Analysis of livelihood vulnerability and coping strategies to climate variability in rural villages of the northwestern Ethiopia

(エチオピア北西部の農村における気候変動に対する生計脆弱性の分析と対処戦略)

Abeje Misganaw Teshager

The United Graduate School of Agricultural Sciences

Tottori University, Japan

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A dissertation submitted to The United Graduate School of Agricultural Sciences, Tottori University in partial fulfilment of the requirements for the Degree of Doctor of Philosophy in Global Arid Land Science

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ACRONYMS AND ABBREVIATIONS

ADLI	Agricultural Development Led Industrialization
°C	Degree Celsius
CRGE	Climate-Resilient Green Economy
ETB	Ethiopian Birr (currency)
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GTP	Growth and Transformation Plan
IPCC	Intergovernmental Panel on Climate Change
Km	Kilometre
LVI	Livelihood Vulnerability Index
m a.s.l	Meter above sea level
mm	millimetre
MoARD	Ministry of Agriculture and Rural Development
MPI	Multidimensional Poverty Index
MVP	Multivariate Probit
NAPA	National Adaptation Programme of Action
PRSP	Poverty Reduction Strategy Paper
SAP	Structural Adjustment Program
SD	Standard Deviation
SLA	Sustainable Livelihood Approach
SLM	Sustainable Land Management
SLMP	Sustainable Land Management Programme
SPSS	Statistical Package for the Social Sciences
SSA	Sub-Saharan Africa
SWC	Soil and Water Conservation
TLU	Tropical Livestock Unit
UNDP	United Nations Development Program
USD	United States Dollar
WLRC	Water and Land Resource Centre

CHAPTER ONE

General Introduction

Chapter 1. Introduction

1.1 Background

Climate change/variability is anticipated to be the main challenge for the sub-Saharan Africa (henceforth, 'SSA') countries, where 95% of the farm land relies on rain-fed agriculture (Boko et al., 2007; FAO, 2005; Antwi-Agyei,). Moreover, low adaptive capacity is the chief factor contributing to most of the regions vulnerability conditions which in turn is attributed to the deep-rooted poverty, insufficient safety nets, lack of technology and poor infrastructure (Boko et al., 2007)

In Ethiopia, agriculture employs 80% of workforce, contributes to 44% of the country's GDP, and accounts for 70% of the export revenue. As such, it is unarguably the mainstay of the economy. Ethiopian smallholder farmers produce 90–95% of the country's agricultural output. However, these farmers are over reliant on rain-fed agriculture and only cover half of rural households' annual food intake requirements. Climate variability and change is still regarded as the source of vulnerability and poverty in Ethiopia (Conway & Schipper, 2011; USAID,2016; Thornton et al, 2008, Deressa et al, 2008). The country has experienced more than 10 drought events since the 1970s (Mohammed et al, 2018); hence, sensitivities are also a product of large inter-seasonal climate variability and the reliance of the economy on rain-fed agriculture (Spielman et al, 2010). Vulnerability to climate variability is evident in terms of social and economic institutional sensitivity to variability in rainfall and the occurrence of extreme climate related shock events (e.g., drought and flood) (Siraw et al, 2018; Conway & Schipper, 2011; Gao & Mills, 2018). The climate projections for 2040 to 2059 show a 1.8 ◦C increase in temperature and, with a higher inter-annual variability in the northern part, rainfall is anticipated to decline (McSweeney et al, 2010). Therefore, as noted by Simane et al (2016), amalgamation of sensitivity to past climate variability and limited adaptive capacity in terms of socioeconomic and institutional aspects, coupled with the projections of anticipated future climate change, suggests that the country will be adversely affected by climate patterns in the years to come (McSweeney et al, 2010). The productivity and sustainability of the smallholder farming sector is vulnerable to the adverse effects of climate variability and land degradation. To tackle this long-standing problem, the government and its partners have put in place policies and programs thus, billions of dollars have been outlaid. Ethiopia's efforts to address the negative impact of climate variability are in the process of shifting from a technocratic perspective of climate and disaster science to long-term efforts at reducing livelihood vulnerability and attaining sustainable livelihoods (Conway & Schipper, 2011). The country's effort to develop and operationalize the Climate Resilient Green Economy as a guiding strategy for climate change adaptation and mitigation efforts is a huge step forward in this regard (FDRE, 2011). Despite all these efforts, poverty is still prevalent in the country.

The northwetern part of Ethiopia, which accounts 88% of the country's population, where much of the country's agricultural produce come from and source of the great blue Nile basin, with a tropical monsoon climate is projected to be affected by the negative effects of climate variability(Conway & Schipper, 2011; FDRE, 2011, Dercon, 2000; Gao & Mills, 2018). This part of the country contributes 43% of the country's total area coverage and 75% of livestock population. Recent reports by the Intergovernmental Panel on Climate Change (IPCC) indicated that the intensity and frequency of extremes are likely to increase over many areas including northwestern Ethiopia. The frequency and intensity of extremes like droughts, floods, and heat waves are expected to change as earth's climate changes, and these changes could occur even with relatively small mean climate changes.

Evidences in Ethiopia have shown that livelihood vulnerability to climate variability often has resulted in prolonged poverty. Although climate variability is a shared global phenomenon, it could substantially be felt by the most vulnerable ones (smallholder farmers). Given the fact that the manifestations of poverty and vulnerability are context-specific, local adaptive or coping measures should be advised. However, little attention has been given to the smaller scale lived experiences of rural villages with climate variability/change, their coping capacity- or lack thereof. Moreover, albeit poverty has been well-studied in the country, efforts to measure from multidimensional perspective and making the indicators locally relevant is still lacking.

Therefore, Ethiopia in general and northwetern region in particular, is a useful case study context in which to undertake more detailed climate vulnerability assessment, and the findings will have wider significance for climate change adaptation and poverty reduction efforts in Ghana and SSA more widely.

1.2 Problem and Justification

Ethiopia, due to its sensitivity to climatic risks and frequency of extreme events, limited institutional capacity, climatic extreme events and the possible negative impacts of projected climate, is vulnerable to climate change (McSweeney et al. 2010, Conway and Schipper 2011).

Some researchers have been conducted to support policies and strategies to reduce the exposure and vulnerability of rural livelihoods to the effects of climate change/variability. In the Ethiopian highlands, Simane et al (2016) revealed that climate change vulnerability is context specific and agroecosystems should be at the centre of future studies. The authors found that midland areas are better off in terms of climate change vulnerability as compared to both high and lowland areas. A similar study in Tigray revealed that climate change exposure and low adaptive capacity were substantially associated, and moreover, they were the major causes of vulnerability among farming communities (Gebrehiwot & Van der Veen, 2013). Similarly, in their comparative study of Ethiopian highlands, Siraw et al (2018) found that watersheds that received soil and water conservation works were less vulnerable to the effects of climate change than those that did not receive any. Owing to the above facts, there are still gaps in our study area where variations exist in agroecological locations, which indicates smaller scale studies are essential to better inform planners. Moreover, there are methodological gaps in the weightage procedure of indicators to measure vulnerability (Adger, 2006; Salvati, 2014; Williams, 2018) and livelihood vulnerability studies need to emphasize one of the most important concerns of Ethiopian rural smallholder farmers, particularly drought (Mohammed et al, 2018). Given the fact that livelihood vulnerability is being exacerbated by the climate variability, and global climate risk index (CRI), Ethiopia is ranked 66th in terms of climate-risk exposure in 2017.which clearly have shown a worrying progress vulnerability since 2014 where we were ranked 125 and 89 in 2016 (Kreft, Eckstein and Melchior, 2015), clearly indicates a more spatially dis aggregated sound studies is needed which can support the climate change adaptation efforts.

In Ethiopia in general and the northwestern part in particular is repeatedly cited as vulnerable to even a small change in rainfall and temperature changes, these has deepened the poverty situation (Dercon, 2000). Diversity in social, economic, environmental and agroecological aspects and its global MPI status next to Nigeria (OPHI, 2018); A more systematic and disaggregated evidences is needed to guide planning and programs. To this end, little attention has been paid to the multidimensional nature of poverty in Ethiopia, and only a few studies have applied the A–F method to study the problem (Alemayehu et al. 2015; Brück & Kebede, 2013; Seff & Jolliffe 2017; Tigre 2018; Woldehanna & Hagos 2013).

Despite the above-mentioned vulnerability conditions and internal and external influencing factors, and multidimensional poverty, households and its partners (e.g government, organizations etc) have accumulated coping/adaptive livelihood strategies. One of these adaptation/coping strategies are famers motive to escape these problems through livelihood diversification. In Ethiopia, climate variability, associated with farm-income variability, is documented as one of the main motivations of rural livelihood diversification strategies. To understand household's response and behaviour in the prevalence of climate risks and shocks and there by formulation of locally tailored development policies and adaptation programs in decidedly rainfed agriculture, it is essential to analyse the drivers and extents of livelihood diversification choice decisions. Due to the demographic, social, economic and institutional capacities rural households possess, they don't obviously suffer equally by the adverse impacts of CC. Therefore, in order for us to analyse livelihood vulnerability and coping strategies, we need to consider the differential livelihood options and resources for livelihood coping strategies to climate effects and poverty situation.

Hence, understanding livelihood vulnerability and poverty and households' coping strategies will serve policy makers in targeting local coping strategies and thereby helps to reducing poverty and improve livelihoods of small-scale farmers in the study area and beyond.

1.3 Objectives

The aim of this study is to analyse the livelihood vulnerability and coping capacity to climate variability in rural villages of the northwestern Ethiopia. The specific objectives are: The specific objectives include;

- √ To analyse the livelihood vulnerability of households to climate variability
- √ To explore multidimensional poverty status of households
- √ To identify the existing coping strategies of households in the face of climate variability.

Research Questions

1. What are the socio-economic, institutional and biophysical factors that to livelihood vulnerability to climate variability?
2. Is poverty prevalent in the rural villages? What are the drivers?
3. What are the local livelihood strategies to cope with the effects of climate variability?
4. What are the determinants of the existing coping strategies?

1.4 Theoretical framework

1.4.1 Livelihood vulnerability to climate variability

Livelihood vulnerability to climate variability and change is a function of exposure, sensitivity, and adaptive capacity (Parry et al, 2007). Exposure refers to changes in climate variability explained by seasonal variations, and it is essentially associated with precipitation and temperature (Gornall et al, 2010)(Fig.1). Sensitivity refers to the degree to which a system could be adversely affected, and it is explained by the potential impact's net effect and people's potential to cope with any adverse consequences. It essentially captures a system's susceptibility to harm associated with environmental and social changes. Adaptive capacity entails the capacity of the system to withstand variability and changes in order to minimize potential damages, to cope with negative consequences, and possibly even benefit from these changes (De Haan and Zoomers, 2005; Adger, 2006; Heltberg et al, 2009; Hertel and Rosch, 2010; Snover et al, 2007). According to Deressa (2009) measures vulnerability could be broadly categorized into two; the indicator and econometric approaches. An indicators approach was usually taken as using wide range of subjective indicators construction base on expert judgements, principal component analysis and history records (Kaly and Pratt, 2000; Cutter et al. 2003; Brooks et al. 2005). Whereas the econometric methods, which use household-level socio- economic survey data to analyze the vulnerability levels of different social groups, include three assessments: vulnerability as expected poverty (VEP), vulnerability as low expected utility (VEU) and vulnerability as uninsured exposure to risk (VER) (Hoddinott and Quisumbing 2003).

Studies on the livelihood vulnerability includes, but not limited to (Luers et al 2003; Tesso et al 2012; Westerhoff & Smit 2009; Antwi-Agyei et al 2013; Hahn et al 2009; Jamir et al 2013; Piya et al 2012;). Regarding the methodology used, they were conceptually derived from the (IPCC, 2001 & 2007 ; Fussel et al , 2007) technically on the constructs of exposure to change, sensitivity to change; adaptive capacity. Many of these methodologies have the limitations like, 1) considerable subjectivity in the selection of variables and their relative weights (Deressa, 2009; Beccari, 2016; Tjoe, 2016) the availability of data at various scales, and 3) the difficulty of testing or validating the different metrics.

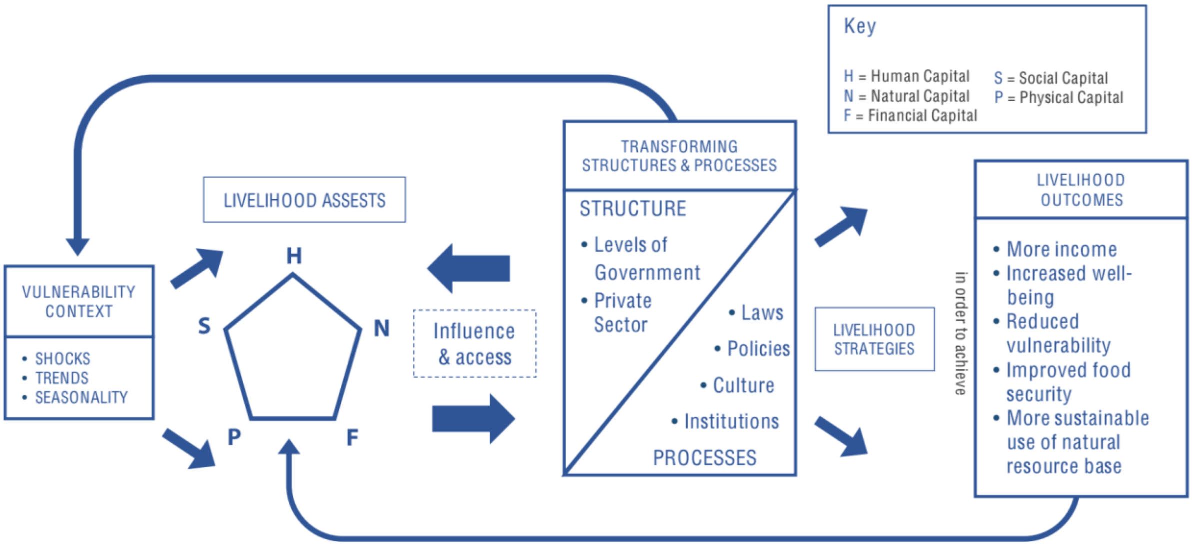

Figure 1 The Sustainable livelihood Approach (source: Carney, 2003)

1.4.2 The motivation for livelihood diversification

In rural areas of developing countries, households combine diverse portfolios of activities in their pursuit of alleviating poverty and improving living standards (Alobo Loison, S ,2015 Elllis, 2000). As defined by Ellis (2000), livelihood diversification refers to the process by which households pool a wide range of activities and social support systems to deal with shocks and improve their welfare. For most smallholder farmers in developing countries, diversification away from agriculture accounts for 30–40% of their overall incomes [Ellis, 2000,1998].

The motivation for livelihood diversification could be categorized as distress and progressive (Ellis, 2000; Smith et al., 2005; Lohmann & Liefner, 2009; Reardon et al., 2000). Rural households diversify either be in preparing and responding the incidence of natural and/or anthropogenic shocks like drought, flooding, conflict, pest infestation (Milgroom and Giller 2013; Kandulu et al., 2012; Cooper et al. 2008; Ellis, 2000) etc. or to cope the shortfall they faced in income and consumption during loose seasons (Waleligan and Nielsen, 2013). Diversification which is driven by distress factors is highly dependent on the household's access to productive assets such as labor, land and livestock (Schwarze, 2004). On the other hand, these distress factors caused diversification is greatly affected by the individual characteristics of the household (Abdulai & CroleRees, 2001). Whereas the progressive type of diversification motivation (Cinner et al., 2010; Ellis, 2000; Reardon et al., 2000) is comprised of the following aspects: realization of strategic complementarities between activities, such as crop and livestock integration, i.e., crop stalks being fed to animals, while animal manure can replace chemical fertilizer; specialization development in that individuals or households will exhibit diverse assets, activities, and income even if there is specialization due to comparative advantage at the level of the individual (Barrett et al., 2001; Reardon et al., 2000). Local engines of growth such as commercial agriculture or proximity to an urban area create opportunities for income diversification in production- and expenditure-linkage activities.

