven insufficient and ineffective for dealing with long-term hazards posed by the consequences of agroecosystem services and climate change in semi-arid areas (ASSAR-RDS, 2015).

External institutions such as governments, non-government agencies, and research groups provide knowledge and information on agroecosystem management and climate change to smallholder farmers in semi-arid areas in northern Ghana. Furthermore, modern and scientific mechanisms for responding to agroecosystem services change and climate change have been introduced (Etwire *et al.*, 2013; Antwi *et al.*, 2015; Nyantakyi-Frimpong & Bezner-Kerr, 2015). The study (i) identifies key agroecosystem services, utilization, and changing trends; (ii) examines perceptions regarding rainfall and temperature variables and gauge data, (iii) measures the household and community vulnerability due to changes in agroecosystem services and climate variability, and (iv) investigates adaptation strategies available and knowledge and information sources of smallholder farming households in the local communities.

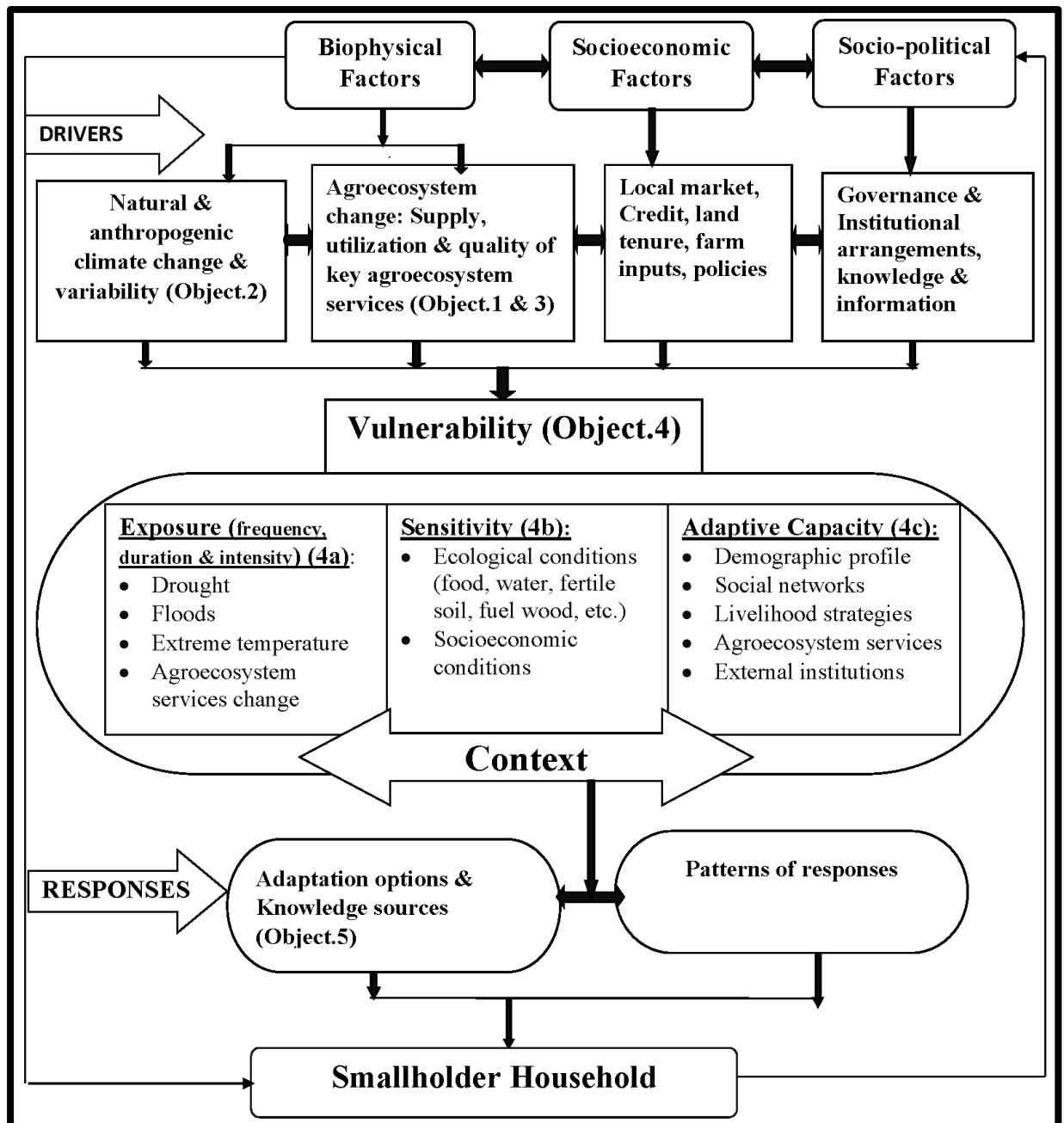


Figure 1: Conceptual Framework for the Assessment of Vulnerability and Adaptation Options.
 (Source: Modified from Tuner II *et al.*, 2003)

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study Area

3.1.1 Site Selection

This research forms part of a larger study conducted by the Adaptation at Scale in Semi-Arid Regions (ASSAR) Project in semi-arid areas of Africa and Asia. In West Africa, the project focused on the dry sub-humid band that extends from the Upper West Region of Northern Ghana through to Southern Mali called the Wa-Bobo-Sikasso transect. In Ghana, two main districts host the ASSAR project, thus, Lawra and Nandom districts both in the Upper West Region.

This study was carried out in the Nandom district, which lies in the north western corner of the Upper West Region of Ghana between Longitudes 2°25 W and 2°45 W and Latitudes 10°20 N and 11°00 S. The Lambussie and Jirapa districts bound it to the East and South, respectively, and to the North and West by the Republic of Burkina Faso. The total area of the district is about 567.6 square kilometres and constitute about 3.1 % of the Region's total land area. The district has 84 communities with 86 % of the inhabitants living in rural areas. The population density is about 89 per square kilometres (Ghana Statistical Service (GSS), 2014). It is the most densely populated district in the region (GSS, 2014). The selected communities for this study are Billengangn, Gengenkpe, Naapaal and Ketuo (**Figure 2**).

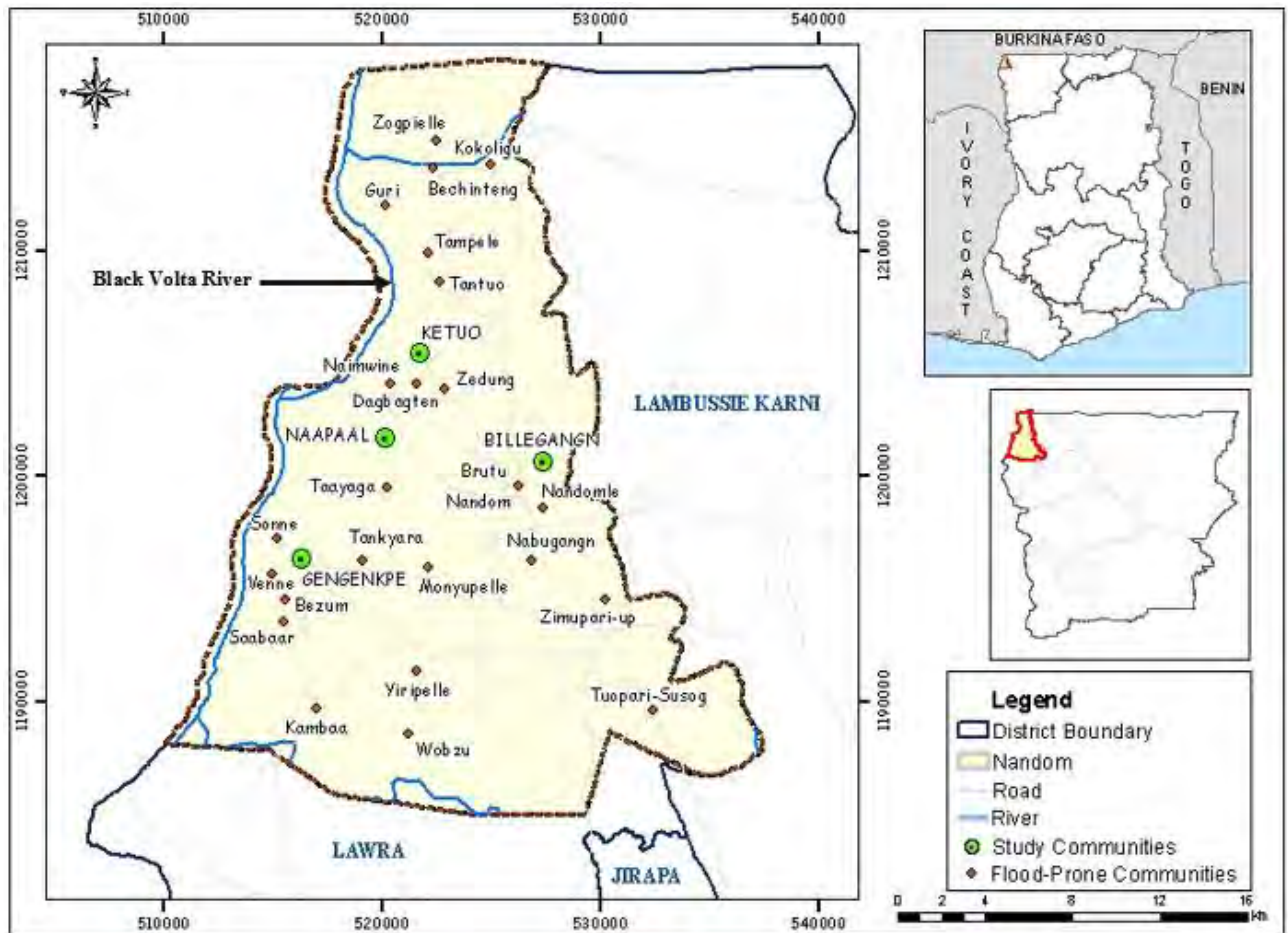


Figure 2: A map of Nandom district showing the study communities.

The study communities were selected based on appropriate guidelines from experts and stakeholders. Discussions and interviews with experts from the EPA and the National Disaster and Mobilization Organization (NADMO) at the district during pre-study and reconnaissance visits in September, 2015 provided valuable information that was used to select these farming communities. The selection of a study community was based on NADMO’s classification of flood risk communities. According to drought and flood risk assessment conducted by NADMO and the UNDP (2015), the entire district is drought prone with about thirty communities considered as flood risk. A list of these communities was obtained from NADMO and the four communities were randomly selected. Billengangn, Gengenkpe, Naapaal, and Ketuo are about 12.55 km, 3.35 km,

3.95 km, and 2.87 km, respectively away from the Black Volta River. This River was cited as a major cause of the flood situation in the study area.

3.1.2 Socioeconomic Environment

The main livelihood activity in the selected communities is cereal crops production that is generally practised under rain-fed conditions. Livestock rearing in the study communities is an alternative livelihood activity. Agriculture is the major source of income for majority of smallholder farmers, which is limited to one main farming season due to a unimodal rainfall pattern from May/June to September/October (Dickson & Benneh, 1988; Antwi-Agyei *et al.*, 2012). This situation results in out-migration of the youth to southern Ghana in search of greener pastures during the dry season. According to the 2010 population and housing census, 85.3 % of households are engaged in agriculture in the Nandom district, with 98.0 % involved in crop production. In terms of industry and commerce, the medium-term development programme reports that the main industries include flour milling, pito brewing, commercial food preparation, shea butter extraction, xylophone making, basket weaving and charcoal burning among others. The study area has three main markets located in Kuturu, Ko and Nandom.

3.1.3 Climate and Vegetation

The study area is tropical continental as is the case in semi-arid regions of Ghana. Thus, all twelve (12) months of the year have an average temperature of above 12 °C and situated inland than near the sea (GSS, 2014). Throughout the year, temperature is high with an average minimum of 22.1 °C at night and an average maximum of 34.8 °C during the day (i.e. GMet data, 1984-2014). The mean monthly temperature ranges

between 21 °C and 32 °C. The highest monthly maximum temperature rises up to 38.9 °C before the rainy season usually in May with lowest minimum temperature falling to about 16.9 °C in December when the Harmattan winds from the Sahara dry up the vegetation (i.e., GMet data, 1984-2014). The rainfall pattern of the study area is unimodal and restricts farming to only the rainy season.

The study area lies within the Guinea Savannah vegetation belt which consist of grasses interspersed with scattered fire resistant trees such as the shea (*Vitellaria paradoxa*), dawadawa (*Parkia biglobosa*), and baobab (*Adansonia digitata*) trees (GSS, 2014). The trees have significant domestic uses such as fuelwood and charcoal, construction of houses, cattle kraals and fencing of gardens by smallholder households. The shorter shrubs and grasses in the vegetation provide fodder for livestock.

The only cash crop trees found in the area are shea (*Vitellaria paradoxa*), “dawadawa” (*Parkia biglobosa*), mango (*Mangnifera indica*), and cashew (*Anacardium occidentale*). According to the District Medium Term Development Plan (DMTDP, 2015), the shea tree is one great economic asset district. These trees are however, threatened by degrading human activities such as bush burning, indiscriminate tree felling for fuel wood, charcoal production, poor agronomic and animal husbandry practices. This situation has been exacerbated by climate-related stresses and extreme weather events like floods and prolonged dry spells. These events decreased vegetation cover and increased soil water evaporation, soil erosion, and depletion of soil fertility (GSS, 2014).

3.1.4 Relief and Drainage

The topography of the district is gently undulating, located at about 180 meters above sea level with a few isolated hills (GSS, 2014). The relative plain topography is suitable

for road construction, distribution of utility lines, general construction work and crop production.

The water table of the area is relatively low, resulting in limited surface water and groundwater resources during the dry season (GSS, 2014). The surface water bodies include a few interconnected streams that enter the Black Volta River, which forms the western boundary of the district. The Black Volta River presents an opportunity for the development of irrigation systems for dry season farming and aquaculture.

The rivers and streams are perennial in nature and most become just intermittent pools in the dry season while others completely dry up. However, there are a number of dams and dugouts, which provide water for irrigation, domestic use, construction and watering of livestock. The interconnected water bodies in the district facilitate storm water drainage, thus, making the district relatively less floodable, except in few low-lying areas and areas in close proximity to the Black Volta River. Though the water bodies in the district have potential for supporting agricultural activities in the dry season, they equally serve as constraints in road constructions and limit access to communities during the rainy season.

3.1.5 Soils

The main soil types in the district are sandstone, gravel, mudstone, alluvium, granite and shale that have weathered into different soil grades (GSS, 2014). Due to seasonal erosion, soil types emanating from this phenomenon are sand, clay and laterite ochrosol. The main textural classes of soil types include loamy-sand and sandy-loam (field work, 2016). The soil pH (1:5) of the study area ranges between 5.6 and 8.0 (field work, 2016). The soil types in the study area can be described as suitable for normal crop growth,

especially, of cereals and root tuber crops such as millet, maize, sorghum and yam with respect to the pH and provide an advantage for the construction of housing units. The soil types also respond positively to the application of organic manure and commercial fertilizers to give high crop yields (GSS, 2014).

3.2 Methodology

The participatory rural household appraisal (PRA) research survey design, otherwise known as participatory rural household appraisal (PRHA) technique (Chambers, 1994) was used for the study through the mixed method approach (qualitative and quantitative). The study collected both qualitative and quantitative data from primary and secondary sources. The PRHA techniques used include; household survey questionnaire with semi-structured face-to-face interviews, key informant interviews and focus group discussions (FGDs). Sampling of farm soils and water were also carried out to assess their contribution to livelihood strategies in terms of quality. The research was conducted between September 2015 and July 2017.

3.3 Reconnaissance Studies

The research was preceded by reconnaissance studies in September 2015 with community meetings and engagement, with chiefs and relevant stakeholders, in addition to secondary data from extensive literature search. The community engagement helped in identifying and mapping out the study communities within the Nandom district. The preliminary study also informed the selection of variables to be investigated and methods of data collection.

3.4 Data Collection

Primary data from the households in the study communities constituted the core of this research. This involved the administration of three data collection instruments to achieve the research objectives. These included standardized household survey (questionnaire), focus group discussions (FGDs) and semi-structured interviews with key informants at the household, community and district levels. The household survey method provided the study with quantitative data with relatively less qualitative data whereas the last two other methods generated purely qualitative data. Each survey instrument was accompanied with a consent letter as attached in **Appendix 2**. The questionnaire items were vetted by the supervisors of the study to ensure its face validity, completeness, accuracy and uniformity (Lokesh, 2002). The questionnaire was pre-tested on selected households in the study communities to ensure reliability of the of the research instrument. Gender balance was taken into consideration. The outcome of the pilot study helped the main study in several ways. First, it provided prior knowledge of the problems to be encountered during the conduct of the main study that included explanation of terminologies like agroecosystem services, unwillingness to respond to the questionnaire. Second, this ensured that the questionnaires were suitable for the chosen sample. Finally, it also ensured that less time was spent on each questionnaire during the actual data collection (Jack & Norman, 2000).

Secondary data sources for the study included information from the District Medium-Term Development Plan (DMTDP, 2015), Gauge climate data from the Ghana Meteorological Agency, drought and flood reports from the NADMO, project reports, journals, textbooks, internet searches and general literature search.

3.5 Participatory Rural Appraisal (PRA)

The participatory rural appraisal method involves a tool kit of interactive and innovative techniques (Chambers, 1994) that allows for the incorporation of new techniques to tackle new research problems that may arise due to its flexibility. The method is interdisciplinary, which makes it useful for explaining complex concepts like agroecosystems, agroecosystem services change, vulnerability, adaptation and climate change. Besides, participants are given opportunity to contribute and exchange ideas freely in an informal setting. The discussions are guided by a checklist, which could be modified to attain the required responses as opposed to predetermined questionnaire. It is also community based and informative as learning takes place through exchange of ideas with field responses. PRA is a field survey method most often targeted at local communities. The specific data collection techniques employed under the participatory rural appraisal were the focus group discussions and the key informant interviews.

3.5.1 Focus Group Discussion (FGD)

The focus group discussion (FGD) is a type of in-depth interview undertaken by a group, whose meetings present characteristics defined with respect to the proposal, size and composition and interview procedures (Freitas et al., 1998; Jenkins *et al.*, 1998). The FGD is a technique that allows for spontaneous expression of ideas and facilitates the interaction of everybody (Jenkins *et al.*, 1998; Ayivor, 2012).

In this study, discussions centred on local knowledge and experiences on four (4) main research themes that bordered on, (i) impacts of rainfall and temperature trends and variability on smallholder farmers livelihood strategies, (ii) trends in availability, utilization and changes in ecosystem services over time, (iii) the scope and nature of

exposure and sensitivity (degree of vulnerability) of smallholder households stemming from changes in agroecosystem and climate and (iv) the adaptation options, knowledge and information sources on adaptation available for managing and responding to agroecosystem and climate change.

During the discussions, issues regarding the scope and nature of challenges confronting smallholder households, adaptive capacities and responses were explored. The discussions centred on major challenges and opportunities of smallholder households, adaptive capacities and responses and their knowledge and information sources for dealing with the identified challenges stemming from agroecosystem and climate change as well as taking advantage of opportunities to improve upon their well-being in the local communities. Four (4) focus group discussions were held with two (2) male and two (2) female groups in Billengangn, Gengenke, and Naapaal whilst two (2) focus group discussion comprising a male and a female group each in Ketuo. The number of FGDs held in each community depended on the total number of discussants available at the time of the study. The FGDs were held in the study communities between 5th and 24 April, 2017. The discussions, which were led by the researcher with the support of a moderator, was facilitated by a checklist of questions (see **Appendix 3**). The discussion guide was made up of four main themes with at least three items each. The FGD involved separate groups of male and female participants who were either household heads or nominated members of the household. The opinions of the various groups assisted the researcher to sufficiently formulate vulnerability indicators for the vulnerability analysis. The FGDs were carried out in the local language “Dagaare”.

Fourteen (14) FGDs were held in four communities with 125 participants comprising 48 percent males and 52 percent females. The ages of the participants ranged between

20 and 82 years. Each FGD consisted of between seven (7) and eleven (11) individuals.

Table 2 shows the breakdown of the number of communities, focus group discussions held as well as the total number of participants.

Table 2: Number of Focus Group Discussions in Respective Study Communities.

Study Community	Number of Focus Group Discussions	Number of Discussants		
		Male	Female	Total
Billengangn	4 (2 male and 2 female groups each)	20	22	42
Gengenkpe	4 (2 male and 2 female groups each)	20	18	38
Naapaal	4 (2 male and 2 female groups each)	9	14	23
Ketuo	2 (1 male and 1 female group each)	11	11	22
Total	14	60	65	125

Source: Field work 2016/17

The FGDs were gender based to reflect the unique opinions of both male and female respondents. This is especially necessary since women in the local communities of the study area are traditionally restricted to expressing themselves freely in the presence of their male (husbands) counterparts. Youth participation was non-existent partly because of migration and for the purposes of receiving education in and out of the district. The FGDs were transcribed and analyzed qualitatively using descriptive methods in the context of major issues under investigation. The individual groups were used as units of measurement and analysis.

3.5.2 Key Informant Interviews (KII)

This technique involved interviewing individuals who were likely to provide expert views, information, ideas, and insights on a particular subject or topic. The key informant interviews obtained qualitative descriptions or experiences of knowledgeable individuals about the research questions (Kvale, 1996; Ayivor, 2012). In this study, key

informant interviews were undertaken involving knowledgeable and opinion leaders of the communities and heads of government and non-government organizations within the district.

In all, ten (10) interviews were held with the relevant stakeholders drawn from government and non-government organizations as well as community opinion leaders between 5th and 24 April, 2017. The stakeholders consulted include NADMO, Nandom Deanery Integrated Rural Development Programme (NANDIRDEP), Department of Agriculture of the Ministry of Food and Agriculture (MOFA), Environmental Protection Agency (EPA), Nandom District Assembly, Community Development Department, Business Advisory Centre/Rural Enterprises Programme, Naapaal Community Opinion Leaders, Billengangn Traditional Authority and Naapaal Traditional Authority. A checklist of questions was used to guide the interview process (see **Appendix 4**).

3.5.3 Questionnaire

The questionnaire was also used to investigate the research problem (Kendall, 2008; Lai & Waltman, 2008; Harris *et al.*, 2010) to provide evidence based household-level data. The questionnaire generated data generated using both closed-ended and open-ended questions including the Likert scale (Harris *et al.*, 2010).

The questionnaire was found to be appropriate for the smallholder farming households because it allowed them to provide their own views and opinions. The questionnaire solicited information on the research questions of this study. In the closed-ended questions, predetermined answers expected from the respondents were provided and the respondents ticked in a box to make a choice whereas with the open-ended type,

spaces were provided for original answers or any unexpected answers from the respondents. The questionnaire was divided into six (6) sections lettered A to F (see **Appendix 5**). The first section (A) collected information on the socio-demographic background of respondents. Such information included gender, age group, level of education, occupation, etc. The section had ten (10) items in it.

The second section (B) collected information on farm characteristics of the respondents and comprised seven (7) items. The third section (C) solicited information on the perception of smallholder farmers on historical and recent rainfall and temperature data and related events in the local communities and had one (1) item of seventeen (17) multiple options. The fourth section (D) collected data on the perception of smallholder farmers on trends in the availability, utilization and changes in ecosystem services over time in the study area and consisted of seven (7) items. The fifth section (E) collected information on the scope and nature of challenges, exposure and sensitivity (degree of vulnerability) of smallholder households due to agroecosystems and climate change and consisted of nine (9) items. Finally, the sixth section (F) collected data on the perception of smallholder farmers on the adaptation options and knowledge sources on adaptation available for managing agroecosystem and climate change. This section comprised fourteen (14) items.

In all, the questionnaire comprised forty-nine (49) items. In addition to the content of the questionnaire, a consent letter was attached at the front page that spelt out the main goal of the study and appeal to the respondents for their cooperation. The consent was attached to certify ethical requirement of the College of Basic and Applied Sciences of the University of Ghana, Legon and encourage the respondents to respond to the questionnaire on schedule.

Six (6) enumerators comprising five (5) males and one (1) female selected from each of the study communities assisted in the administration of the questionnaire to the respondents. The administration of the questionnaire was preceded by a day's workshop organized to explain the items on the survey instruments to the enumerators. The researcher accompanied the enumerators during administration of the instruments, which offered the opportunity to explain terminologies that were not familiar to the enumerators. The questionnaire was administered in the study communities between 14th March and 14th April, 2016. **Appendix 6** shows the picture of some events during the field work.

3.6 Population and Sample Size

Population

The target population for this study was smallholder farmer households drawn from the four communities in Nandom district of the Upper West Region of Ghana. The ages of the smallholder participants ranged from 15 years and older and involved those engaged in crop production (the major agricultural activity). Ideally, the study should have covered more communities in the district to enrich the validity of the results obtained. However, the detailed nature of the research instruments and methods, the statistical models and participatory techniques used curtailed any errors about validity of the research findings.

This study employed the probability proportional to size (PPS) technique (Yansaneh, 2005; Antwi *et al.*, 2015) for the determination of the study population and sample size. According to the 2010 population and housing census (GSS, 2014) analytical report, about 85.3 percent of households in the Nandom district of the Upper West Region of

Ghana are engaged in agriculture and mainly crop production. Based on the above percentage, the study population was derived from the number of households in each of the selected communities involved in agriculture or crop production. The communities selected for the study were Billengangn, Gengenkpe, Naapaal and Ketuo with number of households as 135, 109, 141, and 57, respectively. The number of households engaged in agriculture, that is crop production from each of these communities was calculated as 85.3 percent of their respective numbers of households indicated above. The exact number of households involved in agriculture estimated was 115, 93, 120 and 47 for Billengangn, Gengenkpe, Naapaal and Ketuo, respectively, making an estimated total study population of 375 smallholder farmer households engaged in agriculture (crop production).

Sample Size

The sample size used for the survey questionnaire for each of the study communities was estimated using equation (3.1) (Yamane, 1967; Antwi *et al.*, 2015), at 95% confidence level with degree of variability equal to 0.5.

$$n = \frac{N}{1+N(e)^2} \quad (3.1),$$

where n is the sample size, N is the total population size (total household size) for all the four study communities and e is the sampling margin of error, which in this study is equal to 0.05. From equation (3.1), 194 smallholder farmer households were randomly selected to constitute the sample size. The sample size of communities was then estimated as 60, 48, 62, and 24 for Billengangn, Gengenkpe, Naapaal and Ketuo, respectively, using the probability proportional to size procedure.

3.7 Sampling

3.7.1 Household Sampling and Data Collection

Simple random and purposive sampling techniques were employed to select the study communities from originally classified flood prone communities. The communities were selected in such a way that each had an equal chance of being chosen and each choice was independent of the other. The name of each of the flood risk communities was written on pieces of paper and four (4) were randomly selected for the study.

3.7.2 Soil Sampling

Soil samples were collected from two (2) selected farmlands (1 hectare each) at a depth of 0-20 cm from the study communities, on 20th July, 2016 between 7 am and 2 pm. A total of eight (8) composite soil samples were collected for analysis with each made up of twenty (20) sub-samples (**See Figure 3**). the use of composite samples is permissible. The soil samples were collected with a plastic spade into a plastic bucket and stirred thoroughly to obtain a homogenous mixture. In addition, core samples of moist soil at a depth of 0-20 cm for the determination of bulk density were randomly collected from each farmland. The uniform composite soil samples were packed into transparent zipped lock plastic bags and transported to the laboratory in an ice chest (Lente *et al.*, 2012) for analysis. The soil sampling was done prior to cropping on farmlands that were not previously treated with agrochemicals such as fertilizers and pesticides (Estefan *et al.*, 2013). Discussions and interviews with farmers, agricultural officers, assemblymen, and stakeholders provided valuable information for the identification and selection of these sampled farmlands. The purpose of the soil analysis was to ascertain the quality regarding fertility status and the ability to support the livelihood strategies of farmers.

Soil tests provide a means for determining the fertility status of a soil but do not provide direct means of the actual quantities of plant available nutrients in the soil. Hence, the choice to use the composite samples, which is also an acceptable soil sampling protocol (Estefan *et al.*, 2013).

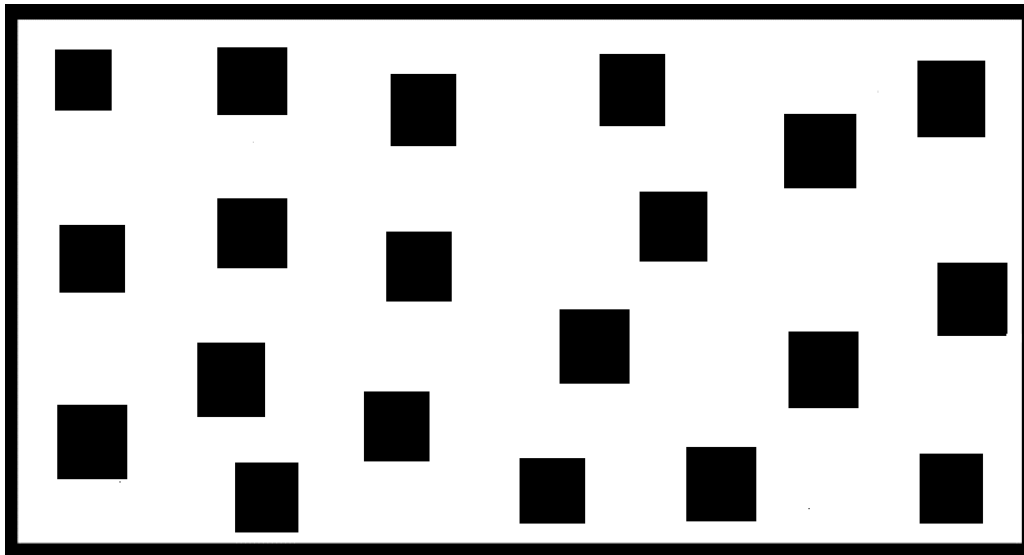


Figure 3: A sketch of random soil sampling of farmland.

3.7.3 Water Sampling

Water from the Black Volta River at points bordering Gengenke, Naapaal, Ketuo and one other River (“Babiara” River) in Billengangn, respectively, were sampled. For each of the rivers, samples were taken from upstream, midstream and downstream. In addition, water from three (3) boreholes from each of the study communities and a hand-dug well from Billengangn were collected for analysis. All water samples were put into previously cleaned–prepared 500 mL plastic bottles. Sample bottles were rinsed with sampled water three times and then filled to the brim in-situ. Separate plastic bottles were used for water samples for the determination of dissolved oxygen (DO), biochemical oxygen demand (BOD), physico–chemical parameters and heavy metals. In all, twenty-five (25) water samples were taken. Winkler I and II were added to BOD

water samples for BOD preservation and 2 mL of 10% HNO₃ to acidify waters for metal preservation. Oxygen was fixed in the sample at the sampling site by the Azide modification method (APHA, AWWA and WEF, 2001). For the 500 mL plastic bottle containing the water sample for the dissolved oxygen determination, 2 mL of Winkler I was added to each sample followed by 2 mL of Winkler II (alkali iodide azide solution) and corked to exclude air bubbles. The plastic bottles were kept on ice and transported to the laboratory for analysis. The water samples for the BOD was kept in dark plastic bottles, placed on ice and then transported to the laboratory. Water samples were collected on July 23, 2016 between 7 am and 2 pm. This was done to be able to transport samples from Nandom to Accra within 24 hours. The GPS coordinates for water and soil sampling points are shown in **Table 3**.

Table 3: GPS coordinates for water and soil sampling location.

Community/Sample Code	Description	Latitude "N"	Longitude "W"	Altitude (m)
Billengangn				
BR1	River upstream	10.85565	-2.75301	267
BR2	Midstream	10.85546	-2.75362	269
BR3	Downstream	10.85537	-2.75462	268
BB1	Borehole	10.85655	-2.75051	267
BB2	Borehole	10.856130	-2.74614	274
BB3	Borehole	10.86089	-2.75029	273
BHDW	Hand dug-well	10.85833	-2.75145	273
BS1	Soil at farm 1	10.85674	-2.74985	269
BS2	Soil at farm 2	10.85730	-2.75183	269
Gengenkpe				
GR1	River upstream	10.81598	-2.87862	239
GR2	Midstream	10.81566	-2.87857	237
GR3	Downstream	10.81533	-2.87859	240

Community/Sample Code	Description	Latitude "N"	Longitude "W"	Altitude (m)
GB1	Borehole	10.82258	-2.85014	271
GB2	Borehole	10.82335	-2.84860	269
GB3	Borehole	10.81939	-2.84514	269
BS1	Soil at farm 1	10.81491	-2.87392	245
BS2	Soil at farm 2	10.81910	-2.85353	267
Naapaal				
NR1	River upstream	10.88959	-2.83705	237
NR2	Midstream	10.88940	-2.83734	235
NR3	Downstream	10.88912	-2.83745	236
NB1	Borehole	10.86969	-2.81036	264
NB2	Borehole	10.86829	-2.80738	267
NB3	Borehole	10.86707	-2.80634	271
NS1	Soil at farm 1	10.88022	-2.82267	250
NS2	Soil at farm 2	10.86588	-2.80062	270
Ketuo				
KR1	River upstream	10.91113	-2.82379	237
KR2	Midstream	10.91142	-2.82364	237
KR3	Downstream	10.91084	-2.82365	238
KB1	Borehole	10.904390	-2.80060	254
KB2	Borehole	10.90619	-2.80699	251
KB3	Borehole	10.90101	-2.79968	254
KS1	Soil at farm 1	10.90928	-2.81404	245
KS2	Soil at farm 2	10.90032	-2.79959	251

Source: Field work, 2016/2017

3.7.4 Rainfall and Temperature Data Collection

A thirty-year historical rainfall and temperature data spanning a period of 1984 to 2014 were obtained from the Ghana Meteorological Agency's (GMet) gauged station at Babile for analysis to examine and understand the extent and nature of variability in mean annual and monthly as well as seasonal rainfall and temperature variables

(Nyantakyi-Frimpong & Bezner-Kerr, 2015). The climate data were taken from the station at Babile (65 % data availability) instead of the one at Lawra because of existing high gaps in the Lawra data (only about 13 % data are available).

In addition, merged satellite dataset (from the combination of gauge and satellite data using merging techniques) for village level rainfall and temperature for the period 1984 to 2014 was obtained from the Ghana Meteorological Agency for analysis and comparison. The mean monthly and annual rainfall and temperature at each of the communities were analyzed for temporal variability and trends. The gauged and merged climate data were compared with the primary data acquired through the community survey based on the perception of respondents on changes in the climatic variables and associated extreme events in the study area. The data on rainfall and temperature were incorporated into the community vulnerability analysis using the Livelihood Vulnerability Index (LVI).

3.8 Method of Analysis

3.8.1 Soil Fertility and Quality Analysis

Farm soil samples were prepared using standard methods (APHA-AWWA-WEF, 2001). Trace elements were analyzed in the Ghana Atomic Energy Commission whilst the physical and chemical analyses were done in the University of Ghana Ecological Lab. The soil samples were placed in plastic trays with labels to ensure easy identification of the samples. The samples were then air and oven dried remove moisture. The samples were ground using ceramic pestle and mortar, all larger aggregates crushed and mixed thoroughly to obtain uniform mixtures. The grinding and sieving was done repeating by returning coarse particles into the mortar and regrinding till all aggregates

particles were fine to pass through a 2 mm sieve. The entire sample of a particular site or farmland was sieved to obtain fine particle sizes with larger surface area for the actions of reagent during physical and chemical analysis. The sieved soil samples were kept in clean plastic bags and stored appropriately.

Soil physical and chemical analyses were conducted to determine the soil nutrient status of the selected farmlands. The parameters analyzed included hydrogen ion concentration (pH), electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), salinity, organic carbon (OC), organic matter (OM), -moisture, dry matter (DM), nitrogen (N), phosphorus (P) and potassium (K). In addition, the levels of the following trace elements were determined in the soil samples: chromium (Cr), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), lead (Pb), nickel (Ni), cadmium (Cd), cobalt (Co), and arsenic (As).

All analyses to determine these parameters in the soil samples followed the standard methods of the American Public Health Association, American Water Works Association, Water Environment Federation (APHA-AWWA-WEF, 2001), and that described by the International Centre for Agricultural Research in Dry Areas, ICARDA (Estefan *et al.*, 2013). Descriptive statistics were used to analyze the laboratory results to assess relationships between and within samples and communities.

3.8.2 Water Quality Analysis

Physical and chemical parameters in water samples. In the laboratory, acidified water samples for trace metal analysis were kept in the fridge at a temperature of about 4 °C. Both physical and chemical as well as bacteriological analyses were carried out on the water samples to assess the water quality.

In the analysis of water samples, the Ghana raw water quality criteria and guidelines by the WRC and the WHO guidelines for drinking water were employed for river (surface) water and groundwater sources, respectively.

Analytical Quality Assurance and Control

- Reagents and standards used in the analysis were obtained from BDH Chemicals Ltd, Poole England and Philip Harris Chemicals;
- Sampling bottles and glassware were washed with acetone, detergents, 0.1 M H₂SO₄ and rinsed with distilled water;
- All the equipment were cleaned with acetone, deionized water, and placed in an oven before each sample treatment
- All equipment were calibrated using the appropriate standards before use.
- The soil samples were taken with a plastic spade.
- Samples were kept in plastic bottles and bags.
- For validation of the analytical procedure, repeated analysis of the soil samples against internationally certified IAEA soil-7 standard reference material were used, and the results were found below 10 % of the certified values.

3.8.3 Observed Rainfall and Temperature Data Validation and Analysis

Observed rainfall and temperature data were subjected to quality control measures to detect and identify possible errors made during data collection, recording, transmitting and archiving (WMO, 2002). Data were analyzed to remove outliers, negative rainfall and temperature values, checked internal consistency and temporal-spatial coherency.

For instance, outliers were removed for cases where the minimum temperature was higher than the maximum temperature. Periods without data for all the rainfall and temperature variables were set to a missing value.

Homogeneity testing was conducted on the data to ensure that time fluctuations in the data were only due to the vagaries of weather and climate. This was done using the standard normal homogeneity test incorporated in the climate data tool (CDT) software. The process involves four (4) steps namely, metadata analysis and quality control; creation of a reference time series; breakpoint detection and data adjustment.

The observed climate data were obtained from the Ghana Meteorological Agency's climate station at Babile in the Lawra District. The purpose was to examine the extent and nature of variability in the rainfall and temperature and the corresponding effects on smallholder livelihoods in the study area (Nkrumah *et al.*, 2014). The GMet station at Lawra and data for recent years (2015 and 2016) were not used due to data unavailability and gaps.

Merged satellite rainfall data for each of the study communities were obtained and analyzed based on TAMSAT rainfall retrieval algorithm calibrated over Ghana using quality control data from weather stations (Grimes *et al.*, 1999). The Raw METEOSAT data spanning as far back as 1981 were obtained and processed by the TAMSAT (Tropical Applications of Meteorology using SATellite data) at the University of Reading in the United Kingdom, UK. The steps followed to merge the rainfall data included: extraction of rainfall estimate values at rain gauge values at each station location; computation of the difference between satellite and rain gauge values at each station location; interpolation of these differences to each grid point or satellite pixel centres and addition of the interpolated differences back to the satellite estimate

(Source: GMet). Climate data tool software and R statistical package were used through regression kriging in the quality control and merging of the data sets (Odeh *et al.*, 1995; Hengl *et al.*, 2004; Hengl *et al.*, 2007).

ANOVA was performed to evaluate the differences in total annual, mean maximum, and mean minimum rainfall values among the four communities studied.

3.8.4 Perception of Climate Change and Weather Events by Smallholder Farmers

The Likert rating scale was used to ascertain and analyze household-level perceptions of climate change and variability as well as extreme weather events. The respondents indicated their level of agreement or disagreement for given statements in respect of climate-related and extreme events in their communities over time. The Likert scale (Likert, 1932) comprises a statement concerning an event and an evaluative part of a list of response categories ranging from “strongly agree” to “strongly disagree”. In this section, the perception of smallholder farmers towards climate change and related events was investigated using a five point Likert scale. The observed climate data were compared with the perception of climate change and weather events by smallholder farmers and their related drivers and effects on livelihood strategies of farmers and policy.

3.8.5 Availability, Utilization and Changes in Agroecosystem Services in Study Area

Literature was reviewed extensively to gather in-depth information on agroecosystem services and other beneficial natural resources that underpin the livelihoods of smallholder farmers in semi-arid regions. In addition, a questionnaire was administered to smallholder households to identify agroecosystem services that support their livelihoods and well-being. Key informant interviews and focus group discussions were

conducted to relevant stakeholders and gendered groups in each of the communities to augment the household questionnaire survey. Key informants were interviewed in respect of their role in the management of agroecosystem services and climate-related issues in the district. The household interviews obtained perceptions regarding the availability and access to agroecosystem services by different groups of smallholder farmers, the changing patterns, and the management and governance of agroecosystem services. The data (i.e. perceptions of farmers) gathered from the survey were analyzed using descriptive statistics and presented as frequencies, percentages, and charts or graphs. The Microsoft Spreadsheet Application (Excel 2016) and SPSS version 22 were employed to capture and process the data of the study.

The Likert scale (Likert, 1932) was employed to identify important trends in the availability and perceived changes in agroecosystem services over time. For instance, ranking terms such as “Very high”, “High”, “Medium”, “Low” and “Very low” and “Increased sharply”, “Increased slightly”, “Remained constant”, “Decreased slightly” and “Decreased sharply” were used to describe the respondents’ perceptions of the extent of availability or supply and change in identified agroecosystem services over time in the study sites.

3.8.6 Vulnerability to Recent Agroecosystem and Climate Change

The conceptual framework adopted from Turner II *et al.* (2003) for this study explains the connections between the drivers of climate change and associated hazards within the vulnerability context in relation to current and expected responses, how climate change and variability and agroecosystem services change affect smallholder farmers in the study area. Household vulnerability to climate change and variability is driven by alterations in biophysical, socioeconomic, and socio-political factors (Hahn *et al.*,

2009; Etwire *et al.*, 2013). The biophysical drivers are mostly the natural and anthropogenic climate variability including extreme weather events. Such events include floods, droughts, bushfires and environmental degradation, and changes in the natural capital assets like agroecosystem services. The socioeconomic drivers comprise policy, demography, land tenure, governance, and economic (local markets) factors whereas the socio-political factors are institutional arrangements and knowledge systems.

The extent of vulnerability of the smallholder farmers is a function of their exposure level, sensitivity, and adaptive capacity. Hence, the impacts of changes in climate and agroecosystem services are dependent on the extent of interaction between exposure, sensitivity, and adaptive capacity (Turner II *et al.*, 2003; Luers, 2005; Smit & Wandel, 2006; IPCC, 2007b; Fussel, 2007, 2009).

According to Ribot (2009) and Turner II *et al.* (2003), vulnerability analysis comprises two key models, the Risk-Hazard (R-H) and the Pressure-and-Release (PAR) models. The R-H considers the impacts of a hazard as the function of the exposure to risk and the sensitivity (dose-response) of the affected system. However, this model has been criticized among other things as its inability to highlight the ways in which the exposed system amplifies the impacts of a hazard. In addition, it is not able to identify the differentiated consequences of hazards among exposed systems and associated components and the inability to explain explicitly how socioeconomic, socio-political, and institutions affect the level of the differential exposure and consequences to the hazard (IPCC, 2001; Hahn *et al.*, 2009).

These shortcomings of the R-H led to emergence of the pressure-and-release (PAR) model, which clearly explains risk as a function of a hazard and vulnerability of the

exposed system. The PAR model identifies the causes and conditions that render the exposed units vulnerable and unsafe. The PAR analyzes the severity and differentiated impacts of the hazard to the exposed social group, system, component or subcomponent (Turner II *et al.*, 2003; Hahn *et al.*, 2009). However, unlike R-H, PAR does not consider the complexities that exist in human-nature and nature-human interactions in terms of the vulnerability of the biophysical components.

Alternatively, the integrated approach of vulnerability analysis takes into consideration the R-H and PAR models (Turner II *et al.*, 2003) and combines both socioeconomic and biophysical drivers into the vulnerability context (Fussel, 2007). This study adopted the integrated approach to assess the vulnerability of households in local communities through the application of the Livelihood Vulnerability Index (Hahn *et al.*, 2009; Etwire *et al.*, 2013). The Livelihood Vulnerability Index (LVI) refers to a quantitative tool that enhances understanding of the contributions of socioeconomic, socio-political, and biophysical drivers to the vulnerability context (Hahn *et al.*, 2009). This approach integrates climatic and non-climatic exposures and adaptation strategies to evaluate livelihood risks of smallholder farmers stemming from changes in agroecosystem services and climate variability. The LVI employs multiple indicators to assess exposure to extreme weather events and climate variability, socioeconomic profile of households that influence their adaptive capacity as well as their sensitivity to effects of climate change due to health, food, and water resources characteristics (Hahn *et al.*, 2009; Etwire *et al.*, 2013). Furthermore, the LVI uses household-level primary data from the field surveys to form sub-components and indices, which are aggregated into major indicators for the estimation of household vulnerability to climate change.

Indicators are quantifiable constructs that provide information either on matters of wider significance than that which is measured, or on a process or trend that otherwise

might not be apparent (Hammond *et al.*, 1995; Vincent, 2004; Vincent, 2007). They are a means of encapsulating a complex reality in a single construct and are of use to decision makers at all levels, particularly in comparing across space and monitoring change over time (Etwire *et al.*, 2013). This quantitative vulnerability analysis is either evaluated using an econometric or indicator approach (Hahn *et al.*, 2009; Etwire *et al.*, 2013). The econometric approach employs regression techniques and uses a lot more secondary data (Antwi-Agyei *et al.*, 2012). The indicator approach was employed to calculate the extent of vulnerability of farming households to changes in agroecosystem services and climate change (Hahn *et al.*, 2009; Etwire *et al.*, 2013).

Vulnerability is a theoretically diverse field and difficult to assess due to the variety of determinants acting and interacting on different scales (Chambers & Conway, 1992; IPCC, 2014). It is therefore appropriate to rely on indicators that best represent the complex underlying local processes that lead to the vulnerability context.

In incorporating sub-components to form major components, several methods such as the gap method and the balance weighted vulnerability index have been used. The gap method assesses vulnerability based on the deviation of a households' empirical impacts and responses from theoretical standard living conditions in the absence of climate change and variability. On the other hand, the balance weighted method correctly values indicators based on the significant contributions each indicator makes into the vulnerability context of smallholder households to climate change and variability (Hahn *et al.*, 2009; Etwire *et al.*, 2013). The balance weighted approach was employed in estimating livelihood vulnerability index (LVI) as described below.

3.8.7 Assessing the Level of Vulnerability of Smallholder Farmers

The Livelihood Vulnerability Index (LVI) used seven major components which include socio-demographic profile (SDP), livelihood strategies (LS), social networks (SN), health (H), access to food (F), access to water (W) and natural disasters and climate variability (NDCV) (Hahn *et al.*, 2009; Etwire *et al.*, 2013) and twenty-one sub-components. The sub-components were generated from household-level primary data based on four key biophysical, socioeconomic, socio-political, and institutional variables.

Each of the sub-components was standardized as an index or major components using Equation (3.2):

$$\text{index}_{s_c} = \frac{s_c - s_{\min}}{s_{\max} - s_{\min}} \quad (3.2)$$

Where s_c is the observed sub-component or indicator for community c , and s_{\min} and s_{\max} are the minimum and maximum values, respectively. After each was standardized, the sub-component or indicators were averaged using Equation (3.3):

$$M_c = \frac{\sum_{i=1}^n \text{index}_{s_{ci}}}{n} \quad (3.3)$$

Where M_c is one of the seven major components (SDP, LS, SN, H, F, W or NDCV) for community c , $\text{index}_{s_{ci}}$ represents the sub-components in each major component. The computed values for each of the seven major components for a community were then averaged using Equation (3.4) to obtain the community level LVI:

$$\text{LVI}_c = \frac{\sum_{i=1}^7 W_{M_i} M_{c_i}}{\sum_{i=1}^7 W_{M_i}} \quad (3.4)$$

Equation (3.29) is expanded to form Equation (3.5):

$$LVI_c = \frac{W_{SDP} SDP_c + W_{LS} LS_c + W_H H_c + W_{SN} SN_c + W_F F_c + W_W W_c + W_{NDCV} NDCV_c}{W_{SDP} + W_{LS} + W_H + W_{SN} + W_F + W_W + W_{NDCV}} \quad (3.5)$$

The weights of each major component, W_{Mi} , is a function of the number of sub-components associated with it. These are included to ensure that all sub-components contribute equally to the overall LVI.

Following from equations (3.2) to (3.4), a new variable, LVI-IPCC is calculated taking into consideration IPCC definition of vulnerability (Hahn *et al.*, 2009; Etwire *et al.*, 2013). The LVI-IPCC comes from the combination of the major components. Rather than merge the major components into the LVI in Equation (3.4), the major components were first combined according to the three categories or functions of vulnerability namely exposure, sensitivity and adaptation capacity using the Equation (3.6):

$$CF_c = \frac{\sum_{i=1}^n W_{Mi} M_{ci}}{\sum_{i=1}^n W_{Mi}} \quad (3.6)$$

Where CF_c is an IPCC-defined contributing factor (exposure, sensitivity, or adaptive capacity) for community c , M_{ci} are the major components for community c indexed by i , W_{Mi} is the weight of each major component and n is the number of major components in each contributing factor. Once exposure, sensitivity and adaptation capacity were calculated, the three contributing factors were then combined using Equation (3.7):

$$LVI - IPCC_c = (e_c - a_c) * S_c \quad (3.7)$$

Where $LVI - IPCC_c$ is the LVI for community, c , expressed using the IPCC vulnerability framework, e is the calculated exposure score for community, c (equivalent to NDCV major component), a is the calculated adaptation capacity score for community, c (weighted average of the SDP, LS, and SN major components) and s is the calculated

sensitivity score for community, c (weighted average of the H, F and W major components) as described in **Table 4**.

The LVI-IPCC is scaled from -1 (least vulnerable) to 1 (most vulnerable). The Microsoft Office Excel 2016, Stata13 and SPSS statistical packages were employed in estimating the livelihood vulnerability index of smallholder households in semi-arid Ghana.

Table 4: Contributing factors to LVI per IPCC approach,

Contributing factor	Major Component
I. Exposure	Natural disasters and climate variability
II. Adaptive capacity	<ol style="list-style-type: none"> 1. Socio-demographic profile 2. Livelihood strategies 3. Social networks
III. Sensitivity	<ol style="list-style-type: none"> 1. Health 2. Food 3. Water

Each of the major components comprised a given number of sub-components or indicators. In all, twenty-one (21) key indicators were used for relative vulnerability analysis of four (4) semi-arid communities using the LVI as described above and in **Appendix 7**. The specific number of sub-components for each of the major components are 4, 2, 2, 4, 2, 2, and 5 for socio-demographic profile, livelihood strategies, social networks, food, water, health and natural disasters and climate change variability respectively.

3.8.8 Analysis of Perceptions of Smallholder Farmers on Adaptation Strategies

Literature was reviewed to identify the adaptation strategies available and used by smallholder farmers to withstand and overcome risks from changes in agroecosystem services (such as soil fertility, food, fuelwood, water, and forest cover) and climate (such as low rainfall, high rainfall, and high temperature) in semi-arid regions. Household survey using questionnaire, focus group discussions, and key informant interviews were conducted at both community and district levels, to identify and rank the adaptation options of smallholder farmer households.

In the household survey, respondents were asked to indicate whether they are adapting and using adaptation strategies to moderate the impacts of agroecosystem services and climate change.

Descriptive statistics were employed to analyze the responses and presented using frequencies, percentages, charts, or graphs. The available adaptation strategies were ranked in order of highest number of responses. Respondents were also asked to indicate reasons why they did not adopt certain adaptation strategies. Factors responsible for each respondent's inability to adopt the available adaptation strategies were captured, ranked, and discussed qualitatively.

Furthermore, households' biophysical, socioeconomic, and institutional factors that influenced adoption of adaptation strategies by smallholder farmers were captured and analyzed.

Multiple regression through maximum likelihood estimation (Wooldridge, 2002) was done using adaptation strategies as the dependent variable and factors marked by respondents as influencing adaptation as independent variables. The Durbin-Watson

Statistic was used to test for autocorrelation among the independent variables in relation to the dependent variable. The independent or explanatory variables identified include availability of agroecosystem services, farm size of respondents in hectares, access to climate information, access to training on best farming practices, farmland ownership, how satisfied a smallholder farmer is with life in relation to major challenges, gender, access to information on managing ecosystem services. The explanatory variables were derived from household characteristics, biophysical, socioeconomic, and institutional factors (Apata *et al.*, 2009; Deressa *et al.*, 2009).

3.8.10 Analysis of Knowledge and Information Sources on Adaptation Strategies

Household surveys with semi-structured questionnaire, key informant interviews and focus group discussions were used to obtain information on the sources of climate-related information and knowledge for smallholder farmers for managing climate variability and extreme weather stresses as well as the changes in agroecosystems and ecosystem services. The data were analyzed qualitatively using descriptive statistics. Frequencies, percentages and charts used to rank and display specific sources of climate information available to respondents. The extent of usage of climate information, knowledge as well as the barriers to accessing climate-related and agroecosystem services management knowledge were identified and presented using frequencies, percentages, means, and charts.

3.9 Limitations of the Study

The research had to address several key terms and themes that are subject to different theoretical and conceptual interpretations. These include vulnerability, agroecosystem services, adaptation, human well-being, and smallholder farmers among others.

Participatory research techniques such as household questionnaire, focus group discussions, and key informant interviews employed in this study are subject to both researcher and participant biases which may affect reliability and validity of findings. More than four communities could have been selected for to widen the scope of coverage in the district and to enrich the household data. However, the detailed nature of interview questions as well as the integration of the quantitative and qualitative data should curtail any weakness. In addition, experts were relied on for their opinions to provide valuable insights into the various research themes.

The gauge data analyzed in this study were limited with regards to gaps in recorded rainfall and temperature values which may represent a challenge for the climate findings. However, the data were subjected to quality control to remove negative values and outliers.

CHAPTER FOUR: RESULTS

4.1 Household Profile of Respondents

This section discusses the results of the socio-demographic, socioeconomic status and farm characteristics of respondents as presented in **Table 5**.

Table 5: Household characteristics of respondents.

Household Profile	Pooled Sample (n=194)	Billengang n (n=60)	Gengenkp e (n=48)	Naapaal (n=62)	Ketuo (n=24)
Gender	%	%	%	%	%
Male	52.6	55.0	60.4	53.2	29.2
Female	47.4	45.0	39.6	46.8	70.8
Gender of Household Head					
Male	68.0	71.4	72.7	64.3	60.0
Female	32.0	28.6	27.3	35.7	40.0
Age Group					
< 20 Years	8.2	21.7	0.0	4.8	0.0
20-29	13.4	11.7	12.5	9.7	29.2
30-39	15.5	13.3	20.8	11.3	20.8
40-49	22.2	18.3	25.0	25.8	16.7
≥ 50 years	40.7	35.0	41.7	48.4	33.3
Marital Status					
Single	19.1	28.3	10.4	22.6	4.2
Married	69.6	58.3	72.9	67.7	95.8
Widowed	11.3	13.3	16.7	9.7	0.0
Level of Education					
Primary	19.1	6.7	14.6	0.0	0.0
JSS/Middle Sch.	17.5	30.0	10.5	32.3	25.0
Sec./Voc./Tech.	5.7	5.0	8.3	12.9	20.8
Tertiary	2.6	1.7	6.3	6.5	4.2
None	54.1	56.7	60.4	48.4	50.0
Household Size					
0-5	29.9	26.7	29.2	35.5	25.0
6-10	56.2	58.3	58.3	56.5	45.8
11+	13.9	12.5	12.5	8.1	29.2
Occupation					
Farming	96.9	95.0	93.8	100.0	100.0
Fishing	0.5	1.7	0.0	0.0	0.0
Others	2.6	3.3	6.2	0.0	0.0
Farm Size (Hectares)					
0-2	73.2	86.7	66.7	69.4	58.3

Household Profile	Pooled Sample (n=194)	Billengang n (n=60)	Gengenkp e (n=48)	Naapaal (n=62)	Ketuo (n=24)
3-4	22.2	8.3	25.0	25.8	41.7
5-6	4.1	5.0	6.3	3.2	0.0
7+	0.5	0.0	2.1	1.6	0.0
Land Ownership					
Family	82.5	86.7	52.1	96.8	95.8
Rental	4.1	3.3	12.5	0.0	4.2
Landlord	9.8	10.0	20.8	3.2	0.0

Source: Field work, 2016

The household survey indicated 52.6 % male and 47.4 % female respondents. However, Ketuo recorded more females (70.8 %) than males (29.2 %). Majority of the respondents (40.7 %) were within the age group of fifty (50) years and above with only a small proportion (8.2 %) within the age group below twenty (20) years. For the gender of interviewed household heads, about 68.0 % were male whereas 32.0 % were female. Ketuo recorded the highest proportion (40.0 %) of female household heads with the lowest (27.3 %) in Gengenkp. The highest proportion of respondents (48.4 %) within age group 50 years and above was recorded in Naapaal whereas the lowest was in Ketuo. Even though respondents were mainly household heads, observation of household composition showed that there were very few young (below 25 years) household members during the survey.

In terms of marital status, the survey showed that 19.1 % of respondents were single, 69.6 % reported married, and 11.3 % widowed. Majority of married respondents (95.8 %) were in Ketuo, whilst the minority (58.3 %) were in Billengangn. However, there was no widow or widower among respondents in Ketuo compared to the other communities.

With regards to educational level, more than half of the respondents (54.1 %) received no formal education or non-formal education, whilst only 19.1 % obtained primary

education. The largest proportion of respondents (60.4 %) with no education was recorded in Gengenkpe, whilst the smallest proportion (48.4) was in Naapaal.

More than half of the survey respondents (56.2 %) had family sizes of between 6 and 10 persons and the highest of this number of household membership was in both Billengangn and Gengenkpe, whilst the lowest was recorded in Ketuo (45.8 %). About 29.2 % of interviewed households in Ketuo reported household size of eleven (11) and above persons whilst Naapaal accounted for (8.1 %). In terms of occupation, majority (96.9 %) of household heads were farmers. The results indicated that most of the respondents (73.2 %) held maximum land sizes of about two (2) hectares with the highest proportion (86.7 %) in Billengangn and the lowest (58.3 %) in Ketuo. Meanwhile, a smaller proportion (0.5 %) of farmers had about seven (7) or more hectares of land holdings in Gengenkpe and Naapaal, whilst no farmer in both Billengangn and Ketuo held up to 7 hectares of land.

The survey revealed three (3) main land ownership systems in the study area, family, rental, and landlord systems. The results indicated that most of the respondents (82.5 %) owned and cultivated family lands, about 9.8 % were landlords of farmlands, and just a few (4.1 %) rented land for farming activities. Naapaal had the highest proportion (96.8 %) of respondents owning land by the family system whereas Gengenkpe had the lowest (52.1 %).

The survey further indicated that about 91.8 % respondents cultivated both maize and groundnut as major crops (**Table 6**), whilst 4.6 % grew vegetables as minor crops. About 96.7 % of respondents in Billengangn cultivated maize representing the highest proportion in relation to other communities. In Gengenkpe, the main crop grown was groundnut represented by 89.6 % of the respondents whilst 95.2 % of respondents in

Naapaal indicated that maize was their major crop. In Ketuo, about 87.5 % cultivated maize, millet, and groundnut.

4.1.1 Major Crops Cultivated

Table 6 shows the major crops cultivated by respondents in the study communities.

Table 6: Major crops cultivated by respondents.

	Pooled		Billengangn		Gengenkpe		Naapaal		Ketuo	
	(n=194)		(n=60)		(n=48)		(n=62)		(n=24)	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
Maize	178	91.8	58	96.7	40	83.3	59	95.2	21	87.5
Millet	146	75.3	34	56.7	41	85.4	50	80.6	21	87.5
Groundnut	178	91.8	56	93.3	43	89.6	58	93.5	21	87.5
Rice	115	59.3	43	71.7	26	54.2	30	48.4	16	66.7
Beans	108	55.7	34	56.7	30	62.5	35	56.5	9	37.5
Vegetables	9	4.6	2	3.3	3	6.3	2	3.2	2	8.3
Guinea Corn	53	27.3	19	31.7	6	12.5	22	35.5	6	25.0
Yam	43	22.2	23	38.3	3	6.3	6	9.7	11	45.8

Source: Field Survey, 2016/2017

4.1.2 Crop Utilization by Respondents

The survey revealed that a high percentage of respondents used all crops produced at the end of the farming season at home (**Figure 4**). They hardly had any surplus of crop yields for sale to improve their income with the exception of groundnuts and beans. The low yield crops identified were maize, millet, guinea corn, and rice. The study identified groundnut as the crop which generated income for respondents in the study

communities because they were able to produce enough to be used at home and also for sale.

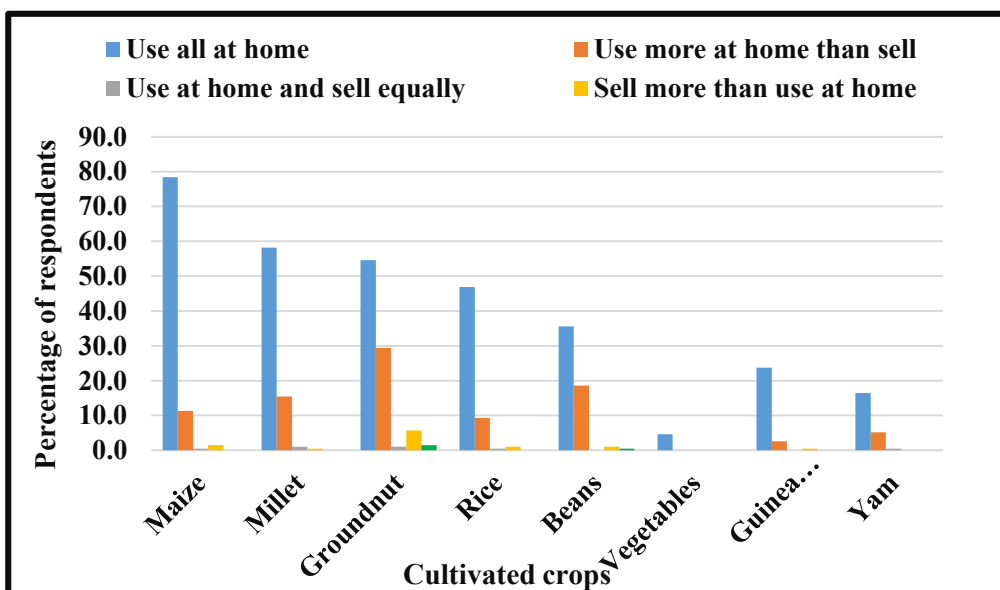


Figure 4: Crop utilization by respondents.

4.1.3 Access to Credit

The results of the survey as presented in **Figure 5** show that only about 14.4 % of the respondents had access to credit whilst a higher proportion (85.6 %) had no access to credit for their agricultural activities.

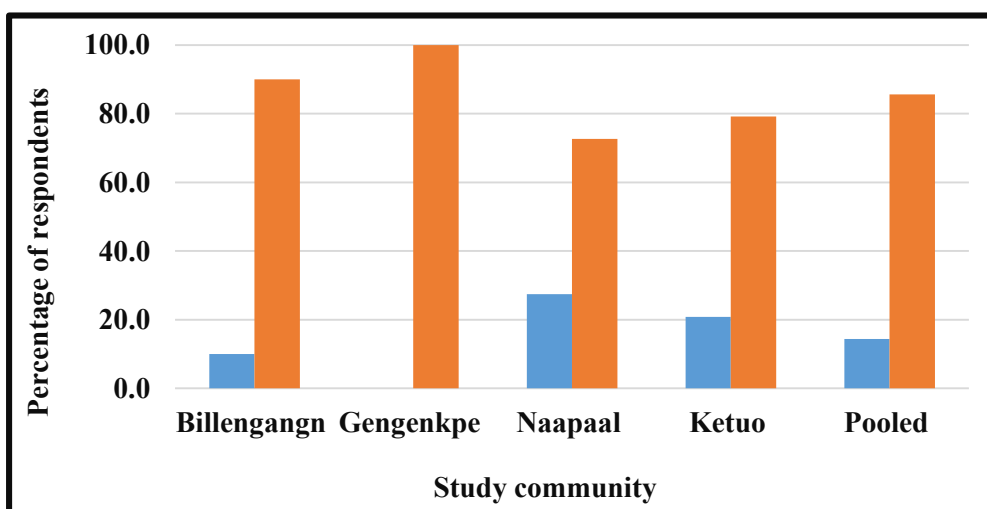


Figure 5: Access to credit by respondents.

None of the respondents in Gengenkpe had access to credit from either the bank or money lenders for their farming activities over the period whilst a higher percentage (27.4 %) in Naapaal indicated otherwise.

Focus group discussions revealed that Naapaal had a “women group” who were able to solicit credit for their farming activities. This group had signed an agreement with Guinness Ghana Limited, where the company gives credit to the women to cultivate sorghum which was then sold to the company. In Ketuo, however, Nandom Deanery Integrated Rural Development Programme (NANDIRDEP), an NGO in agriculture assisted farmers with both technical training and credits for their farming activities. These may be some of the reasons why Naapaal and Ketuo seem to have relatively high percentage of respondents indicating they had access to credit.

As shown in **Figure 6**, about 42.0 % of respondents received amounts between One Hundred Ghana Cedis and Three Hundred Ghana Cedis only (GHs100.00-GHs300.00) and Four Hundred Ghana Cedis and Six Hundred Ghana Cedis only (GHs400.00-GHs600.00). A lower percentage of 16.0 % received between Seven Hundred Ghana Cedis and Nine Hundred Ghana Cedis only (GHs700.0-GHs900.00).

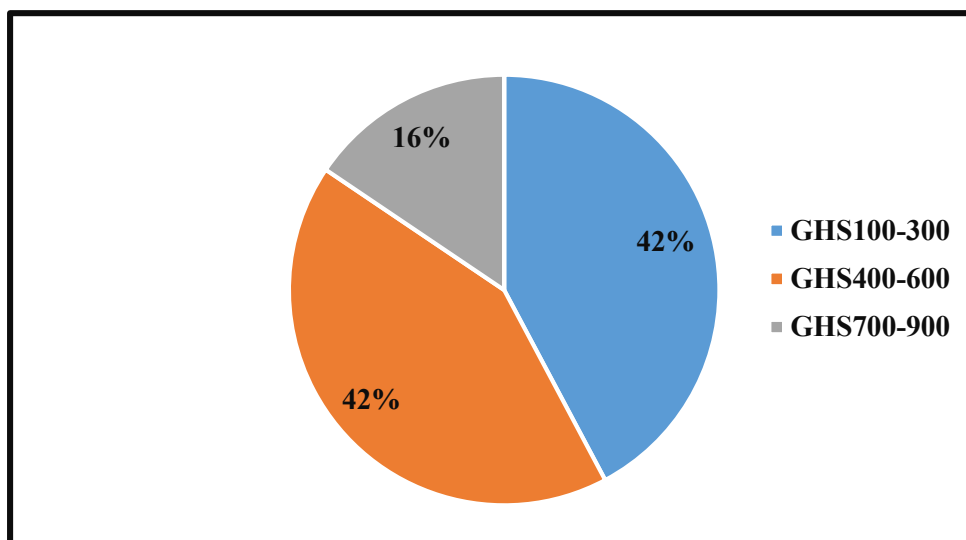


Figure 6: Amount of credit received by respondents (1USD:4.7GHS).

The **Figure 7** shows the sources of credit for respondents and indicated that about half of them obtained credit from money lenders, whereas a quarter got credit from banks and others. Others consisted of family, friends, and the village savings and loans association (VSLA).

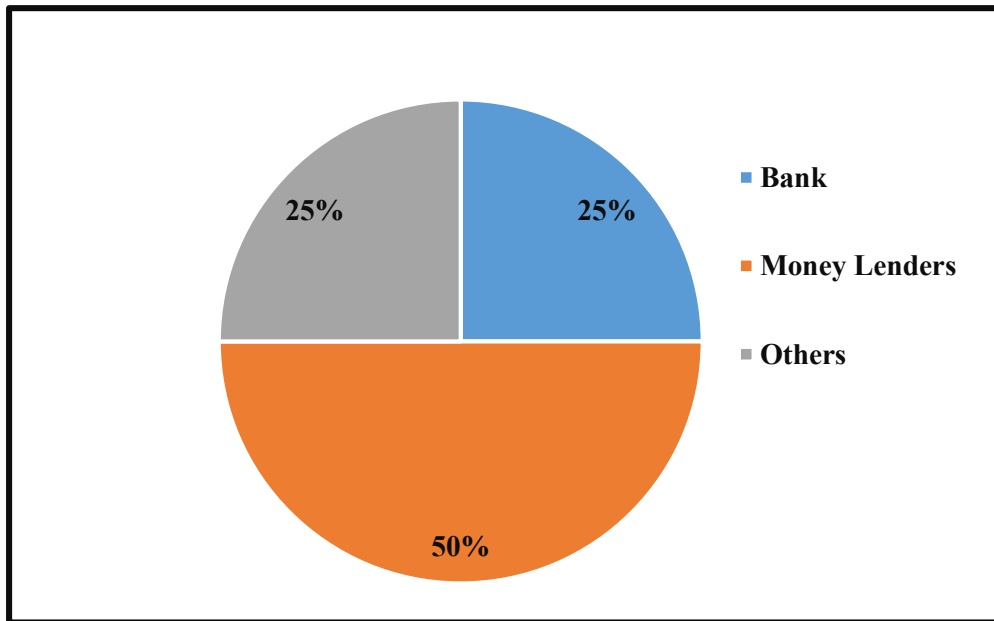


Figure 7: Sources of credit for respondents.

The respondents also indicated reasons why they were unable to access credit as presented in **Figure 8**. Majority of respondents (40.0 %) were not aware of sources of credit in their communities and for some others (32.0 %), they would not be able to pay back if they took any loan. A few indicated they did not have loan guarantors.

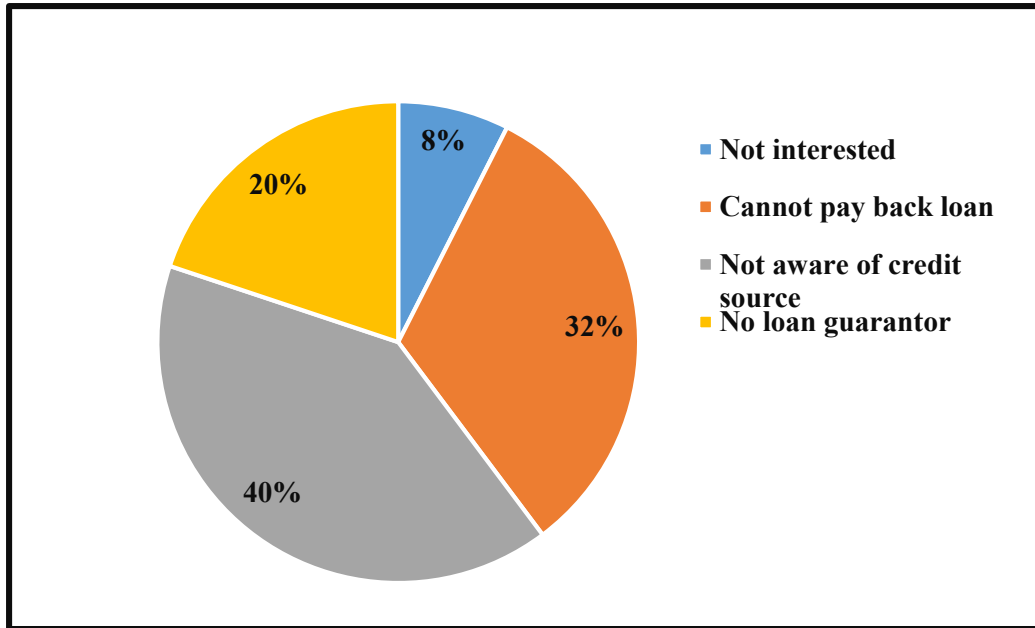


Figure 8: Reasons why respondents (%) do not access credit.

4.2 Soil Fertility Status

Physical and Chemical Properties of Farm Soil Samples from Study Communities

The results of the analysis of nutrients status, chemical, and physical parameters of soil samples from selected farms in the study communities are shown in **Table 7**. The analysis revealed that soil pH ranged from 5.60 to 8.00 with the highest value recorded in Billengangn and the lowest in Gengenkpe. The mean value of electrical conductivity (EC) of the soil samples ranged between 13.30 $\mu\text{S}/\text{cm}$ at the farm in Gengenkpe and 104.00 $\mu\text{S}/\text{cm}$ in Ketuo. The mean value of organic matter (OM) ranged from 0.92 % at Naapaal to 2.22 % at Billengangn. The total nitrogen levels ranged from 0.06 % at a farm sites in Naapaal to 0.22 % in Billengangn.

Table 7: Physical and chemical properties of farm soil samples.

Parameter	Billengangn	Gengenkpe	Naapaal	Ketuo
pH	7.8	5.85	6.35	6.1
Conductivity ($\mu\text{S/cm}$)	62.25	17.5	39.25	67.6
Organic matter (%)	2.22	1.47	0.92	1.10
Organic Carbon (%)	1.29	0.85	0.53	0.64
Moisture (%)	6.33	5.59	8.3	6.11
Nitrogen (%)	0.22	0.09	0.06	0.11
Phosphorus (%)	0.25	0.12	0.15	0.12
Potassium (%)	0.1	0.04	0.06	0.05

FAO (1980) Guidelines organic matter: <0.86 %-low, 0.86-1.29 %-marginal and >1.29 %-adequate for growth of crops.

Table 1 of Appendix 8 shows the levels of total suspended solids and salinity in the soil samples as well as the results of particle size analysis. Two main soil texture were found, loamy-sand for soils from Billengangn and Naapaal and sandy-loam for soils in Gengenkpe and Ketuo. The results of the analysis of all trace metals in soil samples are shown in **Table 3 of Appendix 8**. The results indicated that the concentrations were below the recommended maximum limits (Ewers, 1991). Meanwhile, the concentration levels of Cd and Co were below detection limit except for Co (0.34 mg/kg) at one of the farms in Billengangn.

4.3 Water Quality

4.3.1 Physico-Chemical Parameters in Water Samples

The results of the physico-chemical parameters analyzed in river water samples are shown in **Table 8**.

Table 8: Physico-chemical parameters of Black Volta River samples.

Community	Measured parameters				
	pH	TDS (mg/L)	Conductivity (μ S/cm)	Turbidity (NTU)	BOD (mg/L)
Billengangn	7.80	50.00	53.30	8.00	2.57
Gengenkpe	7.30	18.30	35.60	76.70	3.12
Naapaal	7.40	28.60	33.80	100.00	2.37
Ketuo	7.50	72.00	91.90	68.30	4.20
TWQRs	6.9-8.5	0.450	0-70	0-1	0.0-8.7
WHO	6.5-8.5	1000	-	5	-

TWQRs=Target water quality guidelines by the WRC, WHO=World Health Organization

The pH levels in all river water samples ranged from 7.3 to 7.8, whilst for the boreholes, the range was between 7.2 to 8.9 (**Table 8**). The concentration of total dissolved solids (TDS) in the river water samples were within the range of 18.30 mg/L at Gengenkpe and 72.0 mg/L at Ketuo, whilst in the boreholes the range was 16.8 mg/L at Naapaal to 209.7 mg/L at Ketuo. The measured turbidity levels ranged from 8.0 NTU at Billengangn to 100.0 NTU at Naapaal. Turbidity levels in borehole water samples ranged from 0 to 49 with the highest value at Billengangn, whilst a hand-dug well also recorded a value of 14 at Billengangn (**See Appendix 8**). The levels of electrical

conductivity in water from Ketuo (91.9 mg/L) exceeded the guideline range of 0-70 (TWQRs, 2003).

4.3.2 Major Ions in River Water Samples from Study Communities

The concentration levels of major ions of determines in water samples from the Black Volta River in the study communities are shown in **Table 9**.

Table 9: Major ion in the Black Volta River water samples.

Community	Measured parameters (mg/L)									
	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	NO ₃ ⁻	HCO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻	F ⁻	Cl ⁻
Billengangn	15.23	4.73	0.47	4.87	2.09	0.73	0.29	1.00	0.05	0.40
Gengenkpe	8.37	8.17	0.30	2.20	0.99	0.58	0.15	1.00	0.00	0.27
Naapaal	7.87	7.70	0.30	2.73	0.84	0.70	0.17	5.00	0.00	0.40
Ketuo	9.67	6.90	1.00	3.27	4.80	0.64	0.19	6.00	0.00	0.30
TWQRs	20.00	50.00	32.00	30.00	6.00	Nil	Nil	20.00	1.00	100.00

TWQRs=Target water quality guidelines by the WRC

The concentration levels of Na⁺ measured in water samples at Billengangn was about three times that of K and Mg and thirty-two times that of Ca as presented in **Table 9**. For Gengenkpe, the level of Na was almost equal as K, about twenty-eight times that of Ca and four times that of Mg. The levels of Na at Naapaal was about equal that of K, twenty-six times that of Ca and three times that of Mg. For water samples from Ketuo, the measured value of Na was about equal that of K, ten times of Ca and three times that of Mg.