1.4.3 The household diversification effect on SLM

Sustainable livelihood Approach (SLA), inspired by Chambers and Conway in the 1992's United Nations (UN) Brundtland Commission conference on Environment and Development, has been instrumental in research and development efforts to try to understand and leverage between poverty eradication and sustainable livelihoods outcomes in rural settings (Chambers and Conway, 1992, DFID, 2000). Livelihood is a mean to making a living which comprises capabilities, assets (including both tangible and intangible resources) and activities (Carney, 2003). To achieve a positive livelihood outcome, rural households combine pool of asset endowments (human, natural, financial, physical and social assets) to construct their own livelihoods which in turn could be influenced by the process, structures and policies (Fig.1). The approach considers the vulnerability contexts (seasonality, shocks, trends etc) which shapes the households' asset ownership, the strategies they follow and ultimately the livelihood outcome they intend to achieve (Carney, 2003). Hence, a livelihood could be regarded sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets, while not adversely affecting the environmental resource base. Therefore, with the overall purpose of understanding poverty, the approach promotes the wise integration if social, economic and ecological sustainability. A combinations of livelihood strategies tend to choose to undertake should also be environmentally friendly and being them sustained wellbeing. Our environment and the natural resource base could be negatively affected by our effort of diversifying livelihood activities (Assan et al., 2013, Kassie et al, 2017, Cordingley et al., 2015). The use of natural resource-based livelihood sources to increase income and reduce poverty has a two-way cause–effect association with environmental depletion (Cordingley et al., 2015, Daregot et al., 2015; Kelly, 2013; Lee, 2005; Liu and Lan, 2015). Rural households' engagement in livelihood activities that increase income, and thus reduce poverty, could have varied effects on the environment (Liu and Lan, 2015). A positive effect could be through the decision to allocate labor away from livelihood activities that exploit natural resources to other, less exploitative, livelihood options. Rural households' engagement in these latter activities may induce less environmental degradation (Ellis, 2000; Liu and Lan, 2015). On the other hand, although such livelihood diversification could increase the income of the rural poor, it is possible that some related activities could have a degrading effect on the environment, and poor households could end up living in worse conditions (Harcourt and Sayer, 1996; Salafsky,2000).

1.4.4 Understanding the multidimensional poverty

Poverty is multidimensional in definition and in its manifestations. It has traditional been measured as unidimensional construct and seldom measured by income and consumption indicators. Following Sen's capability approach (Sen, 1984), scholars from around the globe have studied the multidimensional construct that poverty encompasses in any given society (Anthony B. Atkinson, 2003; Batana, 2013; Burchi & Rippin, 2018; J. Stiglitz, Sen, & Fitoussi, 2009; Thorbecke, 2008). In an effort to better understand the multidimensional construct of poverty, Alkire and Foster proposed a new method (A–F method) that uses a composite index which cartels a counting approach with the Foster–Greer–Thorbecke family of poverty metrics (Foster et al. 1984) to satisfy an array of desirable axioms (Alkire and Foster 2011; Atkinson 2003). In addition to the global MPI indicators (Alkire & Foster 2011; Alkire & Santos 2014), there has been a growing interest to include area specific indicators to have a more profound understanding of poverty in each country's context. For example, scholarly efforts in many parts of the world that tried to contextualize the global MPI to specific countries' contexts and launched their findings (e.g Thailand, Afghanistan, Sierra Leone) and section of the community (e.g gender) (Espinoza-Delgado & Klasen, 2018) and livelihood (Vollmer et al, 2017). Even in US, Dhongde and Haveman (2014) contextualized the global MPI to better suit the US context. Though few in number, the A-F method, which has received growing attention in recent literatures and works worldwide, is rarely used and adopted in the poverty researches in Sub Saharan Africa (SSA) in general and in Ethiopia in particular. Some exceptions in Ethiopia are Tigre (2018), Bruck & Kebede (2013) and Seff & Jolliffe (2016).

1.4.5 Expected utility theory

Farmers, in an uncertain and risky environment make decisions. According to expected utility function, based on their assessment and evaluation of likelihood possible outcomes, perception they make decision of doing, adopting actions or otherwise. Among others, utilities and subjective probabilities are the most important factors that determine their evaluation of outcomes and likelihoods. Historical experiences on the patterns of choice helps individual famers to decide on the choices and decisions (Karni 2014). A rational decision maker believes that an uncertain event has (an exclusive and exhaustive list of) possible outcomes for each action (X_i) with a utility of ($U(X_i)$). The choice of decision arises from the utility function combined with the subjective belief (subjective probability of each outcome) (Pi) and prefers a decision with the highest subjective expected utility, i.e., ($\sum(P_i\ (X_i)U(X_i)$). This justifies that different individuals make different decisions because they have different utility functions or different beliefs about the probabilities of different outcomes. With this in mind, in less developed countries like Ethiopia, smallholder farmers usually have no access to reliable information on agricultural and natural resource conditions. They have often made farming decisions with limited or imperfect information (Yesuf and Köhlin, 2008). They may not have accurate knowledge of the consequences of their decisions (Kassie et al., 2018). They, more often, intuitively place perceived probabilities on actions and outcomes. Their beliefs concerning the consequences of the actions are based on a subjective probability distribution which they instinctively assign to each action. Consequently, expected utility theory, especially subjective probability, is a useful theoretical framework to make farming decisions primarily in an imperfect environment. It overtly acknowledges these subjective components of important decisions – the farming decision is an evaluation of the actions under consideration and the perceived probabilities associated with them. Because of the differences in context, experience and other factors, individuals may have different estimates both of the value and probability of outcomes. Therefore, farmers are expected to decide to adopt sustainable land management practices under the framework of expected utility theory.

1.6 Conceptual framework

Given that agricultural production remains to be main source of income, climate variability and change is repeatedly cited as the source of vulnerability in Ethiopia (Conway and Schipper, 2011; USAID, 2016; Thornton, 2008). The increased risk of crop loss and associated frequency of extreme events poses a major threat to food security and poverty reduction efforts. The country has experienced more than 10 drought events since the 1970s (Mohammed et al., 2018); hence, sensitivities are also a product of large inter-seasonal climate variability and the reliance of the economy on rain-fed agriculture (Spielman et al., 2010). Vulnerability to climate variability is evident in terms of social and economic institutional sensitivity to variability in rainfall and the occurrence of extreme climate related shock events (e.g., drought and flood) (Simane et al., 2016; Conway and Schipper, 2011; Gao and Mills, 2018). The climate projections for 2040 to 2059 show a 1.8 ◦C increase in temperature and, with a higher inter-annual variability in the northern part, rainfall is anticipated to decline (McSweeney et al, 2010). Moreover, the AR5 assessment indicated that there will be short spring rains and will get warmer in all four seasons with a potential impact on the livelihoods. Generally, how Ethiopia's economy performs thus depends largely on how small-scale famers perform down the community.

To improve the livelihoods of poor and thereby reduces poverty, climate change adaptation and coping to its immediate risks is a priority for Ethiopian agriculture sector (Bradshaw, Dolan and Smit, 2004; Asfaw et al., 2014). This requires analysing the extent of livelihood vulnerability, existing poverty and coping strategies at smaller scales as lived experiences of rural villages to climate variability (Olsson et al, 2014). Inspired by the Sustainable livelihood Approach (SLA), this study is intended to explore the livelihood, climate multidimensional poverty interplay. In that climate change was cited to put an extra burden to poor people and their livelihoods and has also caused new multidimensionally poor people. Climate related shocks like extreme events and its manifestation (for example drought, pest infestation etc) affect poor people life directly through its direct impact on livelihoods, such as loss of crop and livestock yield, food insecurity and indirectly through increase of food price. Climate change is one stressor that shapes the dynamic and differential livelihood paths. For example, in our study site, Acacia plantation have come to be a dominant source of income since 5 to 6 years, mainly motivated by distress diversification (diversification was motivated by a push factors from poverty situation) (Nigussie et al, 2017). Moreover, rural transient poor who face multiple deprivations likely to fall into cycle of poverty as a result of extreme and recurrent events (like drought), when unable to rebuild their eroded assets. Many events that affect poor people are weather-related and remain overlooked by standard climate observations in many developing countries (Olsson et al, 2014). Even minor changes in precipitation amount or temporal distribution, short periods of extreme temperatures can harm livelihoods (Douglas et al., 2008; Ostfeld, 2009; Midgley and Thuiller, 2011; Bele et al., 2013; Bryan et al., 2013).

Consequently, the evidences of AR4 identified poverty as "the most serious obstacle to effective adaptation" (IPCC, 2007). Therefore, multidimensional poverty status of households in the case villages must be assessed. We borrowed Sen's capability approach and A-F approach to explore the joint deprivation of multiple factors including, education, health, living standard and productive assets endowment by small scale farmers.

Despite the above-mentioned vulnerability conditions and internal and external influencing factors, and multidimensional poverty, households and its partners (e.g government, organizations etc) have accumulated coping/adaptive livelihood strategies. One of these adaptation/coping strategies are famers motive to escape these problems through livelihood diversification. In Ethiopia, climate variability, associated with farm-income variability, is documented as one of the main motivations of rural livelihood diversification strategies. To understand household's response and behaviour in the prevalence of climate risks and shocks and there by formulation of locally tailored development policies and adaptation programs in overwhelmingly rainfed agriculture, it is essential to analyse the drivers and extents of livelihood diversification choice decisions. Due to the demographic, social, economic and institutional capacities rural households possess, they don't obviously suffer equally by the adverse impacts of climate change/variability. Therefore, in order for us to analyse livelihood vulnerability and coping strategies, we need to consider the differential livelihood options and resources for livelihood coping strategies to climate effects and poverty situation. Adaptation strategies would be influenced by myriad of factors including; system characteristics, such that household and farm characteristics (household head's age, gender, education level, income, land size, tenure status etc), social; kinship, participation in socially based organizations (CBOs, FBOs etc)(Deressa et al, 2009), institutional factors; access to climate information, extension access, credit facilities, market access, irrigation and off-farm employment (livelihood diversification)(Deressa et al, 2009; Gebrehiwot et al, 2013)

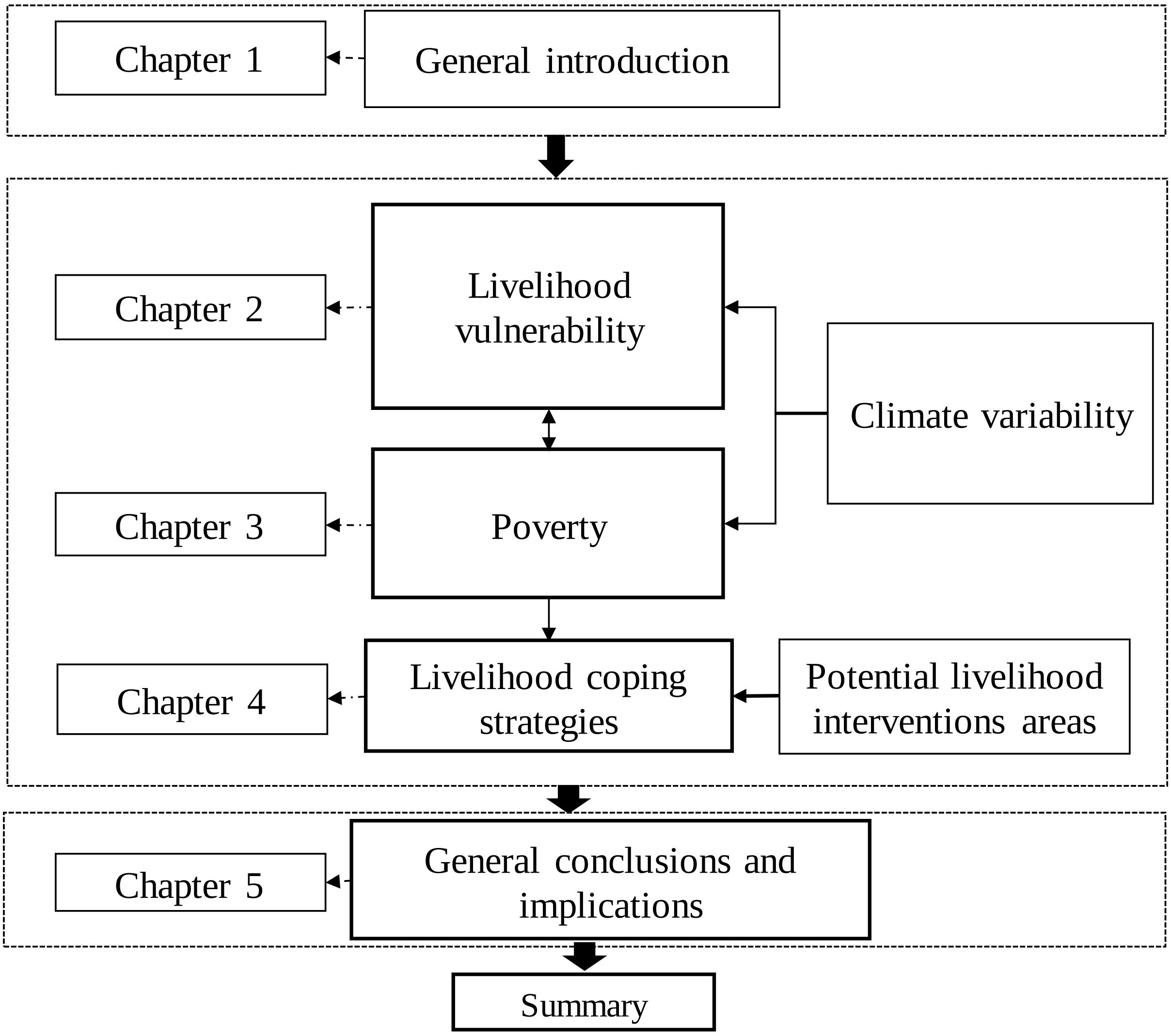

Figure 2 Structure of thesis

CHAPTER TWO

Communities' Livelihood Vulnerability to Climate Variability in Ethiopia

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Chapter 2. Communities' Livelihood Vulnerability to Climate Variability in Ethiopia

2.1 Introduction

2.1.1 Livelihood Vulnerability to Climate Change

A livelihood is a means by which individuals or households make a living (Ellis, 1998). Household livelihood outcomes are a function of a range of components, including livelihood assets, activities, processes, and structures. Smallholder farmers, accounting for 75% of the world's agricultural area (Lowder, Skoet, & Raney, 2016) and 60% of employment (Griek, Penikett, & Hougee, 2010), produce over 80% of the food consumed in the developing world (UNEP, 2013) and are one of the most vulnerable groups of people to climate change (IPCC, 2007; Morton, 2007). The vulnerability has been attributed to their high dependence on ecosystem services and goods, exposure and sensitivity to climate variability, low adaptive capacity, reliance on rain-fed livelihood activities, and often marginal locations in the landscapes (Cooper & Wheeler, 2017; T. Deressa, Hassan, & Ringler, 2008; Mohammed, Yimer, Tadesse, & Tesfaye, 2018). Moreover, adverse consequences of environmental challenges (e.g., climate change) on crop sustainability and productivity could affect farmers' livelihood activities and lower their adaptive capacity (Lobell et al., 2008). According to the Intergovernmental Panel for Climate Change (IPCC), climate change is projected to increase climate-related shocks (e.g., drought) and disproportionately manifest its adverse consequences through human health, food security, and water resources, specifically for rural poor households (IPCC, 2014). The IPCC report emphasized that efforts should focus on enhancing adaptation, reducing exposure, and decreasing the vulnerability of small-scale farmers while enhancing their resilience to shock impacts. These interventions in turn should be informed by evidence of livelihood vulnerabilities (De Haan & Zoomers, 2005), which are shaped by physical, economic, social, and ecological factors and processes (Adger, 2006).

Livelihood vulnerability to climate variability and change is a function of exposure, sensitivity, and adaptive capacity (Parry et al., 2007). Exposure refers to changes in climate variability explained by seasonal variations, and it is essentially associated with precipitation and temperature (Gornall et al., 2010). Sensitivity refers to the degree to which a system could be adversely affected, and it is explained by the potential impact's net effect and people's potential to cope with any adverse consequences. It essentially captures a system's susceptibility to harm associated with environmental and social changes. Adaptive capacity entails the capacity of the system to withstand variability and changes in order to minimize potential damages, to cope with negative consequences, and possibly even benefit from these changes (Adger, 2006; Heltberg, Siegel, & Jorgensen, 2009; Hertel & Rosch, 2010; IPCC, 2014; Snover et al., 2007). Several researchers have attempted to explore the blend between livelihood approaches and vulnerability dimensions as part of a broader study of sustainable livelihood development. Many studies in Africa and elsewhere have found varied results in terms of which factors contribute to overall livelihood vulnerability (Dzoga, Simatele, & Munga, 2018; Peng, Xu, & Wang, 2018; A. Quandt, 2018; Tjoe, 2016; Unks, King, Nelson, Wachira, & German, 2019; Williams, Crespo, & Abu, 2018; Zhang, Zhao, & Tang, 2018). Other studies in this continent (e.g., (e.g. Cooper & Wheeler, 2017; T. Deressa et al., 2008; Mohammed et al., 2018)) have indicated that lower adaptive capacity and higher exposure to climate-related hazards (e.g., drought) are the major contributors to livelihood vulnerability and consequently undermine the sustainability of small-scale farmers' livelihood bases.