For sampled water from boreholes in the study communities as shown in **Figure 9**, the results of the analysis of major ions indicated that for Billengangn, the concentration ranges were Ca^{2+} (3.20-11.20) mg/L, Cl^- (2.99-4.99) mg/L, F^- (0-0.37) mg/L, K^+ (3.70-7.00) mg/L, Na^+ (17.9-73.6) mg/L, NO_3^- (1.37-2.17) mg/L, PO_4^{3-} (0.03-1.63) mg/L, and SO_4^{2-} (8.14-21.93) mg/L.

For Gengenkpe, the ranges were Ca^{2+} (4.80-6.40) mg/L, Cl^- (2.99-4.99) mg/L, F^- (0.23-0.54) mg/L, K^+ (3.00-7.80) mg/L, Na^+ (38.70-44.90) mg/L, NO_3^- (0.35-1.41) mg/L, PO_4^{3-} (0.09-0.48) mg/L, and SO_4^{2-} (5.01-14.15) mg/L.

For Naapaal, the ranges were Ca^{2+} (20.80-35.20) mg/L, Cl^- (0.99-4.99) mg/L, F^- (0.14-0.16) mg/L, K^+ (3.60-6.20) mg/L, Na^+ (30.20-45.20) mg/L, NO_3^- (0.83-3.20) mg/L, PO_4^{3-} (0.89-3.49) mg/L, and SO_4^{2-} (10.05-21.28) mg/L, whilst the ranges for Ketuo were Ca^{2+} (9.60-22.40) mg/L, Cl^- (2.99-4.99) mg/L, F^- (0.14-0.38) mg/L, K^+ (1.50-3.50) mg/L, Na^+ (9.30-91.50) mg/L, NO_3^- (0.23-1.47) mg/L, PO_4^{3-} (0.02-0.13) mg/L, and SO_4^{2-} (27.92-35.15) mg/L (*WHO guideline values; $\text{NO}_3^- = 50$ mg/L*).

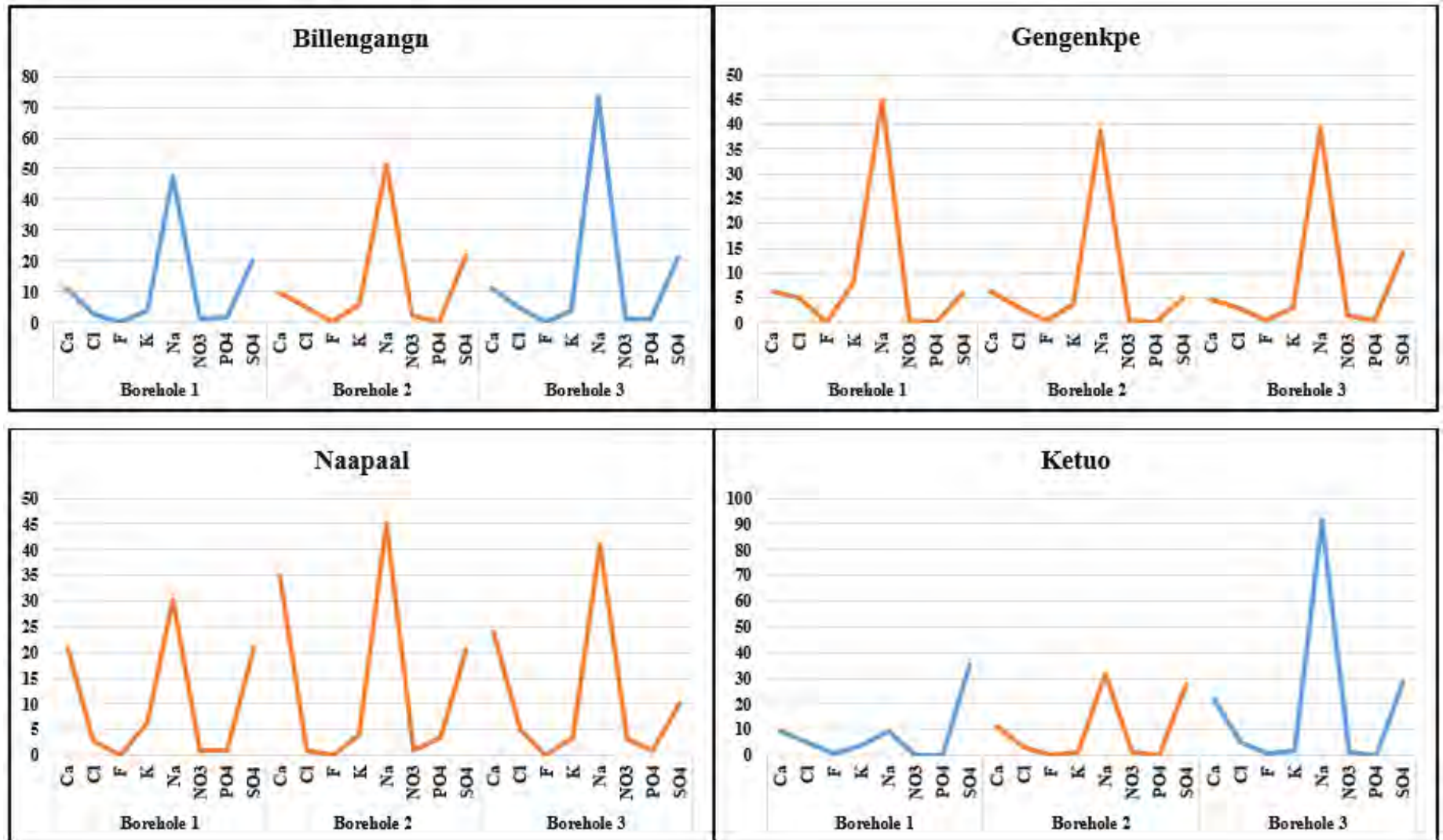


Figure 9: Major ions in borehole water from the study communities.

4.3.3 Trace Metals Results

The concentration levels of Fe, Mn, Pb, Ni, and As in water samples collected from the Black Volta River in the study communities are presented in **Table 10**.

Table 10: Mean concentrations of trace metals in river water.

Community	Trace metals (mg/L)				
	Fe	Mn	Pb	Ni	As
Billengangn	0.122	0.007	0.002	0.006	0
Gengenkpe	0.36	0.013	0.007	0.01	0.01
Naapaal	0.437	0.011	0	0.005	0.004
Ketuo	0.201	0.016	0.006	0.006	0.002
TWQRs	0.1	0.05	10	0	10

NB: *TWQRs=Target Water Quality Ranges, Source: WRC, 2003*). The results of the analysis of trace metals in borehole water is also shown in **Table 5** of **Appendix 8** and indicated that the concentrations of Cr, Cd, Co, and Cu are below detection limits.

The results of trace metal analysis indicated that the mean concentrations of Fe, Mn, Pb, Ni, and As were in the ranges as follows: (0.12-0.44) mg/L, (0.007-0.016) mg/L, (0.0-0.006) mg/L, (0.005-0.1) mg/L, (0.0-0.01) mg/L, respectively. The concentration of Cr, Cd, Co, Cu and Zn were found below detection limit (BDL) in all water samples whilst Fe and Ni exceeded the guidelines of the TWQRs for surface water for domestic use. The results indicated relatively high concentrations of Fe with the highest in water samples from Naapaal and the lowest in Billengangn.

4.3.4 Bacteriological Water Quality

The results in **Table 11** showed that the levels of faecal and total coliform of river water from each of the study communities exceeded the recommended maximum limits of

the target water quality ranges (TWQRs). The highest faecal coliform counts were recorded in water samples from Gengenkpe and the lowest at Ketuo. In terms of total coliform counts, water from Gengenkpe again had the highest whilst Naapaal recorded the lowest. Faecal coliform counts ranged from 10 to 120 (cfu/100 mL), whilst total coliform were between 230 and 1300 (cfu/100 mL).

Table 11: Levels of microbial contamination in River water.

Community/ Water Source	Faecal Coliforms (cfu/100 mL)	Total Coliforms (cfu/100 mL)
Billengangn	30	230
Gengenkpe	120 ²	240
Naapaal	60	400
Ketuo	10	1300
TWQRs (cfu/100 mL)	0	5-100

TWQRs Target Water Quality Ranges for Domestic Water Use (Source: WRC, 2003)

4.4 Rainfall and Temperature Trends in the Study Communities

4.4.1 Gauge and Observed Data

The total annual rainfall data for Babile and the study communities spanning the period 1984 to 2014 are shown **Table 12** and the plots presented in **Figure 10**.

Table 12: Annual rainfall for Babile and the Study Communities (1984-2014).

Variable	Observation	Mean (mm)	Std. Deviation	Min	Max
Billengangn	31	990.4656	151.6828	569.4	1224.0
Gengenkpe	31	958.3438	158.1446	553.1	1126.7
Naapaal	31	981.9031	157.4171	571.6	1161.0
Ketuo	31	976.5469	154.095	560.6	1167.5
Babile(Gauge)	31	981.1516	164.4	565.5	1274.0

Data source: Ghana Meteorological Agency (GMet), Accra.

The long-term mean for the annual rainfall for the study area (Babile) was 981.2 mm with a minimum of 565.5 mm, maximum of 1274.0 mm, and standard deviation of 164.4. The analysis of total annual rainfall for three decades indicated high interannual variability of rainfall amounts.

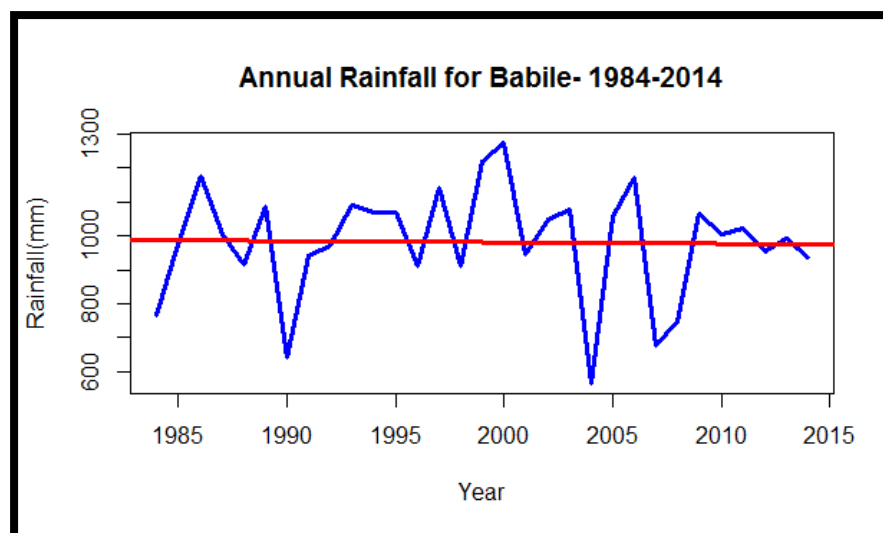


Figure 10: Annual rainfall data-1984-2014 (Source: GMet).

Between 2009 and 2014, the first three years (2009-2011) recorded total annual rainfall values of 1065.8 mm, 1004.8 mm, and 1022.0 mm which were above the annual average with no regular order of trend whilst the last three years per the data (2012-2014) recorded values (951.5 mm, 980.9 mm, and 937.0 mm) below the total annual mean value of 981.2 mm, respectively. The highest total annual rainfall was recorded in the year 2000 (1274.1 mm) and the lowest in 2004 (565.5 mm). Rainfall over the period showed much variability and did not show any visible trend. The trend line as shown by **Figure 10** is not statistically significant with a p-value of 0.83.

The yearly total rainfall anomaly for the study area as shown in **Figure 11** indicated high temporal variability with no regular trend over the period spanning 1984 to 2014. The plot showed clearly that very low total annual rainfall values were recorded in 2004 (note that in 2004, daily rainfall data was available for only nine months), 1990, and 2007. Overall, the study area experienced lower amounts of total annual rainfall between 2011 and 2014.

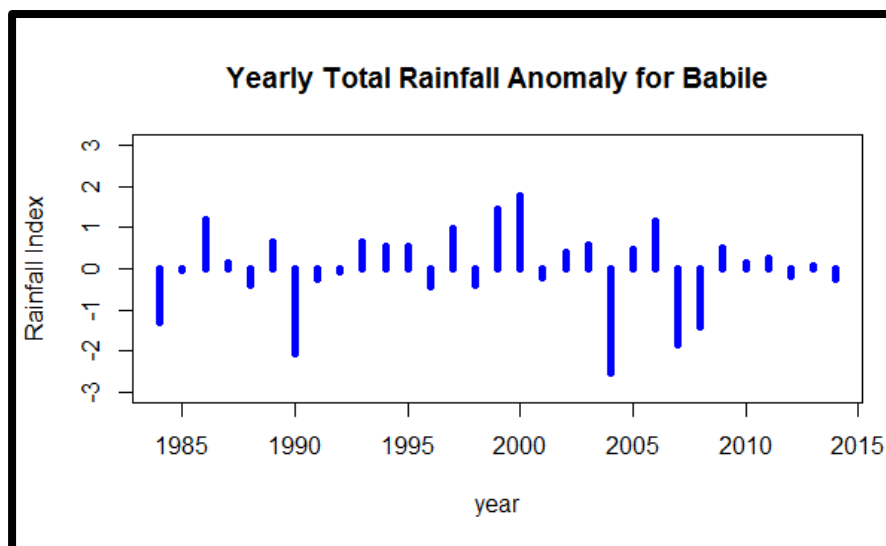


Figure 11: Annual rainfall anomaly plot for 1984-2014 (Source: GMet)

Figure 12 illustrates the seasonal trend by total monthly rainfall for the 31-year period, which indicated that the peak of rainfall in the study area was in August, whilst the main rainy season started in June and ended in October. The results indicated a unimodal rainfall annual cycle over the study area.

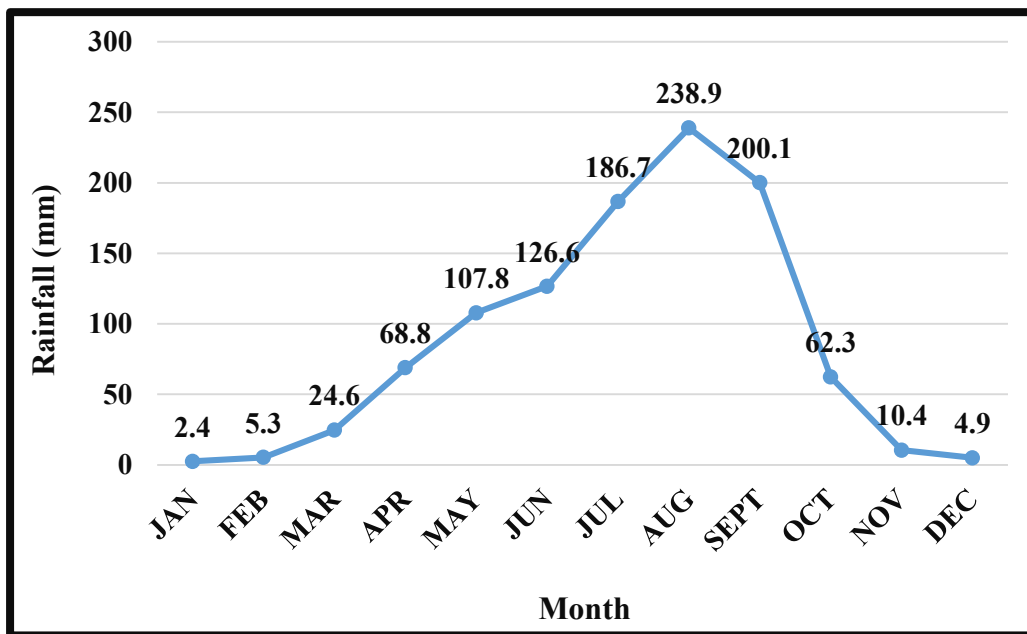


Figure 12: Seasonal rainfall cycle (1984-2014).

The yearly mean maximum temperature observed at Babile is presented in **Table 13**, whilst **Figure 13** illustrates the trend for the annual mean maximum temperature data and the anomaly plot shown in **Figure 14**.

Table 13: Summary of the maximum temperature for Babile and Study Communities (1984-2014).

Variable	Observations	Mean (°C)	Std. Deviation	Min	Max
Billengangn	31	34.8031	0.3188	34.2	35.5
Gengenkpe	31	35.0719	0.3314	34.4	35.7
Naapaal	31	34.9781	0.3289	34.3	35.7
Ketuo	31	35.0156	0.3264	34.4	35.7
Babile (Gauge)	31	34.75323	0.3894	33.9	35.6

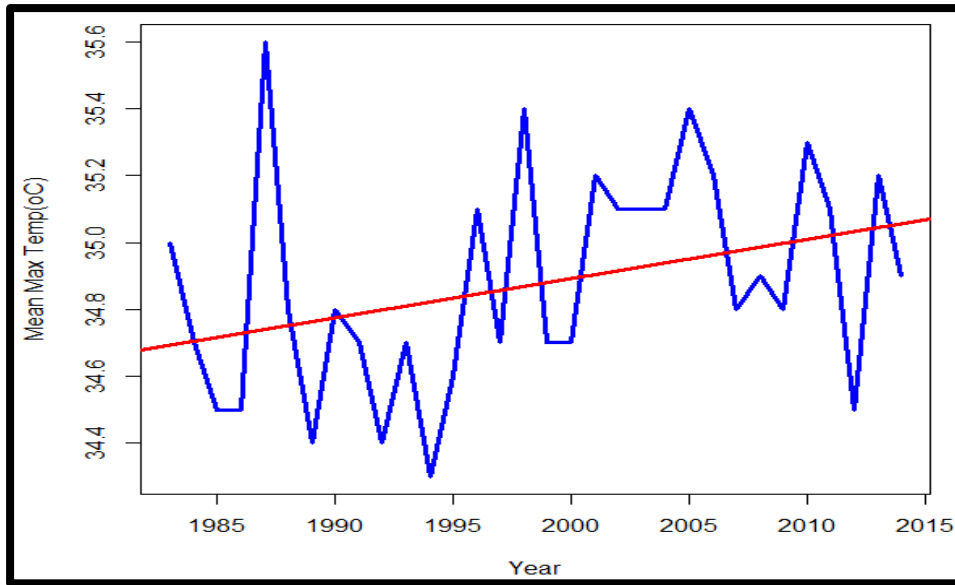


Figure 13: Annual mean maximum temperature for Babile (1984-2014).

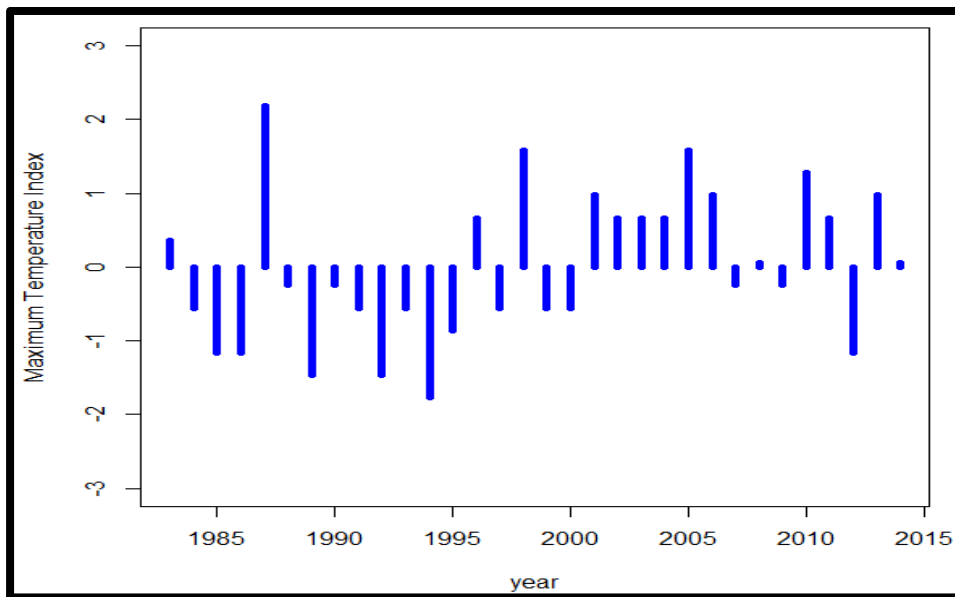


Figure 14: Annual maximum temperature anomaly for Babile (1984-2014).

The results of the analyses showed that the highest mean maximum temperature was 35.6 °C recorded in 1987, whilst 2007 had the lowest, 33.9 °C. The annual mean maximum temperature increased by 0.4 °C over the period. The data analysis indicated an increasing trend of annual mean maximum temperature between 1984-2014.

However, there was no significance difference (p -value=0.129) between the mean maximum temperature values for the period.

The highest monthly mean maximum temperature was recorded in March, whilst August had the lowest (**Figure 15**). The results indicated that temperature over the study area was high from November to march. The hottest month is March and the coldest is August, which is also the peak of the rainy season.

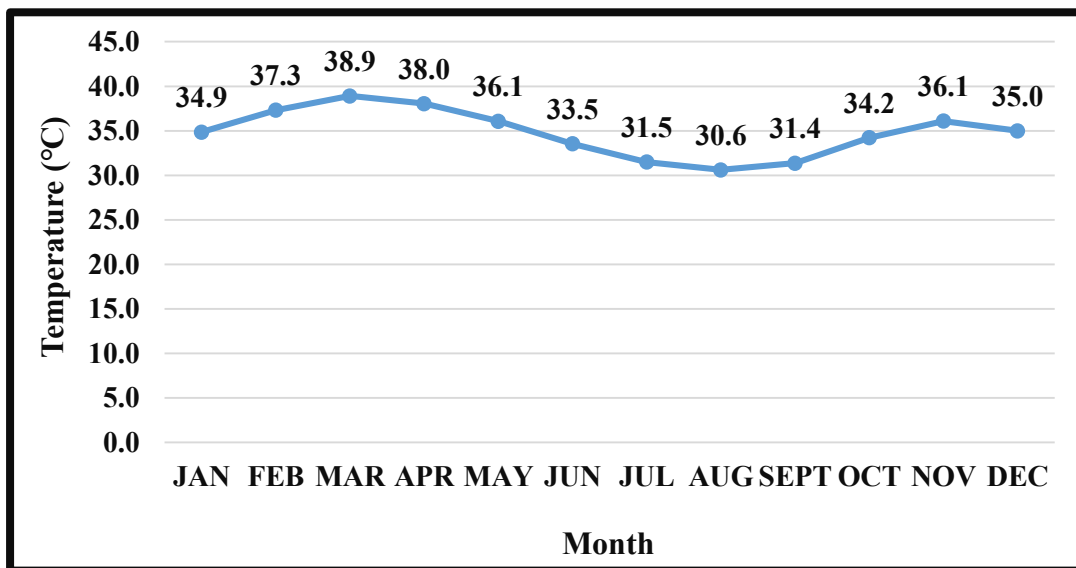


Figure 15: Seasonal maximum temperature cycle (1984-2014).

The yearly mean minimum temperature (nighttime temperature) for Babile and the study communities spanning 1984 to 2014 are presented in **Table 14** and the trend graph in **Figure 16**, whilst the anomaly plot is shown in **Figure 17**.

Table 14: Summary of the minimum temperature for Babile and Study Communities (1984-2014).

Variable	Observations	Mean (°C)	Std. Deviation	Min	Max
Billengangn	31	21.9988	0.3258	21.4	22.8
Gengenkpe	31	22.5281	0.3304	21.9	23.4
Naapaal	31	22.3188	0.3247	21.7	23.2
Ketuo	31	22.4156	0.3204	21.8	23.3
Babile (Gauge)	31	22.1207	0.4316	21.4	22.9

Analysis of the gauge data, indicated that the average minimum temperature recorded was 22.1 °C with minimum value of 21.4 °C (2001), and maximum value of 22.9 °C (2005)., whilst a standard deviation of 0.4316 was recorded. whilst GSS (2014) reported 23 °C.

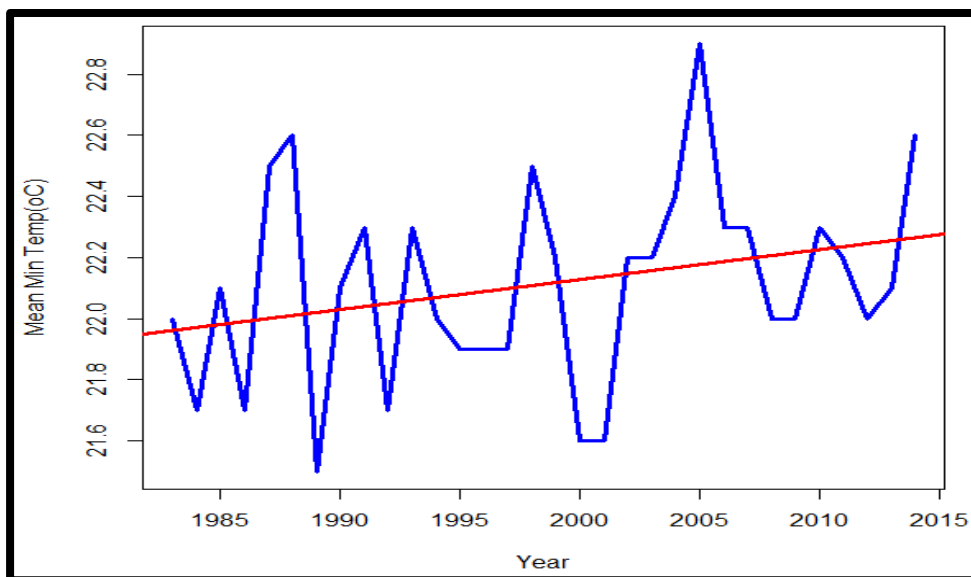


Figure 16: Annual minimum temperature for Babile (1984-2014).

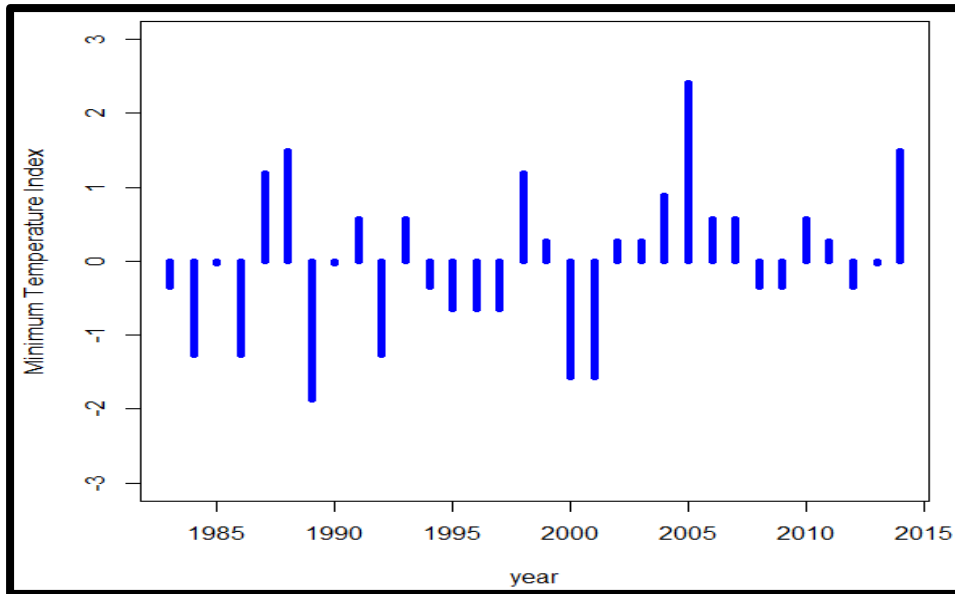


Figure 17: Annual minimum temperature anomaly for Babile (1984-2014).

The anomaly plot above depicts inter annual variation in the night temperature over the study area. However, most of the bars in recent years shows positive anomaly compared to the past.

The seasonal minimum temperature is presented in **Figure 18** and the analysis indicated that the highest was 26.2 °C recorded in April, whilst the lowest value of 16.9 °C was measured in December.

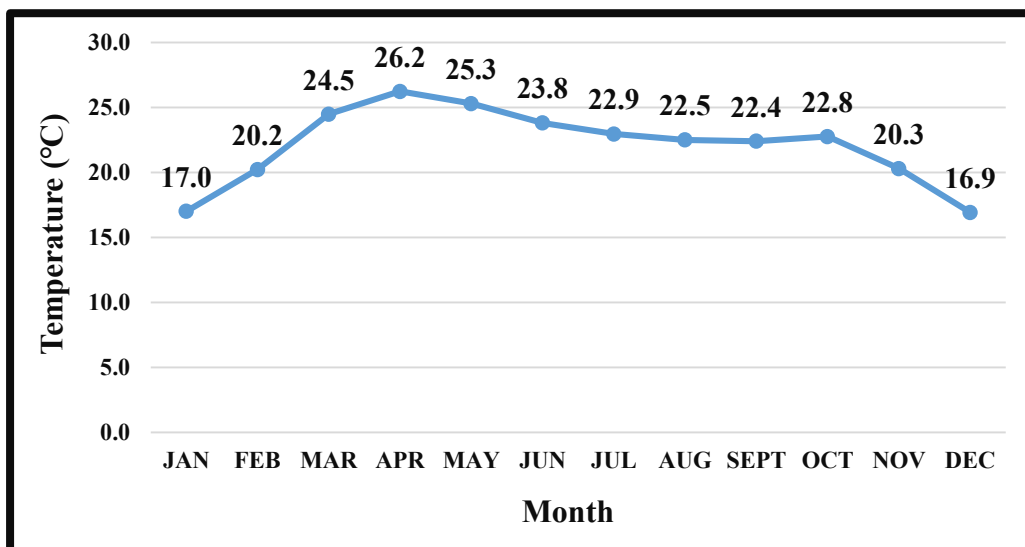


Figure 18: Seasonal minimum temperature cycle (1984-2014).

The analysis of the temperature data showed that high maximum (daytime) temperature was observed in March whilst minimum (nighttime) temperature occurred in April. The analysis depicts that both minimum and maximum temperatures are increasing. This means that its becoming warmer during the day and the night. The results confirmed that the hottest period of the year was march and the coldest was August.

4.4.2 *Perceptions of Rainfall and Temperature Trends in Study Communities*

The survey data on the perceptions of smallholder farmers on rainfall and temperature trends and variability, and related weather events are presented by **Figures 19 to 23**.

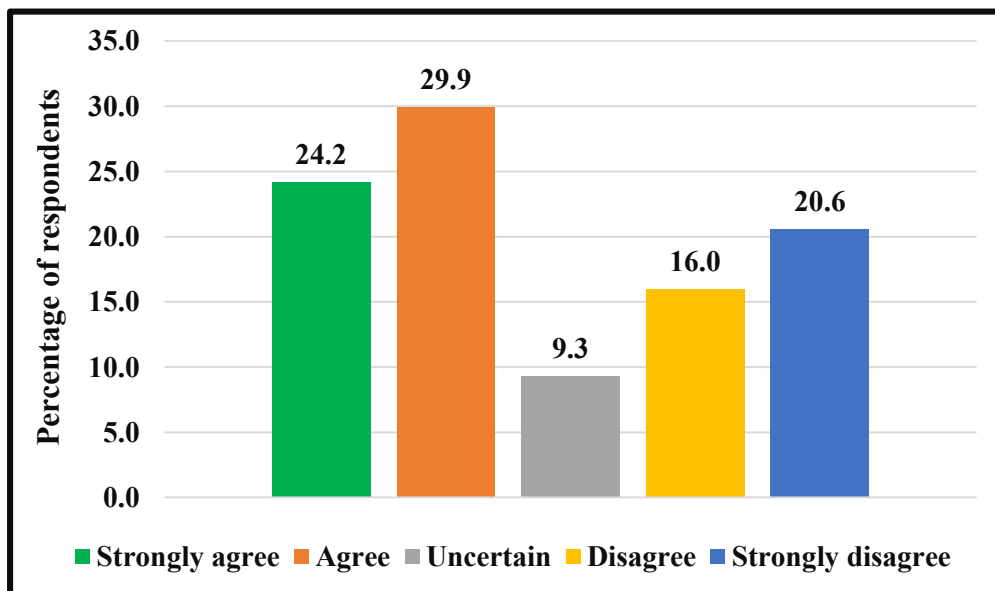


Figure 19: Perception of increased rainfall by respondents (Field work, 2016/2017).

The survey revealed that majority (54.1 %) respondents agreed that annual total rainfall had increased over the last ten years or more, whilst a few were uncertain. About 36.6 % of respondents observed decreased annual total rainfall. Out of the number of respondents who perceived an increasing trend in total annual rainfall over the period under consideration, 56 % were males, whilst 49 % were females.

The perceptions regarding the trends and variations in start of the planting season as shown in **Figure 20** indicated that majority (82.4 %) of respondents agreed that the start of the planting season had changed over the last 10 years or more in the study area.

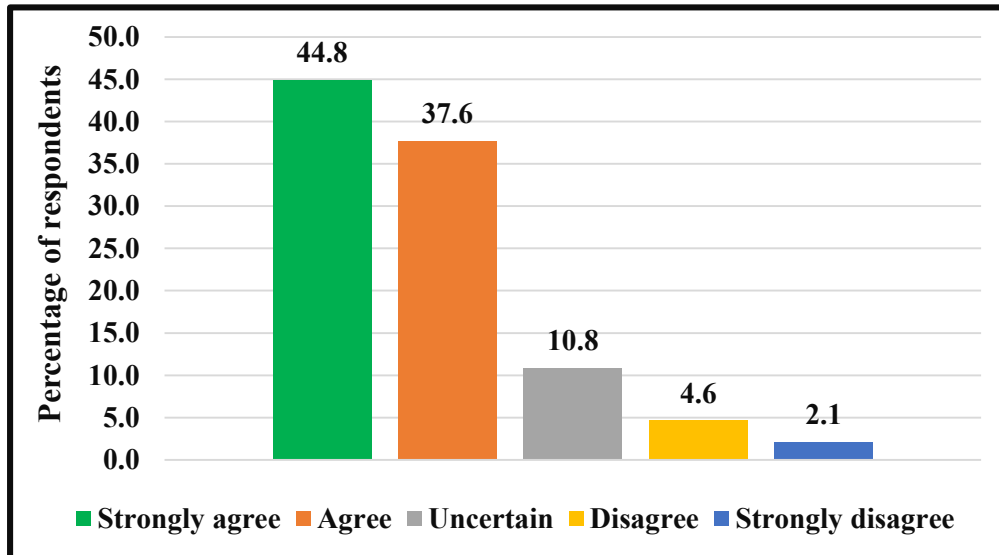


Figure 20: Perception of change of start of planting season by respondents.

Regarding trends in temperature, the perception presented in **Figure 21** indicated that, majority of the respondents agreed they had observed increases in temperature during the last 10 years or more. A few (9.3 %) respondents disagreed that temperature increased over the years.

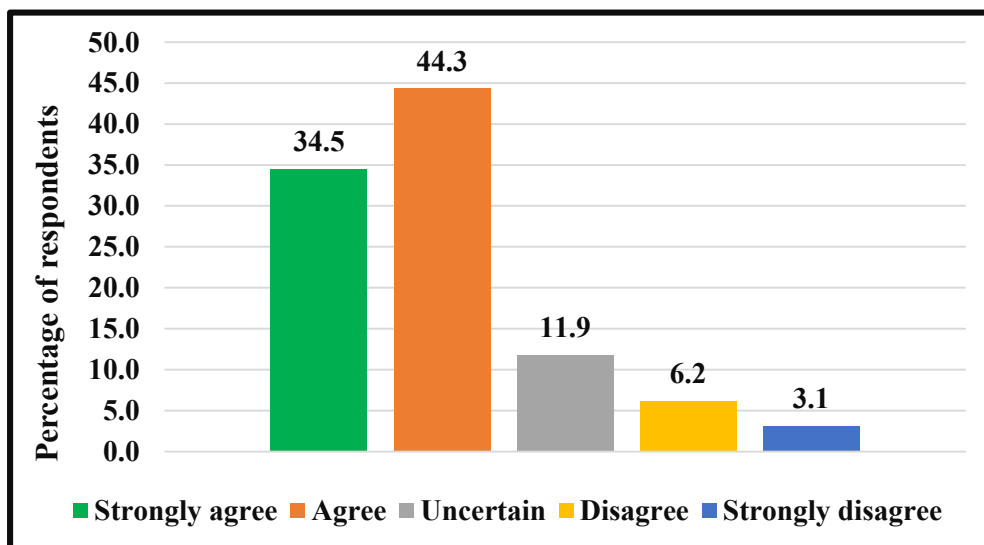


Figure 21: Perception of increased temperature by respondents.

The survey data on respondents who experienced severe droughts over the last 10 years or more are presented in **Figure 22** below. The results indicated that a large proportion of the respondents (69.6 %) experienced severe droughts over the last 10 years with only a few (13.4 %) disagreeing.

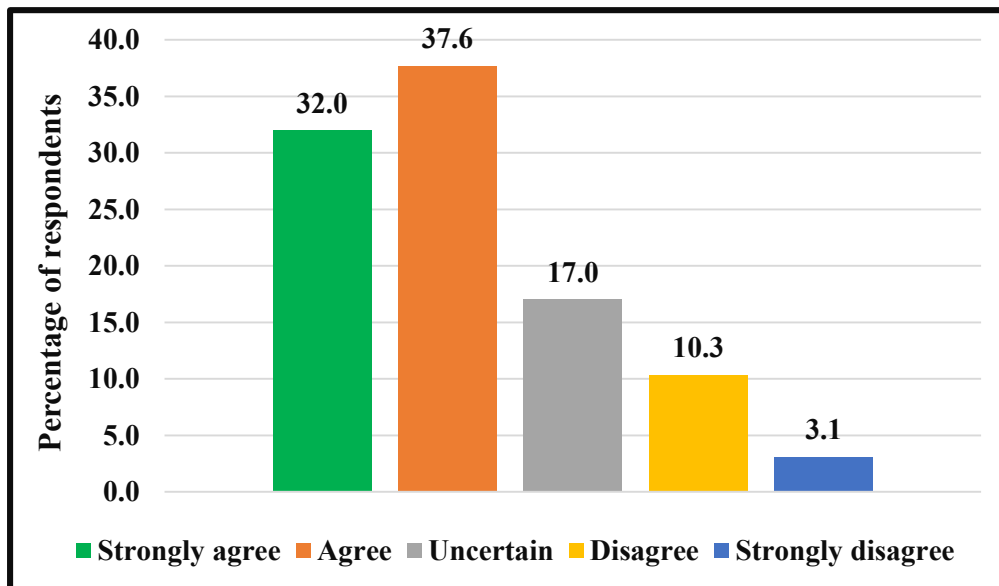


Figure 22: Perception of severe drought by respondents.

The perceptions on severe floods presented in **Figure 23** indicated that about two thirds of respondents (63.4 %) agreed to have experienced severe floods in the last 10 years or more. The proportion of respondents who agreed that they had been affected by floods formed about 63.4 %. The respondents who strongly disagreed were about 18.0 % whilst 18.6 % indicated were uncertain.

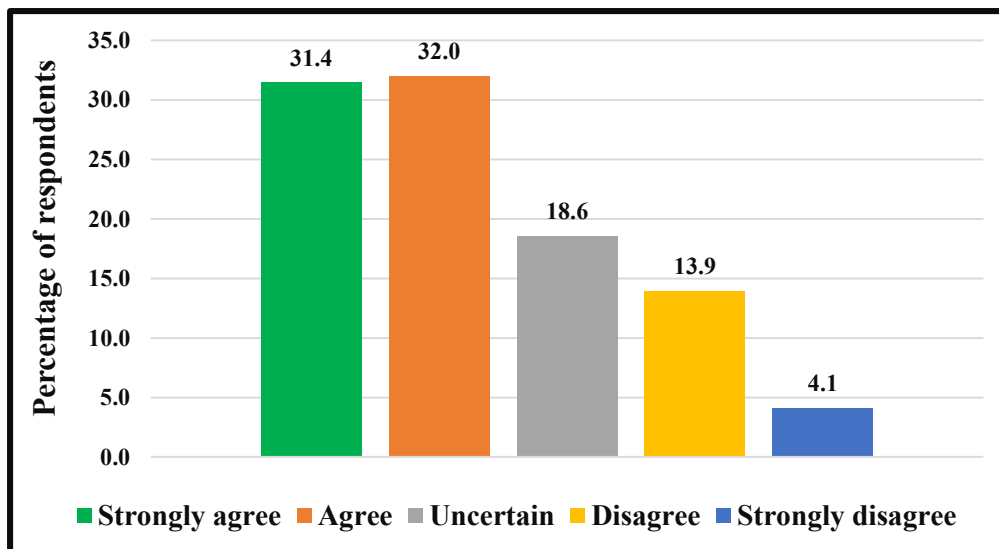


Figure 23: Perception of severe floods by respondents.

Some other survey data on the perceptions of respondents regarding climate change and variability are presented in **Table 15**. The perceptions of respondents on all climate change and variability and related events except total annual rainfall were consistent with the gauge data analyzed. With regards to rainfall, about 75.2 % perceived that the rains started late, for 73.2 %, the rains ended early whilst 77.3 % reported that the rainy season had become shorter. Furthermore, about 66.0 % observed frequent dry spells whilst and 76.3 % observed frequent stronger winds over the past 10 years.

Table 15: Perception of climate change and variability by respondents.

Perceived Trends	Strongly Agree	Agree	Uncertain	Disagree	Strongly
	(%)	(%)	(%)	(%)	Disagree (%)
Rains start early in the last 10 years/more	9.3	16.5	4.1	45.9	24.2
Rains starts late in the last 10 years/more	34.5	40.7	5.2	13.4	6.2
Rains end early in the last 10 years/more	36.6	36.6	4.1	16.5	6.2
Rains end late in the last 10 years/more	9.3	17.0	7.2	43.3	23.2
Rainy season has become shorter in the last 10 years/more	33.5	43.8	7.2	12.4	3.1
Rainy season has become longer in the last 10 years/more	8.8	9.8	8.2	47.4	25.8
Dry spells are more frequent in the last 10 years/more	27.3	38.7	13.4	17.5	3.1
Stronger winds have observed in the last 10 years/more	36.1	40.2	10.8	10.3	2.6

(Source: Field Survey, 2016/2017)

The perceptions of respondents on the impacts of observed rainfall and temperature trends in respect of drought and flooding are shown in **Figures 24** and **25**. The survey data indicated that about 89.7 % of the respondents agreed with the statement that their livelihood strategies were adversely affected by drought, whilst on a few (5.7 %) disagreed. With regards to flooding, about 78.9 % of the respondents also confirmed that they were negatively affected by flooding over the past ten or more years whereas 8.3 % disagreed with the statement.

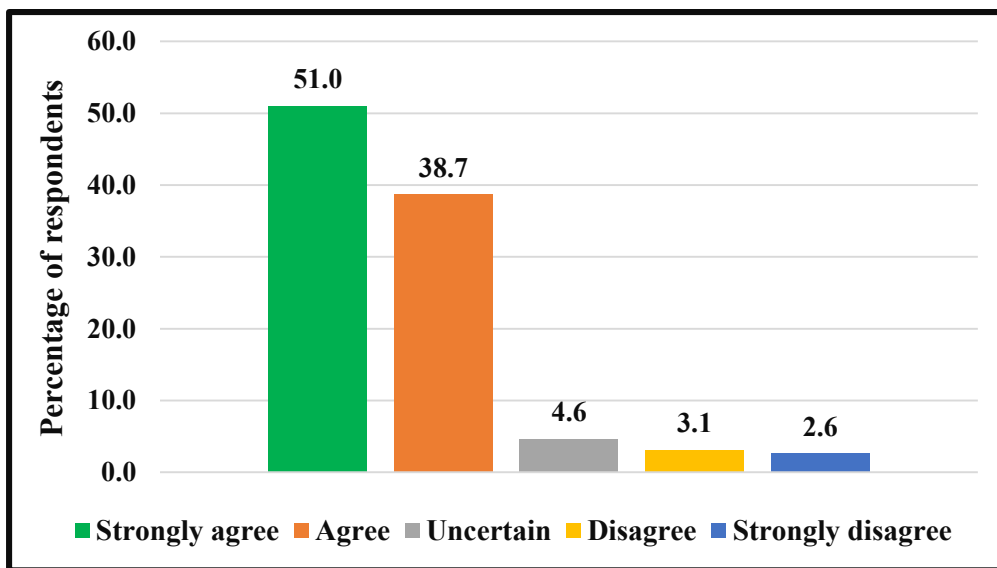


Figure 24: Perception of drought situation by respondents.

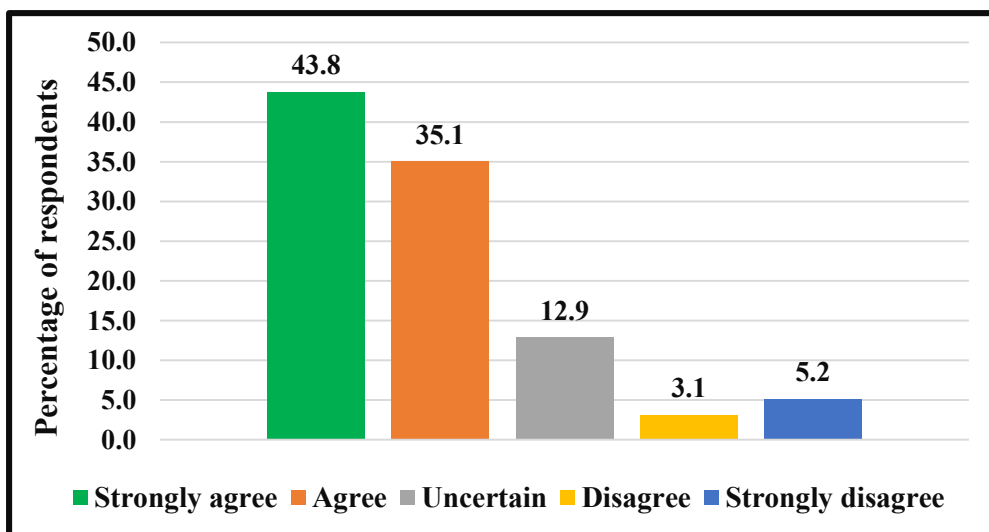


Figure 25: Perception of flood situation by respondents.

The results of the survey indicated that majority of the respondents correctly perceived the changes in temperature, other indicators of rainfall, and not total annual rainfall. Respondents reported having perceived increased total annual rainfall in the last 10 years contrary to the gauge data. The results also showed that about 35.6 % and 35.1 % of the respondents perceived changes in temperature and rainfall, respectively had adversely impacted their livelihoods strategies.

With regards to the impacts of rainfall on livelihoods, the key informant interviews and Focus Group Discussions (FGDs) revealed that low, erratic and unpredicted rainfall patterns were the major challenges to crop production. According to participants, low rainfall had caused drought and in most cases led to crop failure. They also cited heavy rainfall as the main cause of flooding, which in most cases washed away premature crops and livestock. These were summed up by a participant as:

“Too little or too much rainfall at wrong times affect crops and livestock and create food shortage and poverty”

Discussants in FGDs agreed that the rainfall figures have not changed over the years but the distribution was bad for crop production hence poor crop yield. The information gathered was that previously the rains started around April-May and spread all the way to October but in the last 5 to 10 years or more, all the required rains came within 2 or 3 months usually in June-August. Participants in the interviews opined that the rainfall period had become very short over the years reducing the cropping season to two or three months annually. Therefore, for about seven to eight months of the year, smallholder farmers had nothing to do in terms of their livelihood activities. According to participants, the delay and early end of the rains adversely affected crop production and smallholder farmer livelihoods strategies as a whole.

In terms of water resources, participant pointed out that low rainfall had resulted in frequent and early drying up of streams, rivers and dugouts which hitherto supported their crops and livestock. In addition, the low and irregular rainfall pattern adversely affected vegetation growth and the many dugouts available which usually collected rainwater during the rainy season. They contended that the situation impacted negatively on farming and livestock production in the area. Another key informant supported the above assertions by stating that:

“The cropping system of about eighty (80) percent of smallholder farmers in the district is rain-fed, however, rainfall has become erratic and does not support their livelihood activities. The rains arrive late in recent years and the untimely cessation of rainfall within the planting season is now a common experience here and disrupts our cropping systems. This is serious because many of the farmers are incapable of undertaking irrigation farming during the prolong dry periods”

The study gathered that the paramount chief of the Nandom District had placed an annual ban on the celebration of funerals in March-April each year. This was to prevent overcrowding and avoid exposure to the extreme heat wave during this period. The results of the gauge data analysis were consistent with the perceptions of respondents on temperature trends and variability as per the highest seasonal mean maximum and minimum temperature values recorded in March and April.

Participants attributed incidences of pests and diseases in the study to the observed high temperature. They explained that high temperature was responsible for the invasion of croplands by alien plants (weeds) and animals (insects) species in the area. In addition, the frequent and prolonged high temperature led to the early drying up of streams and rivers and loss of soil moisture. They attributed early drying or wilting of vegetation

and the frequent bushfires to high temperature. A key informant noted that most soil microorganisms did not thrive in extreme heat and were not able to perform their roles in enriching the soil for optimal crop production. Discussants in the FGDs noted that the high temperature observed affected labour or work on farms with respect to the size of farmland one was able to cultivate per season. However, some participants noted that high temperature enabled them to preserve their crops.

4.5 Availability, Utilization and Changes in Agroecosystem Services

4.5.1 Agroecosystem Services in the Study Area

Respondents in the survey identified and ranked agroecosystem services perceived to be highly available and as they were able to draw from their environment to support livelihood activities. These agroecosystem services were classified and presented in **Figure 26**.

The provisioning services were roots, fruits, leaves, animal products, barks, seeds, hides, bush meat, fish, honey, mushroom, spices, fodder, cola nuts, and snails. The regulatory agroecosystem services identified were pollination, water quality, air quality (dust or no dust), pest/disease control (disease prevalence), flood control (presence of wetlands and valleys), rain attraction (forest cover), local climate (duration of harmattan) and wind breaks. For cultural agroecosystem services, respondents identified educational, spiritual and religious values, habitats for gods, royal burial grounds, recreation & ecotourism, and aesthetics (outlook of village). The supporting agroecosystem services identified and ranked included NTFP (wood trays, grinders, mortars, pestles, chewing sticks and mats), fuelwood, timber, primary production, soil fertility (crop yield) and soil nutrients (amount of fertilizer used).

In all about thirteen (13) agroecosystem services were perceived by respondents to underpin their livelihoods strategies in the study communities.

Majority of respondents (48.5 %) identified bushmeat as most important agroecosystem service that underpinned their livelihoods because it contributed largely to their food and income needs during prolonged dry spells and drought conditions in the study area. This was followed by freshwater represented by about 39.2 % of respondents. The main freshwater sources for households were boreholes, the Black Volta River, seasonal rivers, and streams as well as hand-dug wells. Averagely, each community had three boreholes which supplied freshwater to them constantly. These water sources were used mainly for domestic purposes with only negligible number of farmers drawing water for irrigation. Fruits were ranked by 38.7 % of respondents followed by soil fertility (30.9 %). High proportion of respondents (96.9 %) in the survey were farmers and depended heavily on the nutrient status of their croplands for crop production. About 24.7 % of respondents indicated that fuelwood was one of the key agroecosystem services that support their livelihoods. Fuelwood was their main source of energy for cooking in the study area. Apart from using fuelwood as a source of energy, it also served as source of income for many households. Generally, households relied on agroecosystem services for food, water, energy, shelter, and income during prolonged dry spells, and climate related extreme events, and crop failure.

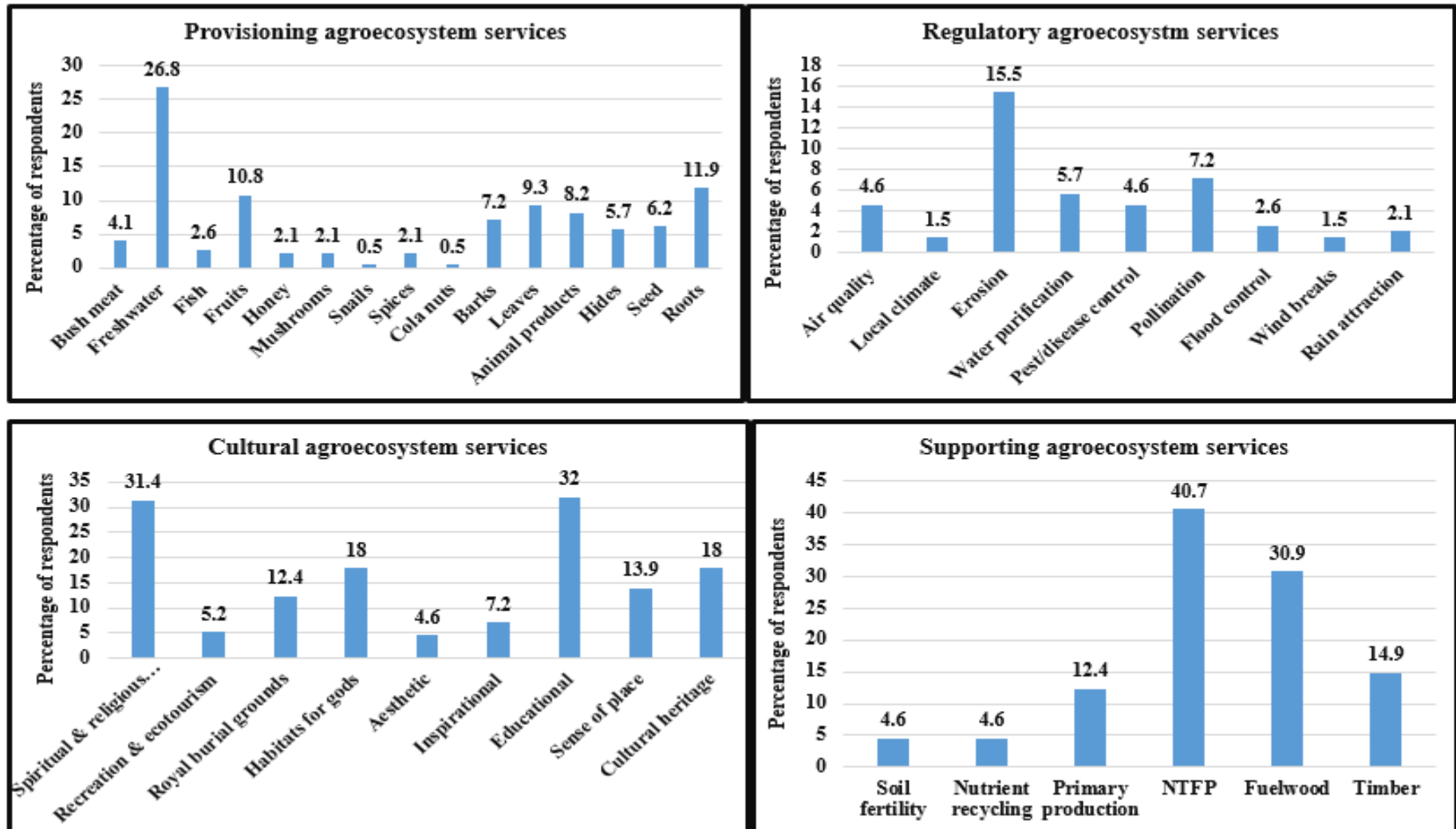


Figure 26: Available agroecosystem services in the study area (Source: Field Survey 2016/2017).
 NB: NTFP=non-timber forest products

4.5.2 Perceptions of Utilization of Agroecosystem Services by Smallholder Farmers

Respondents indicated the extent of their households' access to agroecosystem services during extreme climate events in the study communities (**Figure 27**). Majority (83.0 %) of respondents perceived that they sometimes have access to agroecosystem services, whilst 5.2 % indicated that they never had access to any of the important agroecosystem services in times of climate risks.

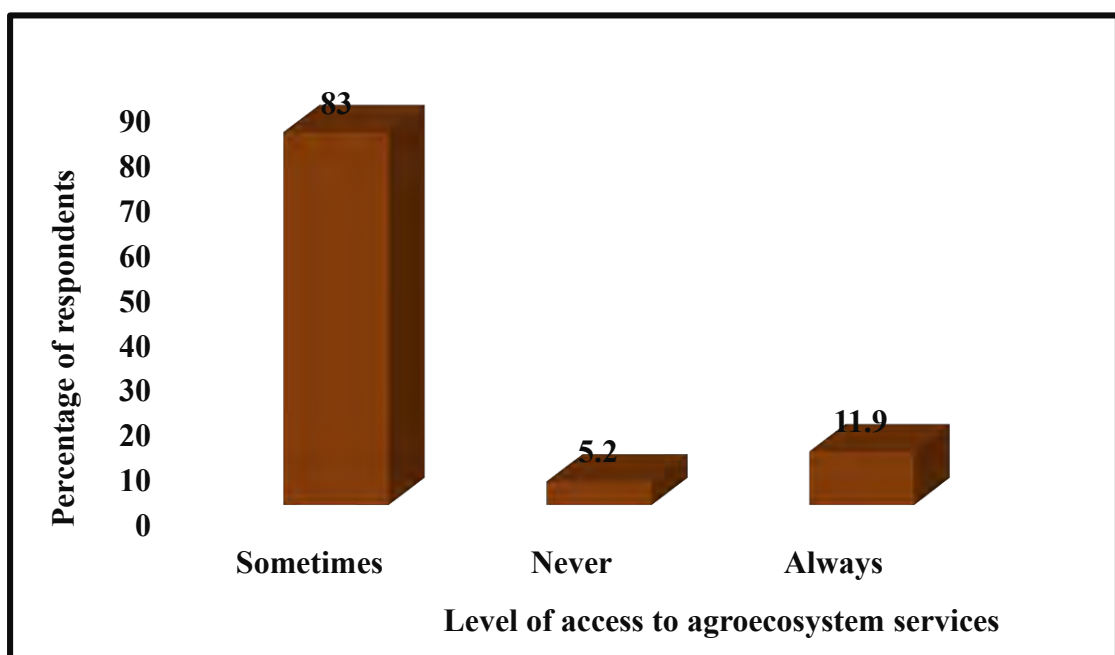


Figure 27: Extent of household's access to agroecosystem services.

Respondents were asked to indicate the state of their household's well-being in relation to other households in terms of the impacts of limited access to agroecosystem services. The results in **Figure 28** revealed that more than half of the respondents (51.0 %) perceived to be in the same state as other households in the study communities. About 20.1 % of respondents indicated that they were better off, whilst 18.6 % perceived they were worse off compared to other households regarding their access to agroecosystem services.

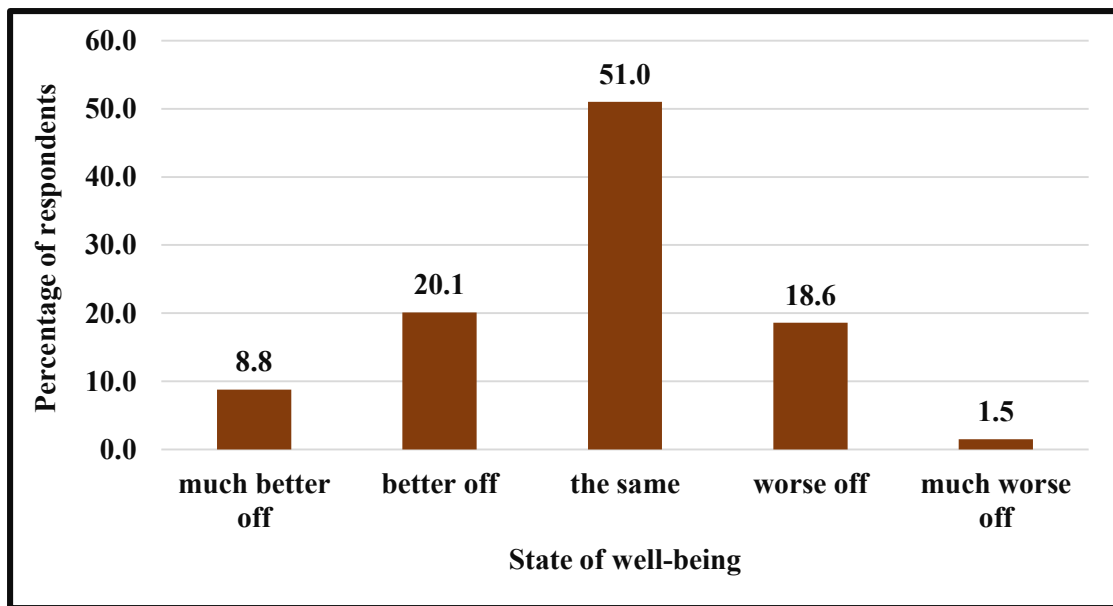


Figure 28: Household's perceptions of relative access to agroecosystem services.

4.5.3 Perceptions of Changes in Agroecosystem Services

The survey regarding observed changes in agroecosystem services indicated that about 91.8 % of the respondents observed changes in agroecosystem services whilst 8.2 % did not observe any change. The perceptions of households on changes in specific agroecosystem services as shown in **Figure 29**, revealed that majority (48.5 %) of respondents observed changes in bushmeat, followed by freshwater (39.2 %), fruits (38.7 %), soil fertility (30.9 %), fuelwood (24.7 %), fish (16.5 %), mushroom (16.0 %), NTFP (e.g. chewing sticks, mats, pestles etc.) (11.3 %), cropland (7.7 %), vegetation (7.2 %), leaves (6.2 %), honey (4.6 %), and animal products (e.g. skin, hides, horns, etc.) (1.0 %), respectively. The survey revealed significant changes in bushmeat, freshwater, fruits, and soil fertility over the years in the study area.

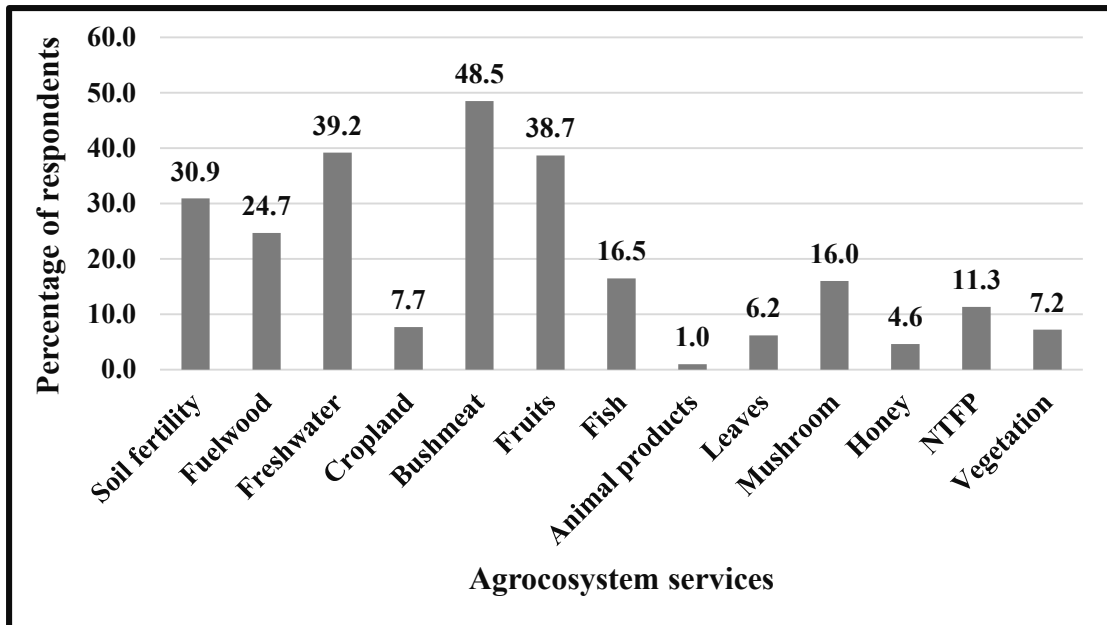


Figure 29: Perceptions of respondents on agroecosystem services change in the study area.

4.5.4 How Long Smallholder Farmers Noticed Changes in Agroecosystem Services

Figure 30 shows the perceptions of smallholder farmers on the period of observed changes in agroecosystem services in the study area.

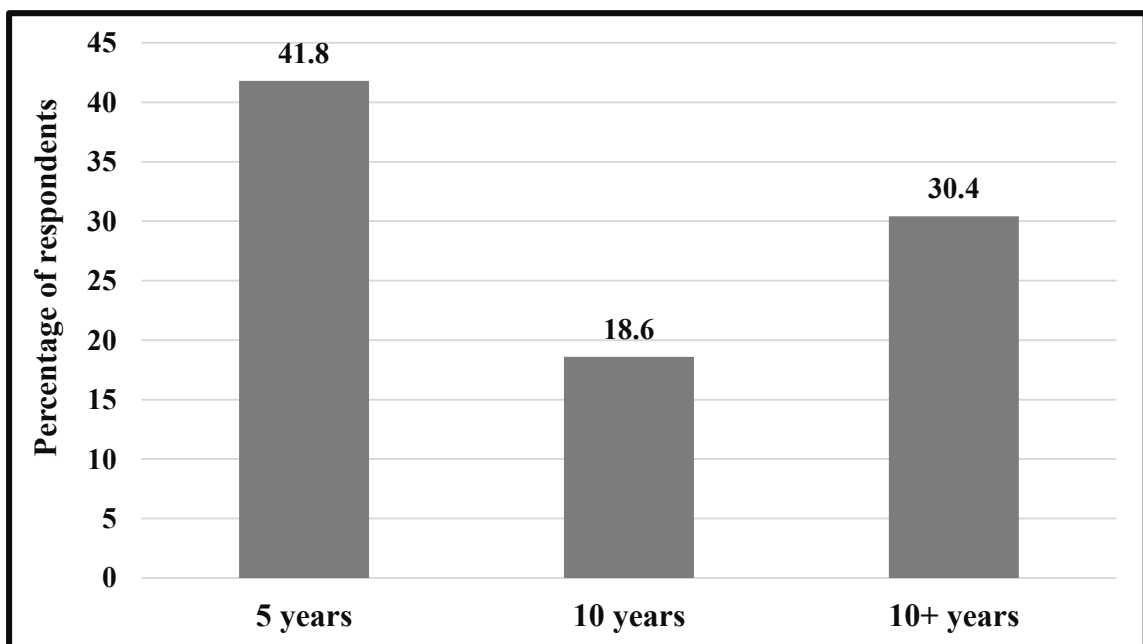


Figure 30: Perceived period of observed agroecosystem services change.

Most (41.8 %) of the respondents reported that they had observed changes in agroecosystem services within the last five (5) years of the study, whilst a relatively smaller proportion (18.6 %) reported indicated the last ten (10) years. Majority of respondents within the age group of 50 years and above perceived changes in agroecosystem services over the past five (5) years. With regards to gender, more males perceived these changes also within the last five (5) years than their female respondents.

4.5.5 Perceived Drivers of Agroecosystem Services Change

The perception of respondents on drivers of agroecosystems and agroecosystem service change is shown in **Figure 31**. The perceived drivers were low rainfall, bush burning, tree cutting, flood, agricultural expansion, population increase, agrochemical use, livestock grazing, extreme temperature, bad farming practices, water pollution, strong winds, overexploitation, and government policy (e.g. extension services, irrigation, bushfires, river buffer zone, ecosystem management).

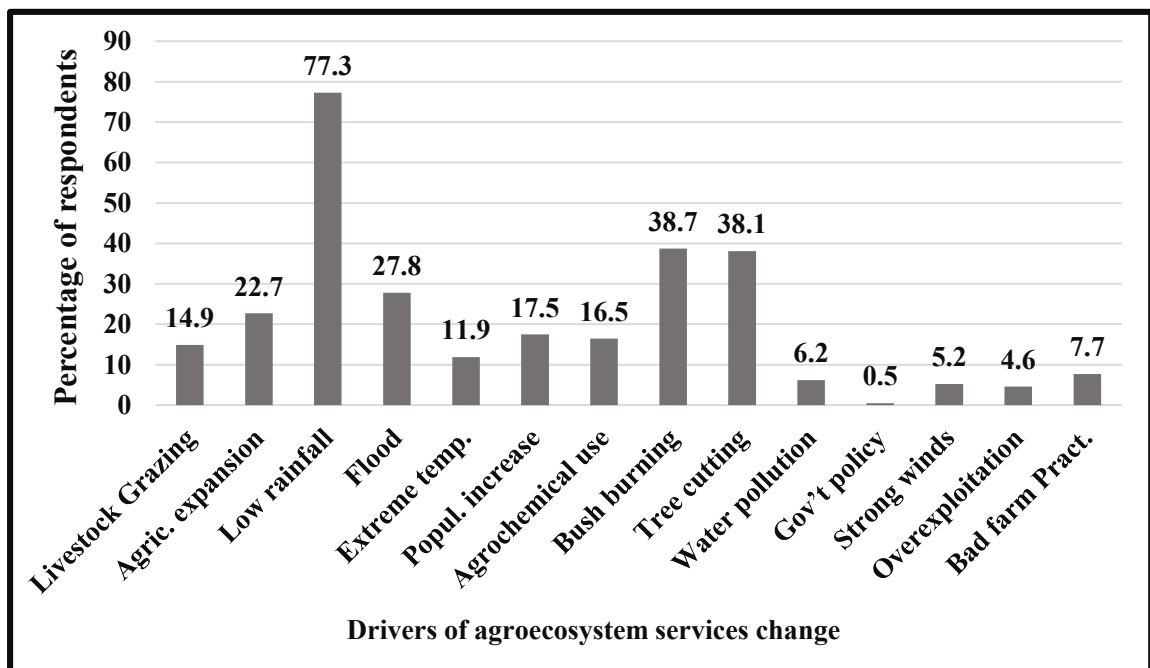


Figure 31: Drivers of agroecosystem services change identified by respondents in study area.

NB: *Bad farming practices include burning of crop residue that expose the soil during the long dry spell, Low rainfall=drought & prolong dry spells*

In addition, respondents indicated the specific factors that caused change in each of the key agroecosystem services (i.e. those that underpinned their livelihoods) identified in the study area as presented in **Table 16**. For soil fertility, one of the key agroecosystem services supporting the cropping systems of smallholder farmers, respondents observed that change was mainly due to continuous cropping, bad farming practices, and low rainfall (drought). The results showed that among the four perceived drivers of change in soil fertility by respondents, only rainfall was climate-related whilst the other three emanated from anthropogenic activities.

Table 16: Perceived drivers of change in specific agroecosystem services.

NO.	Agroecosystem services	Drivers of change
1.	Soil fertility	Continuous cropping (11.9 %), low rainfall (4.6 %), Erosion (3.6 %), bad agronomic practices (10.3 %),
2.	Fuelwood	Tree cutting (18.6 %), Bushfires (5.2 %)
3.	Freshwater	Low rainfall (18.0 %) , Tree cutting (6.2 %), Agrochemical use (5.2 %), Increased population (4.1 %)
4.	Cropland	Overexploitation (4.1 %), Low rainfall (1.0 %), Increased population (1.0 %)
5.	Bushmeat	Bushfires (32.5 %), Excessive hunting (10.3 %)
6.	Fruits	Low rainfall (15.5 %), Strong winds (10.3 %), tree cutting (7.2 %)
7.	Fish	Water pollution 7.2 %), Low rainfall (6.2 %)
8.	Vegetation cover	Bushfires (3.6 %), Tree cutting (2.1 %)

Source: Field work, 2016

For fuelwood, respondents perceived tree cutting as the main driver of change, followed by bush burning (bushfire), and charcoal production. With regard to drivers of change in freshwater, respondents perceived low rainfall, tree cutting, use of chemicals, increased population, bush burning (bushfires), and extreme temperature. For the cropland, respondents perceived overexploitation as a main driver, followed by low rainfall and increased population. Respondents noted that bushmeat was one of the key agroecosystem services that support their livelihoods and subsequently mentioned that they had observed major changes in this service. Respondents also perceived bushfires as a major driver, followed by excessive hunting (overexploitation) and tree cutting as drivers of change in bushmeat. The results of the perceived drivers of change in fruits included low rainfall as a major driver, followed by strong winds, tree cutting, harsh weather and prey birds. Respondents indicated that fruits constitute one of the key ecosystem services that they depend upon especially during the dry season but have observed changes in this services which had affected supply. The results on drivers of change in fish showed that water pollution, low rainfall and overfishing were the main causes. With regard to water pollution, respondents indicated that farming along and close to river banks as well as the use of “dangerous” chemicals were responsible for the decline in fish stocks in their river bodies. Low rainfall was identified as a driver of change in the availability of fish in the area as a result of the early drying up of most rivers and streams.

Respondents perceived drivers of change in vegetation in the area to include bushfires, tree cutting, low rainfall, extreme temperature and increased population (larger household sizes). Most of the respondents indicated that the perennial bushfires do not promote growth of vegetation on the land and therefore had exposed the surface of the land to harsh weather conditions. For mushroom, a key ecosystem services in the study

area, about 15.5% of respondents perceived low rainfall (drought) as the only driver of change whereas for honey, they named tree cutting as the only and main cause of change and loss.

4.5.6 Perceptions on Trends in Changes in Agroecosystem Services

Figure 32 shows the perception of respondents on the observed pattern of change in agroecosystem services. The results indicated that for four key agroecosystem services including soil fertility, fuelwood, freshwater and cropland, respondents observed varied patterns of changes. For soil fertility, more than half of the respondents observed a slight decrease, whilst 26.8 % perceived a sharp decrease.

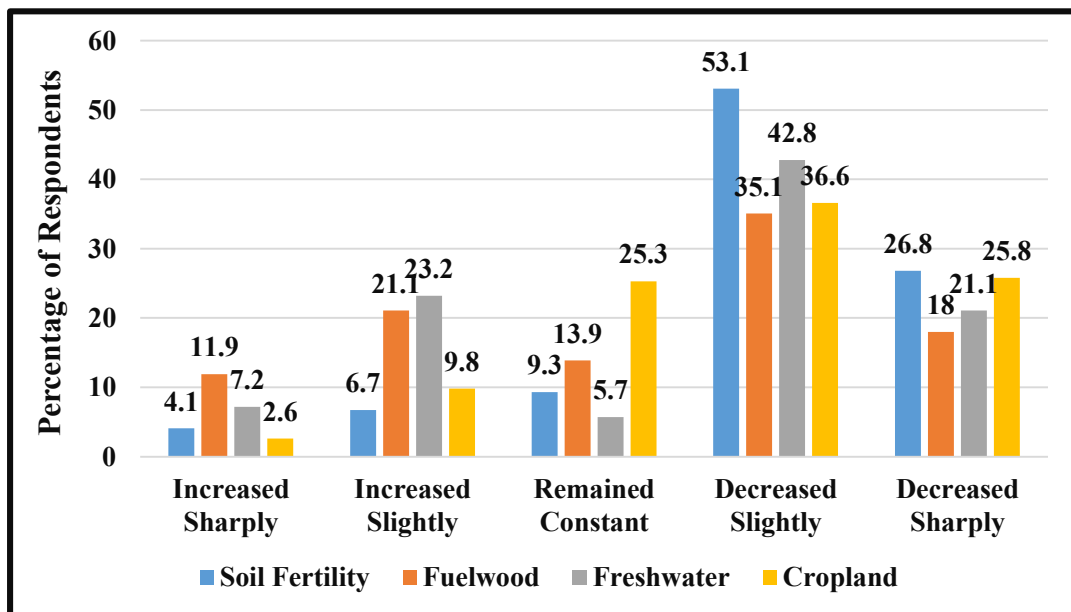


Figure 32: Perceived changing trends in specific agroecosystem services.

With regards to fuelwood, more than a third of respondents perceived slight decrease, whilst 42.8 % observed a slightly decreased pattern in freshwater. About 36.6 % of respondents perceived indicated that they observed a slight decrease in cropland over the years.

The analysis of the results indicated that a high percentage of respondents perceived slight decreases in all the agroecosystem services identified. For instance, 53.1 % of the respondents observed slight decrease in soil fertility, 35.1 % fuelwood, 42.8 % freshwater and 36.6 % cropland, respectively. The respondents observed sharp decreases in soil fertility, cropland, freshwater, and fuelwood.

4.5.7 *Perceptions on Impacts of Changes in Agroecosystem Services on Livelihood Strategies of Smallholder Farmers*

The results in **Figure 33** indicates the extent to which respondents perceived the impacts of changes in specific agroecosystem services on their livelihood strategies.

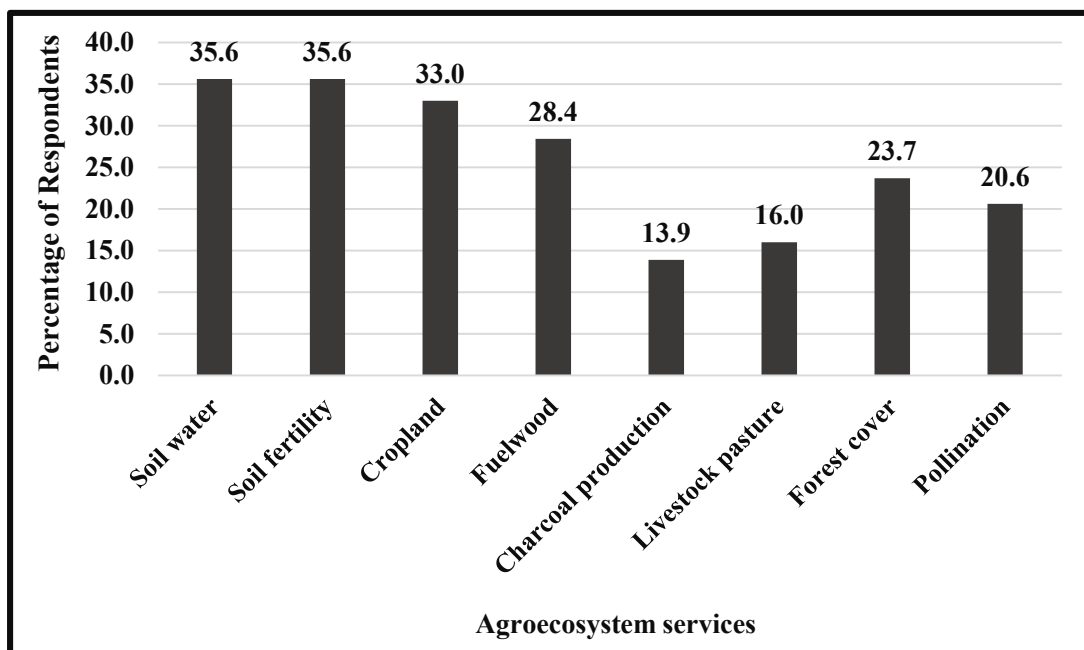


Figure 33: Extent of agroecosystem service impact on smallholder livelihood strategies.