To empirically understand livelihood vulnerability, the fundamental work by Hahn, Riederer, and Foster (2009) to assess community livelihood vulnerability in Mozambique is of great importance. Employing the Sustainable Livelihoods Approach (Chambers & Conway, 1992), Hahn et al. used the IPCC-LVI (livelihood vulnerability index) to investigate communities in terms of their endowment of human capital, financial capital, physical capital, social capital, and natural capital. Environmental shocks and stresses (e.g., drought) related to climate change were viewed from the perspective of each of these types of capital. The methodology has since been applied to study communities and regions elsewhere in the developing world and Ethiopia and provides the foundation for this research as well (Adu, Kuwornu, Anim-Somuah, & Sasaki, 2018; Gebrehiwot & van der Veen, 2013; Huong, Yao, & Fahad, 2018; Peng et al., 2018; Simane, Zaitchik, & Foltz, 2016; Siraw, Adnew Degefu, & Bewket, 2018; Sujakhu et al., 2018; Tjoe, 2016; Zhang et al., 2018).

2.1.2 The Ethiopian Context

Climate variability and change is repeatedly cited as the source of vulnerability in Ethiopia (Conway & Schipper, 2011; Thornton et al., 2008; USAID, 2016). The country has experienced more than 10 drought events since the 1970s (Mohammed et al., 2018); hence, sensitivities are also a product of large inter-seasonal climate variability and the reliance of the economy on rain-fed agriculture (Spielman, Byerlee, Alemu, & Kelemework, 2010). Vulnerability to climate variability is evident in terms of social and economic institutional sensitivity to variability in rainfall and the occurrence of extreme climate related shock events (e.g., drought and flood) (Conway & Schipper, 2011; Gao & Mills, 2018; Simane et al., 2016). The climate projections for 2040 to 2059 show a 1.8 °C increase in temperature and, with a higher inter-annual variability in the northern part, rainfall is anticipated to decline (McSweeney, New, Lizcano, & Lu, 2010). Therefore, as noted by Simane et al. (2016), amalgamation of sensitivity to past climate variability and limited adaptive capacity in terms of socioeconomic and institutional aspects, coupled with the projections of anticipated future climate change, suggests that the country will be adversely affected by climate patterns in the years to come (McSweeney et al., 2010). Ethiopia's efforts to address the negative impact of climate variability are in the process of shifting from a technocratic perspective of climate and disaster science to long-term efforts at reducing livelihood vulnerability and attaining sustainable livelihoods (Conway & Schipper, 2011). The country's effort to develop and operationalize the Climate Resilient Green Economy as a guiding strategy for climate change adaptation and mitigation efforts is a huge step forward in this regard (FDRE, 2011).

Some research has been conducted to support policies and strategies to reduce the exposure and vulnerability of rural livelihoods to the effects of climate change/variability. In the Ethiopian highlands, Simane et al. (2016) revealed that climate change vulnerability is context specific and agroecosystems should be at the centre of future studies. The authors found that midland areas are better off in terms of climate change vulnerability as compared to both high and lowland areas. A similar study in Tigray revealed that climate change exposure and low adaptive capacity were substantially associated, and moreover, they were the major causes of vulnerability among farming communities (Gebrehiwot & van der Veen, 2013). Similarly, in their comparative study of Ethiopian highlands, Siraw et al. (2018) found that watersheds that received soil and water conservation works were less vulnerable to the effects of climate change than those that did not receive any. Owing to the above facts, there are still gaps in our study area where variations exist in agroecological locations, which indicates smaller scale studies are essential to better inform planners. Moreover, there are methodological gaps in the weightage procedure of indicators to measure vulnerability (Adger, 2006; Salvati & Carlucci, 2014; Williams, Crespo, Abu, & Simpson, 2018) and livelihood vulnerability studies need to emphasize one of the most important concerns of Ethiopian rural smallholder farmers, particularly drought (Mohammed et al., 2018).

2.1.3 Study Objectives

By applying the IPCC-LVI (Hahn et al., 2009) at agroecologically contrasting environments, this study aimed at analyzing the livelihood vulnerability to climate change/variability for small-scale farmers in north western Ethiopia, Upper Blue Nile basin. First, the major objective of this manuscript is to provide empirical evidence at smaller scales of how livelihood vulnerability may vary across diverse agroecological ecosystems (Ferede, Ayenew, Hanjra, & Hanjra, 2013). A second, and much more minor, objective is to address methodological gaps related to weightage of indicators so that robust conclusions can be drawn (Adger, 2006; Salvati & Carlucci, 2014; Williams, Crespo, Abu, et al., 2018). Lastly, we aim to shed light on the community level obstruction (constraints) indicators to limiting climate change/variability adaptive response mechanisms (Huang, Huang, He, & Yang, 2017).

2.1.4 Significance of the Study

Despite being few in numbers, recently, livelihood vulnerability to climate variability/change studies have received growing attention in Ethiopia. Most of these studies were broader in scale and used political administrations (e.g., districts, regions, and national) as unit of analysis, while others focused on vulnerability to food insecurity and poverty. Almost all of them have adopted the LVI-IPCC livelihood measure, using subjectively evaluated indicators to construct the indices. However, studies at the national level are not believed to show the full picture of socioeconomic livelihood and the variability of other adaptive capacities at lower scales, and findings may not precisely indicate the necessary information for practical implications. Furthermore, these studies have underestimated the importance of studying past drought episodes on the current livelihoods of communities. The present study provides a sounder quantitative analysis of livelihood vulnerability using the Shannon entropy weighting procedure at a lower scale (watersheds in this study), whereby the locations represent contrasting agroecological environments. Therefore, in this study, we argue that small-scale farmer level studies would help to better understand the adaptive capacities of communities, and hence would help decision-makers tailor policies to the local conditions. Moreover, to further help fine-scale decision making at the community level, we adopted an obstruction degree analysis, which enabled us to bring up the specific constraint indicators of adaptive capacity that varied by study locations. Hence, the current study can be adopted for similar agroecological environments, watersheds, and communities in Ethiopia and other developing countries. More broadly, we also contribute to the limited existing literature of rural livelihood vulnerability analysis studies in Ethiopia and other developing countries. For instance, the methodology could be adopted for national level objective climate vulnerability studies and promotes the inclusion of climate related shocks as part of the analysis.

2.2 Materials and Methods

2.2.1 Study Area

This study was carried out in the following three different agroecological environments of the northwestern highlands of Ethiopia in the Upper Blue Nile basin: Guder (highland), Aba Gerima (midland), and Dibatie (lowland) (Figure 1). Area selection was determined by their differences in elevation, cropping system, and precipitation (Hurni et al., 2016), and these three watersheds were selected because they represent a range of different agroecological and socioeconomic characteristics. Households in the study areas primarily make their livelihoods from a mixed crop–livestock production system. The major crops grown are barley (*Hordeum vulgare* L.), teff (*Eragrostis tef* Zucc.), wheat (*Triticum aestivum* L.), and potato (*Solanum tuberosum* L.) (Nigussie et al., 2017c). Cattle, sheep, goats, donkeys, and horses are the dominant livestock raised.

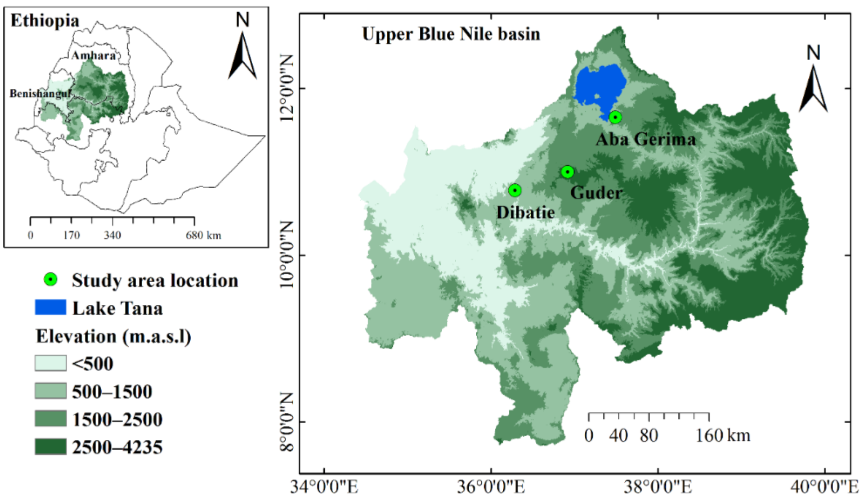

Figure 3 Location map of the study areas.

Aba Gerima watershed is categorized as humid sub-tropical, with an annual rainfall that ranges from 895 to 2037 mm. Guder is moist tropical, with an annual rainfall of 1951–3424 mm, and Dibatie is tropical hot humid, with an annual rainfall of 850–1200 mm (Nigussie et al., 2017c). Data from nearby meteorological stations shows that there has been notable climate variability since 1982 (Berihun et al., 2019b). Despite being in different agroecological environments, the watersheds are characterized by similar rainy (June to October) and dry (November to May) seasons, and more than 86% of the rainfall is concentrated during the rainy season.

Most farmers in these areas have subsistence-based livelihoods supplemented by additional sources of non-and off-farm income. In the past decade, most farmers in Guder and Aba Gerima have shifted from growing food crops to growing green wattle (Acacia decurrens) (*Wendl. f.) Willd.* and khat (*Catha edulis*), respectively (Abeje et al., 2019; Nigussie et al., 2017a). Notable droughts have occurred in these areas, for example, in 1984/1985, 1992/1993, 2000/2001, and 2015/2016 (Mohammed et al., 2018).

2.2.2 Data and Sampling Procedures

We used a mix of data collection methods and sources. First, meteorological data (temperature and rainfall) were gathered from the Ethiopian National Meteorology Station for the period from 1982 to 2016. Second, we conducted a participatory rural appraisal (Chambers & Conway, 1992) to select the specific local indicators of livelihood vulnerability, as defined by the communities themselves. Twenty individuals from each community participated in this appraisal (for a total of 60). Third, we considered the newly identified livelihood vulnerability indicators and developed a draft questionnaire to be administered in a pilot test administered to five households in each watershed.

Finally, primary data were obtained from sampled respondents using a structured questionnaire administered in face-to-face interviews conducted in October and December 2018. The topics included sociodemographic profiles, food, water, social networks, livelihood strategies, health, and climatic shocks. To select sample households for the study, we used a two-stage sampling procedure. We first selected watersheds according to their agroecological and socioeconomic differences and household respondents from each watershed were selected randomly by using a probability proportional to size sampling procedure. Due to its simplicity, the purposive selection of the watersheds, and the proportional to size sampling, we followed and adopted Cochran's representative size to proportions formula. Therefore, based on the sampling procedures of Cochran (Cochran, 1977), we first calculated the required sample size to be 391 from the full household lists of all three watersheds. We then randomly selected 130 households from Aba Gerima, 132 households from Guder, and 129 households from Dibatie. The questionnaire was first developed in English and then translated into the Amharic language. Enumerators were trained on each question and practiced doing mock interviews.

Under supervision, the enumerators interviewed each head of household (male or female). In the absence of the household head, elders who were willing to participate in the interview were interviewed. The first author did all the supervisory work and quality checks throughout the data collection period. On average, each interview took 60 min.

2.2.3 Data Analysis

This study generally followed the IPCC-LVI construction methodology, which is essentially based on a sustainable livelihood framework (SLF) (Hahn et al., 2009). Data management and analyses were performed with Stata ver. 15 (StataCorp LLC, College Station, TX, USA), MS Excel, and XLSTAT.

2.2.4 Meteorological Data Analysis

To understand the long-term trends of rainfall and temperature, we analyzed the climate variability/change and the significance of monotonic trends by using the Mann–Kendall (MK) test for long-term metrological records (Abdi, 2007). The MK test and Sen's slope estimator (with Pettitt's homogeneity test) were applied to the time-series data from 1982 to 2016 for the three watersheds.

The standardized precipitation index (SPI) was used to characterize historical drought patterns and periods in the study watersheds. The SPI uses a Z-score to explore unusual weather events that happened in the past. SPI is a normalized index in time and space and was computed following Thomas B. McKee (1993). To characterize drought intensity, the author suggested that SPI can be calculated on a time scale from 1 month to 72 months. For the purpose of this study, we chose a 3-month time scale to assess the main rainy season. We used statistical software developed by Tigkas, Vangelis, and Tsakiris (2015), called the Drought indices Calculator (DrinC), in the drought analysis.

2.2.5 Measures of Livelihood Vulnerability

We followed an inductive approach for the construction of an overall formative composite index where we could explore the community (watershed)-scale livelihood vulnerability based on SLF (Chambers & Conway, 1992; DFID, 1999) and the pragmatic approach of Hahn et al. (2009). Presently, many different composite index constructions are usually criticized for their subjective weighting procedures because they may result in misleading information (Beccari, 2016; Miller, Witlox, & Tribby, 2013). Including the pioneering work by Hahn et al., scholars in Ethiopia and elsewhere in the world followed the subjective weighting of components/indicators to construct the composite index. This is based on the number of questions included under the indicated component, which is inappropriate whereby the information is not quantitative, exclusive, and partial or incomplete. Unlike the subjective methods, in this study, we applied an objective weighting procedure by which it is more appropriate to give precise evidences for prioritizing planning areas (based on the value of sub-components), which seeks attention and remedies to reducing the livelihood vulnerability of communities to the adverse effects of climate variability/change. The Shannon entropy method, an objective weighting method that has been recommended as robust (Peng et al., 2018; Tjoe, 2016; Yang, Xu, Lian, Ma, & Bin, 2018), was used to generate an evaluation score for each indicator. The following computation procedures were used (for a more detailed description of the procedures, see the Supplementary Materials): (1) We standardized all 33 indicators (as provided in Table 1 in the results section) by using a dimensionless processing technique that helps facilitate easy comparison of score values. In this case, the variables have a positive functional relationship with vulnerability, and a higher value is generally understood to indicate greater vulnerability. (2) The proportion of indicators in an evaluation matrix was computed. (3) An individual entropy value for each indicator was calculated. (4) The entropy weight for each indicator was computed. (5) A comprehensive index value was constructed for each community. The minimum value was scaled to 0 (least vulnerable) and the maximum was scaled to 1 (most vulnerable) (see the Supplementary Materials for more details).

In the results, we found that adaptive capacity was the most salient factor influencing overall IPCC-based livelihood vulnerability in the combined study area. As a result, we additionally followed a weighting and aggregation procedure for this dimension. Williams et al. (Williams, Crespo, Abu, et al. (2018) suggested that, in Africa, the adaptive capacity dimension of smallholder farmers' livelihood vulnerability assessments should be emphasized to better inform decision-making. Therefore, we adopted a degree of obstruction model (Huang et al., 2017) to discover which factors limit adaptive capacity (see the Supplementary Materials for more details). A higher value (percentage points) indicates that the indicators could have a higher hindering capacity in terms of limiting households' capacity to respond to the effects of climate change. This model is widely applicable in urban land-use management as a mathematical decision approach (Shen, You, & Wu, 2014).

Table 1 Description of vulnerability indicators and summary statistics.

Dimensions	Components	Vulnerability Indicators	Summary Statistics			*p*-Values	References
			Aba Gerima	**Guder**	**Dibatie**		
Exposure (Exp)	Climate	Mean standard deviation of monthly average rainfall (mm)	44.8	87.1	43.4		[31,57]
		Mean standard deviation of monthly average of average minimum daily temperature (°C)	12.7	9.5	14.6	a **	[32]
		Mean standard deviation of monthly average of average maximum daily temperature (°C)	27.5	25.2	28.1	a **	[32]
		Frequency of climate-related hazards (no.)	2.9	2.3	3.6	a **	[32]
		Access to warning information (%)	55.4	44	91.5	b ***	[57]
		SPI for the wet season	0.016	0.02	0.01		[57,58]
Adaptive capacity (AdapCap)	Sociodemographic	Age of household head (years)	48	53	45	a **	[32]
		Dependency ratio (%)	0.91	0.72	0.94	a **	[31]
		Households with female heads (%)	13	20	10	b **	[31]
		Household heads who have not attended school (%)	79.2	72.7	62.0	b ***	[29,31]
	Livelihood strategies	Households without members working outside the community (%)	3.9	38.6	27.9	b ***	[29,31]
		Households with no other source of income	25.8	34.2	40.1	b ***	[29,31]
		Agricultural Livelihood Diversification Index	0.29	0.29	0.26	a ***	[29,31]
		Livestock Diversification Index	0.6	0.24	0.61	a ***	[29,31]
		Households who have not participated in natural resource management activities (%)	30	16	65	b ***	[31,58]
	Social networks	Average receive-give ratio (%)	1.06	1.27	1.07	a ***	[29,58]

		Borrow-lend ratio (%)	0.32	0.18	0.16	a **	[29,58]
		Households are not members of community-based organizations (%)	4	2	11	b **	[29,58]
		Households are not members of farmer-based organizations (%)	6.15	57.6	24.8	b ***	[29,58]
		Households who have not gone to local government (%)	33.33	13.6	82.2	b ***	[58]
		Households who have no communication devices (%)	52.31	39.4	20.2	b ***	[58]
Sensitivity (Sen)	Health	Walking distance to health service (′)	56.77	68.4	34.2	a ***	[32]
		Households who reported chronic illness (%)	25.38	14.4	49.6	b ***	[32]
		Households where a member missed work/school due to illness (%)	35.38	30.3	53.5	b ***	[32]
		Number of times where households were exposed to epidemics	1.4	0.5	1.5	a ***	[32]
	Food	Households mainly dependent on family farm for food (%)	95.4	74.2	91.5	a ***	[31,58]
		Average number of months households struggle to get food (no.)	0.2	1.3	0.3	a ***	[32]
		Households who did not save seed (%)	37	34	25	b *	[32]
		Average crop diversification (index)	0.24	0.39	0.37	a ***	[29,58]
		Households with plots with high soil erosion status (%)	8	14	6	b ***	[32]
	Water	Households who reported water conflicts (%)	12.3	3.0	9.3	b **	[31]
		Households who reported lack of consistent access to water (%)	68.5	47	83.7	b ***	[29,31]
		Average walking time to water source (′)	0.09	0.15	0.1	a ***	[31]

Source: Field survey. * $p < 0.10$. ** $p < 0.05$.*** $p < 0.001$. [a] F-statistic and [b] $\chi 2$ test for mean differences "Average Agricultural Livelihood Diversification Index (range: 0.20–1): The inverse of (the number of agricultural livelihood activities +1) reported by a household, e.g., a household that farms, raises animals, and collects natural resources will have a Livelihood Diversification Index = 1/(3 + 1) = 0.25; Average Receive: Give ratio (range: 0–15): Ratio of (the number of types of help received by a household in the past month + 1) to (the number of types of help given by a household to someone else in the past month + 1); Average Borrow:Lend Money ratio (range: 0.5–2): Ratio of a household borrowing money in the past month to a household lending money in the past month, e.g., if a household borrowed money but did not lend money, the ratio = 2:1 or 2 and if they lent money but did not borrow any, the ratio = 1:2 or 0.5; Average Crop Diversity Index (range: >0–1)a: The inverse of (the number of crops grown by a household +1), e.g., a household that grows wheat, maize, beans, and barley will have a Crop Diversity Index = 1/(4 + 1) = 0.20" (Hahn et al., 2009).

2.3 Results

2.3.1 Vulnerability Indicators

Profiling of livelihood vulnerability indicators was documented and analyzed for the three contrasting agroecological environments. Table 1 presents descriptions and summary statistics of vulnerability indicators used for the development of IPCC-LVI. It highlights the major differences between the three research areas in regards to climate, demographics, livelihoods, and other metrics. These differences allow for analysis and discussion of how livelihood vulnerability may vary in different agroecosystems. Guder had the highest deviation from the rainfall trend (87.1 mm), as compared to Aba Gerima (44.8 mm) and Dibatie (43.4 mm). The highest values for both average minimum (14.6 °C) and maximum temperatures (28.1 °C) were recorded in Dibatie ($p < 0.001$), which also had the lowest SPI and the most drought episodes. Aba Gerima (79.2%) had the highest proportion of households who did not attend school and the highest proportion of households (96.2%) with members who work outside their community. A larger percentage of sampled households in Dibatie (65%) did not participate in natural resource management works ($p < 0.001$) as compared to the other two communities. More households reported chronic illness in Dibatie (49.6%) as compared to the other sites ($p < 0.001$), and Dibatie households reported less contact with the local government offices for any kind of service ($p < 0.001$). Households in Aba Gerima reported more water-related conflicts as compared to Dibatie and Guder, and they also had the highest percentage (37%) of households who did not save seed for the next growing season. Most households in Aba Gerima (95.4%) and Dibatie (91.5%) reported that their own farm was their main source of food, whereas the proportion was lower in Guder (74.2%) ($p < 0.001$). From the participatory rural appraisal, communities in all three watersheds were able to bring two new indicators to be used as part of the overall IPCC-LVI. These indicators were environment related indicators; namely, the level of household participation in natural resource management works and the soil erosion status in their farms. These indicators showed significant difference amongst the study watersheds ($p < 0.001$).

2.3.2 IPCC-based Livelihood Vulnerability

In terms of overall IPCC-LVI, Aba Gerima was found to be more vulnerable, with an aggregate score of 0.37 (on a scale of 0 to 1), followed by Dibatie and Guder at 0.35 and 0.34, respectively (Figure 2a). The adaptive capacity of smallholder farmers made the greater contribution relative to the other dimensions in terms of explaining livelihood vulnerability (0.15, 0.14, and 0.13 in Aba Gerima, Guder, and Dibatie, respectively), followed by sensitivity (0.14, 0.12, and 0.13) and exposure (0.08, 0.08, and 0.09) (Figure 2b).

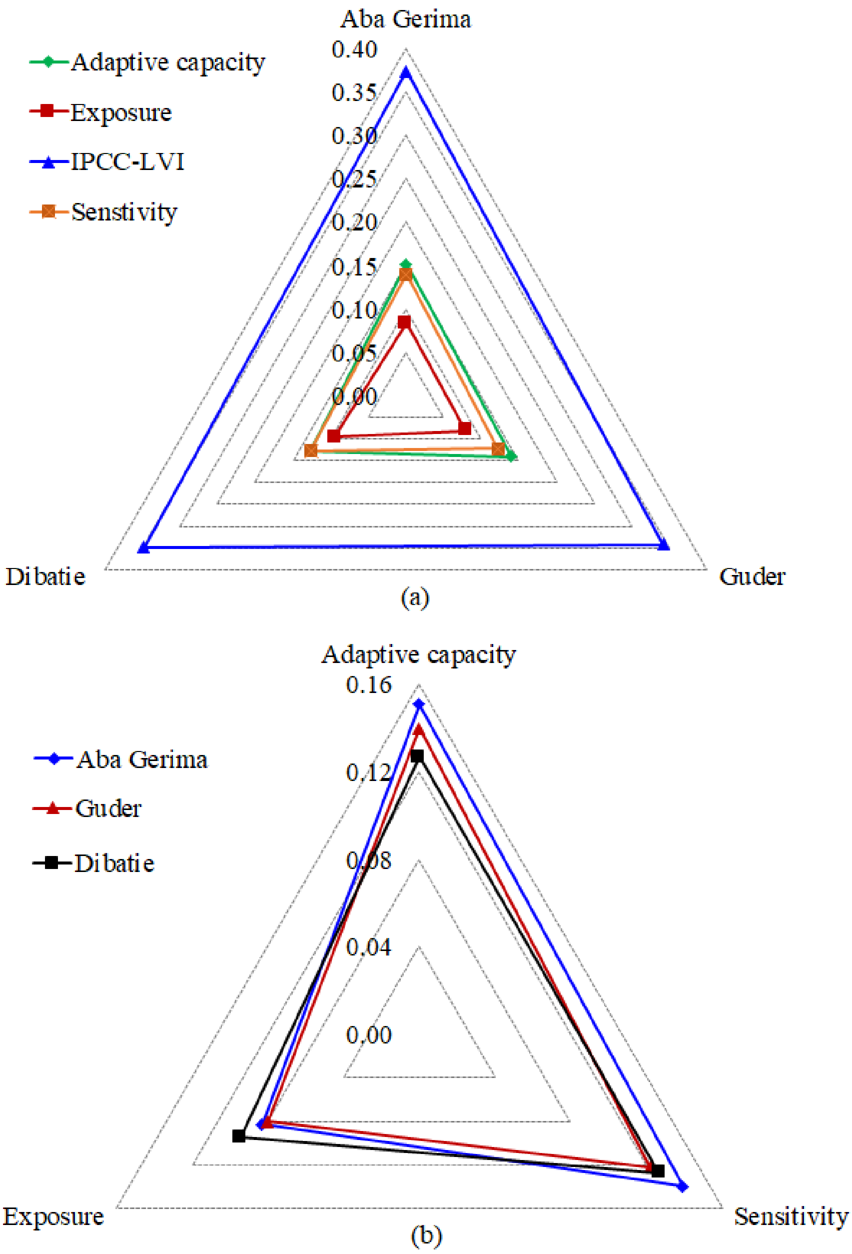

Figure 4 IPCC-based livelihood vulnerability (IPCC-LVI) (a) and its dimensions (b) in the three watersheds.

2.3.3 Exposure to Climate Shocks

Figure 3 shows the climate exposure trends (rainfall and temperature) in the three agroecological areas. In the IPCC-LVI, the exposure score at Dibatie was slightly higher (0.09) than that of both Aba Gerima and Guder (0.08). This dimension was aggregated from rainfall and temperature data, the number of climate-related shocks, household access to warning information about these shocks, and SPI. Although there was no significant SPI trend in the watersheds, there has been recurrent drought episodes at the Dibatie and Aba Gerima sites (Figure 4). Climate variability anomalies, as measured by SPI, made a substantial contribution to the exposure to livelihood vulnerability in Dibatie and Aba Gerima. Conversely, although Guder experienced relatively severe drought episodes in 1984/1985, this watershed has been less vulnerable to rainfall deficits since then. A higher temperature and lack of access to warning information made a notable contribution to the overall exposure in Aba Gerima (Table 1).

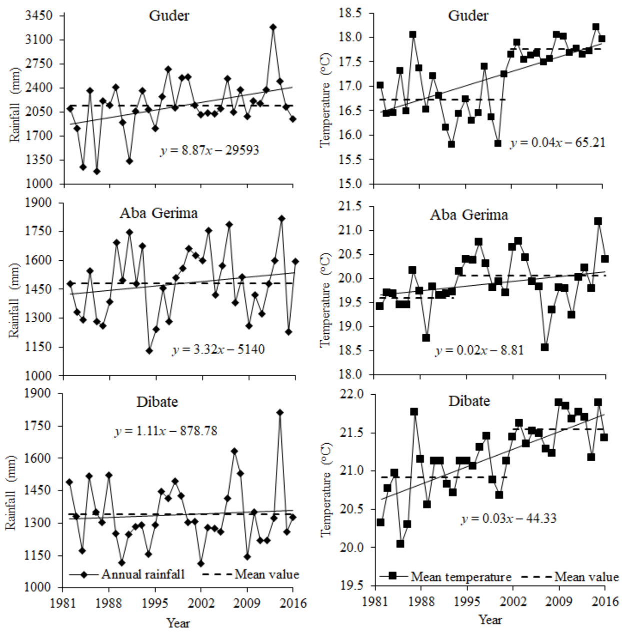

Figure 5 Climate trends (rainfall and temperature) in the three watersheds.

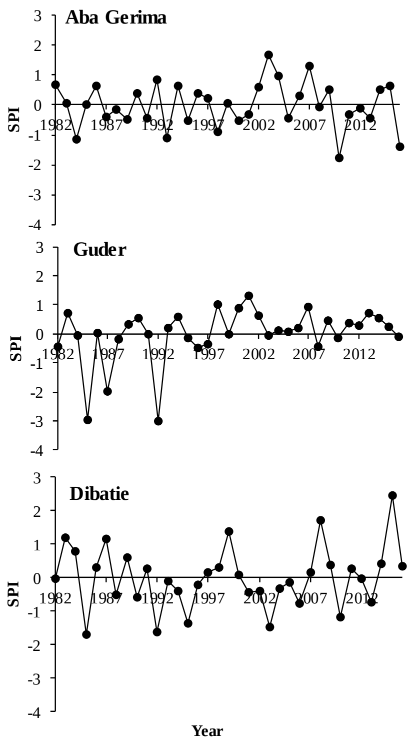

Figure 6 Standard Precipitation Index (SPI) for the three study sites.

The mean annual rainfall of Aba Gerima was 1482.5 mm, with a SD of 178.6 mm and a coefficient of variation (CV) of 12.1%. The value was much higher in Guder (2145.3 ± 395.3 mm, CV = 18.4%) and lower in Dibatie (1339.5 ± 150.1 mm, CV = 11.20%). The average monthly temperature decreased from lowland to highland; that is, in the order Dibatie > Aba Gerima > Guder (Figure 3). Dibatie had more hot years, with the average maximum and minimum ever-recorded temperature of 21.9 °C in 2015 and 20.0 °C in 1985. The average maximum ever-recorded annual temperature in Guder was 18.2 °C in 2015 and the minimum was 15.8 °C in 1993. The Mann–Kendall test showed no significant long-term monotonic trend in the rainfall amount, with Z_c of 1.3, 0.9, and 0.4, for Guder, Aba Gerima, and Debatie watersheds, respectively (Table 2, Figure 3) in the study watersheds. Similarly, Pettitt's test showed strong homogeneity in annual rainfall in the three watersheds, indicating that annual rainfall did not change significantly over the study period (Table 2, Figure 3). Therefore, the null hypotheses H_oa and H_ob for the two tests for annual rainfall in the three watersheds were accepted. In contrast, the watersheds showed a significant increasing trend in temperature during the study period ($p < 0.05$). The Z_c values of 3.92 in Guder, 2.07 in Aba Gerima, and 4.55 in Dibatie confirmed that there were significant changes in annual temperature over the study period (Table 2). The mean annual temperature increased by 0.04 °C per year in Guder watershed, 0.02 °C per year in Aba Gerima, and 0.03 °C per year in Dibatie from 1982 to 2016.

Table 2 Monotonic trend (Mann–Kendall) test and significant change (Pettitt's homogeneity) test for two climate variables (annual rainfall and mean annual temperature time series) for 1982–2016 in three watersheds.

Climate Variable	**Watershed**	**Mann–Kendall Test**			**Pettitt's Test**		
		Zc	***p***	H_0^a	**K**	***p***	H_0^b
Rainfall	Guder	1.30	0.20	A	134.00	0.20	A
	Aba Gerima	0.90	0.30	A	108.00	0.60	A
	Dibatie	0.40	0.90	A	68.00	0.40	A
Temperature	Guder	3.92	<0.0001	R	272.00	<0.0001	R
	Aba Gerima	2.07	0.04	R	172.00	0.03	R
	Dibatie	4.55	<0.0001	R	258.00	<0.0001	R

H_0^a is the null hypothesis that there is no monotonic trend in the time series for annual rainfall or mean temperature; H_0^b is the null hypothesis that there is no significant change in the time series data for annual rainfall or mean temperature (the data are homogeneous). The null hypotheses are accepted (A) or rejected (R) at significance level $\alpha = 0.05$.

The three watersheds experienced drought episodes with varied intensities (Figure 4). For example, 1984/1985, 1992/1993, and 2015/2016 were recorded as drought years of moderate intensity for Aba Gerima watershed, but 2003/2004 and 2007/2008 were very wet and moderately wet years, respectively. Guder and Dibatie also experienced severe drought in 1984/1985 and1992/1993, but 2001/2002 was very wet. Dibatie also experienced drought in 1994/1995, 2003/2004, and 2010/2011. Except Guder, the MK trend test showed a decrease in SPI values across two other watersheds, suggesting a frequent drought incidence at a 3-month (Ethiopian summer) time scale, but there was no statistical evidence of any positive or negative trend. However, we can still justify that there have been recurrent drought episodes in Dibatie and Aba Gerima sites.