The respondents reported that for a change in any of the identified agroecosystem services there was differentiated impact on the livelihood strategies. The results of the survey showed that severity of the impact of change in agroecosystem services in order

of importance was soil water, soil fertility, cropland, fuelwood, forest cover, pollination, livestock pasture, and charcoal production.

The focus group discussions (FGDs) and key informant interviews revealed that smallholder farmers relied heavily on the fertility of the soil as an agroecosystem service for food production as well as fuelwood for energy and income, freshwater from rivers, streams and dugouts for dry season farming and livestock watering, cropland for crop production and livestock grazing pasture, non-timber forest products (wooden trays, pestles, chewing sticks, mats), vegetation and forest cover, fruits (shea and “dawadawa”) and fish.

In response to the question: “How has the supply and utilization of agroecosystem services changed over the years?” a key informant from the EPA answered:

“We don’t have any data to show but then with our experiences from the farmers, they will always tell you the yield they use to get back 10 years’ time for an acre and then the yield they have now, is the major determinant that we use to tell that they are really suffering when it comes to the changes that have affected their farming. Like 10 years back, someone will tell you that he gets 10 bags for an acre and today when he farms one acre how to even get 1 bag is a problem”

Also, a male discussant in a FGDs stated emotionally as follows:

“In the “hiin” river, fish harvesting used to be every three years but now it is done annually with very little catch. There are no bigger trees around the river. Our rivers have become shallow caused by siltation and sedimentation as a result of farming close to the river banks and also due to bushfires”

4.6 Vulnerability to Changes in Agroecosystems and Climate

4.6.1 Exposures and Sensitivities of Respondents (Smallholder Farmers)

The major challenges, risks, and shocks reported by respondents were low income levels, food shortage, low crop yield, hunger, low soil fertility, cholera, low rainfall, cropland (farmland) shortage, fuelwood shortage, flood, water pollution, environmental degradation, and bushfires (Figure 34).

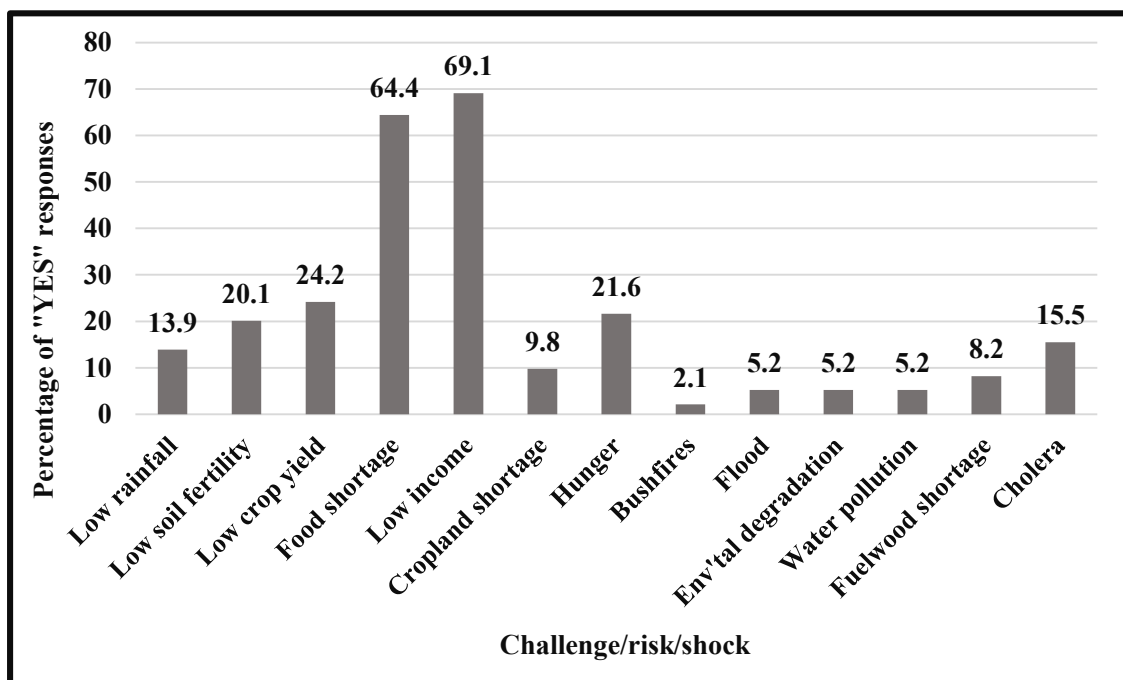


Figure 34: Major exposures of respondents.

The survey found that respondents faced a myriad of challenges that made them vulnerable to the impacts of climate change. The findings showed that a large proportion of respondents (69.1 %) cited low income whilst 64.4 % mentioned food shortage as their major challenges amidst the others. Other challenges included low crop yield, low soil fertility, and then hunger. In all the survey identified about thirteen (13) major challenges of smallholder farmers.

The main challenges participants and discussants in key informant interviews and FGDs identified were bushfires, deforestation, low income, extreme heat, floods, erratic rainfall, drought, and windstorms. Others included lack of agricultural extension services, lack of improved seeds, soil infertility, pest and diseases, lack of chemical fertilizers, inadequate cropland, hunger, crop failure, lack of tractor services, lack of irrigation services, poverty, loss of economic trees, depletion of fish stocks, soil erosion, lack of access to farm inputs, lack of access to labour, and lack of access to markets. These data are consistent with the survey on the major challenges of smallholder farmers in the study.

In terms of social differentiation with respect to gender, responses from the FGDs indicated that the major challenges above affected both male and female groups. However, the female groups pointed out that lack of access to cropland, labour, and tractor services were among their major worries.

4.6.2 Causes of Major Challenges of Smallholder Farmers

In **Figure 35**, respondents associated the identified livelihood challenges, risks or shocks with several drivers. The results of the survey indicated that the major drivers of challenges, risks or shocks of smallholder farmers were low rainfall, bushfires, tree cutting, soil infertility, low crop production, and increased population.

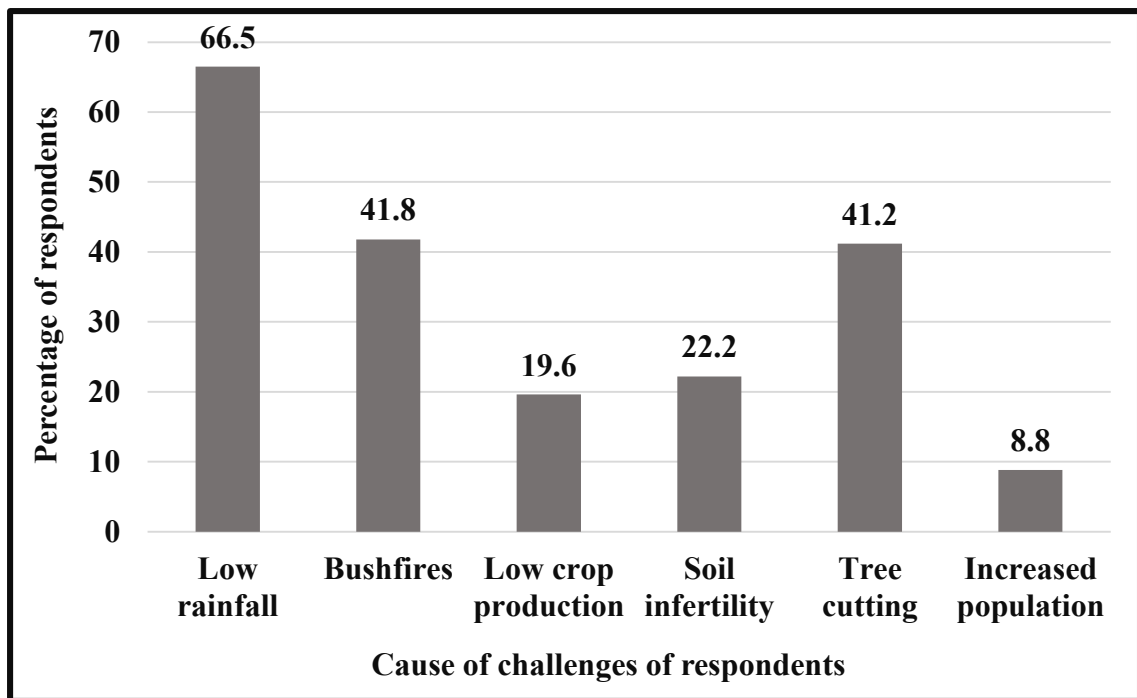


Figure 35: Causes of major challenges/risks/shocks (sensitivities) of respondents.

Even though, respondents did not rate high low rainfall as a major challenge in relation to food shortage, low income, low crop yield, hunger and low soil fertility, it was perceived by majority of the respondents (66.5 %) as a major cause of their challenges, risks and shocks.

The survey identified low rainfall and bushfires as the main drivers of challenges of smallholder farmers. In FGDs and key informant interviews, participants recognized drivers of challenges such as deforestation, extreme heat, floods, windstorms, lack of agricultural extension officers, lack of improved seeds, pest and diseases, lack of chemical fertilizers, continuous cropping on same land and lack of financial support and markets.

4.6.3 Perceptions of Social Groups' Vulnerability to Agroecosystems Change

The results of the survey on the perceptions of vulnerability of different social groups to changes particular agroecosystem service in the study area are presented in **Figure**

36. In terms of changes in cropland, majority of respondents perceived both men and women as most vulnerable. For food supply, most of the respondents stated men, women, and children were more vulnerable. For changes in soil fertility, half of the respondents perceived both men and women to be most vulnerable. In terms of changes in fuelwood, over two-thirds of the respondents claimed women were most vulnerable while with regard to changes in charcoal production, majority of the respondents identified men as most vulnerable.

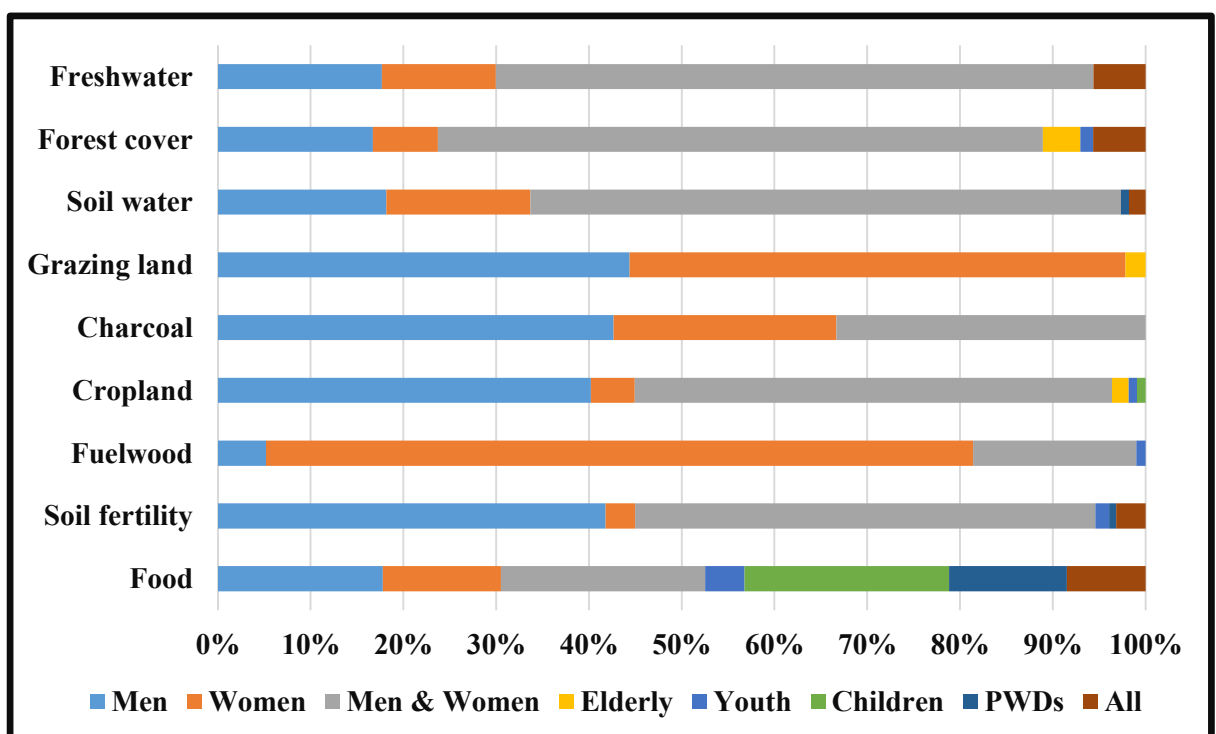


Figure 36: Perceived most vulnerable group to changes in agroecosystem services and climate.

The results also indicated that over half of the respondents perceived women as most vulnerable to changes in grazing land or pasture, whilst for 44.0 %, men were most vulnerable. For changes in soil water, most of the respondents reported that both men and women were equally most vulnerable. The survey also showed that about sixty-five percent of respondents perceived both men and women as most vulnerable to forest cover changes and non-timber forest products. Majority of respondents perceived that

both men and women were most vulnerable to changes in freshwater in the study communities.

The survey results further revealed that gendered groups (male and female) were the main social groups in the study area and in terms of which social group was most vulnerable to changes in agroecosystem services, a high proportion of respondents cited both men and women. The exception was observed with regards to changes in fuelwood, where a high percentage (76.0 %) of respondents perceived women as most vulnerable whereas 42.0 % and 40.0 %, respectively indicated that men were most vulnerable to changes in soil fertility and cropland.

However, in the FGDs, discussants in most cases agreed that children were most vulnerable followed by women in all situations of changes in agroecosystem services. They argued that for persons with disabilities (PWDs) and the elderly, other able-bodied family members always cared for their welfare.

4.6.4 Dealing with Vulnerability to Agroecosystem Service Change

Most of the respondents reported that the responsibility of dealing with challenges associated with the observed changes in freshwater was mainly that of the household (**Figure 37**). For changes in food supply, more than half of the respondents said it was the household that dealt with any observed change. In terms of changes in soil fertility, majority claimed that it was the individual that dealt with the changes while a large portion indicated that the community was responsible for dealing with any changes associated with soil water. In terms of changes in fuelwood, large percentage of respondents indicated that the individual was responsible for dealing with the changes observed. For changes in forest cover, a higher proportion of the respondents said it was the community that dealt with the changes.

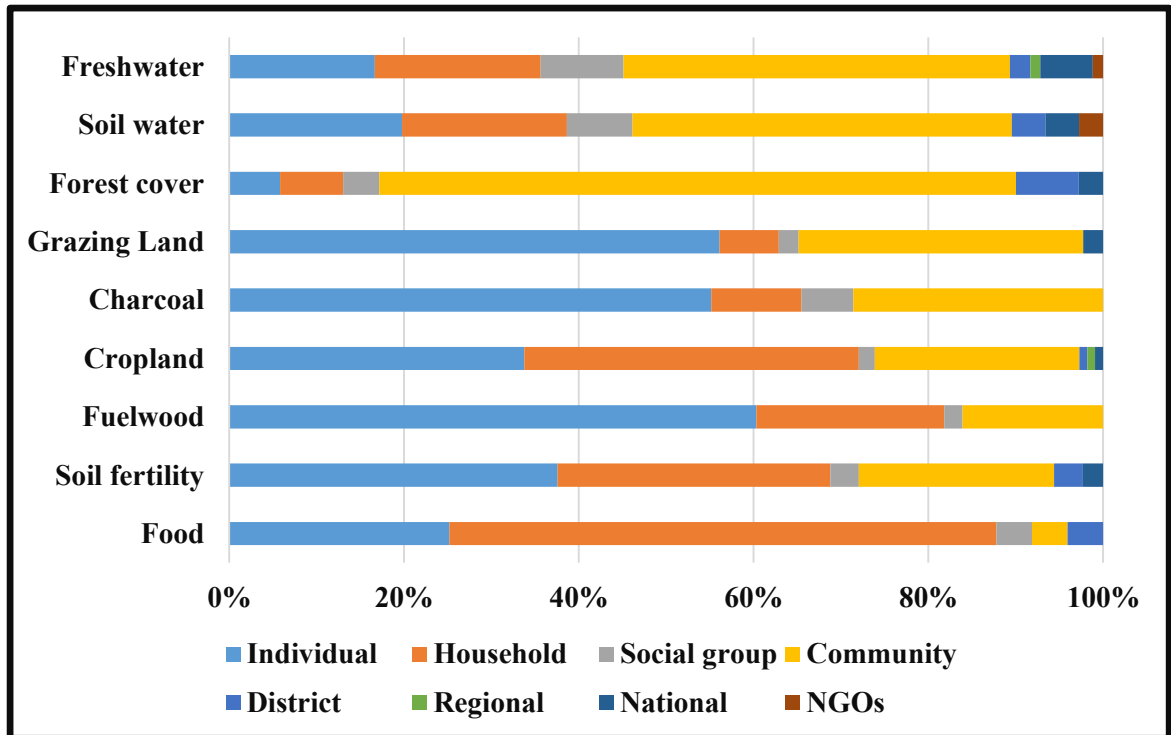


Figure 37: Responsibility for dealing with changes in the agroecosystem services and climate.

In terms of changes in grazing land, most respondents claimed that it was the individual that dealt with the changes. With regards to changes in cropland, respondents reported that the household was responsible for dealing with any change observed. Finally, for more than half of the respondents, the individual was responsible for dealing with changes that occurred in charcoal production.

4.6.5 Perceptions of the Level of Satisfaction with Life by Respondents

Figure 38 shows the survey data on the perceptions of smallholder farmers on their subjective well-being.

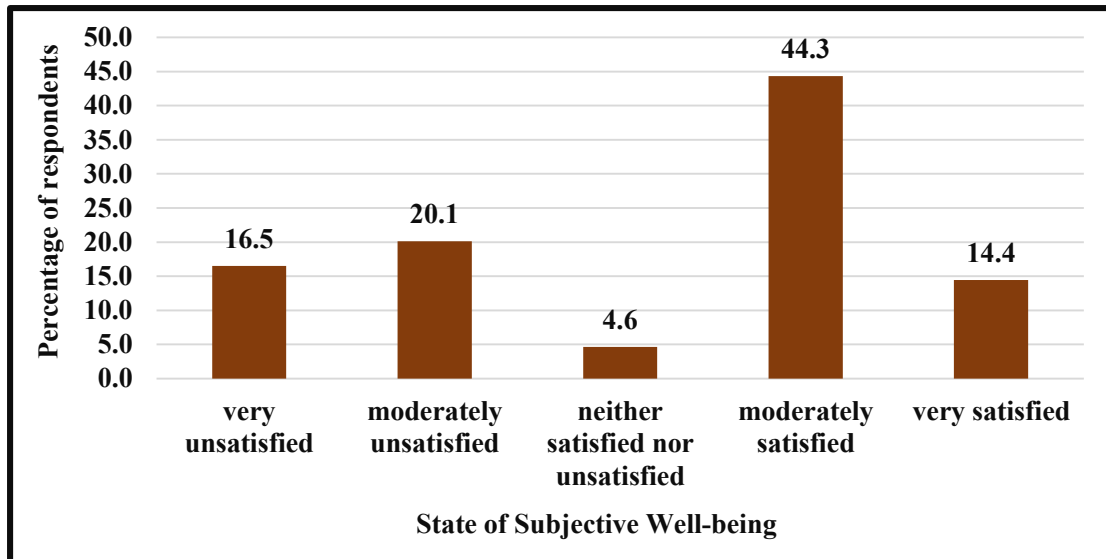


Figure 38: Subjective well-being of respondents in the study area.

The survey data revealed that majority (44.3 %) of the respondents reported to be moderately satisfied with life as a whole (acceptance of the current impacts of climatic and agroecosystem services change) with only a few (4.6 %) who were neither satisfied nor unsatisfied. However, more than fifteen percent of the respondents felt very unsatisfied with life as a whole. About two-thirds of the respondents felt satisfied with life as a whole with respect to the ability to cope with current challenges.

In terms of comparing the study communities (**Figure 39**), a high proportion (59.7 %) of respondents in Naapaal reported to be moderately satisfied followed by households in Ketuo (45.8 %), Billengangn (38.3 %), and Gengenkpe (31.3 %). No respondent in Gengenkpe reported very satisfied with a few in Billengangn, Ketuo and Naapaal. The highest proportion of respondents who reported very unsatisfied with life as a whole were in Gengenkpe. The survey data also showed that a high percentage of respondents (74.2 %) in Naapaal were satisfied with life as a whole with a few of them in Gengenkpe.

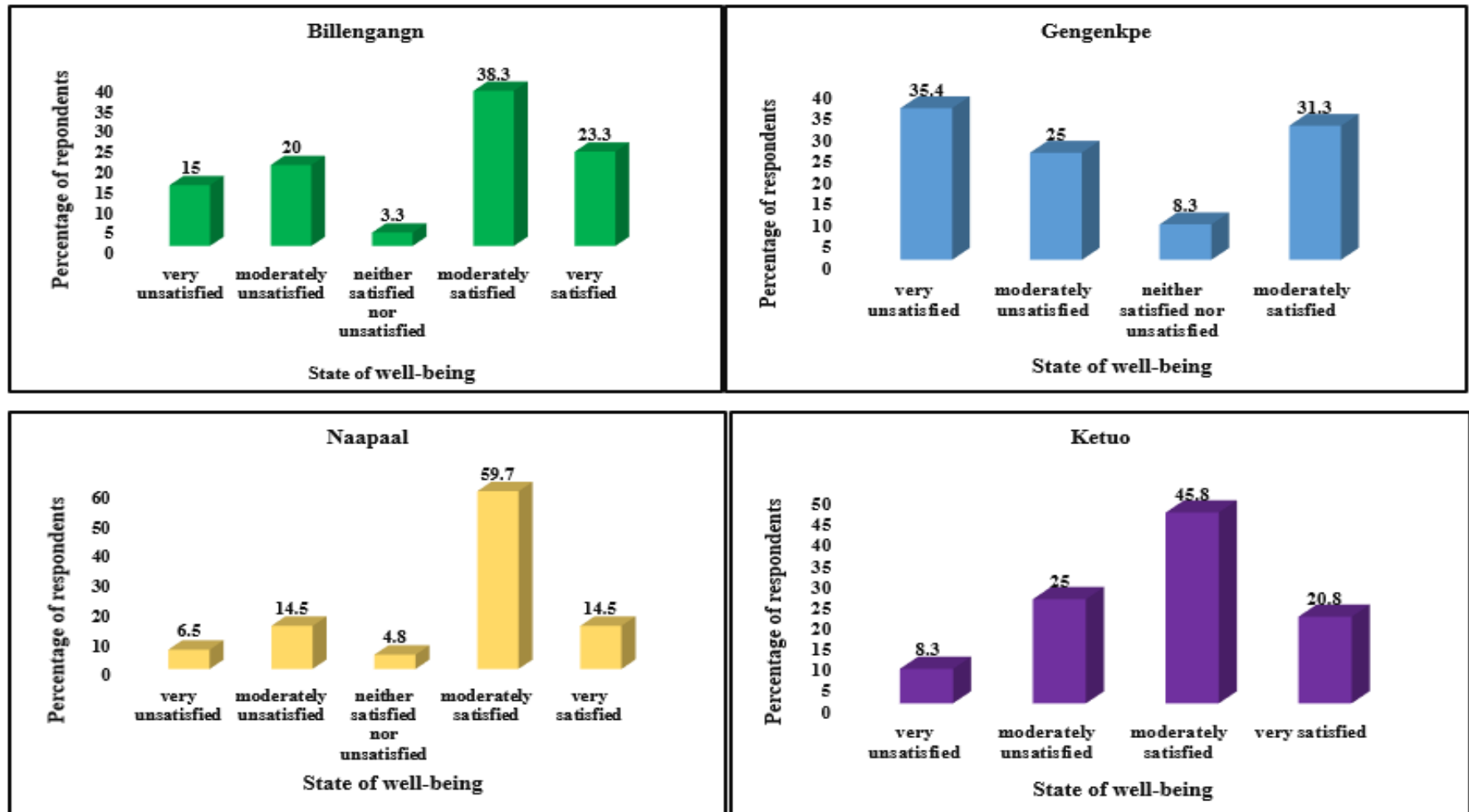


Figure 39: Subjective well-being of the study communities.

4.6.6 Estimated Vulnerability of the Study Communities

The results of the estimation of the level of vulnerability of households in the study communities are presented in **Figures 40 to 43** as well as in **Tables 1 and 2** of **Appendix 7**.

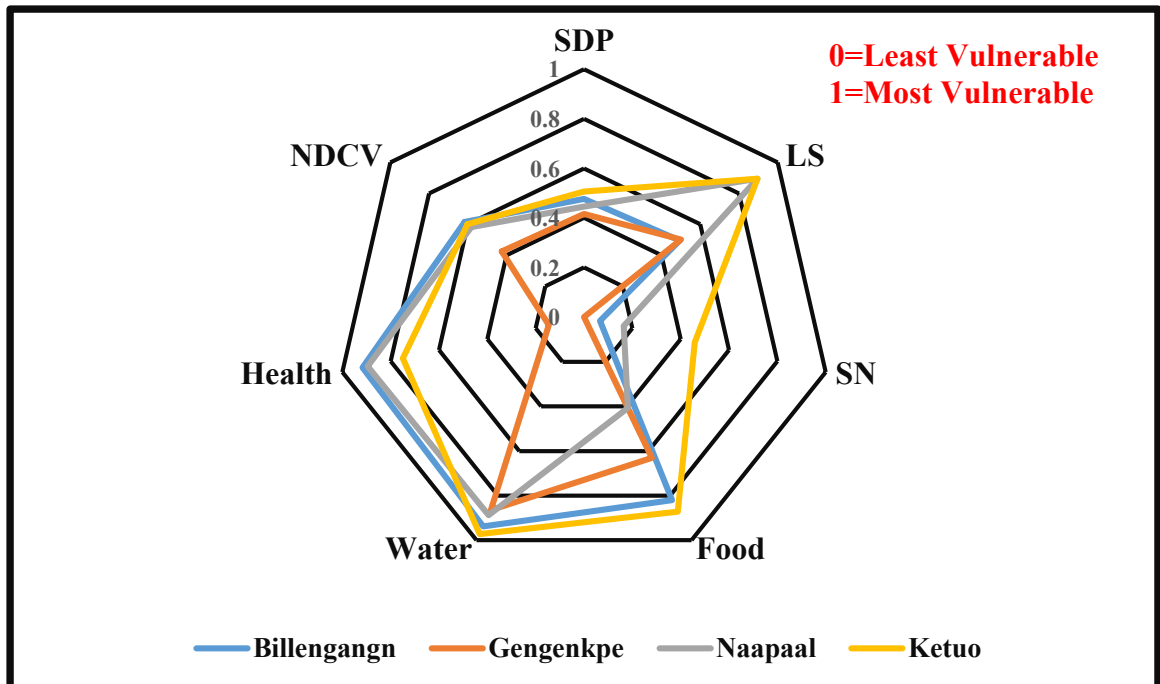


Figure 40: Vulnerability spider diagram of major components of LVI.

The livelihood vulnerability index for the socio-demographic profile (SDP) for households in Billengangn, Gengenke, Naapaal, and Ketuo were 0.477, 0.416, 0.446 and 0.528, respectively. These results indicated that Ketuo (0.528) was most vulnerable whereas Gengenke (0.416) was least vulnerable in terms of socio-demographic profile. The LVI in respect of livelihood strategies (LS) for Billengangn, Gengenke, Naapaal, and Ketuo were 0.495, 0.501, 0.895, and 0.895, respectively. The result indicated that Ketuo (0.895) and Naapaal (0.895) were the most vulnerable and the least vulnerable community was Billengangn (0.495).

The results also indicated that the composite LVI for social networks (SN) was 0.067, 0.0, 0.164, and 0.459 in Billengangn, Gengenkpe, Naapaal and Ketuo, respectively. Hence, the most vulnerable community in terms of social networks was Ketuo whilst the least vulnerable was Gengenkpe.

For the vulnerability index for the food, the results showed that Ketuo (0.872) was most vulnerable while the least vulnerable was Naapaal (0.407). The LVI for Billengangn and Gengenkpe in terms of food were 0.820 and 0.631, respectively.

The LVI for water in Billengangn, Gengenkpe, Naapaal, and Ketu were 0.937, 0.865, 0.887, and 0.972, respectively. This indicated that Ketuo (0.972) was most vulnerable whereas Gengenkpe (0.865) was least vulnerable in terms of water.

The result of the LVI for health showed 0.917, 0.146, 0.895, and 0.750 for Billengangn, Gengenkpe, Naapaal and Ketuo, respectively. Hence, the most vulnerable community concerning health was Billengangn (0.917) whilst Gengenkpe (0.146) represented the least vulnerable community.

With regards to natural disaster and climate variability (NDCV), Billengangn (0.616) was the most vulnerable whereas the least vulnerable was Gengenkpe (0.424) in terms of this major component. The composite LVI for Billengangn, Gengenkpe, Naapaal and Ketuo were 0.616, 0.424, 0.582 and 0.602, respectively.

The overall livelihood vulnerability indices as shown in **Figure 41** for Billengangn, Gengenkpe, Naapaal, and Ketuo were 0.624, 0.426, 0.611 and 0.703, respectively. The overall livelihood vulnerability index estimation incorporates the socio-demographic profile, livelihood strategies, social networks, food, water, health, and natural disaster and climate variability major components to analyze the vulnerability of households.

The results of the overall LVI indicated that Ketuo was most vulnerable (0.703) whilst Gengenkpe (0.426) was the least vulnerable community.

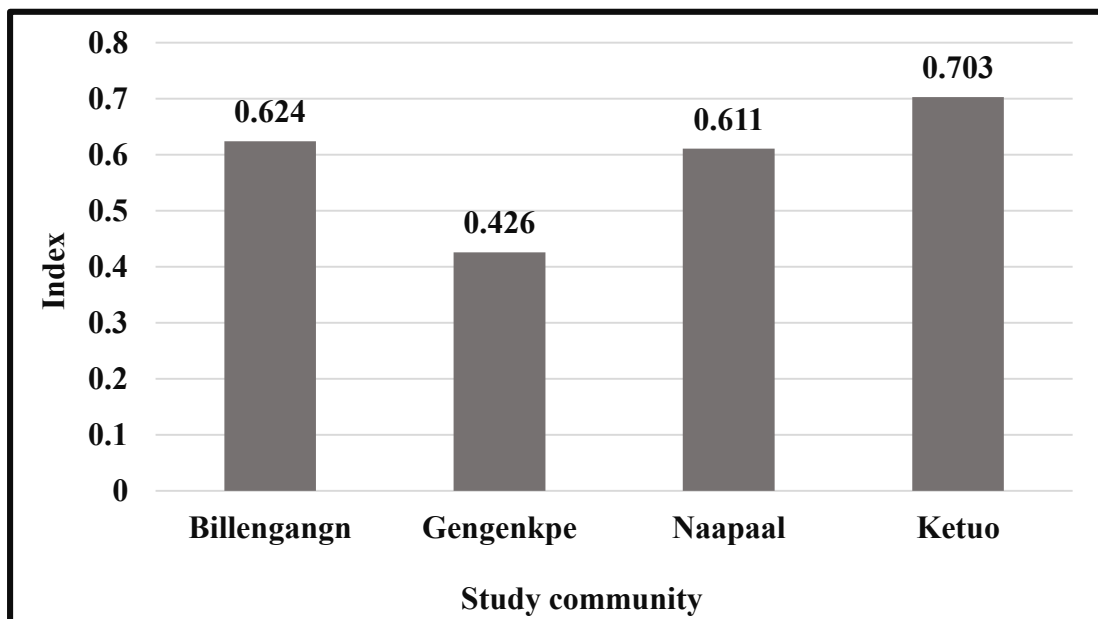


Figure 41: Estimated overall livelihood vulnerability indices of respondents.

Furthermore, the results of the LVI in **Figure 42** and in accordance with the IPCC's definition of vulnerability showed that Ketuo (0.602) was the community with most vulnerable households (i.e. comprising socio-demographic, livelihood strategies, and social networks). The community that was most sensitive to climate change and variability and agroecosystem services change was Billengangn (0.891) in respect of food, water, and health. The most vulnerable community with respect to exposure to natural disaster and climate variability and agroecosystems change was Billengangn (0.612). In terms of adaptation capacity for the four study communities Ketuo (0.620) was more vulnerable followed by Naapaal (0.502), Billengangn (0.346), and Gengenkpe (0.306). For sensitivity, Billengangn (0.891) was more vulnerable followed by Ketuo (0.865), Naapaal (0.730), and Gengenkpe (0.547), whilst in terms of exposure, Billengangn (0.612) was more vulnerable followed by Ketuo (0.602); Naapaal (0.582,) and Gengenkpe (0.424), respectively.

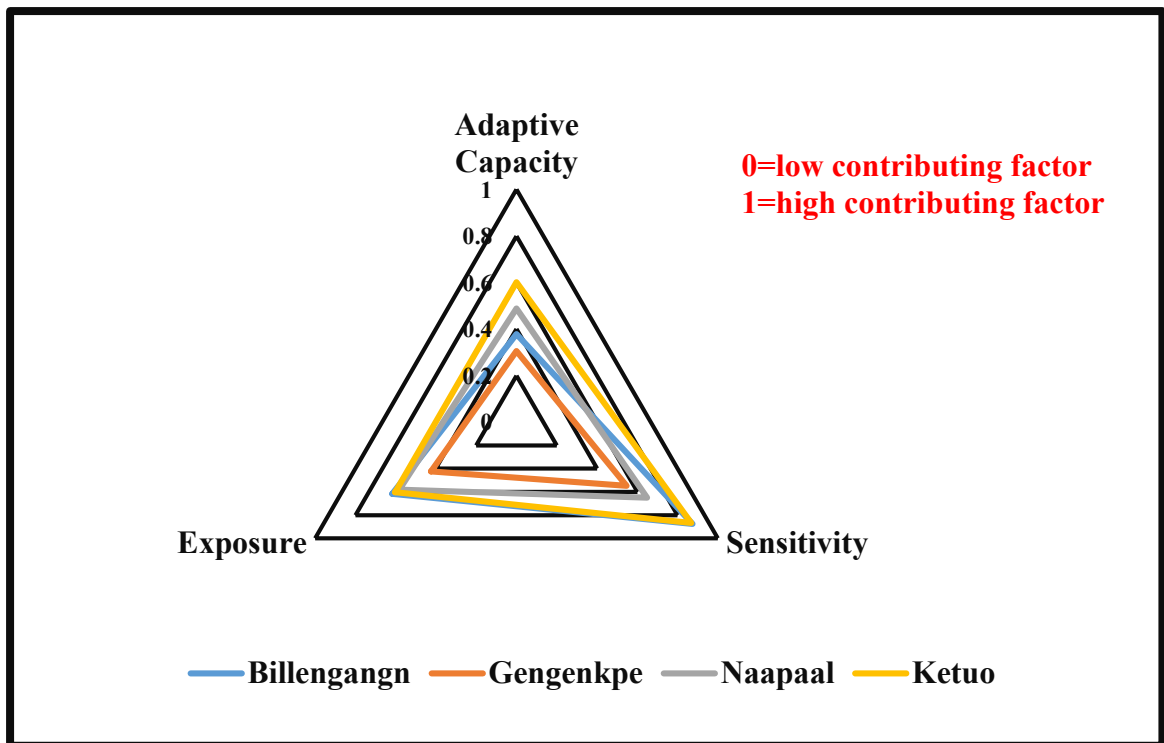


Figure 42: Vulnerability triangle diagram for IPCC contributing factor.

The indices for IPCC-LVI as shown in **Figure 43** for the study communities indicated that even though there was no much differences between the values as per the range of zero (0) to one (1), Ketuo was most vulnerable whilst Billengangn, and Naapaal were the least vulnerable.

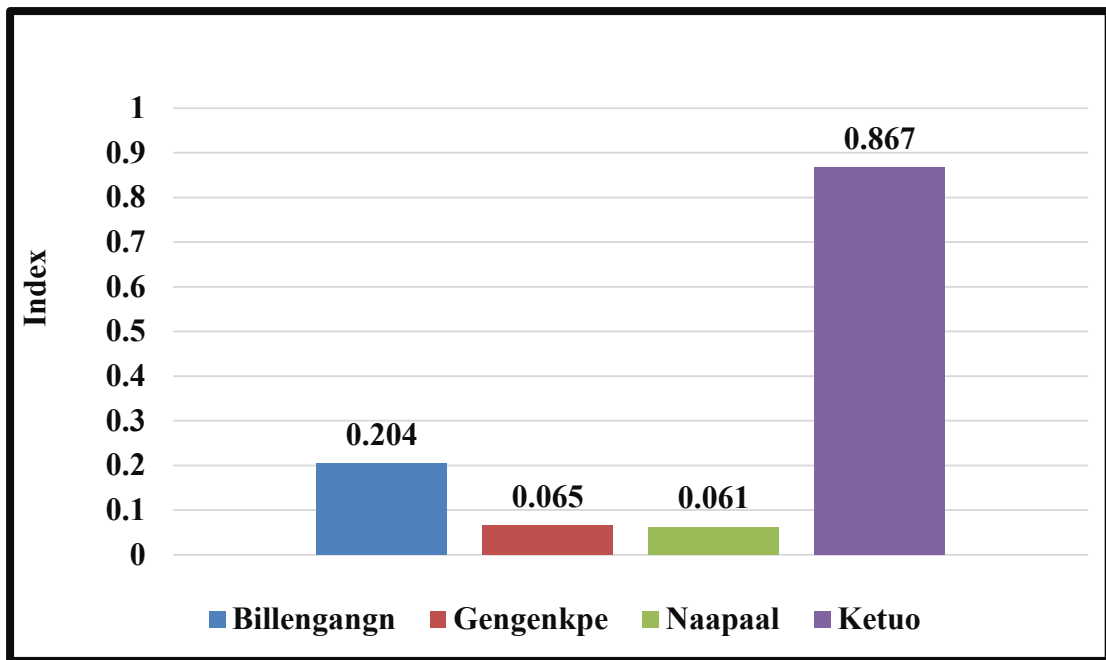


Figure 43: LVI-IPCC value for the study communities.