2.3.4 Sensitivity

Aba Gerima had the highest score for the sensitivity dimension of the IPCC-LVI (0.14), followed by Dibatie (0.13) and Guder (0.12) (Figure 2). Combined across all three watersheds, the food component had a higher score than the water and health components (Figure 5), particularly in Guder (0.07). Crop diversification (0.03) and on-farm food source (0.02) were the main contributors among the five indicators that made up the food component. In Aba Gerima, reliance on on-farm agriculture (0.03) and a low tradition of saving seed (0.01) substantially contributed to the overall sensitivity score. Compared to Aba Gerima (0.006) and Dibatie (0.007), Guder had a lower level of lower crop diversification (0.028). Guder also had a relatively low contribution from the health component (0.025) as compared to Dibatie (0.042) and Aba Gerima (0.048). In addition, inconsistent access to water (part of the water component) played a relatively higher role in Dibatie (0.025) and Aba Gerima (0.021) relative to Guder (0.014).

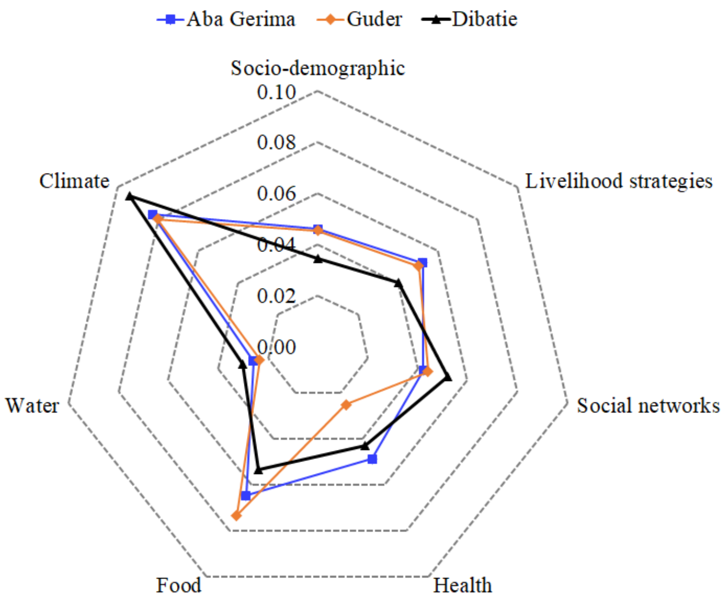

Figure 7 Contribution of major components to the overall IPCC-LVI in all watersheds.

2.3.5 Adaptive Capacity

A slightly higher vulnerability due to lower adaptive capacity was revealed in Aba Gerima (0.15) as compared to Guder (0.14) and Dibatie (0.13). The livelihood strategies component had the highest contribution (0.052) in Aba Gerima, followed by the sociodemographic (0.046) and social networking (0.042) components. Overall, literacy status (0.024) contributed the most to aggregate adaptive capacity, followed by age (0.0173) and livestock ownership (0.0171). In

Guder watershed, low adaptive capacity was attributable to households' restricted options for livelihood strategies (0.050) and low sociodemographic characteristics (0.040). Social networking (0.052) had the greatest contribution in Dibatie, but a lack of contact with the local government office (0.024) contributed to their lower adaptive capacity.

2.3.6 Factors Obstructing Adaptive Capacity

Overall, availability of a higher number of dependents, low participation in community-based organizations (CBOs), a higher borrowing-lending ratio, and being a female-headed household were the most important limiting factors for adapting to climate change. In Aba Gerima, the top three indicators obstructing a household's adaptive capacity were the dependency ratio (9.8%), a low degree of participation in CBOs (9.0%), and fewer household members working outside the community (9.0%). In Guder, the main factors were the dependency ratio (9.8%), low participation in CBOs (9.1%), and a higher borrowing-lending ratio (8.9%), and in Dibatie, they were dependency ratio (9.4%), lack of other sources of income (9.0%), and a higher borrowing-lending ratio (8.6%) (Figure 6).

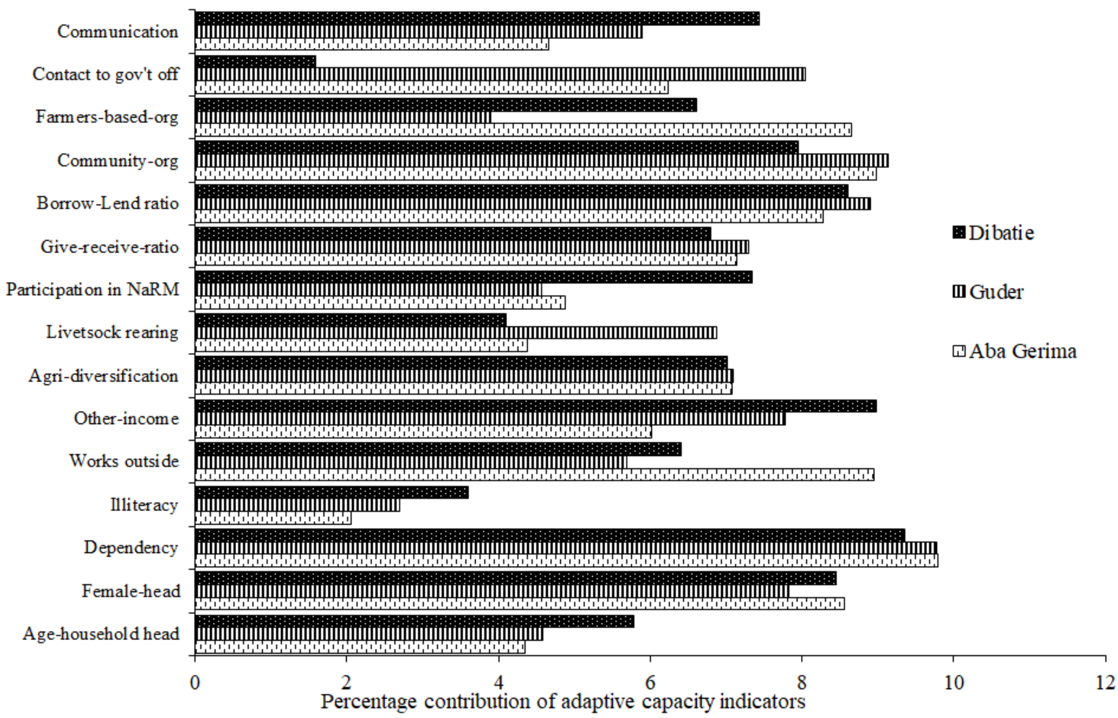

Figure 8 Obstacles and the degree of obstruction in the adaptive capacity of the three study areas

2.4 Discussion

2.4.1 Livelihood Vulnerability Index

Communities in all three watersheds were vulnerable to the adverse effects of climate change variability because of high exposure, high sensitivity, and low adaptive capacity. In relative terms, Aba Gerima (midland) watershed was found to be the most vulnerable and Guder (highland) the least. The total score for Aba Gerima was 0.37, with 0.15, 0.14, and 0.08 contributed by adaptive capacity, sensitivity, and exposure, respectively. Though the findings showed here the relative difference among the study sites and have some methodological and indices differences, studies carried out in Ethiopia was explored in some parts of Tigray and other Ethiopian highlands 0.13-0.48 level of livelihood vulnerability to climate change (Simane et al., 2016; Siraw et al., 2018; Gebrehiwot et al., 2013). The corresponding scores for Dibatie were 0.35, 0.13, 0.13, and 0.09 and for Guder, they were 0.34, 0.14, 0.13, and 0.08. Interestingly, despite the very different contexts on each of the three communities, they showed relatively similar scores in the dimensions of the IPCC-LVI. Conversely, in their national scale study Ferede et al. (2013) noted that the highland part of Ethiopia is more vulnerable compared to other agroecological zones. A possible reason for the two differences could be emanated from the scale of unit of analysis, whereby we used a watershed scale which helped us to gain the necessary details about livelihood vulnerability. Moreover, we also showed that adaptive capacity had relatively higher contribution for the overall livelihood vulnerability compared to its counterparts.

Aba Gerima was found to be the most vulnerable area, mainly because of its limited adaptive capacity and higher sensitivity. The sensitivity may be a result of the area's severe soil erosion status and the fact that households are not sufficiently participating in sustainable land management activities. In the same study area, References (Nigussie et al., 2017b, 2017c) found that the community's lower economic adaptive capacity affected its adoption of natural resource management practices. Ecological indicators such as soil depletion have also been shown to contribute to the vulnerability of village communities in Tanzania and South Africa (Grothmann et al., 2017). In contrast, Guder was relatively less exposed to climate-related shocks. We found few drought episodes and an increasing rainfall trend in this area, so it is possible that communities in this watershed were less exposed to drought episodes and did not experience water shortages. An agroecological-based climate change vulnerability study in the

Ethiopian highlands also found that highland agroecosystems are relatively less vulnerable to climate change shocks (Simane et al., 2016).

2.4.2 Exposure

Although the study area has had increasing rainfall, the trend was not significant at any of the sites. The watersheds studied have a unimodal rainfall pattern, and the rainy months occur mostly during the summer season (usually from mid-June to mid-September). Temperature did show a significant increasing trend at the study sites. Berihun et al. (2019b) also found that station data showed a significant upward trend in temperature but not rainfall in north-western Ethiopia. Moreover, Fenta et al. (2017) also did not observe a monotonic trend in rainfall time series data in Ethiopia, and Teshome (2016) found an increasing temperature trend in the Dembia District in the Upper Blue Nile basin. Furthermore, our findings are in line with other similar studies, which revealed observed trend changes in the Ethiopian highlands and elsewhere, with a mean annual temperature increase range between 0.028 °C and 1.65 °C from 1955 to 2016 (Abebe, 2017; Alemayehu & Bewket, 2017). In contrast, Samy et al. (2019) reported a significant decreasing trend in rainfall in the southwestern part of the Upper Blue Nile basin. SPI results indicated that all the three watersheds were affected by drought episodes in 1984/1985, 1987/1988, 1992/1993, 2000/2001, 2010/2011, and 2015/2016, which is in line with other research results of drought experiences in Ethiopia (T. T. Deressa, Hassan, & Ringler, 2011; Mohammed et al., 2018). Similarly, in their work in the northern part of Ethiopia, Kasie, Adgo, Botella, and García (2018) indicated that household livelihood systems were very much connected to the increment in their income, and this has been hurdled by the recurrent drought episodes (e.g., the 2015 El Niño).

Communities in Guder were found to be less exposed to climate-related shocks in five indicators (mean annual rainfall, mean annual maximum temperature, mean annual minimum temperature, number of shocks, and access to warning information). This could be partly attributed to the fact that the area has received more rainfall than the others (Figure 3). Moreover, despite experiencing drought episodes in 1984/1985 and 1992/1993, the watershed had a positive SPI and an increasing rainfall tendency in the study period. In Ethiopia, rainfall is crucial for predominantly rain-fed agriculture; hence, having more years of normal rainfall and more rainy days means better production and productivity for small-scale farmers (Gao & Mills, 2018). In turn, having better agricultural productivity may enhance the adaptive capacity of the people. This result is in line that of with Simane et al. (2016) who reported that highland agroecological systems were relatively less exposed to the effects of climate variability. Despite the higher amount of rainfall, Guder has had less exposure to soil erosion problems, which could be attributable to the unprecedented expansion of *A. decurrens* plantations across the watershed in the past decade (Nigussie et al., 2017a). The plantations might have helped the watershed by restoring the ecosystem of degraded hillsides and intercepting rainfall (Berihun et al., 2019a). In addition, the contribution of agroforestry to rural livelihood resilience was noted in A. K. Quandt, Neufeldt, and McCabe (2017), who showed the contribution of agroforestry in response to the impacts of climate-related hazards like drought and flooding. For example, during drought, many tree species still produced fruit for household consumption and sale, while staple food crops, such as maize, did not survive.

As compared to Guder and Aba Gerima watersheds, Dibatie watershed has been more exposed to climate-induced shocks and experienced more anomalies in the last 35 years. Despite that this watershed is located in a regional state known for its forest resources, it has been subject to overgrazing, deforestation, and poor farming practices, which has advanced desertification in the Nile basin (UNDP, 2017) (UNDP, 2017). Our findings are not in agreement with those of T. Deressa et al. (2008), who revealed that households in Benishangul Gumuz had experienced fewer numbers of droughts and floods. A possible reason for this difference could be that they did not use station-level data to study vulnerability, whereas our SPI analysis did, and it showed that the area has experienced some types of meteorological and agricultural drought in the past 35 years. The SPI for Dibatie indicated relatively high climate variability, particularly dry spells and a significant increasing temperature trend ($p < 0.001$), which might have had negative impacts on crop production and livestock rearing. Late and untimely rainfall arrival in lowland agroecosystems and/or high temperatures during the crop development stage could cause a decline in yield and increase the community's exposure and ultimately contribute to increased vulnerability (Parry et al., 2007). Rurinda et al. (2014) noted that increased rainfall variability together with rising temperatures reduces soil moisture availability and increases the risk of crop failure.

2.4.3 Sensitivity

The overall sensitivity score, which included the health, food, and water components, was lower than the overall adaptive capacity score for all three watersheds. The food component was the primary contributor in all three cases. A study carried out in Myanmar similarly revealed the food component substantially contributed to the sensitivity dimension of farm households' climate change vulnerability (Oo, Van Huylenbroeck, & Speelman, 2018). A slightly higher sensitivity score was estimated for the Aba Gerima watershed as compared to Guder and Dibatie, which was mainly attributable to its sensitivity to the food and health components. Aba Gerima farmers generally had a lower level of food source diversification, which could trigger enhanced sensitivity. In addition, in Aba Gerima, land is being utilized to expand production of khat, which reduces the amount of land available for food production (Abeje et al., 2019). Moreover, no access to agricultural technology, a high degree of water abstraction from ground water aquifers for khat fields, and higher soil erosion severity also could have played roles in the sensitivity of households in this study site. Similarly, a higher livelihood sensitivity associated with landscape greenness, soil fertility, soil erosion, water availability, pasture availability, and plot condition was reported by Siraw et al. (2018) in the Ethiopian highlands.

Dibatie scored better on crop diversification as compared to its counterparts. Crop diversification should make household livelihoods less sensitive to climate-related adverse effects. The Benishnagul Gumuz region, particularly Dibatie, besides other crops, has a notable tradition of ground nut cultivation (Nega, Mausch, Rao, & Legesse, 2015), which is well known as a drought-resistant crop (Reddy, Reddy, & Anbumozhi, 2003). Dibatie, however, also had a relatively higher contribution from the soil erosion and seed-saving indicators. Ebabu et al. (2018) and Abeje et al. (2019) also reported that this watershed had higher land degradation problems as compared to Aba Gerima and Guder. Guder, representing the highland area, had lower crop diversification and, consequently, is relatively more sensitive to the effects of climate-related shocks. Saving seed for the next growing season is also not often practiced in Aba Gerima and Guder watersheds. This could possibly be related to their shift to the more remunerative cash-based khat plantation and A. decurrens monocropping (Abeje et al., 2019).

Health-related problems made a greater contribution to the sensitivity dimension in Dibatie and Aba Gerima as compared to Guder. Community discussion participants at both of these sites reported that government health services in their proximity do not work properly, and they usually use private health services in the nearest town, which usually costs more than the government services. More household members were reported to miss school due to health problems in Dibatie, which is most likely related to their greater experience with chronic illness. Health problems could result in a shortage of family labour for operating agricultural lands. A similar study in Ghana revealed that the sensitivity of farmers to the impacts of climate variability was partly contributed from their higher exposure, especially in households who do not own enough livelihood capital to support agricultural labour (Williams, Crespo, & Abu, 2018).

The water component comprised consistent water access, water resource conflict, and average time to fetch water. Guder was relatively better off than the other two watersheds, and its lower sensitivity score might be associated with recent improvements in its broader ecosystem, and the presence of *A. decurrens* plantations and other sustainable land management activities (Abeje et al., 2019; Berihun et al., 2019a; Nigussie et al., 2017a). Excessive extraction of water for irrigating khat farmlands could serve as a potential point of conflict among downstream and upstream farmers. Farmers in Aba Gerima reported that they had no consistent access to water sources, and the time it took them to fetch water was longer as compared farmers in the other watersheds. Moreover, the distance from the river to their farms was somewhat longer, which largely limited their ability to irrigate their farms. Whereas irrigation directly minimizes the impacts of climatic stresses such as droughts, farmers at all three sites are at increased risk of water availability due their dependence on natural water sources. A similar study noted a more pronounced livelihood vulnerability to drought in rural Iran, and it was mainly associated with access to water sources (Keshavarz, Maleksaeidi, & Karami, 2017).

2.4.4 Adaptive Capacity

Adaptive capacity plays an essential role in responding to the adverse impacts of climate change/variability, reducing livelihood vulnerability, and helping people to achieve sustainable livelihoods (Jamshed, Rana, Mirza, & Birkmann, 2019). Communities in all three watersheds were significantly less able to adapt to the effects of climate change. A household’s endowment of essential livelihood assets contributes to its adaptive capacity, which ultimately determines its livelihood vulnerability to certain negative consequences. Overall, communities in Aba Gerima were found to be more vulnerable, in a large part because of their low adaptive capacity, which was mainly attributable to limitations in the livelihood strategies and sociodemographic components. These components were, in turn, made up of elements, such as a relatively higher rate of illiteracy, higher age, and lower rate of engagement in livestock rearing. Possible reasons for lower livestock production may be a reduced availability of feed and restrictions on grazing in some parts of the watershed (Nigussie et al., 2018). Their lower engagement in livestock rearing may also be associated with their larger family size and their relative affluence due to their proximity to Bahir Dar city and their greater engagement in the production of cash crops (i.e., khat). In a study conducted in Kenya, livestock diversification was shown to be an important indicator in terms of lowering sensitivity to multiple stresses related to climate change (Unks et al., 2019). Even though the Dibatie (lowland) watershed exhibits a slightly better adaptive capacity as compared to the other two sites, in part because of its better social networking component score, households had little contact with local government offices, which ultimately constrained their institutional adaptive capacity to climate change vulnerability. Government offices are responsible for services related to response to climate-related shocks, such as issuing warnings, training residents about climate-smart technologies, providing information about markets, and delivering inputs. Hence, weaker contact with government offices may negatively affect the provision of these services. In addition, as we learned from the community discussions, most of the interviewed households are not entitled to own land, and thus cultivate land through informal renting arrangements. Land tenure insecurity has been cited as one of the constraints of production and productivity for households in Benishangul Gumuz (Lavers, 2018; Teklemariam, Azadi, Nyssen, Haile, & Witlox, 2016). In addition, effective, timely, and appropriate delivery of climate related warning information is of greater advantage lower levels of administration (e.g., district level) planning and decision making for adaptation planning in the Ethiopian case (Kassie et al., 2013). In a similar study done along the Nile basin, access to climate related information was indicated as a significant driver for household adaptation to the adverse effects of climate variability/change (Di Falco, Veronesi, & Yesuf, 2011).

A lower extent of livelihood diversification contributed to lower adaptive capacity in the Guder and Aba Gerima watersheds, possibly because the wider coverage of *A. decurrens* and khat plantations in these areas reduced the amount of land that could have been used for the production of food crops (Abeje et al., 2019). Climate variability in the form of drought could have more impact on communities with less diversified livelihood strategies (Call, Gray, & Jagger, 2019). A study of weather shocks in Ethiopia indicated that off-farm livelihood diversification enhanced the capacity households to cope with climate-related shocks (Gao & Mills, 2018). A similar study in Kenya revealed that, as part of adaptive capacity, short- and long-term climate change adaptation should be supported by CBOs and enhanced social networking (Dzoga et al., 2018). Communities in Guder showed a relatively high level of vulnerability in terms of participating in farmer-based organizations and a lack of communication devices to receive climate-related information. Rural community awareness on the causes and impacts of climate calamities on their lives and livelihoods can be improved by education. In addition, the more educated community members are, it is highly likely that they will adopt climate smart technologies (IPCC, 2014). Guder had a relatively higher education level, which indicates communities in this area should be more likely to adapt to the effects of climate change. A similar study carried out by T. T. Deressa, Hassan, Ringler, Alemu, and Yesuf (2009) indicated that level of education plays an essential role in terms of choice of climate adaptation strategies and, hence, affects livelihoods. Likewise, low literacy was shown to contribute to higher vulnerability of households in Ghana (Williams, Crespo, & Abu, 2018).

2.4.5 Obstruction Factors of Communities' Adaptive Capacity

A larger number of dependents, low degree of participation in CBOs and FBOs, and lack of contact with the local government were major obstacles limiting community adaptive capacity. Moreover, being a female-headed household, not having other sources of income, and having a shortage of family labour were also major obstacles in all studied watersheds. As climate change/variability puts households under extra pressure, households with a shortage of labour could be more vulnerable by limiting their ability to diversify their income sources or go outside the community for employment. The availability and quality of human capital, including active working labour, has been shown to affect household adaptive capacity to climate change (Burton, Soussan, & Hammill, 2003). A lower degree of participation in community- and farmer-based organizations was a substantial obstacle, primarily because these organizations provide important services to the communities. For example, CBOs include informal social networking schemes where households help each other during periods of social, as well as economic, problems. Social networking essentially reduces a community's vulnerability to the adverse effects of climate change (Adger, 1999). Female-headed households generally have a marginal role in all walks of life and are denied many opportunities, which makes them more vulnerable to the effects of climate change (Nabikolo, Bashaasha, Mangheni, & Majaliwa, 2012). Female-headed households may not have access to social services and information because of socially constructed problems related to inequality, and this could limit their capacity to mobilize available resources to adapt to the negative effects of climate-related shocks them (Deressa et al., 2011, 2009). Similarly, a gender specific study in Ghana revealed that female headed households, due to their low sociodemographic profile, low social network, and lack of access to water and food, were indicated as vulnerable to the impacts of climate change/variability compared to their counterparts(Alhassan, Kuwornu, & Osei-Asare, 2019). Moreover, in Central Nepal, limited access to communication and reliable information on climate related hazards and low participation in local based organizations made female head households vulnerable (Sujakhu et al., 2019).

2.5 Conclusions and Implications

As a consequence of the great heterogeneity in socioeconomic capacity and livelihoods across different communities, similar exposure to climate variability and climate change poses differential impacts on different groups of people at different scales. Rural households in the Upper Blue Nile basin rely on rain-fed agriculture for their livelihoods. This sector is vulnerable and sensitive to the risks and impacts of climate-related shocks/hazards, particularly considering the accumulated negative effects of past droughts. This study aimed to analyze the vulnerability of smallholder farmer livelihoods to climate change/variability in three watersheds of the Upper Blue Nile basin in Ethiopia. We developed and applied a multi-indicator and quantitative methodology that helped show the relative livelihood vulnerability differences among agroecologically different watersheds as a function of exposure, sensitivity, and adaptive capacity. To compute more precise indices, we utilized Shannon's entropy evaluation computation to assign objective weights to the proxy indicators that made up the composite index.

Temperature showed a significant increasing trend over the 35-year study period. Extreme drought episodes were more pronounced in Guder (the highland). In contrast, Aba Gerima (midland) and Dibatie (lowland) experienced more frequent drought episodes. Drought episodes were observed in 1984/1985, 1987/1988, 1992/1993, 2000/2001, 2010/2011, and 2015/2016 in all study watersheds, which is consistent with the national historical record.

In terms of the overall IPCC-LVI score, Aba Gerima was found to be relatively more vulnerable, with a score of 0.37. With similar exposure to climate variability, communities' livelihood vulnerability was mainly attributed to their low adaptive capacity and higher sensitivity to proxy indicators. Guder had the lowest IPCC-LVI score (0.34). Smallholder farmers' adaptive capacity contributed the most, relative to other dimensions, in terms of explaining livelihood vulnerability, with scores of 0.15, 0.14, and 0.13 in Aba Gerima, Guder, and Dibatie, respectively. Dibatie watershed, representing the lowland agroecological setting, had the greatest contribution from the exposure dimension (climate-related indicators) as compared to the other two sites. Results indicated that communities with more diversified livelihood strategies are less vulnerable to the impacts of climate change. The obstruction degree analysis showed that some indicators were turned out to have constrained the adaptive capacity of communities to climate variability effects. These indicators include, but are not limited to the availability of a higher number of dependents and being a female-headed household, low participation in CBOs, lack of alternative income sources, and less engagement in community borrowing and lending cultural practices. In this study, by adopting the Shannon entropy weightage procedure, we tried to address the challenges of subjective measurement of livelihood vulnerability to better inform interventions actions.

Given the predominant rain-fed agricultural system in the Upper Blue Nile basin, enhancing adaptive capacity and mitigating sensitivity should be prioritized to help communities adapt to the adverse impacts of climate change. For example, empowerment of female-headed households (e.g., by improving their livelihood bases, increasing their social role, etc.) will enhance their social position, increase their opportunities, and help reduce their vulnerability. Diversifying livelihood options and food sources will also help reduce sensitivity.

This study has practical implications for agroecological heterogeneous policy development and program design in sustainable livelihood development and climate change adaptation programs. More specifically, it will have practical implications by filling the gap between the broader theoretical aspect of livelihood vulnerability to climate change to the day to day decision making at lower administration and planning scales. In addition, providing sound scientific evidence employing objective weighting and appropriate aggregation procedures will not only further improve livelihood vulnerability analysis methods, but also has practical implications for providing better information in the prioritization of countermeasures to address factors that contribute to vulnerability.

CHAPTER THREE

Multidimensional poverty and inequality: insights from the Upper Blue Nile basin, Ethiopia

Chapter 3. Multidimensional poverty and inequality: insights from the Upper Blue Nile basin, Ethiopia

3.1 Introduction

Goal 1 of the UN's Sustainable Development Goals (SDGs) is to 'end poverty in all its forms everywhere' (UN 2015). This goal not only underscores the importance member states attach to ending poverty but also the importance they place on trying to understand and measure each country's well-being/poverty conditions across all possible facets. Unfortunately, there is no universal agreement as to what well-being is or how to measure it, and empirical studies mainly focus on income or consumption aspects of well-being (Alkire & Santos 2014; Ravallion, 2011). Following Sen's capability approach (Sen 1984), scholars from around the globe have studied the multidimensional construct that poverty encompasses in any given society (Anthony B. Atkinson, 2003; Batana, 2013; Burchi & Rippin, 2018; J. Stiglitz, Sen, & Fitoussi, 2009; Thorbecke, 2008). Several methods in measures of poverty are known to be axiomatic and are extensions of uni-dimensional indices (Alkire and Foster 2011; Atkinson 2003), whereas others use fuzzy-set approaches (Achille & Betti 2006; Martinetti 2005). In an effort to better understand the multidimensional construct of poverty, Alkire and Foster proposed a new method (hereafter the A–F method) that uses a composite index which combines a counting approach with the Foster–Greer–Thorbecke family of poverty metrics (Foster et al. 1984) to satisfy an array of desirable axioms (Alkire and Foster 2011; Atkinson 2003). The United Nations Development Program (UNDP) has replaced the human poverty index (HPI) with the global Multidimensional Poverty Index (MPI), in part because of its wider application and essential novel characteristics (UNDP 2010).

Ethiopia is one of the poorest countries in the world and has chronic problems with drought-prone agriculture (Dercon 2004). Little attention has been paid to the multidimensional nature of poverty in Ethiopia, and only a few studies have applied the A–F method to study the problem (Alemayehu et al. 2015; Brück & Kebede, 2013; Seff & Jolliffe 2017; Tigre 2018; Woldehanna & Hagos 2013). The country has great diversity in terms of climate, landscape and livelihood patterns, and it has been cited as one of lowest-income countries in the world, with a Human Development Index of about 0.435 (UNDP 2014). Moreover, income inequality is apparent in the country, which has a reported (inequality) Gini coefficient of about 0.336 (UNDP 2014). According to a global MPI report for 2018, Ethiopia is second only to Nigeria in the number of multidimensionally poor people in Africa (OPHI 2018). Hence, Ethiopia is an interesting study case to better understand and address the multidimensional nature of poverty.

To date, to the best of our knowledge, no study has tried to combine the use of participatory exercise to select indicators and included agro-ecological divergence when addressing multidimensional poverty in the upper Blue Nile basin in Ethiopia. In an effort to operationalise the MPI, many scholars focused on the issues of poverty cut-offs and weighting structures (Brück & Kebede 2013; Espinoza & Julio 2017; Heshmati & Yoon 2018; Tigre 2018), but relatively little attention has been paid to those affected by poverty and their agro-ecological realities (Campbell 2002; Chambers 1994; Frediani 2007). As noted in many poverty reduction programs, there is considerable divergence among poverty actors operating at different levels in defining what specifically makes up multidimensional poverty. Our goal was to fill in this knowledge gap by using the local villagers' poverty criteria as a basis. To do so, we integrated the use of the participatory exercise and A–F method to study multidimensional poverty measures. The A-F approach has several advantages. It is intuitive and easy to interpret, and it has compelling and desirable properties of decomposability among population sub-groups and across locations (Alkire & Foster 2011; Alkire & Santos 2014). It is also flexible and allows dimensions and indicators to be contextualised. Finally, ordinal indicators can be included, which is commonly the case with multidimensional poverty analysis (Alkire & Foster 2011; Alkire & Santos 2014). The A–F method uses a double cut-off procedure: a deprivation cut-off referring to a threshold value for each indicator and a poverty cut-off encompassing a count of weighted dimensions an individual has to experience to be considered multidimensionally poor (Alkire & Foster 2011). For the sake of comparison and to capture any limitations of the use of MPI as it is believed not to be sensitive to inequality among multidimensional poor individuals, we also applied the Correlation Sensitive Poverty Index (CSPI) (Burchi & Rippin 2018).

Specifically, we explored multidimensional poverty and inequality in three different agro-ecological settings in the upper Blue Nile basin, Ethiopia. The present paper contributes to the literature in several ways. First, despite the many efforts to measure multidimensional poverty in Ethiopia, this is the first to combine agro-ecological differences and household cross-sectional data other than data from the Ethiopian Rural Socioeconomic Survey and/ or Demographic and health survey. Second, to the best of our knowledge, this is the first attempt in Ethiopia to incorporate new indicators into the global MPI to better account for data limitations and use decomposability characteristics to visualise agro-ecological differences.

Third, inequality among multidimensionally poor individuals is addressed. Finally, although the existing literature on income/consumption poverty in Ethiopia is prolific, studies that combine the MPI and CSPI are lacking and this study fills that gap.

The paper is organised as follows. Section 2 describes the methodology we applied to estimate multidimensional poverty and conduct the robustness analyses. Section 3 presents data descriptions, multidimensional estimation results, and comparisons with alternative measures, as well as robustness and sensitivity analysis results. Section 4 presents conclusions and relevant implications.

3.2 Methods

3.2.1 Study area

The study was carried out in three agro-ecologically different sites in the regional states of Amhara and Benishangul-Gumuz in Ethiopia (Fig. 1). The Aba Gerima site is located in the Bahir Dar Zuria District of Amhara in the northwestern part of Ethiopia. This site represents a midland agro-ecological system. Guder, representing a highland area, is situated in Fagita Lekoma District, Amhara, and Dibatie is in a lowland area in Benishangul-Gumuz (CSA 2007). The livelihood of residents of rural communities in these locations is primarily derived from low-input mixed crop-livestock subsistence mixed crop–livestock production system.