The LVI-IPCC computations based on the integration of adaptation capacity, sensitivity, and exposure variables of the vulnerability analysis were 0.204, 0.065, 0.031 and 0.867, for Billengangn, Gengenkpe, Naapaal, and Ketuo, respectively. The values used for the LVI-IPCC estimation were derived from the seven major components of the LVI. The results indicated that Ketuo (0.867) was the most vulnerable whereas Naapaal (0.061) was the least vulnerable community.

4.7 Adaptation Options of Smallholder Farmers

Figure 44 shows the results of the perceptions of smallholder farmers on adaptation strategies employed on their farms to improve crop production and to overcome impacts of changes in agroecosystem services and climate. The survey showed that a large proportion of respondents (91.8 %) reported the use of organic manure and inorganic (chemical) fertilizers (80.4 %). Other adaptation strategies used were tree planting, no

bush burning or burning of crop residues on their farms, mulching, crop diversification, use improved seeds, and change of farming practices.

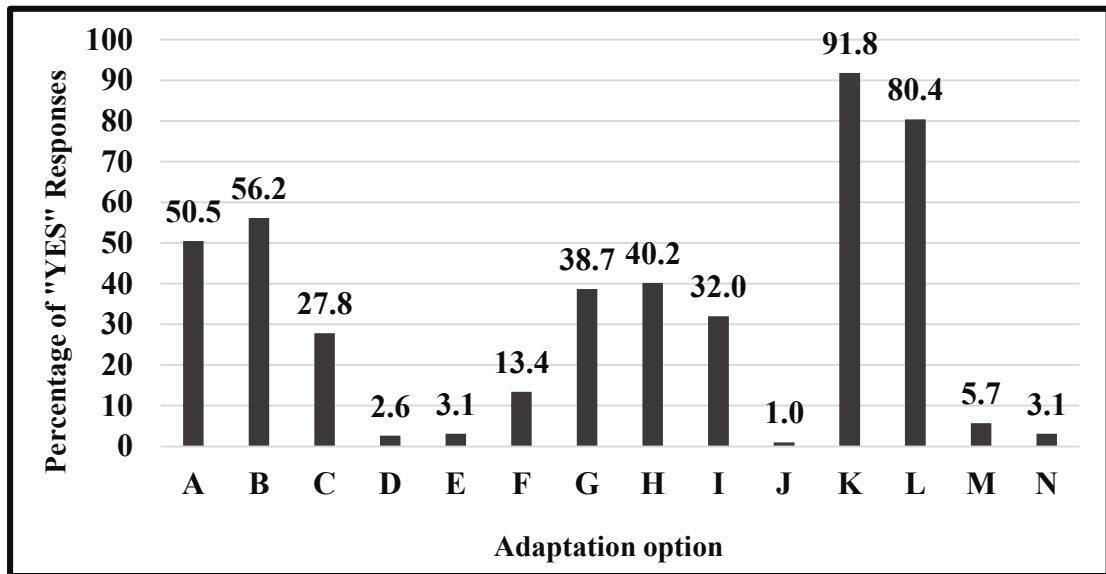


Figure 44: Adaptation options and strategies of respondents.

Note: A=Avoidance of bush burning, B=Tree planting, C=Changing farming practices, D=Increasing farm size, E=Growing drought resistant crops, F=Livestock production, G=Crop diversification, H=Mulching, I=Improved seeds, J=Attracting pollinators, K=Application of Organic manure, L=application of Fertilizer, M=Terracing, N=Trenching

The results indicated that the adaptation options used less frequently by smallholder farmers were increasing farm sizes, growing drought resistant crops, livestock production, attracting pollinators, terracing, and trenching.

FGDs revealed that effective adaptation strategies of smallholder farmers were soil enrichment and soil water conservation strategies such as stone bonding and compost usage. Other feasible adaptation strategies included “no burning and no tree cutting”, application of chemical fertilizers, dry season farming, livestock rearing, relocation of farms from flood prone areas to upland areas, ponding of small water bodies to conserve water in their farms, planting trees on depleted lands, creation of fire belts to protect crops on the farms, ridging to hold water on farms to conserve soil moisture.

The other category of adaptation options employed by discussants was livelihood diversification strategies. These included raising seedlings for sale, sale of forest products (fruits and leaves), sale of fuelwood, hunting, engaging in construction of home buildings for a fee. In most cases, the women were engaged in weaving, migration, formation of village savings and loans association (VSLA), soap and pomade making, “pito brewing”, and shea butter processing. Few respondents had also resorted to forming farmer groups to support members as the case of Naapaal where there was a vibrant “sorghum growers” association of women.

4.7.1 Perceptions of Farmers on Determinants of Adaptation Strategies

The survey identified factors that influenced farmers’ decision whether to use or not use a particular adaptation option as in **Table 17**. The study found that a large proportion of respondents cited cost and not known (lack of information) as reasons why they were not using certain adaptation strategies available in the study area. For instance, majority of farmers reported that the use of drought resistant crops was not known, whilst those who even knew mentioned cost as the reasons for not adopting that option. In terms of diversification of crop, a high percentage of respondents reported the option was not known or had no information about it, and for some it was expensive. Most respondents also indicated that mulching was not known. Majority of farmers were not adopting the use of improved seeds because they did not know about it, whilst a few mentioned cost as a barrier. More than half of the respondents did not know about attracting pollinators as an adaptation strategy.

Table 17: Factors that affect utilization of available adaptation strategies.

Adaptation strategies	Cost (%)	Not Known (%)	Not Sufficient Information (%)	Uncertain Outcome (%)	Not Enough (%)
Drought Resistant Crops	23.2	28.9	3.2	4.6	1.0
Diversification of Crops	19.6	26.8	7.2	4.6	2.6
Mulching	14.9	20.6	13.9	4.6	4.6
Improved Seeds	18.0	33.0	13.4	2.6	2.6
Pollination	11.3	55.2	16.0	6.2	7.2
Organic Manure	6.2	2.1	1.5	1.5	4.6
Fertilizer	18.6	0.5	1.0	0.5	3.1

Source: Field Survey, 2016/2017

4.7.2 Determinants of Adaptation Strategies for Smallholder Farmers

Factors that influenced adoption or otherwise of indigenous and introduced adaptation strategies of smallholder farmers were availability of agroecosystem services, farm size of respondents in hectares, access to climate information, access to training, farmland ownership, how satisfied a respondent is with life in relation to major challenges, gender and access to information on managing ecosystem services. However, regression analysis indicated access to climate information, how satisfied a respondent is with life with regards to major challenges, and availability of agroecosystem services were the significant determinants of adaptation strategies (see **Table 18** and the output in **Appendix 9**). Durbin-Watson statistic also showed that some of the predictors were autocorrelated.

Table 18: Significant determinants of adaptation strategies.

Model	Unstandardized Coefficients		Standardized Coefficient	t	Sig
	B	Std. Error	Beta		
(Constant)	1.806	.095		19.013	.000
Access to training	-.008	.024	-.018	-.321	.748
Access to climate information	-.397	.030	-.688	-13.200	.000
Gender	.015	.023	.034	.644	.521
Farm size of participant in hectares	-.018	.019	-.047	-.912	.363
Farmland ownership	.012	.013	.046	.911	.363
Access to information on managing Agroecosystem services	.003	.025	.006	.110	.913
How satisfied a farmer is with life in relation to major challenges	-.023	.008	-.144	-2.780	.006
Available Agroecosystem services	.090	.037	.119	2.435	.016

a. Dependent Variable: adaptation strategies.

4.8 Knowledge and Information Sources on Adaptation Options

The perceptions of household respondents on the knowledge and information sources on available adaptation strategies are shown in (Figure 45). The survey found that, majority of respondents received information on agroecosystem services and climate change through radio services, followed by family and friends, village leaders such as traditional authorities and assembly members, government authorities like the District Assembly, extension officers, and school teachers.

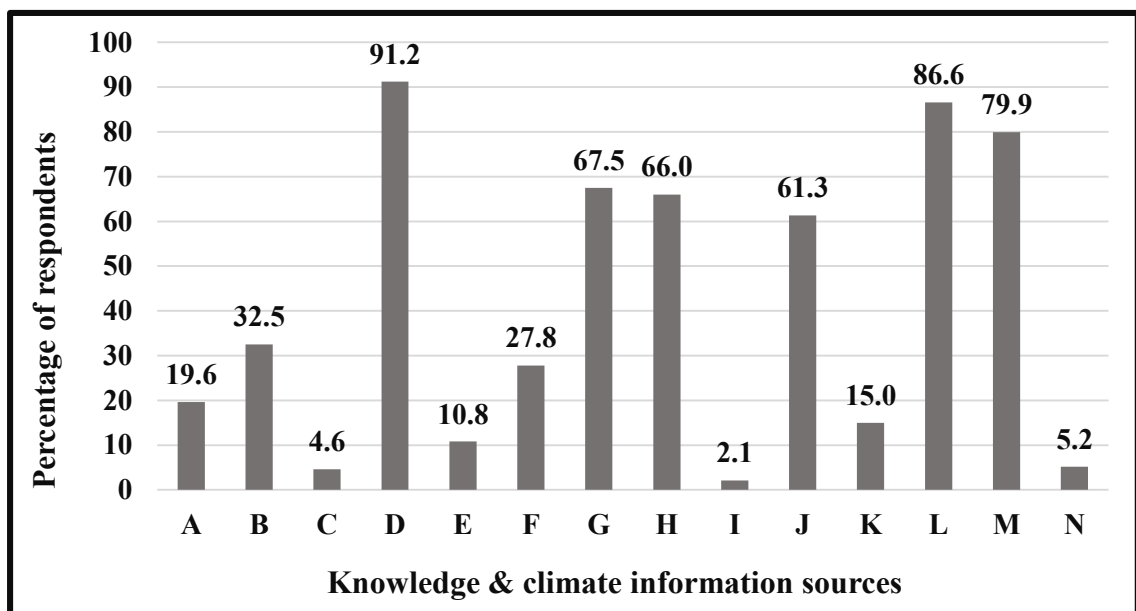


Figure 45: Source of knowledge and climate information for respondents.
 NOTE: A=Meteorological services, B=Indigenous forecast information, C=Newspaper D=Radio, E=TV, F=NGOs, G=Government Authorities (District Assembly), H=Extension Officers, I=Internet, J=School/Teachers, K=Visiting Climate Experts, L=Family & Friends, M=Village Leaders (Traditional Authorities), N=Government publications

The survey data showed that the main source of climate and agroecosystem services information in the study area was the radio (VON FM 97.1 MHz). Respondents also relied on family and friends and community leaders for information regarding extreme weather event forecast or warning.

Other sources of knowledge and information identified by discussants during focus group discussions included the Department of Agriculture, NANDIRDEP, NANDMO, and NGOs (e.g. PRUDA, ADVANCE Care International). A key informant from the Department of Agriculture/Ministry of Food and Agriculture (MOFA) intimated that their outfit collaborates with the District Assembly to provide extension services to 9 operational areas in the district through training programmes. During these programmes farmers were provided with skills regarding soil enrichment practices, non-burning of crop residue, bushfire prevention, and tree planting.

The survey further revealed that MOFA through extension services provided training on improved farming practices to farmers, whilst NADMO and GNFS sensitized farmers on bushfire prevention and flood management. The EPA in collaboration with partners created awareness and trained farmers on good environmental management practices to safeguard existing agroecosystem services.

4.8.1 Trustworthiness of Knowledge and Information Sources

Figure 46 shows the results of the perceptions of smallholder farmers on whether they trusted the knowledge and information sources on adaptation. Most respondents indicated they strongly agreed that they trusted radio, followed by extension officers, village leaders such as traditional authorities, family and friends and school teachers.

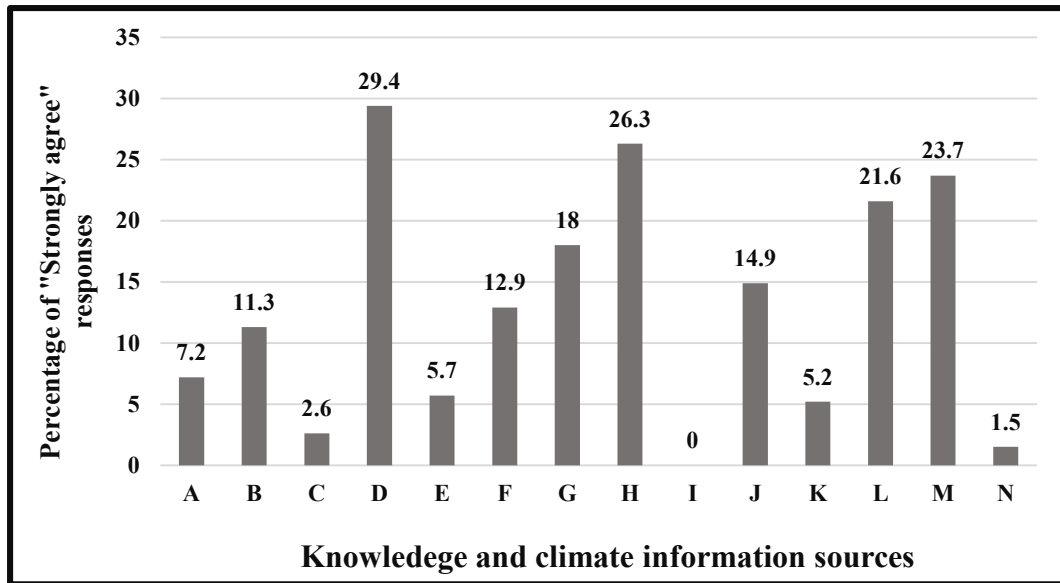


Figure 46: Trustworthiness of sources of knowledge and climate information.
 NOTE: A=Meteorological services, B=Indigenous forecast information, C=Newspaper D=Radio, E=TV, F=NGOs, G=Government Authorities (District Assembly), H=Extension Officers, I=Internet, J=School/Teachers, K=Visiting Climate Experts, L=Family & Friends, M=Village Leaders (Traditional Authorities), N=Government publications.

4.8.2 Sufficiency of Knowledge and Information Sources

Respondents were asked to indicate the whether the climate information ever received were sufficient and the result of the survey is shown in **Figure 47**. The results indicated that majority reported that knowledge and information from the radio were sufficient, next was family and friends and followed by government authorities (District Assembly), and village leaders (traditional authorities), extension officers, and school teachers.

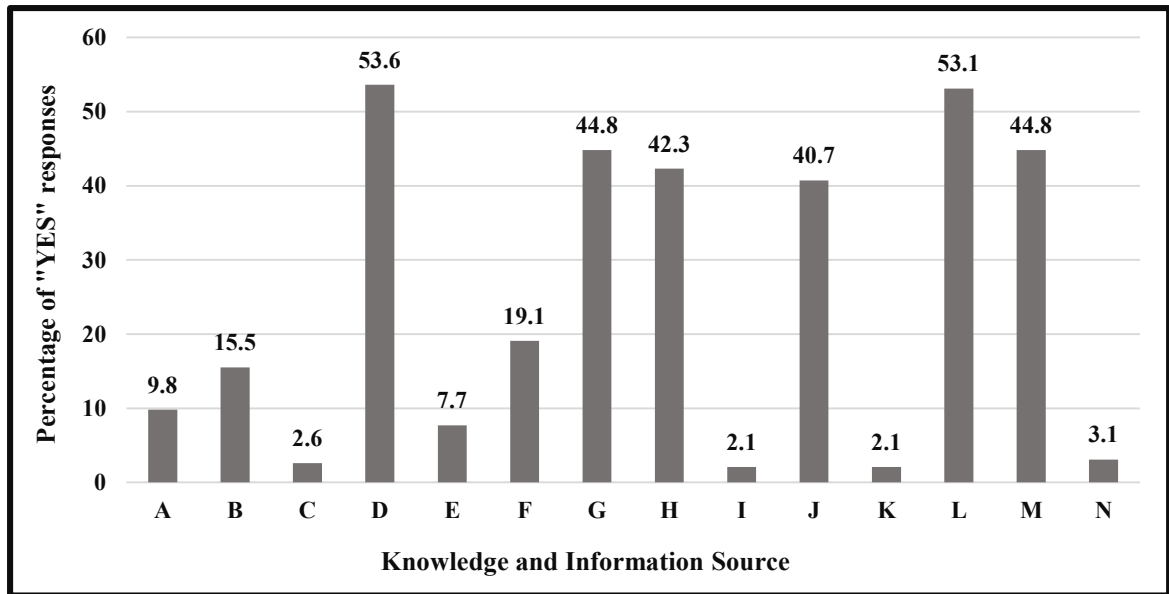


Figure 47: Percentage of respondents on whether source of knowledge and climate information is sufficient.

A=Meteorological services, B=Indigenous forecast information, C=Newspaper, D=Radio, E=TV, F=NGOs, G=Government Authorities (District Assembly), H=Extension Officers, I=Internet, J=School/Teachers, K=Visiting Climate Experts, L=Family & Friends, M=Village Leaders (Traditional Authorities), N=Government publications.

4.9 Managing Changes in Agroecosystem Service and Climate

4.9.1 Institutional Support in Managing Changes in Agroecosystem and Climate

For smallholder farmers to effectively manage the potential impacts of changes in agroecosystem services and climate, both government and non-government institutions were expected to support them. **Figure 48** shows the survey data on which institutions provided support to respondents. All the respondents reported receiving support from their chiefs and elders (traditional authorities) while almost all of them mentioned that they received support from co-farmers, followed by the District Assembly, NGOs and Department of Agriculture (MOFA).

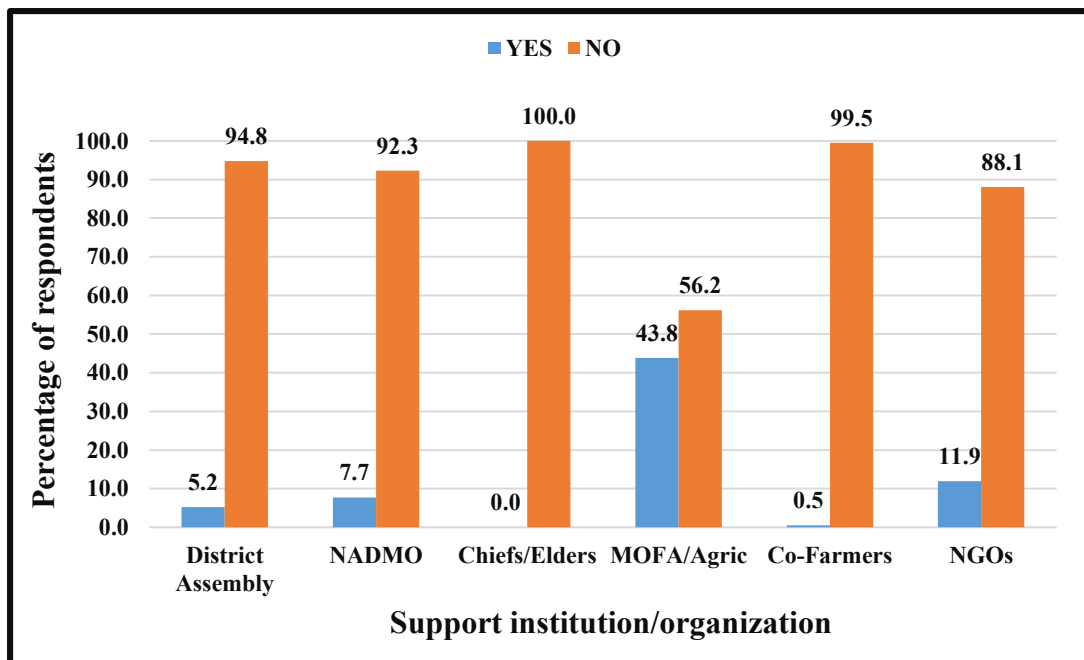


Figure 48: Support institutions/organizations identified by respondents.

The survey revealed that a large portion of respondents relied on village leaders such as chiefs and assembly members for support with regards to the management of changes associated with agroecosystem services such as water, food, fuelwood, forests cover and croplands and climate change and variability. Smallholder farmers in the study area depended on colleague farmers (Co-farmers) for information on climate change and agroecosystem services management practices. The District Assembly was reported by a most respondents to be supportive of their livelihood activities in respect of agroecosystems and climate change. Other institutions cited by respondents as sources of information for the management of these changes were NADMO, NGOs and Department of Agriculture or MOFA.

4.9.2 Types of Training on Agroecosystems Change Management

The survey data showed that respondents received training with regards to management of agroecosystem change. The results indicated that respondents were divided over whether they received training or not. About 50.5 % of the respondents reported not

receiving any training while 49.5 % claimed that they received some training. However, three main areas of training were identified by respondents and include bushfires prevention, soil enrichment practices and tillage practices as shown in **Figure 49**.

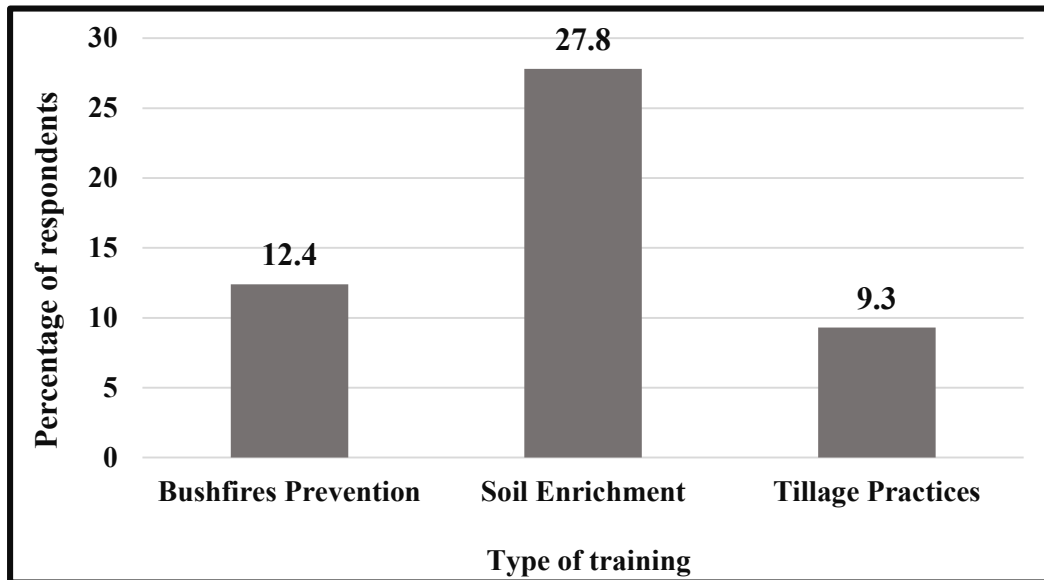


Figure 49: Type of training received by respondents.

Results of the study showed that majority of respondents received training on soil enrichment practices followed by bushfire prevention and then best tillage practices. According to participants, the aim of all training activities was geared at improving soil fertility for high crop production and maintenance of vegetation, water and forest resources.

CHAPTER FIVE: DISCUSSION

5.1 Household Profile and Farm Characteristics

The findings revealed that the interviewed households consisted of 52.6 % males and 47.4 % females. However, the 2010 population and housing Census report for the study district comprised 48.4 % males and 51.6 % and females (GSS, 2014). The results of gender distribution in the study communities were in contrast with the established census data except Ketuo that recorded 70.8 % female participants. Gender plays crucial roles in the distribution and right to the use of some natural resources such as land and its associated agroecosystem services (Boon & Ahenkan, 2011). The level of access to certain assets in the study area was governed by the gender of the household head. Majority of female respondents revealed that they did not have access to fertile land for crop production. This is because traditionally, males own land and even when a male household head passes away his properties would be inherited by the brothers. The relatives of the man hold the right to the use of the deceased's assets at the expense of the widow who eventually assumes the responsibilities of the household head. This situation has implications for vulnerability and adaptation to agroecosystem services and climate change in these communities (Bohle *et al.*, 1994; Rurinda *et al.*, 2014; Hameso, 2015).

Majority of the respondents were within the age group of fifty (50) years and above. This age group has implications for vulnerability of smallholder farmers with regards to food production.

The proportion of respondents who did not have any education in the study area was 54.1 % with the highest in Gengenke (60.4 %). According to the 2010 population and

housing census (GSS, 2014), 50.2 % of the population 11 years and above in the district had basic levels of education, whereas 49.2 % had no education. The level of education of smallholder farmers has implications for understanding changes in their environment and adoption of adaptation strategies as well as the extent of acceptance and use of climate information and best agronomic practices (Hameso, 2015).

Meanwhile, the 2010 population and housing census (GSS, 2014) reported that the average household size for rural areas in the district was 6.2. In addition, Nyantakyi-Frimpong & Bezner-Kerr, (2015) reported 7.8 as mean household size of respondents in a related study. The findings in this study revealed that about 56.2 % of interviewed households had household sizes between 6 and 10. Household size can be described as a “mixed bag” for families because of the associated negative and positive implications. The size of a household is significant with regard to access and use of agroecosystem services and the ability to cope with changes. For example, a larger household size has negative impacts on the amount of farmland holdings of each member of the family and food production, which may amplify vulnerability to climate change (Antwi-Agyei *et al.*, 2012; Etwire *et al.*, 2013). On the other hand, a higher proportion of household members gives the household an advantage in terms of labour for economic activities and support for the aged and persons with disabilities.

In terms of occupation, majority of household heads (96.9 %) were smallholder farmers. This result is similar to a study conducted among households in northern Ghana by Etwire *et al.* (2013) and in Ethiopia by Hameso (2015), where over 96.0 % of participants were farmers. In addition, the 2010 population and housing census reported 85.3 % of households engaged in agriculture in the Nandom district.

A larger proportion (73.2 %) of respondents in this study held about two (2) hectares of land. The 2010 population and housing census report was not clear on the average farm size of households, however, according to the medium-term development plan (MTDP) of the Nandom district, the projected average farm size per farmer for 2015 was 4.3 hectares. In a related study in the Upper West Region, Nyantakyi-Frimpong & Bezner-Kerr (2015) reported a mean land size of farmers of 1.5 hectares. The amount of land holdings and the percentage of respondents involved in agriculture has significant implications for the level of vulnerability and adaptability (World Bank, 2007; Morten 2004) of the smallholder farmer to climate change, since land constitute one of the most important natural capital assets in semi-arid areas. Land holdings affects diversification of smallholder livelihood activities with regards to access to options of soil and land management practices (Deressa et al., 2009; Antwi-Agyei *et al.*, 2012).

Land ownership in the study area is largely the family land system where the farmlands cultivated by households belonged to their own families. The land tenure system of famers has implications for their vulnerability and adaptation strategies in terms of changes in agroecosystem services and climate. For example, landlords were able to lease part of their land holdings to others from which they received a share in the proceeds. Women discussants complained that they did not have rights to own land and had to depend on their husbands and friends, who leased smaller and mostly infertile parcels of farmland to them. In a related study, Antwi-Agyei *et al.* (2012) reported that complex land tenure systems were serious constraints to adaptation to climate change and variability in vulnerable districts in northern Ghana.

The major crops cultivated by farmers in the study area were maize, groundnut, millet, rice, beans, and guinea corn. Cereals such as maize, millet, and guinea corn serve as vital staple food crops for smallholder farmers and are equally vulnerable to low and

erratic rainfall regimes because they require adequate water for growth (Schlenker & Lobell, 2010). Yam and vegetables were cultivated on relatively smaller scale. Similarly, the district reported production of sorghum, groundnut, millet, cowpea, maize, rice, soya beans, and yam in their crop yield projection for 2016 and claimed that there is an advantage in the production of groundnuts and cowpea (DMTDP, 2015). The district report is consistent with the findings of this study in terms of crops cultivated. The implication is that there is the opportunity to improve the livelihoods of farmers through vegetable production during the dry season by irrigation using water from the Black Volta River. There is the need for government policy on institutional support to build capacity for irrigation farming all-year round.

Crop utilization here was a measure to determine whether households were able to store enough food, sell, and reserve some as seeds for future use. It was also an indication of adequate crop production over the years. The findings in this study suggest that more households consumed all crops produced within the season and are unable to even save some as seeds for the new farming season.

A large percentage of household (85.6 %) never received credit to support their farming activities over the years. Meanwhile, studies have shown that access to credit positively enhance adaptation strategies (Gbetibouo, 2009; Etwire *et al.*, 2013) of farmers. For example, farmers who have access to credit are able to purchase improved crop varieties, engage in irrigation, and acquire new technologies to adapt to the changing climate conditions. It was observed from FGDs and key informant interviews that respondents who were members of organized groups such as women groups and Village Savings and Loans Association (VSLA) had access to credit for their farming activities compared to those without any group or association. The findings revealed that the formation of groups may be a transformative strategy to adapt to climate change and

extreme events in the study area. The main sources of credit were the bank and money lenders.

The results of the survey data on household profile and farm characteristics were incorporated into assessment of vulnerability of households in the study communities. The information gathered was used in the development of indicators for the livelihood vulnerability index (LVI) model.

Generally, households relied on the VSLA for financial support whilst many who were not members seemed helpless in times of difficulties during prolonged dry periods.

5.2 Soil Fertility Status

Analyses of soil samples from selected farms in the study area indicated mean pH range between 5.60 and 8.0. In a related study, the Savannah Agricultural Research Institute (SARI) of the Council for Scientific and Industrial Research (CSIR) (2013) reported pH ranges from 5.35 to 6.25 in soil samples from five districts of the Upper West region. The pH is one of the important chemical properties of agricultural soil that influences the solubility and availability of soil nutrients, minerals and other elements for plant use. The pH range in soil that is acceptable for growth of most crops is from 3 to 9 (Estefan *et al.*, 2013). The results of the pH values in this study implies that the soil were suitable for growth of crops. Usually soil pH between 5.5 and 7.0 stimulates the availability of nitrogen, phosphorus, and decomposition of crop remains by soil microorganisms.

Electrical conductivity (EC) is an indication of soil salinity, which influences the degree to which the soil is suitable for crop growth (Estefan *et al.*, 2013). EC values of range

0-2000 $\mu\text{S}/\text{cm}$ are good for all crops but between 2000 to 4000 $\mu\text{S}/\text{cm}$ may not be favourable for crops. However, most crops will not grow well with values between 4000 and 8000 $\mu\text{S}/\text{cm}$.

With regards to organic matter, the analysis indicated a minimum of 0.92 % at a site in Naapaal and a maximum of 2.22 % at a farm in Billengangn. Similarly, CSIR-SARI (2013) reported lower trends of organic matter content (0.64-1.45 %) in topsoils in the study region. The findings from this study implies that farm soils had marginal to adequate levels of organic matter (Estefan *et al.*, 2013). Soil organic matter influences soil aggregate formation, nutrient reserves and its availability, moisture retention, and biological activity. Soils of semi-arid rain-fed areas have normally less than 1.5 % of soil organic matter (FAO, 1980; Estefan *et al.*, 2013). According to Estefan *et al.* (2013), levels of organic matter in soil less than 0.86 % can be described as low, 0.86-1.29 %, marginal and more than 1.29 % as adequate (FAO, 1980; Martins & Lindsay, 1990). The FAO (1980) guidelines further note that total nitrogen (N) of 0.10 % or greater is adequate for growth of most crops in dry land areas (Estefan *et al.*, 2013). The levels of total nitrogen measured at selected farms ranged between 0.06 % and 0.22 %. In the same region, CSIR-SARI (2013) reported total N range of 0.0-0.10 % lower than what was recorded in this study. The type of soil in the study area is typical of dryland areas and can be considered as suitable for growth of most crops as per the measured values. Generally, the levels of chemical and physical properties of soil samples analyzed were marginal to adequate and may support growth of plants and contribute positively to the agricultural livelihoods of farmers.

The trend analysis of the soil properties over the years could not be done because literature search and consultations with the Department of Agriculture at the Nandom District Assembly did not find any historical data on soil levels in the district.

Soil is an important natural resources that provide supporting agroecosystem service in terms of soil fertility (Boon & Ahenkan, 2011; Smith & Sullivan, 2014). Soil forms the basis for other agroecosystem services providing smallholders farmers with, fibre, food, and fuel for their livelihoods and well-being.

5.3 Water Quality

According to the Joint Monitoring Programme for Water Supply and Sanitation (JMP, 2008), about 29 % of rural population in worldwide rely on unimproved water sources. The Ghana Water Policy notes that access to enough safe water is a fundamental human need and efforts must be made to manage and sustain the quality of available water resources (Government of Ghana, 2007). In addition, a study by Rossiter *et al.* (2010) that analyzed the quality of water resources in Ghana sampled only two boreholes from the Upper West Region and no samples were taken from the Black Volta River. Hence, the water quality assessment objective of this study was to ascertain the quality with respect to domestic water use. The focus was to determine the extent to which water resources in the study area contribute to the agroecosystem services provisioning role of water in terms of quality and the effects on livelihood strategies of households. The findings revealed that the mean pH range of the river water was 7.3 to 7.8 whereas that of the borehole water was 7.2 to 8.5 indicating neutral to slightly alkaline. However, concentration of all other water quality parameters including physico-chemicals, ions and nutrients and heavy metals were found below the TWQRs in term of the River water and WHO drinking guidelines for the borehole water.

This study found that the concentration levels of turbidity in all river water samples exceeded the recommended guideline values of 1.0 NTU and 5.0 NTU of the WHO. The high levels of turbidity usually affect acceptability of water (WHO, 2011). The high levels of turbidity may be as a result of farming activities along the river. The pH values of river water samples were found within the TWQRs (6-9) with the highest value recorded in Billengangn (7.8) and lowest in Gengenkpe 7.3). The measured pH levels in the river water samples indicated neutral to less basic water sources in the study communities (**Table 8**). It has been suggested that at pH less than 6, elements such as Fe and Al become highly soluble, whilst atmospheric oxides may dissolve at a pH more than 8.5 (Rossiter *et al.*, 2010) and low pH levels adversely affect aquatic life. Rossiter *et al.* (2010) reported pH range of between 3.7 to 8.9 from various water sources in Ghana. In terms of electrical conductivity (EC), the highest concentration was in the river water at Ketuo, whilst the least was at Billengangn. EC is indication of the total dissolved solids (TDS) and salinity in the water sample, which may affect acceptability by users in terms of taste. High TDS in water may cause corrosion of home appliances and equipment such as hand pumps (Rossiter *et al.*, 2010).

In addition, the concentrations of all the ions measured in river water samples were within the TWQRs guidelines. This is an indication that there may not be any associated health, aesthetic, scaling, and corrosion issues for households regarding the domestic water use (WHO, 2011). However, the concentration of NO_3^- measured in river water samples at Ketuo (4.80 mg/L) was near the upper limits of the threshold of the guideline value of 6.00 mg/L (TWQRs) and 50 mg/L (WHO). Pelig-Ba *et al.* (2004) reported a mean of 93.3 mg/L of NO_3^- and a maximum of 511 mg/L in groundwater in the northern region of Ghana, whilst Rossiter *et al.* (2010) found 508 mg/L of NO_3^- in water samples in the Western, Southern Volta, Northern and Upper East regions of Ghana. Nitrate,

NO_3^- is naturally occurring in water and in relatively small amounts as revealed in this study. High levels of NO_3^- stimulates plant growth such as algae and may cause objectionable eutrophication that produces secondary pollution from subsequent death and decay of plants (Baird & Cann, 2012). A situation that may affect the use of the river water or which may pose health risk to households and cause disease burden for households. For instance, nitrates are converted to nitrites in the intestines and once absorbed into the bloodstream, nitrites prevent haemoglobin from transporting oxygen (Baird & Cann, 2012). High NO_3^- N levels in drinking water (>10 mg/L) are linked with health problems (i.e. methemoglobinemia). High levels of NO_3^- N in water for human consumption should be avoided, such water is however, suitable for irrigation as it is an additional source of nutrients.

The levels of two ions Sodium, Na^+ and Sulphate, SO_4^{2-} were relatively high in borehole water samples from all study communities with very high Na^+ concentration recorded in Billengangn. However, Naapaal recorded remarkably high concentrations of Calcium, Ca^{2+} compared to other water from other communities. Na^+ usually combines with chloride, Cl^- to produce salty taste in water that is detectable at about 250 mg/L. Calcium causes hardness of water which affects acceptability of drinking water. According to the WHO (2011), calcium has a taste threshold of between 100-300 mg/L, which is largely determined by the associated anion whereas that of magnesium is less. However, water hardness of less than 100 mg/L may cause rusting in water pipes. Sulphate, SO_4^{2-} is not a notable toxic anion, however, in water containing Ca^{2+} forms hard scale in steam boilers. In large amounts, SO_4^{2-} in combination with other constituents gives a bitter taste to water and may affect acceptability in terms of aesthetic (Rossiter *et al.*, 2010). Concentrations above 250 mg/L may have a laxative effect, but 500 mg/L is considered safe (WHO, 2011). Hardness of water is usually

indicated by the precipitation of soap scum and the excess soap required for cleaning purposes, which may pose economic burden to households. Hardness may also affect acceptability of drinking water since the degree of hardness of water vary from one community to another (WHO, 2011).

The results of trace metal analysis indicated minimal contamination of water samples in the study area. The concentration of Cr, Cd, Co, Cu and Zn were found below detection limit (BDL) in all water samples, whilst Fe and Ni exceeded the guidelines of the TWQRs for surface water for domestic use.

The bacteriological analyses revealed that all river water samples from the study area exceeded the guideline values. Consequently, respondents reported cases of diarrhoea and cholera as a major challenge.

The implications of the concentration levels of the ions measured for the households in the study communities are in respect of health and aesthetic concerns. For health, nitrate NO_3^- levels were considered which indicated there may not be health risk problems, whilst for aesthetic, SO_4^{2-} levels do not indicate any major risk for households. High levels of fluoride cause skeletal and dental fluorosis and may create health concerns for households. Freshwater supply as an agroecosystem service provisioning may not be impaired as the water quality regarding ions levels were generally acceptable per the guideline values. Water quality has implications for households with regards to high levels of calcium and magnesium, which may cause scaling of home appliances, corrosion, and creates economic burden which will eventually enhance vulnerability and hinder adaptation of smallholder farmers to climate.

In summary, based on the mean values of pH measured (mean range, 5.6 to 8.0) soils in the study area were generally suitable for growth of most crops and may support the

agricultural activities of households. This implies that the sampled soils may play the agroecosystem services provisioning role in the study area.

On the other hand, the physico-chemical parameters, ions, and heavy metals analyzed were below the TWQRs for surface water and WHO drinking water guidelines except for turbidity in all water sample. Generally, the physical and chemical water quality may not pose adverse impacts on human health and aesthetics due to the low levels detected. However, the results of the bacteriological analysis of water samples from the Black Volta River indicated high counts of total coliform and faecal coliform. This may result in the outbreak of water-borne diseases like cholera in the area since most of the farmers drunk from the river during working hours on their farms. The soil pH values were transformed and integrated into the livelihood strategies component, whilst the mean levels pH, NO_3^- , and SO_4^{2-} of river water samples were aggregated into the water component of the LVI for the vulnerability analysis.