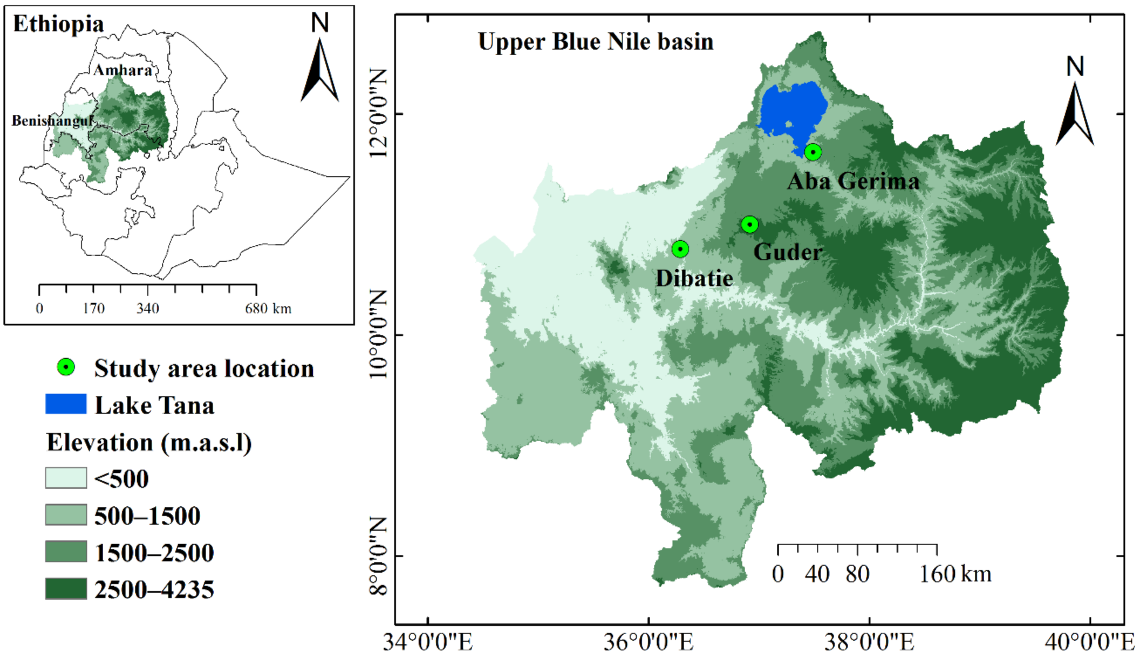

Figure 9 Map of the study area in the upper Blue Nile basin of Ethiopia.

The study areas range from 1479 to 2900 meter above sea level (masl) and from the high- to lowland climatic zones representing three different agro-ecological regions (Dega, Woyena Dega and Kolla) of the upper Blue Nile basin (Table 1) (Nigussie et al. 2017). The major crops grown are maize (Zea mays), barley (*Hordeum vulgare* L.), teff (*Eragrostis tef* Zucc.), wheat (*Triticum aestivum* L.), and potato (*Solanum tuberosum* L.) (Nigussie et al. 2017). Cattle, sheep, goats, donkeys, and horses are the dominant livestock raised.

Table 3 Study area characteristics

Site	Total area (ha)	Altitude (masl)	Average annual rainfall (mm)	Average temp (℃)	Major soil types
Aba Gerima	719	1922–2250	895–2037	13–27	Nitosols, Leptosols
Guder	743	1800–2900	1951–3424	9.4–25	Acrisols, Nitosols
Dibatie	700	1479–1709	850–1200	25–32	Vertisols, Nitosols

The Aba Gerima site is categorised as humid subtropical, Guder is moist tropical, and Dibatie is tropical hot humid (Nigussie et al. 2017; Ebabu et al. 2018) (Table 1). Most farming in these areas is subsistence-based, with some farmers having additional sources of non-farm or off-farm income. Recently, farmers in Guder and Aba Gerima have shifted from croplands to growing green wattle (*Acacia decurrens*) and khat (*Catha edulis*), respectively (Nigussie et al. 2017).

3.2.2 Sampling procedure, data, and data analysis

We followed a two-stage data collection process. First, we conducted a participatory exercise (described below) (Chambers 1994) to identify locally relevant MPI parameters and to study the functional relationships of the global MPI with the demographic and socio-economic characteristics of local households in our study areas. The exercise helped to develop final indicators and dimensions to better understand the local definitions of poverty and wealth (Table 2). Second, on the basis of the participatory discussions and a review of the relevant literature, we developed the final survey questionnaire and administered it to sampled households as described below.

The three sites were purposefully selected to represent their respective agro-ecological settings. As stated by different scholars in participatory wellbeing research, there is often divergence between what is important for the local people and what outsiders think (Narayan et al. 2009). Hence, it is advised in wellbeing research that the importance of indicators should be sensitive to particular socio-economic and cultural setting (McGregor et al. 2015). A typical participatory exercise, for example in Kenya, helped to bring a '*free choice of decision making*' as a locally relevant indicator of wellbeing (Abunge et al. 2013).

Prior to conducting the main household survey, in this particular study, we had to go through a series of steps to identify and define multidimensional poverty dimensions and indicators relevant to our study contexts. We conducted 3 focus group discussions in respective study sites. Our discussions were generally guided by the questions 'what do they [local people] mean when they say "rich", "better off" and "poor"?" and 'what are the indicators they use to define their own deprivations. To overcome some limitations of focus group discussions, we then administered and made a semi-structured individual interview for 21 respondents using a Global Person Generated Index (GPGI) (Camfield et al. 2010; Camfield & Ruta 2007). The GPGI was selected for its desirable property of best scoring locally defined wellbeing indicators (Camfield et al. 2010; Michalos 2014; Rasolofoson et al. 2018). After organizing the dimensions and fine tune the indicators drawn from the participatory exercise, clustering was done on the basis of existing literatures, empirical evidences and the global MPI (Alkire & Foster 2011). The last phase was of weighting their relative importance, due to its essential characteristics of practicability, reliability, empirical and theoretical basis, we used the '*participatory numbers'* method (White 2013). Consequently, a typical pairwise ranking method was applied to weigh up relevant indicators which were thoroughly selected by the participants (Gay et al. 2016). People were given with limited number of domains and facilitated to the trade-off they can make amongst these domains. Following Barahona *et al.* (2003) procedures we analysed the subjects and finally drew their relative weighting.

On the basis of these indicators, we developed a structured questionnaire and conducted pilot surveys (three at each site) to examine the appropriateness of the designed set of questions to selected households. Finally, the household survey was administered following a multi-stage random sampling design.

Altogether, the heads of 390 households were surveyed in the three study locations. Detailed information was collected on a household's key socioeconomic parameters, including demographic characteristics, education, asset holdings, health status, access to water and sanitation, energy sources, income, shocks/stresses, and production and sale of crop and livestock products. Data management and analysis were performed using Excel ver. 13 (Microsoft Co., Ltd., Redmond, WA, USA) and Stata ver. 15.1 (Stata Corp LP, College Station, TX, USA).

3.2.3 Methodology

On the basis of available literature on the MPI and information gathered from the participatory exercise, local indicators and weights were selected to inform our quantitative approach to measuring multidimensional poverty in the sites. A summary of locally defined and later refined (especially as they apply to the global MPI) dimensions and indicators is presented in Table 3.

We used the A–F method to determine the simultaneous deprivation of households relative to different poverty indicators (Alkire & Foster 2011). The method uses the MPI as a composite index to assess poverty; its theoretical premise is based on Sen's argument that the choice of relevant functions and capabilities for any poverty measure reflects a value judgment rather than a technical exercise or the multifaceted indicators and targets set in the Millennium Development Goals (Alkire & Foster 2011). The method was chosen for many reasons, including its axiomatic and decomposable features, its accounting for the breadth of poverty not captured in dashboard-type and other estimates of multidimensional poverty, and its methodological robustness, intuitive characteristics, and growing popularity in the field (Alkire et al. 2015). With the method, we could identify all measures of poverty: incidence, intensity/breadth, MPI (adjusted head count ratio) and inequality (Alkire & Foster 2011). In addition, we were able to explore the composition of poverty in many different subgroups (socio-demographic and location), indicators and dimensions. Finally, the most desirable part of this method is that it is very adaptable to different contexts and purposes, in that different dimensions and indicators can be selected depending on the purpose at hand. As stated by Gaddis and Klasen (2013), unlike income poverty measures, the MPI relies on empirical observations of actual achievements (or lack thereof) in key dimensions of poverty. It is thus less prone to prediction errors. Despite being one of the best methods available to measure multidimensional poverty, the A–F method has been criticised for being insensitive to inequality measures (Burchi & Rippin 2018; Rippin 2016). To address this limitation and add a new perspective for comparison, we estimated the CSPI, which is sensitive to inequality (Rippin 2016). In addition, multidimensional poverty status was evaluated in the context of income quartiles.

3.2.4 The A–F method

The proposed methodology has identification and aggregation stages in which an achievement matrix for each household is created. To begin, let $\boldsymbol{X_{ij}} \in \boldsymbol{R}_{+}$ refer to an indicator's achievement matrix for each individual under consideration, where $i = 1, \dots, n$ represent individuals and $j = 1, \dots, d$ are indicators within the selected dimensions. Let Z_j be the deprivation cut-off of indicator *j* denoting the minimum level of achievement. In the matrix, individual achievements are the row vectors (X_i), while the marginal distribution of achievements are aligned in the column vectors (X_j). The deprivation of individual i in indicator *j* is given as $g_{ij}^0 = 1$ where $X_{ij} < Z_j$, and $g_{ij}^0 = 0$ otherwise. The relative importance of each indicator in defining the deprivation of each individual is weighted by the assigned indicator's weight given by $W = (W_1, \dots, W_d)$ such that $\sum_{j=1}^{d} W_j = d$. The identification stage starts with setting up deprivation matrix $\boldsymbol{g^0} = [\boldsymbol{g_{ij}^0}]$ of which the elements are $g_{ij}^0 = W_j$ if $X_{ij} < Z_j$ and $g_{ij}^0 = 0$ otherwise. The deprivation matrix constructed for each individual identifies who is deprived in which indicator and the indicator's given weight. A deprivation count vector is constructed from the g^0 matrix with vector $C = (C_i, \dots, C_n)$ and its elements$C_i = \sum_{j=1}^{d} g_{ij}^o$. This method follows a double cut-off strategy, where the function is defined as $\rho_k(X_i;\, Z) = 1$ if $C_i \geq k$ and $\rho_k(X_i; Z) = 0$ otherwise. The poverty cut-off is denoted by k, which indicates the proportion of minimum weighted deprivation an individual must experience to be identified as multidimensionally poor. Choices of weights and poverty cut-offs follow a normative value judgement, where $k \in [min(w_j), d]$. As explained in (Alkire & Foster 2011), it should be exposed to a sensitivity analysis to achieve robust findings. For example, a union identification criterion is achieved when $k = min(w_j)$, whereas $k = d$ leads to an intersection criterion. Consequently, Alkire and Foster (2011) advised the use of an intermediate criterion $k = 0.33$, where k could preferably range between 0.33 and 0.50. Once a deprivation score and poverty status were computed for each individual, the next step was to construct a censored deprivation score matrix where the deprivation of those identified as non-poor is ignored. This guarantees the aggregate poverty measure is insensitive to the achievements of people identified as non-poor. A censored deprivation matrix is defined as $g_{ij}^{0}(k) = g_{ij}^{0}$ when $C_i \geq k$ and $g_{ij}^{0}(k) = 0$ otherwise. Analogously, the count censored deprivation score vector is defined as $C_i(k) = C_i$ when $C_i \geq K,$ and $C_i(k) = 0$ otherwise. In the aggregation stage, we computed the adjusted head count ratio (M_0) measure of poverty, which refers to the proportion of population (H) who are poor and the degree to which they are deprived given the set of deprivation indicators (I). By adjusting the incidence of multidimensional poverty by intensity, M_0 (which is the product of the two) satisfies dimensional monotonicity. This means that, if a poor individual becomes deprived in an additional indicator, M_0 will increase by definition. M_0 is computed as follows:

$$M_0(X;Z) = \frac{1}{nd}\sum_{i=1}^{n}\sum_{j=1}^{d} g_{ij}^{0}(k)$$

Because M_0 is a weighted sum of individual poverty, it is possible to decompose it into two types of sub-indices. First, it can be broken into population sub-groups. Let l refer to the number of intended population sub-groups such that

$$M_o = \sum_{s=1}^{l} \frac{n_s}{n} M_o^{(s)}$$

and the contribution of population subgroup s to the overall M_o is estimated as;

$$C_s = \frac{n_s}{n} x \frac{M_o^{(s)}}{M_0} \text{ for } s = 1, \dots, l$$

where $\frac{n_s}{n}$ and $M_o^{(s)}$ are the population share and the adjusted head count ratio of subgroup s, respectively.

Second, M_o can also be broken down by the indicators that make up the overall poverty level. The percentage contribution of an indicator to overall poverty can be computed as the censored headcount ratio multiplied by its relative assigned weight, divided by the overall M_o measure. It can be denoted as follows:

$$M_o = \sum_{j=1}^{d} \left(\frac{w_j}{d}\right) h_j(k)$$

The contribution of an indicator j to the overall M_o is

$$C_j = \frac{w_j}{d} \times \frac{h_j(k)}{M_o} \text{ for } j = 1, \dots, d$$

where $h_j(k)$ represents the censored head count ratio of indicator j. There is a relatively high (or low) deprivation in an indicator when $C_j/\left(\frac{w_j}{d}\right)$ deviates severely from one (Alkire and Santos 2014). In addition, the dimensional contribution to poverty can be obtained by simply summing C_j within a particular dimension. Moreover, in the present study, we calculated inequality among multidimensionally poor households and disaggregated it by location. We used a separate decomposable inequality measure that makes use of a positive multiple variance to determine inequality deprivation counts among the poor (Seth & Alkire 2014). The separate inequality measure was calculated as follows:

$$I_q = \frac{4}{q} \sum_{i=1}^{q} [C_i(k) - A]^2$$

where I_q represents the separate inequality measure among poor individuals and across sub-groups, q is the number of multidimensionally poor households, and C_i stands for the deprivation score of each household on each indicator. k is the poverty cut off and A is the breadth of poverty. To overcome the previously discussed limitations by Rippin (2016), we calculated the CSPI for comparative purposes. This method is sensitive to inequality among the multidimensionally poor population and uses a union criterion procedure to identify the poor. CSPI can be computed as follows:

$$CSPI = \frac{1}{n} \sum_{i=1}^{n} \sum_{j=1}^{d} \left(w_j g_{ij}^{o}\right) 2$$

In addition, we computed income quartiles to evaluate their relationship with the multidimensional poverty status of households in the study areas. Alkire and Santos (Alkire & Santos 2014) recommend conducting a sensitivity analysis for the cut-offs and weighting structure, so we applied cut-off dominance analysis and rank correlation testing varying the cut-off (k) from 1 to 12 and evaluating four additional dimensional weighting structures.

3.2.5 Dimensions, indicators and deprivation cut-offs

For an ideal poverty assessment, dimensions and indicators are best identified and evaluated by poor people themselves (Campbell 2002; Chambers 1994). We shared Sen's (2005) perspective that there should not be a pre-determined ideal list of basic capabilities that defines the target domains of poverty. Consequently, our analysis was based on the notion that the choice of dimensions and indicators should be made by using normative, value-based decision-making (Alkire et al. 2015). On the basis of the findings of the participatory exercise (Table 2) and results from various relevant studies, we selected four equally weighted dimensions as the basic components of capabilities: livestock and land holding, education, health and standard of living (Alkire & Foster 2011; Alkire & Santos 2014; Sen 2000; CSA 2011; Shapiro et al. 2017). We re-affirmed the importance of all indicators in the global MPI and typical proxy correlates of multidimensional poverty were also defined in our study sites (Table 3). These dimensions were subdivided into 12 indicators, all of which have been confirmed to influence the poverty status of households in the upper Blue Nile basin in previous research (Berihun et al. 2013; Hailu & Nagaraja 2017; Maru 2010; Woldehanna & Hagos 2013). Cut-offs were derived from the participatory exercise and other published sources (Alkire & Santos 2014).

Table 4 Summary of major indicators and mapped to the MPI specific to the study sites

Indicators	Significance	Descriptive summary	Mapped/not mapped to MPI
Livestock, including oxen, cows, horse, and sheep	Mentioned in all three sites, usually not ranked first but oxen are usually viewed as the threshold between poor and non-poor. Livestock's importance was majorly discussed in Dibatie site	'If an individual owns a pair of oxen, then he is considered as better off since he is able to farm his own land independently.' If HH owns ≥ 2 cows for milking or ≥ 2 oxen, they surpass the threshold for rich; in Guder, owning ≥ 4 horses or ≥ 4 sheep would be categorised as rich.	Livestock holding could be mapped as one of the indicators because it was mentioned in all three sites.
Land	Mentioned in all sites	Land is the most important productive asset mentioned by participants, especially Dibatie where they reported that it determines their wealth status. In Aba Gerima where ≥ 0.25 ha in irrigated *khat* land would make a huge difference (HH who owns ≥1.5 ha land is considered rich). Land ownership for *A. decurrens*, eucalyptus, and apple cultivation influences the threshold in Guder.	As land ownership was given higher attention in all sites, it was mapped to the MPI
Corrugated steel roof	Mentioned in all three sites	HHs with ≥50 corrugated sheets are thought of as rich and those with none are poor.	HHs with no corrugated steel roof panels are identified as poor. Mapped to the MPI
Does daily labour, rents house, has no land and no livestock	Mentioned in all three sites	These are the poorest households, and they were mentioned in all sites.	Those livelihood means identified by HHs weren't not taken as part of the MPI, but land livestock were mapped
Vehicle ownership	Mentioned in Guder only	Richer HHs have some form of transportation.	These were not mentioned at every site, so this category was not included.