5.4 Rainfall and Temperature Trends and Variability

The findings confirmed the unimodal nature of the rainfall annual cycle in the sudan savannah zone of Ghana (Nkrumah *et al.*, 2014). The observed high variability nature of annual rainfall cycle over the study area affected the selection of livelihood strategies of smallholder farmers significantly in study communities.

On the other hand, majority of respondents' perceptions regarding total annual rainfall contradicted the observed gauge rainfall trend, which was decreasing. The perceptions of respondents in this study may be attributed to the erratic and unpredictable nature of rainfall and the many indicators of precipitation which prevents accurate perceptions. For example, many of the respondents reported having experienced severe floods and

therefore, rainfall had increased over the period. Besides the uneven rainfall distribution might have contributed to these perceptions. The IPCC (2007a) reported that about 90 % models were believed to have either overestimated or underestimated rainfall in given regions. However, in a related study in the Upper West Region, Nyantakyi-Frimpong & Bezner-Kerr (2015) reported that the perceptions of smallholder farmers reflected the gauge data analyzed. These authors found that most farmers perceived that total rainfall decreased over a two-decade period. Similarly, in southern Nigeria, Apata (2011) reported that about 58 % of respondents perceived decreased rainfall trend over a 10-year period. Other studies reported that majority of farmers perceived a decrease in total rainfall events in the Upper West region and noted that a great number of farmers agreed that the onset and cessation of the rains was difficult to predict (Antwi-Agyei *et al.*, 2012; Etwire *et al.*, 2013).

The implication is that we are experiencing warmer days in recent years compared to the past though the trend is not significant. The findings regarding the monthly mean maximum temperature showed highest in March and lowest in August, which is similar to values (21 °C and 32 °C) reported by Ghana Statistical Services (2014) for the district. Similarly, this analysis indicated an average minimum temperature of 22.1 °C whereas the GSS (2014) reported 23 °C. The anomaly plots revealed interannual variation in night temperature, which means that it's becoming warmer during the night in the study area. This has implication for human and crop health as was found from the household survey, where respondents reported recent incidences of cerebrospinal meningitis. The study further confirmed that the paramount chief and the elders of the Nandom Traditional area had placed a ban on the celebration of funerals between March and April. This was to avoid overcrowding during the heat periods and prevent related diseases.

Furthermore, the observed high temperature had adversely affected the selection of livelihood strategies by smallholder farmers. For example, migration of farmers to the southern part of Ghana had been attributed to high temperature (GSS, 2014), whereas the prevalence of other diseases like skin diseases were linked to high temperature and extreme heat by participants in this study.

However, participants of the FGDs also contended that high temperature enhanced decomposition of organic matter on their fields and decay of compost materials as well as aided in the preservation of harvested crops. Nyantakyi-Frimpong & Bezner-Kerr (2015) found that most farmers perceived temperature and number of extreme events such as droughts, floods, and strong winds increased. Apata (2011) also reported that about 53 % of respondents perceived an increased trend in temperature.

Only a small proportion (8.7 %) of respondents disagreed with the perception that there was a change in the planting season. In terms of gender perception, 81 % of males and 79 % females observed a change in the start of the planting season whilst majority of these respondents were within the ages of 50 years and above. Nyantakyi-Frimpong & Bezner-Kerr (2015) also reported that farmers perceived the planting rains to be erratic which adversely impacted on their livelihood strategies.

Several authors reported that perceptions on the trends and variations in climate events greatly influenced the decisions of smallholder farmers with respect to their livelihood activities in the Upper West Region (Antwi-Agyei *et al.*, 2012; Etwire *et al.*, 2013; Antwi *et al.*, 2015; Nyantakyi-Frimpong & Bezner-Kerr, 2015).

The analysis of both observed and perceived climate data confirmed that smallholder farmers were exposed to high interannual, seasonal, and inter-monthly variability of

rainfall and increasing trends of temperature. These trends had exacerbated challenges associated with rain-fed agriculture in the study area.

In conclusion, the study discovered that majority of the respondents demonstrated adequate knowledge and awareness of trends and variability in rainfall and temperature except total annual rainfall. However, there was general lack of capability on the part of households to effectively adopt available adaptation strategies.

With regard to gender, a high percentage of males showed greater understanding of climate trends and variability than their female counterparts. In terms of age, greater proportion of those who demonstrated adequate knowledge on climate trends were within 50 years and above.

The findings on the analysis of rainfall data for three decades spanning 1984 to 2014 revealed evidence of high rainfall variability, seasonal variations, and decreasing trend of rainy days over time. The findings on temperature variables, indicated that participants and respondents observed high temperature and excessive heat waves in recent years and had adversely affected the selection of their livelihood activities in local communities. The general observation was that the farming period had become shorter with late arrival and early end of the rains.

5.5 Perceived Trends in Availability, Utilization, and Agroecosystem Services Change

Availability of agroecosystem services.

Agroecosystem services play important role as sources of food, fibre, energy, and income for many smallholder farming households (Boon & Ahenkan, 2011; Smith & Sullivan, 2014; Boafo *et al.*, 2016). According to Millennium Ecosystem Assessment

(2005), ecosystem services are natural benefits that flow from the environment to society and agricultural production. For Boon & Ahenkan (2011), ecosystem services constitute the foundation of livelihoods and human well-being, particularly, for natural resource depended households. Besides, these services provide alternative sources of livelihoods for households (Boafo *et al.*, 2016). For instance, in this study about 40.7 % of respondents indicated high availability of non-timber forest products (NTFPs) such as chewing sticks, mats, pestles and mortars, and other provisioning services such as bushmeat, fruits, honey, fish and mushroom, which contributed to food and income needs of households in times of extreme weather events (e.g. floods and droughts). In a related study, Boafo *et al.* (2016) observed that products such as leaves, tree barks, roots, spices, and animal products contributed greatly to the medicinal needs (provisioning services) of farmers in the Upper West Region. Findings in this study revealed that a small proportion of respondents indicated high availability of fodder (1.0 %), cola nuts (0.5 %), and snails (0.5 %), which they attributed to low rainfall and harsh weather conditions as well as bush burning by smallholder farmers.

In addition, Boafo *et al.* (2016) opined that there were missing linkages between agroecosystem services and human well-being in the Upper West Regions because provisioning ecosystem services that formed significant part of livelihood assets were either lost or had become scarce. Even though, provisioning agroecosystem services provide a safety net function for majority of poor rural households and communities, the availability of these services was now a matter of concern to local authorities and farmers.

This survey observed that majority of the regulatory agroecosystem services were not available in the study environment for easy withdrawal by households to support their livelihood strategies. The findings showed that only a small proportion (7.2 %) of

respondents indicated high availability of pollination, whilst about 1.5 % indicated availability of wind break (i.e. presence of trees and forest cover). In Australia, Smith & Sullivan (2014) identified pollination as an important ecosystem service that supports crop production and yield. The high level of unavailability of regulatory services as found in this study had implications for the welfare of smallholders in terms of fruit and cereal production, housing security. and health.

Generally, the survey revealed relatively high availability of cultural services in the study area compared to provisioning, regulatory, and supporting services. Majority of the respondents indicated high availability of educational services, and spiritual and religious values, and aesthetics.

FGDs and key informant interviews revealed that during harsh weather conditions, households depended on domestic and wild fruits for food and income. Some of these fruits included mango (*Mangnifera indica*), “dawadawa” (*Parkia biglobosa*) and Shea (*Vitellaria paradoxa*) nut. The Shea nuts provide alternative livelihoods for households where most women engaged in processing of Sheabutter to generate income to support their households.

Discussants further indicated that farmers relied heavily on the fertility of the soil for their livelihood activities. They also depended on fuelwood for energy and income, freshwater from rivers, streams, and dugouts for dry season farming and livestock watering, cropland for crop production, and livestock grazing pasture, non-timber forest products (wooden trays, pestles, chewing sticks, mats), vegetation, and forest cover, fruits (shea and “dawadawa”) and fish.

However, farmers were worried about soil infertility, which they considered as one of the major challenges confronting them and had led to low crop yield and food shortage.

Boon & Ahenkan (2011) suggested that adequate policy measures ought to be instituted to effectively enhance ecosystem services management and climate change adaptation in Ghana due to the important roles these services play in the livelihoods of natural resource dependent communities. The significance of these findings is that majority of smallholder farmers recognized and depended on specific agroecosystem services at specific times of the year.

Utilization of agroecosystem services.

Material well-being refers to what people have and use to achieve their goals whereas subjective well-being dwells on people's own perceptions and feelings about a situation and quality of life based on values and beliefs that shape these perceptions (McGregor, 2006, 2008; White, 2010). On the other hand, relational well-being refers to what people do and how they interact with others to achieve their needs and quality of life. Material well-being in this perspective was perceived as access to agroecosystem services to support an individual's livelihood activities in the study area. Respondents were requested to indicate their state of well-being with regards to access to available agroecosystem services. The findings showed that majority (51.0 %) of the respondents perceived to be in the same state of well-being as other households.

The periods and seasons of the year when respondents depended on agroecosystem services were planting, rainy, dry seasons, and whole year. The survey data showed that during the dry season, respondents depended on bushmeat, honey, fruits, and freshwater and relied on freshwater, fish, bushmeat, fruits, fuelwood, soil fertility, leaves, and NTFP throughout the year. Analysis of the perceptions indicated that respondents relied on the provision of agroecosystem services in the selection of livelihood strategies throughout the year.

Observed changes in agroecosystem services.

According to Gbetibouo (2009), for smallholder farmers to effectively adapt to changes in the environment, they must first of all observe and identify these changes. Also, Sinare *et al.* (2016) assessed ecosystem services and benefits in Burkina Faso and concluded that the population in rural areas relied heavily on local ecosystem services for sustaining their well-being. These authors noted that farmers recognized the changes as well as the role of agroecosystem services in their livelihoods which presented a good foundation for mitigation measures to restore and preserve these services in the communities. The implication is that the perceptions of smallholder farmers on the changes in specific agroecosystem services gives the opportunity to ameliorate the adverse impacts and take advantage of the current situation and develop effective adaptation and coping strategies in semi-arid areas.

How long changes in agroecosystem services were noticed.

The findings from the survey revealed that majority of the respondents aged fifty (5) years and above observed changes in agroecosystem services within the last five years of the study period. Smallholder farmers have noticed these changes and are worried and so community leaders have initiated some actions to restore and preserve the agroecosystem services. Such action included tree planting, enforcement of bye-laws on bush burning, and avoidance of farming along river banks. With regards to seasons when particular agroecosystem services were relied on, majority of the respondents reported the whole year, because the farming season had reduced to about three months (from August to October).

Drivers of agroecosystem services change.

The analysis of the perception of smallholder farmers with respect to the specific agroecosystem services such as soil fertility, freshwater, cropland, fuelwood, fruits, fish, vegetation, mushroom and honey, showed that in order of frequency, low rainfall, tree cutting, bush burning, increased population, and extreme temperature were the major drivers of agroecosystem services change.

A few of the respondents claimed that government policy regarding bush burning, irrigation, agricultural extension services, river buffer zones, and tree cutting played a role in observed changes in agroecosystem services in the study area. In a study of perceptions of farmers in Australia, Smith & Sullivan (2014) reported that the drivers of ecosystem service change were agrochemical (fertilizer and pesticide) application, soil degradation, invasive weeds, urbanization and poor government action. These authors also observed that farmers perceived themselves to be vulnerable to the loss of ecosystem services and specifically most vulnerable to loss of soil health. Smith & Sullivan (2014) concluded that most of the threats to ecosystem services originated from agricultural practices. In northern Ghana, Boafo *et al.* (2014) also identified drought, climate variation, land conversion, overharvesting, and loss of traditional ecological knowledge as the main drivers of change in ecosystem services. They suggested that an examination of various ecosystem services and well-being at the local scale was needed for the development of effective adaptation and coping strategies for smallholder farmers.

Changing trends in agroecosystem services.

It was also observed that a relatively high percentage of respondents perceived slight increases in freshwater whilst about a quarter of respondents observed that cropland

had remained constant as compared with the other agroecosystem services in that category. Farmers further indicated that because the cropland has remained constant over the years, with corresponding increases in household sizes, farmlands were scarce. Smallholder farmers also demonstrated knowledge of the patterns of changes in key agroecosystem services, which forms an indication for effective adaptation (Gbetibouo, 2009).

Perceived impacts of changes in agroecosystem services.

According to Boon & Ahenkan, (2011), ecosystem services form the foundation of the livelihoods and well-being of smallholder farmers, especially those living in resources constraint areas such as semi-arid areas.

Participants and discussants in this study alluded to the fact that agroecosystem services underpinned their livelihoods but had undergone changes in terms of losses over the years.

Participants also mentioned fruits as one of the agroecosystem services that support them economically and as a source of food in times of low rainfall and droughts. For example, the Sheanuts and “dawadawa” are two economic fruits in the study area that underpin the livelihoods of households. However, they lamented losses to these agroecosystem service and cited factors such as frequent bushfires and tree cutting as the main causes.

In conclusion, this study has established empirically that the perceived agroecosystem services that underpinned the agricultural livelihoods of smallholder farmers were associated with sectors such as food production tied to soil fertility, water, energy tied to fuelwood, and shelter from non-timber forest products.

Farmers recognized that agroecosystem services had undergone changes over the years, especially, their farm soils had become infertile leading to low crop yield. The perceived soil infertility was attributed to bushfires and burning of crop residues that expose the soil to harsh weather conditions, indiscriminate felling of trees, continuous cropping and limited cropland for the increased population.

In the midst of these changes in agroecosystem services, participants and discussants noted that there were agroecosystem services that provide them with opportunities to improve their livelihoods with little assistance from government and non-government institutions. These agroecosystem services included water supply from the Black Volta River for irrigation farming during the prolong dry spells, fruits such as Sheanuts and “dawadawa” from the shea and “dawadawa” trees, different varieties of traditional seeds and crops, non-timber forest products from community forests, fish from the Black Volta River, and cropland for irrigation and dry season farming.

In terms of agroecosystem service change, majority of respondents (91.8 %) indicated they observed changes in these services in their communities. The study further found that a large proportion of respondents (41.8 %) indicated they perceived these changes in the last five (5) years of the study period whilst 30.4 % said more than ten (10) years.

The survey data showed that the causes of agroecosystem and agroecosystem change were low rainfall (drought), bush burning (bushfires), tree cutting (deforestation), floods and agricultural expansion (extension of farming to flood prone, river banks and forest areas). It is clear from the survey data that both climatic and non-climatic drivers are responsible to agroecosystem and agroecosystem services change in the study area. Furthermore, the drivers of change for specific agroecosystem services were identified. Respondents cited continuous cropping on the same parcel of land and bad agronomic

practices for change in soil fertility, tree cutting and bushfires for fuelwood, low rainfall and tree cutting for freshwater change, low rainfall and increased population for cropland change, bushfires and excessive hunting for change in bushmeat, low rainfall and strong winds for observed change in fruits, water pollution and low rainfall for change in fish, bushfires and tree cutting for vegetation change, low rainfall for change in mushroom and tree cutting as the sole driver for observed change in honey.

In terms of agroecosystem service change and the resultant effects on livelihood strategies, the study revealed that changes specific services such as soil water, soil fertility, cropland, fuelwood, forest cover, pollination, pasture and charcoal had adversely affected smallholder farmers. The findings on the trends in availability, utilization, and changes in agroecosystem services revealed that (i) farmers recognized about thirteen (13) agroecosystem services that underpinned their livelihood strategies and well-being, (ii) there were observed changes in specific agroecosystem services over the years, which have adversely affected livelihood strategies, (iii) there were important drivers of change (both climatic and non-climatic) in specific agroecosystem services in the study area.

For policy implications, these findings provide household-level data which can be relied on to formulate adaptation strategies that may be robust and effective at the local scale.

5.6 Level of Vulnerability of Smallholder Farmers

Exposures and Sensitivities of Respondents (Smallholder Farmers)

The results of the survey indicated that food shortage and low income were major challenges of respondents. The other challenges mentioned included low crop yield,

low soil fertility, and hunger. These findings were similar to what Nyantakyi-Frimpong & Bezner-Kerr (2015) found in a related study of the relative importance of climate change in the context of multiple stresses in the Upper West Region of Ghana. These authors concluded that low income and lack of access to credit were the major challenges of smallholder farmers. In this study, household respondents identified thirteen (13) major challenges or worries of smallholder farmers. These were both climatic and non-climatic stressors that contributed to the level of vulnerability and reduced adaptive capacity of smallholder farmers. Nyantakyi-Frimpong & Bezner-Kerr (2015) made similar observations in their study, where farmers claimed that they were used to the impacts of climate change and not worried about climate change. It is worth noting that about 15.5 % of respondents considered cholera as a major challenge, ahead of low rainfall (13.9 %), which is a climatic stress.

Causes of Major Challenges of Smallholder Farmers

According to the survey data, the major causes of the challenges of smallholder farmers were low rainfall, bushfires, tree cutting, soil infertility, low crop production, and increased population. The findings again revealed that vulnerability of smallholder farmers to climate change and variability was driven by both climatic (rainfall) and non-climatic (bushfires) stresses. It was also evident that most of the causes of the major challenges of respondents were cited as drivers of agroecosystem services change. In a study that analyzed vulnerability of smallholder farmers in the three regions of northern Ghana, Etwire *et al.* (2013) concluded that the Upper West Region was most vulnerable to climate change as a result of lack of food and water resources and recommended the need for measures to boost food production in the region. This study also found that the second major challenge of smallholder farmers was food shortage. Other water related challenges included cholera and water pollution.

Perceptions of Social Groups' Vulnerability to Agroecosystems Change

Perceptions of vulnerability of different social groups to changes in agroecosystem services was strongly dependent on the agroecosystem service concerned. For cropland, soil fertility, soil water, freshwater, forest cover, and food, both men and women were equally affected. For firewood and grazing, women tend to be more vulnerable. For charcoal, men were perceived to be most vulnerable.

Dealing with Vulnerability to Agroecosystem Service Change

This study identified groups that were responsible for tackling risks associated with changes in each of the agroecosystem services of respondents. The findings were that the individual smallholder farmer was responsible for dealing with changes that occurred in four (soil fertility, fuelwood, grazing land and charcoal production) out of the nine agroecosystem services investigated. The household dealt with changes in three agroecosystem services (freshwater, food supply and cropland), whilst the community was responsible for dealing with two, that is, changes in soil water and forest cover. The findings imply that for the changes in agroecosystem services, it was the individual and the household concerned that dealt with any risk associated with these changes with little or no support from the district or national levels.

Perceptions of the Level of Satisfaction with Life by Respondents

Vulnerability of smallholder farmers can be determined using the well-being concept, where vulnerability to changes in agroecosystem services and climate depends on the state of the three components of well-being as stated earlier. According to McGregor (2006), White (2010), and Gough & McGregor (2007), subjective well-being concerns people's own perceptions about how they feel about their conditions and quality of life

as a whole in the context of their values and beliefs. Majority of the respondents reported to be moderately satisfied with life as a whole (acceptance of the current impacts of climatic and agroecosystem services change) with only a few who were neither satisfied nor unsatisfied. The results further indicated that Gengenkpe had the lowest proportion of respondents who were very satisfied, satisfied or moderately satisfied with life as a whole. These findings imply that Gengenkpe was perceived to be most vulnerable among the study communities with regards to subjective well-being.

The LVI and LVI-IPCC for Households in the Study Communities

Findings from the overall livelihood vulnerability index (LVI) estimation suggested that Ketuo households were most vulnerable and sensitive to adaptive capacity due to challenges with food, health, and water, indicators, whilst Naapaal households were least vulnerable to impacts of agroecosystem services and climate. It was observed that Billengangn (0.616, 0.874) may be more exposed to climate change impacts and more sensitive to food, health, and water, whilst Gengenkpe (0.426, 0.547) may be less exposed and less sensitive. Based on socio-demographic, livelihood strategy, and social network, Ketuo (0.602) may be more vulnerable in terms of adaptive capacity, whilst Gengenkpe (0.306) may be less vulnerable. Furthermore, the overall LVI-IPCC scores indicated that Ketuo households (0.867) may be more vulnerable whereas households in Naapaal (0.061) may be less vulnerable to observed changes to agroecosystem services and climate in the study communities. Analyses of the sub-components and major components of the LVI suggested that Ketuo showed greater vulnerability on the socio-demographic profile index than the other study communities. The level of vulnerability of households in Ketuo may be attributed to the reported higher proportion (40.0%) of female-headed households and a smaller proportion (50.0 %) of household heads that attended school. A higher percentage (100.0 %) of household respondents in

Ketuo and Naapaal reported relying solely on agriculture for income and therefore showed greater vulnerability on the livelihood strategy major component. Based on social networks, Ketuo recorded the highest score (0.459), whilst Naapaal scored an index of (0.164). Households in Naapaal also reported a higher percentage (27.4 %) of respondents who received credit for their farming activities, which suggested why Naapaal was found to be least vulnerable in the LVI-IPCC analysis.

In a related study of vulnerability of smallholder farmers to climate change in the three region of northern Ghana using the livelihood vulnerability index, Etwire *et al.* (2013) found the Upper West Region as the most sensitive to climate events and attributed it to the region's lack of food and water resources.

5.7 Adaptation Strategies of Smallholder Farmers

Adaptation Strategies used by respondents included (i) Crop diversification and others, mainly soil related use of manure, application of fertilizers, crop residues; and trenching, ridging, or terracing; and (ii) Livelihood diversification strategies “pito” (local drink prepared from millet) brewing; shea butter processing; and soap making (iii) Migration. Those they did not include (i) growing drought-resistant varieties; (ii) improved seeds; and the attraction of pollinators.

The findings showed that a large proportion of respondents were unable to adapt most of the introduced adaptation strategies. These included growing drought resistant crops, improved seeds, crop diversification, and attraction of pollinators. The inability of farmers to adopt such strategies were attributed to lack of information and cost. For example, respondents reported use of traditional seeds inherited from ancestors and claimed that those seeds were better than new varieties or improved seeds introduced.

In a related study in northern Ghana, Etwire *et al.* (2013) identified inorganic fertilizer application, compost application, planting in rows, planting trees, establishing fire belt, and reducing farm size as actual adaptation strategies of farmers.

The findings in this study was that farmers rather increased farm sizes to overcome low crop yield and other impacts of agroecosystem services and climate change instead of reducing the farm size as reported by Etwire *et al.* (2013). Apata (2011) identified mixed farming, mulching, zero tillage, early or late planting, making ridges as actual adaptation strategies of smallholder farmers in Southern Nigeria. In Tanzania, Lyimo & Kangalawe (2010) identified smallholder adaptation strategies to include growing drought tolerant crops, early planting, rainwater harvesting, cultivation in wetlands and seasonal migration.

In a related study in northern Ghana, Etwire *et al.* (2013) identified key determinants of adaptation as access to agricultural extension services, noticing unpredictable temperature, and total farm size. What these imply is that factors that determine adaptation strategies differ from one location to another even among different groups of farmers.

5.8 Knowledge and Information Sources of Adaptation Strategies

The findings found that the main knowledge sources on adaptation for farmers were: radio, family members, traditional leaders, District Assembly, extension officers, and school teachers. The institutions that provided households with information on climate and management of agroecosystem services were chiefs and elders (traditional authorities), District Assembly, NADMO, NGOs, EPA, and Department of Agriculture (MOFA). Meanwhile the Department of Agriculture were in dying need of extension

officers. At the time of the survey, there were only three (3) extension staff manning nine (9) operational areas.

The general observation was that, these institutions lacked funding and the staff strength to provide adequate support to smallholder farmers regarding climate adaptation. In view of these issues, even though, key informants from agencies such as the EPA, the Department of Agriculture, and NADMO claimed they provide households with training and skills on agroecosystem services management and disaster prevention, many household respondents seemed unaware of these programmes. However, a few them reported having received training in the areas of bushfires prevention, soil enrichment practices, and best tillage practices. For smallholders to adapt effectively and boost crop production, both government and non-government institutions must increase efforts to provide them with the required information on appropriate adaptation strategies.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

2.4 Conclusion

Contribution of Soil and Water Quality to Agroecosystem Services and Livelihood Strategies of Smallholder Farmers

Soil and water samples were analyzed to ascertain the status of soil fertility and the quality of water resources in the study area. Soil and water are two key resources that contribute to agroecosystem services in semi-arid areas and their quality and health have implications for smallholder livelihoods strategies. The conclusion drawn for this objective was that the soil quality was generally suitable for crop production and in comparing it to other studies, the parameters analyzed in this study were in most samples marginal to adequate for plant growth. The study has also provided baseline data on physical and chemical properties of soil in the district for further soil quality studies that would provide guidance for fertilizer application management.

In terms of water quality, with the exception of total coliform (TC) and faecal coliform (FC), all other parameters measured were within the TWQRs guidelines of the Water Resources Commission. The counts of TC and FC in water from the Black Volta River was of much concern because most of the farmers drunk water from the river while they work on their farms. Farmers reported incidences of cholera which could be attributed to the water quality. The quality of water from boreholes in study communities was generally acceptable per the WHO drinking water Guidelines.

Generally, the chemical and physical properties of soil samples analyzed indicated marginal to adequate with regards to the guidelines ranges of the ICARDA (Estefan *et al.*, 2013) and may support growth of plants and contribute positively to the agricultural

livelihoods of farmers. Microbial levels in water samples from the Black Volta River exceeded the guidelines for domestic water use and may pose human health problems, and thus cannot be said to support the health needs of the local communities.

Perceptions of Smallholder Farmers on Rainfall and Temperature Trends and Variability in Study Communities

The gauge or observed data from the study area were analyzed and compared with the perceptions of respondents in the household survey and participants in FGDs and key informant interviews. The results revealed that perceptions of smallholder farmers regarding climate change were high and in most cases consistent with the gauge data except their perceptions on annual rainfall. The wrong perceptions with regards to the annual rainfall may be attributed to the different indicators of precipitation. Smallholder farmers recognized the key drivers of the changing climate trends as well as their adverse impacts on livelihoods strategies and human well-being. Most farmers cited human activities as major causes of climate change and related events in study communities even though some of them claimed climate change was punishment from God.

Perceptions of Smallholder Farmers on the Availability, Utilization and Changes in Agroecosystem Services

To effectively analyze vulnerability of farmers to changes in agroecosystem services and climate change, the study first identified key agroecosystem services that sustain and support agricultural livelihoods of smallholder farmers through an assessment of the perceptions of the farmers. It further analyzed the nature and extent of changes in these services as well as the drivers of observed change through household surveys and participants in FGDs and key informant interviews. The study found that there were

agroecosystem services within study communities that underpinned the agricultural livelihoods of smallholder farmers. Smallholder farmers identified key agroecosystem services such as bushmeat, freshwater, fruits, soil fertility and fuelwood. The study found that farmers perceived changes in agroecosystem services and identified the driver of these changes. They also perceived themselves to be vulnerable and unable to manage to these changes.

Vulnerability of Smallholder Farmers to Changes in Recent Agroecosystems and Climate Variability

The study examined the challenges, risks and shocks of respondents to understand how these exposures and sensitivities have contributed to vulnerabilities of smallholder farming households and communities. The challenges identified relate to sectors such as food, water, shelter, energy and finance. These included low income levels, food shortage, low crop yield, hunger, low soil fertility, cholera, low rainfall, cropland (farmland) shortage, fuelwood shortage, flood, water pollution, environmental degradation, and bushfires.

The data from these evaluations and analysis provided variables that were used to generate indicators for the livelihood vulnerability index (LVI) analysis. The vulnerability analysis showed Ketuo was most vulnerable while Naapaal was least vulnerable. The most vulnerable community (Ketuo) was also sensitive to adaptive capacity.

Perceptions of Smallholder Farmers on Adaptation Options and Knowledge Sources on Adaptation Available for Managing Changes in Agroecosystem and Climate

The study identified a number of adaptation strategies employed by smallholder farmers to cope and adapt to agroecosystem and climate change. Generally, most of these

adaptation strategies were soil fertility-related and include use of manure, application of fertilizers, non-burning of crop residue, trenching or ridging, terracing and crop diversification. Many farmers also used livelihood diversification strategies such as “pito” (local drink prepared from millet) brewing, sheabutter processing, soap making and migration. The study recognized that prominent adaptation options such as growing drought resistant varieties, improved seeds and attraction of pollinators were not used by most farmers. Respondents identified barriers to using such introduced adaptation options that include cost and lack of information.

Finally, the study identified three factors that determine adaptation strategies of smallholder farmers in semi-arid Ghana as access to climate information, how satisfied a farmer is with life in relation to current climatic and ecosystem change and availability of ecosystem services in the study area.

2.5 Recommendations

Following the presentation and discussion of results and conclusions drawn from the study, a number of recommendations can be made:

First, detailed research should be conducted to determine the quality of soil nutrients within the district using the data and findings of this study as a baseline. This is important so as to provide guidelines for fertilizer applications and soil management practices of smallholder farmers. The study observed that farmers perceived loss of soil fertility and therefore resorted to indiscriminate and inappropriate use and application of fertilizers and other agrochemicals. However, there is limited data on soil and water quality from the Nandom district.

Second, since livelihoods and well-being of smallholder farmers were strongly tied to critical agroecosystem services in semi-arid areas, academia should conduct economic evaluation of the key agroecosystem services to identify the actual contribution of agroecosystems to ecosystem services. This will provide data for policy and decision making with respect to management of these services and improvement of livelihoods of smallholder farmers.

Third, the existing ecosystem-based management framework policy guidelines as outlined in the Ghana climate change policy should be incorporated into the District Assembly's environmental management plans and actions for implementation by the EPA.

Fourth, government as an employer, should engage more agricultural extension officers to provide agricultural extension services to farmers. This is key because according to the officials of Department of Agriculture, the office had only three (3) agricultural extension officers, who manage nine (9) operational areas.

Fifth, there were currently many non-governmental organizations (NGOs) in the district rendering several farm and community based adaptation services to smallholder farmers, whose activities were fragmented. The district assembly should liaise with them to identify their plans and activities in the various communities. The study recognized that there were duplications with regard to training and services the NGOs provide to communities and in some cases the same communities were supported by more than one NGOs whilst other communities never received any assistance.

Also, the Department of Agriculture and the District Assembly should assist farmers obtain improved seeds and early maturing varieties. Farmers should be encouraged to form groups to enable them access credit for their farming activities.

The District Assembly should take steps to provide irrigation services (small dams and water pumping machines) for smallholder farmers to carry out dry season farming with the existing potential from the Black Volta River. This will generate income, reduce poverty, and hunger all year round.

Further research should be conducted on the economic valuation of agroecosystem services to determine their actual contribution to the livelihood strategies of local communities in semi-arid Ghana.

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APPENDICES

Appendix 1: Graphical Representation of Trends & Projections of Temperature & Rainfall for Ghana Until 2080

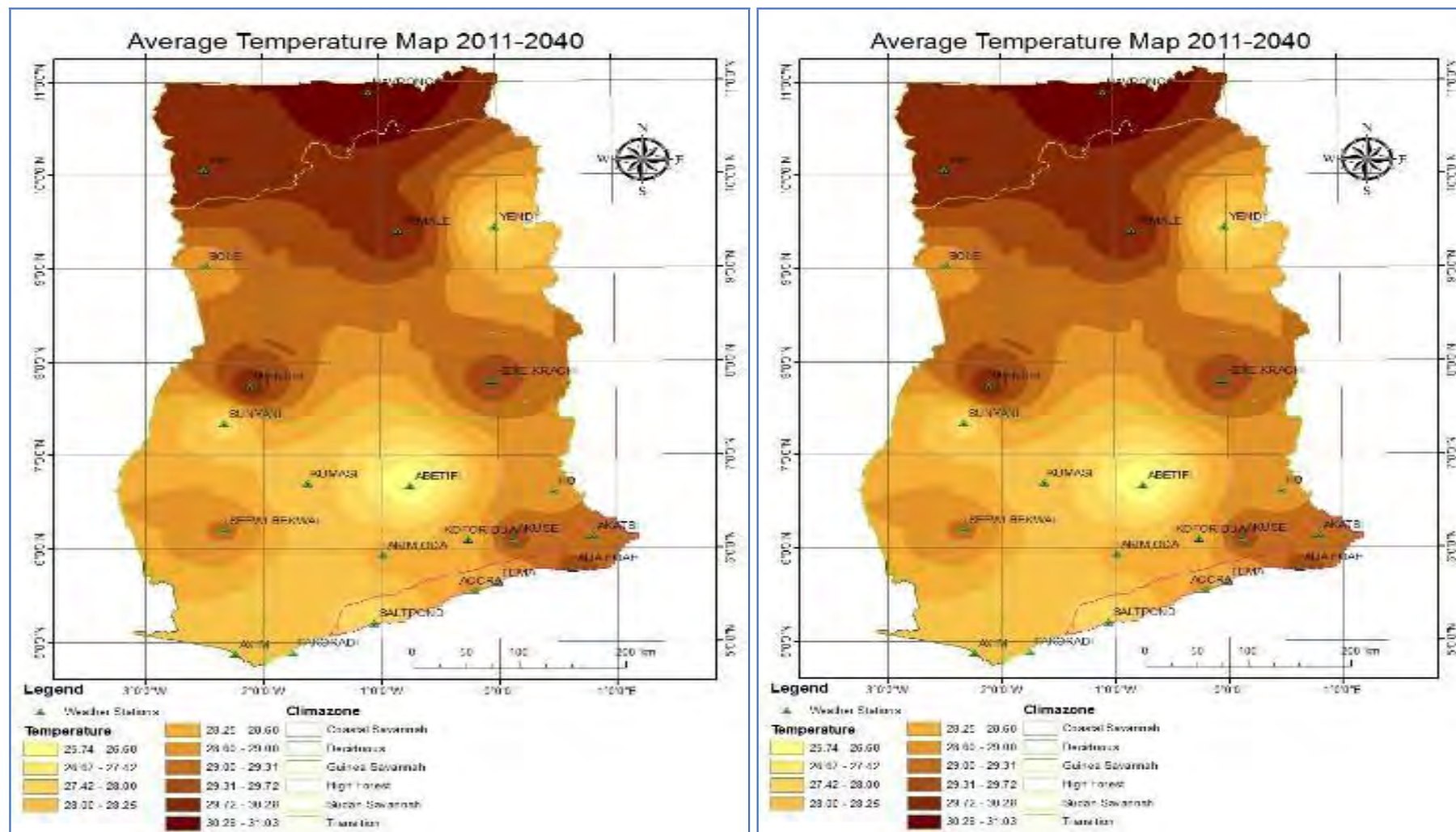


Figure 1: Maps of projected mean temperatures 1980-2010 (left) 2011-2040 (right)

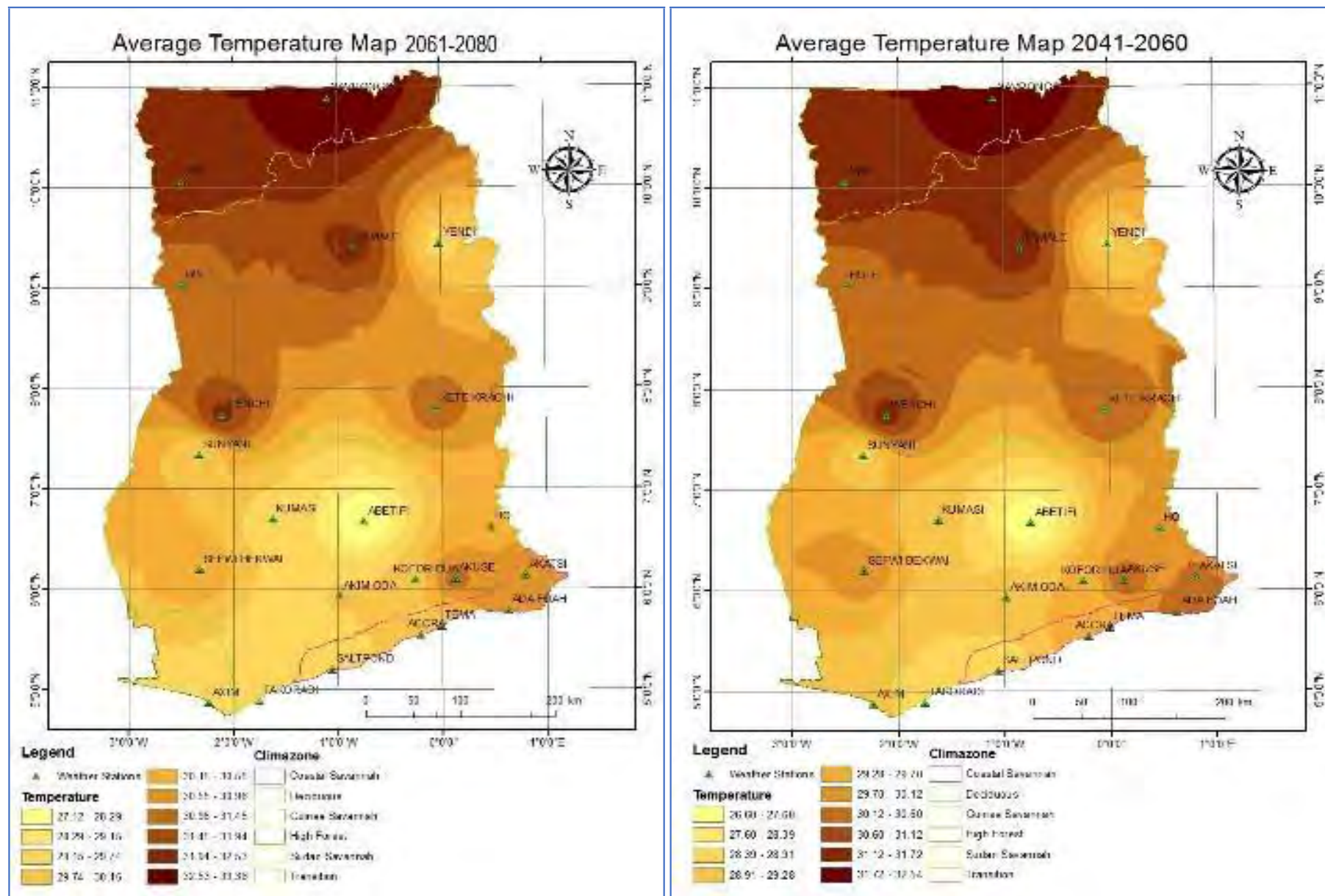


Figure 2: Maps of projected mean temperatures 2041-2060 (left) and 2061-2080 (right).

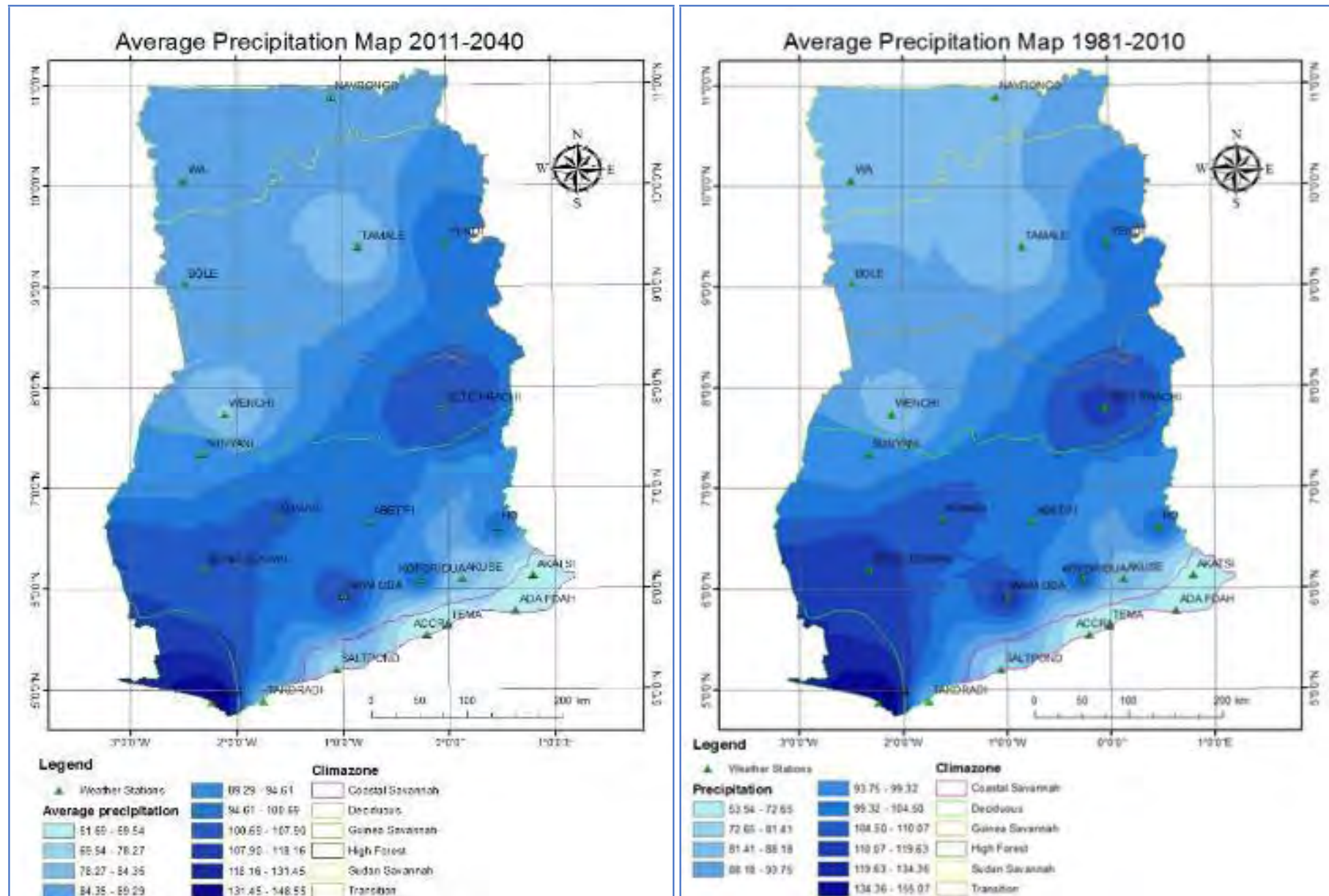


Figure 3: Maps of projected mean rainfall 1980-2010 (left) and 2011-2040 (right)

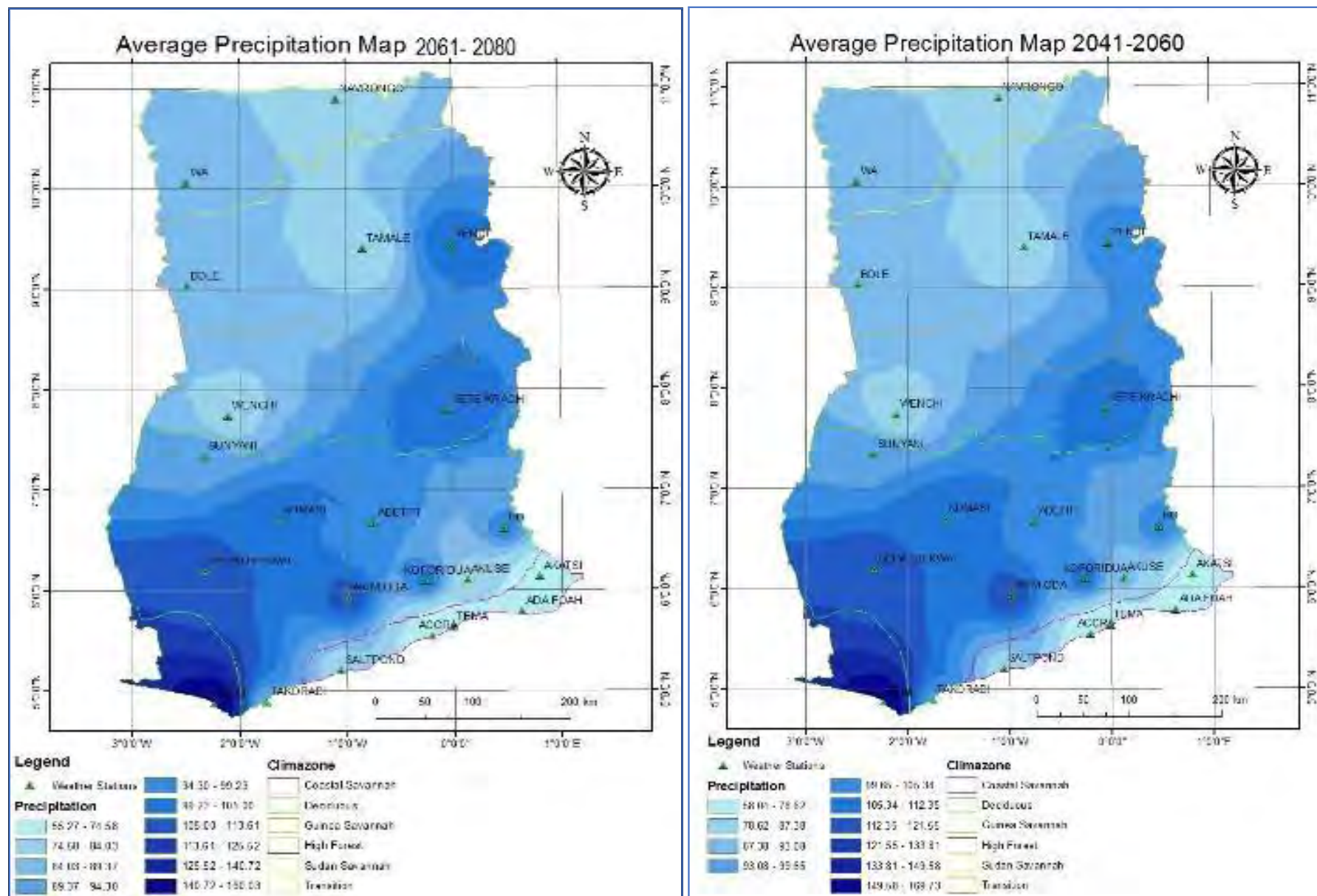


Figure 4: Maps of projected mean rainfall 2041-2060 (left) and 2061-2080 (right). (Source: Ghana's 3rd National Communication to UNFCCC, 2015)

Appendix 2: Ethical Consent Letter

UNIVERSITY OF GHANA



COLLEGE OF BASIC AND APPLIED SCIENCES

Ethics Committee for Basic and Applied Sciences (ECBAS)

Official Use only
 Protocol number
 ECBAS 028/15-16

PROTOCOL CONSENT FORM

Section A- BACKGROUND INFORMATION

Title of Study:	Vulnerability and Adaptation of Smallholder Farmers to Changes in Agroecosystems and Climate in Semi-Arid Regions: The Case of Nandom District of Ghana
Student Investigator:	ISHMAEL LENTE
Certified Protocol Number	ECBAS 028/15-16

Section B– CONSENT TO PARTICIPATE IN RESEARCH

The purpose of this study is to examine and understand the scope and nature of vulnerabilities and adaptation options of smallholder farmers to agroecosystem services and climate change in semi-arid areas of the Nandom District of the Upper West Region, Ghana.

Please, we would really appreciate it if you could spare about one hour (1hr) of your time for this interview. You are randomly and purposefully selected to kindly participate in this survey. Participation is completely voluntary and one has the right NOT to participate in this survey at all or stop participation at any point in time during the survey.

The answers you give will add to a larger study working toward ensuring better policies and programs for helping farmers as they face a variety of problems. No risk associated with this survey is anticipated and there will be no monetary or any material benefits accompanying this survey.

All reports made out of this survey would not mention any names and all analysis would be in general terms. No names would accompany photos unless you give specific permission and you can refuse having your photo taken at any time. Reports from this survey would be made available to the research community and policy makers.

If you have any questions about the research and whom to contact in case of research-related injury and any issues on your rights as a participant you can contact the address below:

Ishmael Lente

Institute for Environment and Sanitation Studies (IESS)

College of Basic and Applied Sciences

University of Ghana. Legon

ishmaelente@yahoo.com or inlente@st.ug.edu.gh

0244105770

Section C- VOLUNTEER AGREEMENT

"I have read or have had someone read all of the above, asked questions, received answers regarding participation in this study, and am willing to give consent for me, my child/ward to participate in this study. I will not have waived any of my rights by signing this consent form. Upon signing this consent form, I will receive a copy for my personal records."

.....

.....

Name of Volunteer

Signature or mark of volunteer

Date.....

If volunteers cannot read the form themselves, a witness must sign here:

I was present while the benefits, risks and procedures were read to the volunteer. All questions were answered and the volunteer has agreed to take part in the research.

.....

.....

Name of witness

Signature of witness

Date.....

I certify that the nature and purpose, the potential benefits, and possible risks associated with participating in this research have been explained to the above individual.

.....

.....

Name of Person who obtained Consent

Signature of Person who obtained Consent

Date.....

Appendix 3: Focus Group Discussion Guide

**UNIVERSITY OF GHANA, LEGON
COLLEGE OF BASIC AND APPLIED SCIENCES
ENVIRONMENTAL SCIENCE PROGRAMME**

Community identification

Questionnaire ID:		Date:	
District		Community:	
GPS coordinates	X	Y	Altitude
Facilitator 1			
Facilitator 2			

Demographic characteristics

Categories	Total	Males	Females	occupation
Focus group composition				
Other social groups:				

**SECTION A
Farm Characteristics of Respondents**

- Q1** What is the mode of farmland acquisition in this community?
- Q2** What crops do you plant, in order of importance? *Utilization of production: [1] use all at home [2] use more at home than sell [3] Use at home and sell equally [4] sell more than use at home [5] sell all*

Crops in order of importance	What do you use this crop for (using the typology above)

- Q3** How and where do you access credit (money) and farm inputs for your farming activities and what is the average amount received? If not, why?
- Q4** What is your average total income for the farming season?

SECTION B

Trends and Variability of Rainfall and Temperature in Study Communities

- Q5 What changes have you observed in the **rainfall pattern** in your community in the past 10 years or more?
- Q6 What changes have you observed in **Temperature** in your community in the past 10 years or more?
- Q7 How was your farming activities (agricultural livelihoods) affected, and which extreme weather events caused these?

SECTION C

Perceived Trends in Availability, Utilization and Changes in Agroecosystem Services in Study Communities

- Q8 What agroecosystems and ecosystem services (**Natural benefits that flow from your environment**) support your farming activities (agricultural livelihoods) and well-being?
- Q9 How have these services been changing in this area?
- Q10 What are the drivers of these changes in this area?
- Q11 Which of these services are you losing or have lost?

SECTION D

Challenges and Perceived Vulnerability of Smallholder Farmers

- Q12 What major challenges, shocks or risks do you face in your community recently?
- Q13 What is the cause (s) of each challenge/ risk/shock facing your household/community?
- Q14 How do you deal with this challenge/shock/risk?
- Q15 How have these challenges affected livelihoods of your household/community and what aspects of life is/are most affected?
- Q16 Who is most vulnerable due to the observed changes in agroecosystem services (**natural benefits**) and climate/weather extreme events in your household/community?
- Q17 Who is responsible for dealing with these challenges of the household/community?

SECTION E

Adaptation Strategies and Knowledge Sources of Smallholder Farming Households

- Q18 What strategies/measures do you use/adopt to overcome the changes that occur in your environment that affect your farming activities and well-being?
- Q19 What adaptive measures are available to your households for improving upon farm practices in the community and which ones do you use?
- Q20 What adaptive measures are you NOT able to use/adopt and why?
- Q21 Where does your household get information from to make decisions about preparing for and responding to drought (low rainfall), flood (intense rainfall) and high temperature?
- Q22 What institutions/organizations help you in your agricultural livelihood activities?

THANK YOU

Appendix 4: Key Informant Interview Guide

Section A Background characteristics

1. Name of Officer/respondent.....
2. Unit/Department.....3. Designation/Rank.....
4. Educational background5. Gender.....
- 6 No. of years at post.....

Section B Agroecosystems and Ecosystem Services Supply and Change

- Q1** What natural services (agroecosystem services) are you able to draw from your environment to support your farming activities?
- Q2** How is supply and utilization of these services changing over time?
- Q3** What are the key drivers (causes) of change in the environment and agroecosystems and ecosystem services in this district/area?
- Q4** What key natural services (Agroecosystem services) have been degraded and are at risk in your district?
- Q5** What management measures, plans and policies are in place to deal with degradation of agroecosystem services (e.g. soil and water resources) in this district?

Section D Rainfall and Temperature Patterns and Smallholder Livelihood Strategies

- Q6** What changes have you observed in the **rainfall pattern** in your district in the past 10 years or more years?
- Q7** What changes have you observed in **temperature** in your district in the past 10 years or more years?
- Q8** What specific livelihood activities and strategies have been adversely affected and which extreme weather events caused these?

Section E Exposures and Sensitivities of Smallholder Households due to Agroecosystems and Climate Change

- Q9** What major challenges, shocks and risks confront smallholder-farming households as a result of climate/weather extreme events and changes or loss of the agroecosystem services (natural benefits) in your environment in this district?
- Q10** What is the cause (s) of each challenge/ risk/shock?
- Q11** How have these challenges affected livelihood/well-being of households and what aspects of life is/are most affected?
- Q12** Who suffer the most to climate/weather extreme events and loss of the ecosystem services (natural benefits)?

Section F Adaptation Options and Strategies for Smallholder Farmers

- Q13** What measures are used to manage changes in the natural services (agroecosystem services) and climate in this district?
- Q14** What are the knowledge and information sources of smallholder households for managing these changes?
- Q15** What adaptive measures/strategies have your outfit put in place to manage **challenges of crop production** by smallholder farmers in this district?
- Q16** What are the challenges your outfit faces in the management of changes or loss of natural services (agroecosystem services) and climatic risks?

Thank You

Utilization of production: [1] use all at home [2] use more at home than sell [3] Use at home and sell equally [4] sell more than use at home [5] sell all

Q15 Are you able to access credit for your farming activities? 1). Yes [] 2). No []

Q16 If yes, what is the source and how much? Source: 1). Bank [] 2). Moneylender [] 3). Others (specify)..... Amount in GHs 1). Less than 100 2). 100-300 3).400-600 4). 700-900 5). 1000 and above

Q17 If no, why?

SECTION C

Characteristics of Rainfall and Temperature Variables

Q18 Please, indicate how you observe the following events in your community over time (Use 1 to 5)

Climate Change and Variability (climate trend)	1. Strongly agree, 2. Agree, 3. Uncertain 4. Disagree, 5. Strongly disagree				
	1	2	3	4	5
Observed increase in total rainfall events in the past 10 or more years					
Observed decreased in total rainfall events in the past 10 or more years					
Observed a change in start of planting season					
Rains start early recently					
Rains starts late recently					
Rains end early recently					
Rains end late recently					
Rainy season has become shorter recently					
Rainy season has become longer recently					
Dry spells are more frequent in the past 10 or more years					
Observed severe droughts in the past 10 or more years					
Temperature has increased in the past 10 or more years					
Temperature has decreased in the past 10 or more years					
Observed severe floods over the past 10 or more years					
Observed stronger winds over the past 10 or more years					
Drought situations have affected the livelihoods of your household					
Flood situations have affected the livelihoods of your household					

SECTION D

The Availability and Changes in key Agroecosystem Services that Support Agricultural Livelihoods of Smallholders

Q19 Please, indicate by ranking the items in the following list, as you are able to draw these natural benefits or ecosystem services from your local environment.

1= very high, 2= high, 3=Medium, 4= Low and 5=very low

Ecosystem Services	Rank	Ecosystem Services	Rank	Ecosystem Services	Rank	Ecosystem Services	Rank
Bush meat		Barks		Pest/disease control (weeds/insects)		Educational (schools)	
Fresh water		Leaves		Pollination (insects/bees)		Sense of place (
Fish		Animal products (goats/sheep/fowls/horns)		Flood control (wetlands)		Cultural heritage (belief systems)	
Fruits		Hides (animal skins)		Wind breaks (forest cover/trees))		Soil fertility	
Honey		Seed		Rain attraction (forest)		Soil Nutrient	
Mushrooms		Roots		Spiritual & religious values (pacification of gods/churches/mosques)		Primary production	
Snails		Air quality (dust)		Recreation & ecotourism		Non timber forest products (Wooden trays, Grinders, Mortars, Pestles, Chewing sticks, Mat)	
Spices		Local climate (heat/cold)		Royal burial grounds (cemetery)		Fuel Wood	
Cola nuts		Erosion control (vegetation cover)		Habitats for gods		Timber	
Fodder		Water purification (water quality)		Aesthetic			

Q20 Which agroecosystem services support your livelihood in your community?

Agroecosystem Services (Natural Benefits) (in order of importance)	Q21 What time or period do you depend upon this agroecosystem service?

Q22 Have you observed any changes in these agroecosystem services (natural benefits) indicated above in the past recent years? 1). Yes [] 2). No []

Q23 If yes, how long have you noticed these changes? 1). 5 years [] 2). 10 years [] 3). More than 10 years []

Q24 What do you think is most responsible for the changes in each of the agroecosystem services that support your livelihood in this community?

Agroecosystem Services (Natural Benefits or services) (in order of importance)	Drivers of change in this agroecosystem service

Q25 Please, indicate how each of the agroecosystem service (natural benefit) you mentioned above has changed in your community in the past 10 years (Use 1 to 5)

Agroecosystem services (Natural benefits)	1. <i>Increased sharply</i> 2. <i>Increased slightly</i> , 3. <i>Remained constant</i> 4. <i>Decreased slightly</i> , 5. <i>Decreased sharply</i>				
	1	2	3	4	5

Q26 How would you say your social group’s access to agroecosystem services compares to that of other groups? a) Less access [] b) The same [] c) More access []

SECTION E

Vulnerability of Smallholder Farmers due to Agroecosystem Services Change and Climate

Q27 What major challenges, shocks and risks do you face because of the changes in agroecosystem services (natural benefits) and climate in your household or community?

Major challenges/risks/shocks in order of importance	Q28 What is the cause (s) of this challenge/ risk/shock?	Q29 How do you deal with this challenge/shock/risk

Q30 Please, indicate the extent to which change in the following agroecosystem services (natural benefits) and climate variables affect your farming activities and well-being.

Rank using 1= *very high*, 2= *high*, 3= *medium*, 4= *low* and 5=*very low*

Agroecosystem Services/Climate Variables	Rank
Soil water	
Soil fertility	
Cropland	
Fuel wood collection	
Charcoal production	
Livestock grazing/pasture	
Forest cover	
Pollination	
Rainfall	
Temperature	
Credit	

Q31 Who suffer the most to change in agroecosystem services (natural benefits) and climate indicated in sections C and D above in your household?

For Q31, use {1}. Men [2]. Women [3]. Men & Women [4]. Elderly [5]. Youth/Young [6]. Children [7]. Persons with Disability (PWD) [8]. Others (specify)}

Agroecosystem Services/Climate	Who suffer most from change in this agroecosystem service? (use the typology above)	Q32 Who is responsible for dealing with this change or loss? (use the typology below)

For Q32, use [1]. Individual [2]. Household [3]. Social group [4]. Community [5]. District [6]. Regional [7]. National [8] NGOs (specify) [9]. Others (specify)

Q33 Does your household have access to key agroecosystem services (natural benefits) you need to make changes to your agricultural livelihood when there are difficulties—specifically during drought (low rainfall), flood (high rainfall) and extreme high temperatures? 1) Sometimes [] 2) Never [] 3) Always []

Q34 Comparing your household to other households in this area/community, would you say that your household's access to key agroecosystem services (natural benefits) is: a). Much better off [] b). Better off [] c) The same [] d) Worse off [] e) much worse off []

Q35 How satisfied are you with your life as a whole these days in relation to the challenges discussed so far? a) very unsatisfied [] b) moderately unsatisfied [] c) neither satisfied nor unsatisfied [] d) moderately satisfied [] e) very satisfied []

SECTION F

Adaptation Options and Knowledge Sources of Smallholder Farmers for Managing Agroecosystem Services Change and Climate

Q36 Please indicate whether your household has adopted any of the strategies/farm practices listed below (Use 1 to 3 for Q36 and Q37 and 1 to 5 for Q38)

Adaptive measures/coping strategies	Have adopted this strategy?	Q37 Compared to other households	Q38 If no, why not?
	1. Yes 2. No 3. Uncertain	1. Less access 2. The same 3. More access	1. Cost 2. Not known 3. Not sufficient information 4. Uncertain outcome 5. Not enough
1. Growing drought resistant crops			
2. Diversifying crops and livestock-growing new varieties of crops and breeds of livestock			
3. Mulching (covering the soil to keep in moisture)			
4. Using seeds that grow better in dry weather conditions/using improved seeds			
5. Attracting pollinators using baits			
6. Using organic manure			
7. Using fertilizer			

Q39 What strategies do you use to overcome the changes that occur in your environment that affect your livelihood and well-being?

.....

Q40 Where does your household get information from to make decisions about preparing for and responding to drought (low rainfall), flood (intense rainfall) and high temperature?

Sources of climate related knowledge	Do you use this source of information? (1. Yes 2. No)	Q41 This source of information is trustworthy (use scale 1-5 below table)	Q42 Do you feel that this source of information is sufficient? (1. Yes 2. No)
1. Meteorological services			
2. Indigenous forecast information			
3. Newspaper			
4. Radio			
5. TV			
6. NGOs			

Sources of climate related knowledge	Do you use this source of information? (1. Yes 2. No)	Q41 This source of information is trustworthy (use scale 1-5 below table)	Q42 Do you feel that this source of information is sufficient? (1. Yes 2. No)
7. Government Authorities (district office)			
8. Extension officers			
9. Internet			
10. School/teachers			
11. Visiting climate experts (universities)			
12. From family and friends			
13. Village leaders (traditional authorities)			
14. Government publications			
15. Others (specify)			

For Q41, (Scale of 1 to 5): 1. Strongly agree; 2. Agree; 3. Uncertain; 4. Disagree; 5. Strongly disagree)

Q43 Which institutions/organizations help you in your livelihood activities?

Formal institutions in order of importance	Specific Help/Role of institution	Informal institutions in order of importance	Specific Help/Role of institution

Q44 Who is responsible for managing the key agroecosystem services (natural benefits) in your community?
 1).....2)3)

Q45 Do you have access to information on the use and management of the agroecosystem services (natural benefits) in your community? 1). Yes [] 2). No []

Q46 If yes, who provides this information?

Q47 Do you receive training from any institution or organization on the use and management of the agroecosystem services (natural benefits) in your community? 1). Yes [] 2). No []

Q48 If so, what kind of training?

Q49 Who provides the training?

THANK YOU

Appendix 6: Pictures on Field Work-2016/2017





Courtesy: Ishmael Lente (2016/2017)

Appendix 7: LVI Indices & Indicators

Table 1: Indexed sub-components, major component for natural disasters and Climate change and overall LVI for the Four Communities

Sub-component	Billengangn	Gengenkpe	Naapaal	Ketuo	Major Components	Billengangn	Gengenkpe	Naapaal	Ketuo
Percentage of female headed household	0.450	0.396	0.468	0.708	Socio-demographic profile	0.477	0.4157	0.446	0.528
Percentage of households where the head has not attended school	0.567	0.604	0.484	0.5					
Percentage of average person living in a household	0.440	0.277	0.365	0.52					
Average age of female headed household	0.450	0.386	0.467	0.382					
Percentage of Major occupation of household being agriculture	0.950	0.938	0.9	0.9	Livelihood strategies	0.495	0.501	0.895	0.895
Average agricultural livelihood diversification index	0.040	0.063	0.89	0.89					
Percentage of household that have access to credit	0.100	0	0.247	0.792	Social networks	0.067	0	0.164	0.459
Percentage of household that got assistance from banks	0.033	0	0.081	0.125					
Percentage of household that depends on farming as main source of food	0.833	0.649	0.855	0.75	Food	0.820	0.631	0.407	0.872
Average crop diversity index	0.550	0.275	0.353	0.87					
Percentage of household that do not save crops	0.967	0.667	0.371	0.917					
Percentage of household that do not save seeds	0.933	0.932	0.048	0.95	Water	0.937	0.865	0.887	0.972
Percentage of household that have notice water variability	0.950	0.750	0.887	0.958					
Percentage of household that depends solely on natural water source	0.923	0.980	0.887	0.985					

Percentage of household that use bark of tress for medicinal purpose	0.850	0.125	0.806	0.875	Health	0.917	0.146	0.895	0.75
Percentage of household that uses leaves for medicinal purpose	0.983	0.167	0.984	0.625					
Percentage of household that do not receive flood control service	0.900	0.271	0.71	0.708	natural disaster and climate variability	0.616	0.424	0.582	0.602
Percentage of household that do not receive wind breaks warning	0.750	0.375	0.774	0.875					
Mean standard deviation of monthly average minimum temperature (1983-2014)	0.21998	0.2253	0.22319	0.22415					
Mean standard deviation of monthly average maximum temperature (1983-2014)	0.34809	0.35069	0.34977	0.35024					
Mean standard deviation of monthly average precipitation(1983-2014)	0.864	0.899	0.856	0.851					
Overall livelihood vulnerability index						0.624	0.426	0.611	0.703

Table 2: LVI-IPCC Contribution Calculation for the Four Communities

Contributing Factors	Major Components	Major Component Values				Number of Sub Component	Contributing Factors			
		Billengangn	Gengenkpe	Naapaal	Ketuo		Billengangn	Gengenkpe	Naapaal	Ketuo
Adaptive Capacity	socio-demographic profile	0.477	0.4157	0.446	0.528	4	0.379	0.306	0.488	0.602
	livelihood strategies	0.495	0.501	0.895	0.895	2				
	social networks	0.067	0	0.164	0.459	2				
Sensitivity	health	0.917	0.146	0.895	0.75	2	0.874	0.547	0.649	0.867
	food	0.820	0.631	0.407	0.872	4				
	water	0.937	0.865	0.887	0.972	2				
Exposure	natural disasters and climate variability	0.616	0.424	0.582	0.602	5	0.616	0.424	0.582	0.602
LVI-IPCC Value							0.204	0.065	0.061	0.867

Appendix 8: Soil and Water Quality Results

Table 1: Mean Concentrations of pH and Physical Parameters in Soil Sample

Community/ Soil Sample	pH	Conductivity ($\mu\text{S/cm}$)	TDS (mg/L)	TSS (mg/L)	Salinity (‰)
Billengangn					
Farm 1	7.6	103.1	55	218	0.0
Farm 2	8.0	21.4	12	350	0.0
Gengenkepe					
Farm 1	5.6	12.3	7	304	0.0
Farm 2	6.1	22.7	13	509	0.0
Napaal					
Farm 1	5.9	51.4	29	360	0.0
Farm 2	6.8	27.1	15	244	0.0
Ketuo					
Farm 1	5.8	31.2	17	361	0.0
Farm 2	6.4	104.0	6	307	0.0

Source: Field work, 2016

Table 2: Textural Classes of Soil Samples

Community/ Soil Sample	% Sand	% Silt	% Clay	Textural Class	Bulk Density (g/cm³)	% Porosity
Billengangn						
Farm 1	81	14	5	Loamy-Sand	1.16	56.3
Farm 2	78	15	7	Loamy-Sand	1.11	53.5
Gengenkpe						
Farm 1	75	16	9	Sandy-Loam	1.14	57
Farm 2	73	14	8	Sandy-Loam	1.12	54
Napaal						
Farm 1	84	3	13	Loamy-Sand	1.28	51.7
Farm 2	87	5	11	Loamy-Sand	1.23	49.5
Ketuo						
Farm 1	73	10	17	Sandy-Loam	1.00	51
Farm 2	69	13	15	Sandy-Loam	1.11	53

Source: Field work, 2016

Table 3: Mean Concentrations of Trace Metals in Soil Sample

Community/ Soil	Cr (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	Cd (mg/kg)	Co (mg/kg)	As (mg/kg)
Billengangn										
Farm 1	0.32	219.0	56.16	2.88	5.96	0.56	2.86	BDL	0.34	2.48
Farm 2	0.20	217.5	42.14	2.66	2.26	0.60	1.98	BDL	BDL	2.52
Gengenkpe										
Farm 1	BDL	211.3	31.96	1.50	0.58	BDL	2.60	BDL	BDL	0.30
Farm 2	BDL	207.0	14.96	1.44	1.02	BDL	3.28	BDL	BDL	0.36
Napaal										
Farm 1	0.36	213.7	18.00	1.96	1.68	0.48	3.30	BDL	BDL	2.6
Farm 2	0.44	219.6	66.96	2.38	1.06	BDL	4.76	BDL	BDL	0.32
Ketuo										
Farm 1	0.96	216.9	58.64	2.42	0.86	0.64	2.88	BDL	BDL	2.72
Farm 2	BDL	213.4	22.34	1.34	0.60	0.64	0.84	BDL	BDL	2.72
RML (mg/kg)	100*	50000**	2000**	60*	200*	100*	50*	1.5*	50*	-

RML=Recommended Maximum Limited for Agricultural Soils (Source: *Ewers, 1991), **FAO/WHO, 2001

Table 4: Mean Concentrations of Physico–Chemical Parameters of Water Resources in Study Area

Community/ Water Source	pH	TDS (mg/L)	TSS (mg/L)	Conductivity (μS/cm)	Salinity (‰)	Turbidity. (NTU)	Colour. (TCU)	Alkalinity. (mg/L)	BOD (mg/L)
Billengangn									
River	7.8	50.0	6.7	53.3	0.0	8.0	8	53.3	2.57
Borehole 1	8.2	65.2	0.0	123.1	0.1	0.0	9	116.0	1.63
Borehole 2	8.2	56.8	35.0	116.7	0.0	49.0	9	100.0	1.14
Borehole 3	8.3	76.9	49.0	157.0	0.1	0.0	10	144.0	2.64
Dug-out well	7.2	22.4	9.0	43.0	0.0	14	3	14.0	2.44
Gengenkpe									
River	7.3	18.3	59.3	35.6	0.0	76.7	3	42.7	3.12
Borehole 1	7.5	48.6	0.0	99.1	0.0	0.0	5	52.0	2.44
Borehole 2	7.9	47.9	0.0	94.1	0.0	0.0	5	80.0	2.03
Borehole 3	7.9	52.6	0.0	107.5	0.0	1.0	7	100.0	2.64
Napaal									
River	7.4	28.6	73.3	33.8	0.0	100.2	2	37.3	2.37
Borehole 1	8.5	16.8	0.0	186.1	0.1	2.0	8	184.0	1.83
Borehole 2	8.6	89.9	0.0	212.0	0.1	0.0	8	222.0	1.22
Borehole 3	8.4	103.7	0.0	203.0	0.1	0.0	9	188.0	2.24

Community/ Water Source	pH	TDS (mg/L)	TSS (mg/L)	Conductivity (μS/cm)	Salinity (‰)	Turbidity. (NTU)	Colour. (TCU)	Alkalinity. (mg/L)	BOD (mg/L)
Ketuo									
River	7.5	72.0	48.0	91.9	0.1	68.3	7	40.7	4.20
Borehole 1	8.9	209.7	0.0	427.0	0.2	0.0	12	430.0	2.64
Borehole 2	8.3	54.7	0.0	110.0	0.0	0.0	10	78.0	2.24
Borehole 3	8.3	97.2	7.0	200.0	0.1	4.0	11	202.0	1.22

WHO (2011) Guidelines for Drinking water: pH=6.5-8.5, TDS=1000, Turbidity=5, Colour=15, TWQRs: pH=6.9, EC=0-70, TDS=0-450, Turbidity=0-1

Table 5: Mean Concentrations of Trace Metals in Borehole Water

Community/ Water Source	Fe (mg/L)	Mn (mg/L)	Pb (mg/L)	Ni (mg/L)	As (mg/L)
Billengangn					
Borehole 1	BDL	BDL	BDL	0.0011	BDL
Borehole 2	0.315	0.005	BDL	0.0095	BDL
Borehole 3	BDL	0.003	BDL	BDL	BDL
Dug-out well	0.0235	0.004	BDL	BDL	BDL
Gengenkpe					
Borehole 1	BDL	0.008	BDL	0.025	0.002
Borehole 2	BDL	0.0035	BDL	BDL	0.002
Borehole 3	BDL	BDL	0.016	0.006	0.0015
Napaal					
Borehole 1	BDL	0.003	0.008	BDL	0.015
Borehole 2	BDL	BDL	0.008	BDL	0.015
Borehole 3	BDL	BDL	0.0135	0.003	0.003
Ketuo					
Borehole 1	BDL	BDL	BDL	0.0185	BDL
Borehole 2	BDL	0.003	BDL	BDL	BDL
Borehole 3	0.0125	BDL	BDL	0.008	BDL
TWQRs (mg/L)	0-0.1	0-0.05	0-10	-	0-10

WHO (2011) Guidelines for Drinking water: Cu=2.0, Zn=4.0, Fe= 3.0, Mn=0.4, Pb=0.010, Cr=0.05, Ni=0.070, AS=0.010, Cd=0.003, Meanwhile, Cr, Cd, Co, Cu and zinc were below detection limit (BDL) in all water sample. TWQRs=Target Water Quality Ranges (Source: WRC, 2003)

Appendix 9: Durbin-Watson Statistic Output

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.759 ^a	.576	.558	.146	1.680

a. Predictors: (Constant), availability_ecosystems, Farm Size of participant in hectares, access_climate_info, access_training, Farmland Ownership, How satisfied a smallholder farmer is with life in relation to major challenges, Gender, Access to information on managing Ecosystem Services

b. Dependent Variable: adaptation_strategies

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.340	8	.668	31.441	.000
	Residual	3.928	185	.021		
	Total	9.268	193			

a. Dependent Variable: adaptation_strategies

b. Predictors: (Constant), availability_ecosystems, Farm Size of participant in hectares, access_climate_info, access_training, Farmland Ownership, How satisfied a smallholder farmer is with life in relation to major challenges, Gender, Access to information on managing Ecosystem Services

Residuals Statistics

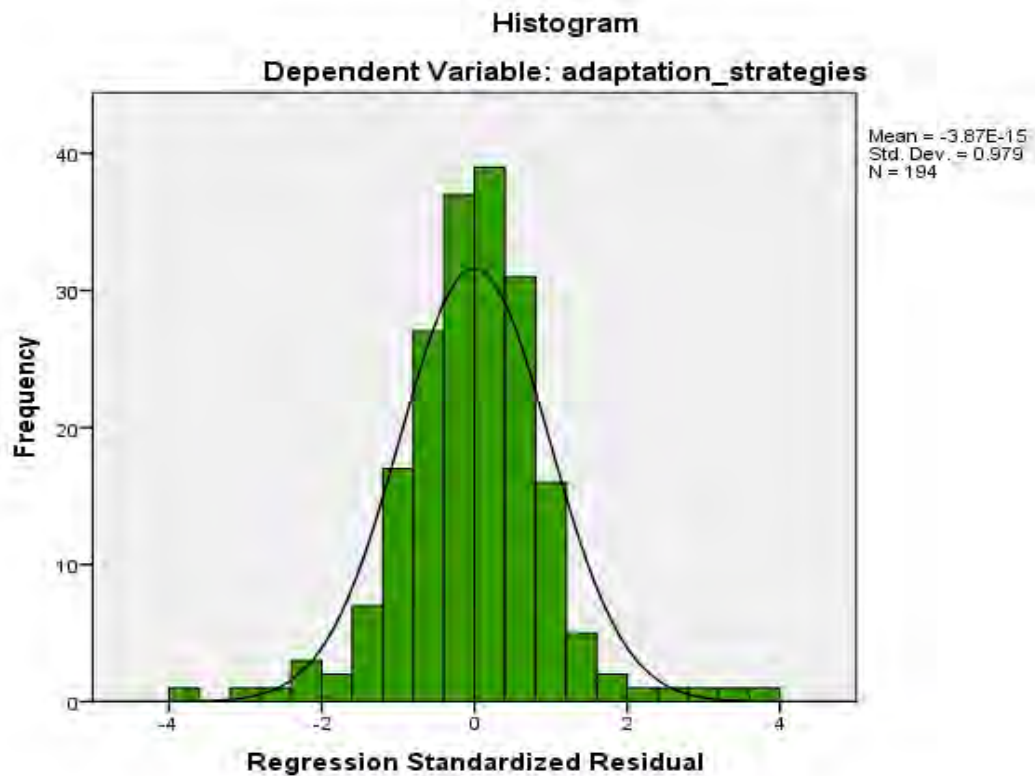
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.09	1.91	1.56	.166	194
Residual	-.565	.555	.000	.143	194
Std. Predicted Value	-2.830	2.117	.000	1.000	194
Std. Residual	-3.880	3.807	.000	.979	194

a. Dependent Variable: adaptation_strategies

Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	1.806	.095		19.013	.000
access_training	-.008	.024	-.018	-.321	.748
access_climate_info	-.397	.030	-.688	-13.200	.000
Gender	.015	.023	.034	.644	.521
Farm Size of participant in hectares	-.018	.019	-.047	-.912	.363
Farmland Ownership	.012	.013	.046	.911	.363
Access to informtion on managing Ecosystem Services	.003	.025	.006	.110	.913
How satisfied a smallholder farmer is with life in relation to major challenges	-.023	.008	-.144	-2.780	.006
availability_ecosystems	.090	.037	.119	2.435	.016

a. Dependent Variable: adaptation_strategies



Normal P-P Plot of Regression Standardized Residual

Dependent Variable: adaptation_strategies