HH=household; the table only summarizes most important indicators discussed before weighting

The dimensions, the indicators used to measure them, and the respective deprivation cut-off levels are presented in Table 3. Our participatory exercise results showed that land and livestock are the most essential assets rural households own for supporting and upholding their livelihoods, a finding that has been confirmed by several studies in the region (Burns and Bogale 2010; Gorfu 2016; Shapiro et al. 2017; Tegebu et al. 2012). Households were considered to be deprived if they don’t own any agricultural land or livestock (at least 1 ox or 1 horse or at least 2 goats, 2 sheep, or 10 chickens) (Table 3). Very recently, this dimension has gained special attention as crucial productive assets in a new effort to align MPI with SDGs (Alkire & Jahan 2018).

According to Sen (2000), household education level contributes to capability deprivation. In rural households, education plays an important role by increasing income potential and improving well-being via a better standard of living. Education also serves a larger role in enhancing democracy, equality, justice and freedom (Alkire & Foster 2011; Robeyns 2006; Stiglitz 1999). Deprivation in the education dimension was measured by indicators of current school attendance, years of schooling and adult literacy.

In Ethiopia, including in the study areas, children are supposed to attend school beginning at the age of 7 years (Schaffner 2004). In addition, the Government of Ethiopia has a specific national early childhood education policy (Astatke and Kassaw 2017). Therefore, a household was deemed to be deprived in education if it had school-age children who were not currently attending school. This indicator does not address the quality (in terms of skill and knowledge) of the educational experience, but as explained by, Alkire & Seth (2009) it is the only option available in terms of measuring children’s exposure to learning exercises in developing countries. Moreover, the use of this indicator is supported by a well-established literature that has pointed out the benefits of early childhood education (Campbell et al. 2014; Jiao et al. 2017).

Similar to the global MPI, we set a threshold of 6 years of schooling for adults (Alkire et al. 2015). We considered every adult in a household and compared their years of education to the threshold. Consistent with the global MPI, the entire household is considered deprived if no household member has completed 6 years of education. We also considered adult literacy, such that a household was deemed to be deprived if there was at least one illiterate adult in the household.

Health was included in three out of eight Millennium Development Goals and very concrete targets were set. Later, Goal 3 of the SDGs signified how important health is to household well-being (Alkire & Jahan 2018; UN 2013). Even though health has been cited as the most difficult dimension to measure (Alkire & Santos 2014), it has consistently been noted as one of the most important dimensions of well-being and plays a dominant role in the capability approach (Sen 1999; Stiglitz et al. 2012). Because of data constraints, we deviated from the global MPI and used two indicators to measure the health dimension: overall health status of the respondents and the ability to pay for chronic illness (i.e., pay health-care costs). These indicators are admittedly not as comprehensive as, for example, the body mass index (BMI) in terms of being an informative indicator of the health dimension (Alkire and Santos 2014). A household was considered deprived if a member reported that his or her health status had not improved in the past five years and non-deprived otherwise. Many studies have noted the importance of overall health status and health-care costs as proxies for well-being (Ali 2014; Balcha 2016; Bilal et al. 2011; Bradley et al. 2012; Nada 2007). Here, due to the inaccessibility of health facilities in proximity to the rural community, the health cost burden to the government and the community is huge (Helmut 2014; Mebratie et al. 2015; Zergaw et al. 2002).

Living standard as a dimension refers the function of materials, goods, necessities and wealth that a household as a socio-economic unit needs to lead a ‘decent’ life. Standard-of-living (sometimes referred to as quality-of-life) indicators are therefore related to these functions; that is, they represent the means rather than ends. As noted by Sen (1984), living standard, as an essential part of human existence, refers to the freedom associated with material capabilities. As with the global MPI, we included this dimension because it is an essential part of human well-being. Similar studies conducted in developing countries have shown that this is the most dominant indicator of multidimensional poverty (Alkire and Santos 2014; Espinoza and Julio 2017). As a proxy for this essential dimension, we adopted almost all of the indicators from the global MPI, except those related to household safety.

From the community participatory exercise, we determined that the type of roof better explains the well-being status of rural households than floor materials (which actually do not vary that much across wealth status). Therefore, for this indicator, households who own homes with galvanized steel roofs were regarded as non-deprived and those who have roofs made of other materials (e.g., thatch or any other roof types) were deemed to be deprived.

Other indicators were access to electricity, cooking fuel, clean water, sanitation, and various household assets, all of which are closely related to the functions needed to help attain a better quality of life (Alkire & Santos 2014). Following Alkire and Santos (2014) and SDG Goal 6, households were deemed to be deprived or non-deprived for each indicator based on the deprivation cut-offs defined in Table 3. Households that did not have access to electricity were regarded as deprived. Likewise, if a household used charcoal, firewood, straw or dung as a cooking fuel, we considered it to be deprived. Households were deemed to be deprived if they lacked either private or shared sanitation facilities and their water source was an unprotected well, spring or river/dam/lake/stream. Finally, the standard-of-living dimension includes an asset indicator, which covers ownership of some durable (consumer) goods, and is similar to the one used by the global MPI (Alkire and Santos 2014). A household that does not own more than one of the following assets was deemed to be deprived: a TV, mobile telephone, bike (motorized), motorbike, or refrigerator. In addition, if they own a car or similar vehicle, they were deemed to be non-deprived in this dimension. Because of data limitations, we implicitly assume (as does the global MPI) that 'access to' water, sanitation, electricity and some durable goods implies the effective use of such items and the resulting enhanced well-being. However, we had limitations in addressing issues related to the quality, quantity, availability and even price of the services or goods in many cases (Klasen et al. 2012; Sorenson et al. 2011); likewise, having access to some assets does not ensure control over their use (Brickell and Chant 2010; Ragasa et al. 2013).

Once we selected the indicators, we defined indicator weights and poverty cut-offs to derive the overall indices and sub-indices of multidimensional poverty for each study location. Weights and poverty cut-offs were set following established value judgement procedures (Alkire and Foster 2011; Alkire and Santos 2014). We adopted an equal weighting scheme from the A–F method in which a relative weight of 1/4 was assigned to each of the four dimensions. Within each dimension, equal weights were assigned to each indicator (Table 3). A second cut-off for identification of multidimensional poverty was set at 1/3 (Alkire and Santos 2014). Robustness and sensitivity analyses were done by evaluating alternative weighting structures and poverty cut-offs

Table 5 Dimensions and indicators for the multidimensional poverty analysis

Dimension domain	Indicator	Deprived if…	Relative Weight
Land and livestock ownership	Agricultural land livestock ownership	Does not own any agricultural land or livestock (at least 1 ox or 1 horse or at least 2 goats, 2 sheep, or 10 chickens)	1/4
Health	Improvement of health	In the last 5 years, household health conditions haven't improved	1/8
	Health cost	Doesn't have the ability to pay for serious/chronic illness	1/8
Education	Adult illiteracy	Presence of at least one illiterate adult in the household	1/12
	Highest grade obtained	No household member who is 13 years old and above has completed six years of schooling	1/12
	School attendance	Any school-age child in the household that is currently not attending school during the current academic year	1/12
Living standard	Electricity access	The household doesn't have access to electricity	1/24
	Sanitation	The household does not have a private toilet whether indoor/outdoor or flush/non-flush and does not have access to a public or shared facility	1/24
	Housing material (roof)	The home roofing material is not galvanized steel (i.e., it is thatch or other materials)	1/24
	Drinking water safety	The household has no access to; given the water from shallow well, deep well, or tap water is safe or safe drinking water is more than 30 min walking from home roundtrip.	1/24
	Cooking fuel	The cooking fuel is charcoal, firewood, straw, or dung	1/24
	Assets	The household has no at least 1 asset in 1 of the 3 asset categories: access to information (mobile phone or landline, radio, or TV), mobility (bicycle (motorized), motorbike, motorboat, car, truck, or animal wheel cart), and refrigerator	1/24

3.3 Results and Discussion

3.3.1 Aggregate deprivation by indicator

Before identifying the multidimensional poverty status, household's achievement was measured against the deprivation indicators. Fig. 2 shows the deprivation to all identified indicators in three sites. The uncensored deprivation results revealed substantial deprivation differences across indicators and sites (Fig. 2). For example, households in Guder are highly deprived in terms of years of schooling (70%), whereas Dibatie has a higher proportion of people deprived in the adult literacy indicator (72%). In the health dimension, the highest deprivation rates were found in Aba Gerima (81.1%) and Dibatie (77.4%) for health cost. The land and livestock ownership indicator showed the highest deprivation rate (43%) in Dibatie. A possible explanation for this, as it was obtained in our participatory exercise, most households in this area rented land from members of specific ethnic groups who own the land rights in that area.

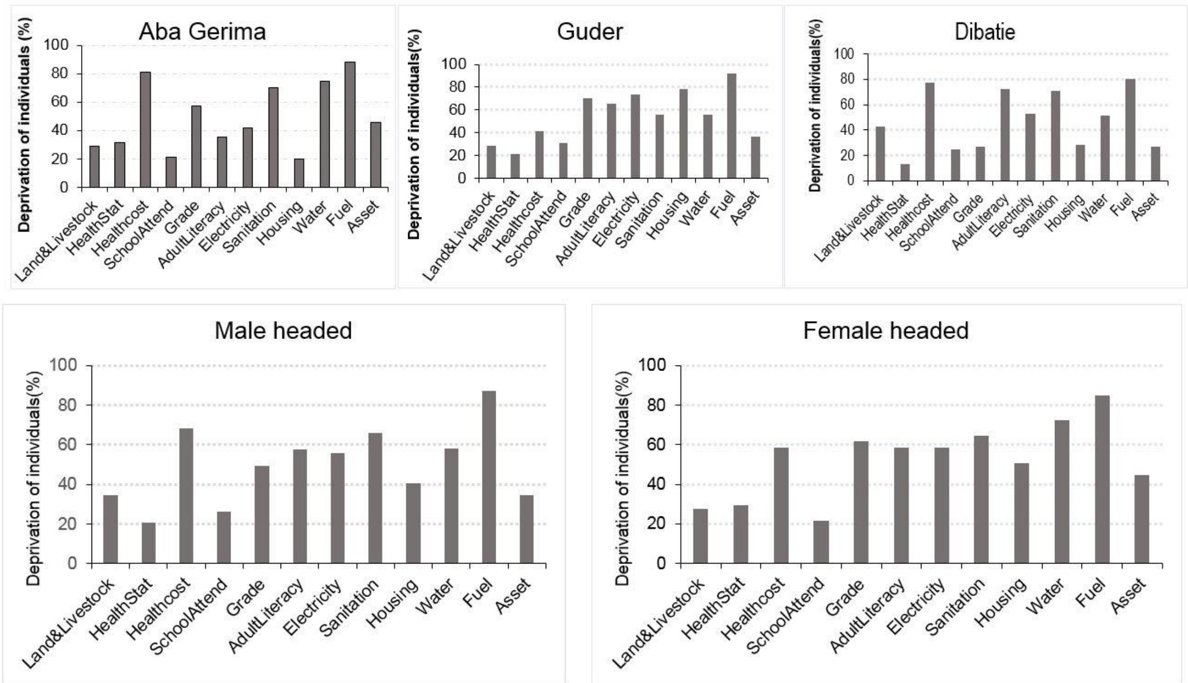

Figure 10 Aggregate deprivation by indicator across location and gender.

Fig. 2 also presents the results for each indicator by gender. We found evidence of a substantial difference in years of schooling between men and women, with female-headed households having a much higher rate of deprivation (62% vs. 49%). Besides, women are more deprived in water access (72% vs 58%). Conversely, male-headed households had a higher rate in the health-care cost indicator (68% vs.58 %). In Table 4, we present some further analysis on the proportion of households deprived in each indicators with their absolute and relative estimates. As can be noted from Table 4, there is no substantial difference in land and livestock ownership (3%) and cooking fuel access (4%) between Aba Gerima and Guder study sites. Conversely, higher difference was estimated between these sites in housing (98%) and adult literacy (84%) where Guder was found to be better in both indicators. When Aba Gerima was compared with Dibatie, overall health status (58%), grade (in years of schooling) (53%) and health care cost (58%) were relatively better in Dibatie whereas Aba Gerima was better in Land and livestock holding (47%) and adult literacy (49%) (Table 4). As can be noted from Table 4, Dibatie site was more deprived in terms of paying for health cost (86%) and Sanitation (25%) compared to Guder site, where as Guder was better in Land and livestock holding (50%) and adult literacy (10%)

Table 6 Proportion of households deprived in various indicators and their agro ecological difference (relative and absolute): Source; Authors' estimates

Indicators	[a]Aba Gerima	[b]Guder	[c]Dibatie	Difference between Aba Gerima & Guder		Difference between Aba Gerima &Dibatie		Difference between Guder & Dibatie	
	Deprivation (SE)	Deprivation (SE)	Deprivation (SE)	Absolute	Relative	Absolute	Relative	Absolute	Relative
Land Livestock	29.13 (0.00068)	28.46 (0.00089)	42.857 (0.00118)	0.67**	0.977	13.72***	1.471	-14.40***	1.506
Health Stat	31.5 (0.00058)	21.54 (0.00069)	13.534 (0.00078)	9.96***	0.684	17.96***	0.43	8.00***	0.628
Health cost	81.1 (0.00086)	41.54 (0.00069)	77.444 (0.00088)	39.56***	0.512	3.66***	0.955	-35.91***	1.864
Grade	57.48 (0.00049)	70 (0.00056)	27.068 (0.0005)	12.52***	1.218	30.41***	0.471	42.93***	0.387
Adult Literacy	35.43 (0.00041)	65.39 (0.00051)	72.18 (0.00052)	29.95***	1.845	36.75***	2.037	-6.80***	1.104
School Attend	21.26 (0.00053)	30.77 (0.0005)	24.812 (0.0004)	9.51***	1.447	3.55***	1.167	5.96***	0.806
Electricity	41.73 (0.00021)	73.85 (0.00027)	52.632 (0.00023)	32.11***	1.77	10.90***	1.261	21.21***	0.713
Sanitation	70.08 (0.00027)	56.15 (0.00026)	70.677 (0.00026)	13.93***	0.801	0.60***	1.009	-14.52***	1.259
Housing	19.69 (0.00027)	78.46 (0.00028)	28.571 (0.00024)	58.78***	3.986	8.89***	1.451	49.90***	0.364
Water	74.8 (0.00028)	56.15 (0.00025)	51.128 (0.00022)	18.65***	0.751	23.66***	0.684	5.03***	0.91
Fuel	88.19 (0.00035)	92.31 (0.00034)	80.451 (0.00027)	4.12***	1.047	7.74***	0.912	11.86***	0.872
Asset	45.67 (0.00021)	36.15 (0.00022)	27.068 (0.00022)	9.52***	0.792	18.60***	0.593	9.09***	0.749

Deprivation= Deprivation by indicators, standard errors (SE) were estimated following the bootstrap estimate of the standard error proposed by Efron (1981), with 1000 stratified bootstrap replications. Significance levels= *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

3.3.2 The incidence and intensity of multidimensional poverty

We estimated the overall multidimensional poverty measures for all study sites combined and measures for incidence, intensity and inequality. Our results revealed that the multidimensional head count ratio (*H*) (the proportion of multidimensionally poor population), the deprivation share across the multidimensionally poor (*A*), the estimated adjusted head count ratio (M_0) (which entails both the percentage of population who are multidimensionally poor (*H*) and the average percentage deprivation experienced by each households (*A*)) and inequality among the multidimensionally poor (*Iq*) were 84%, 50%, 42% and 46%, respectively. There were substantial differences observed among the indicators in terms of their contribution to the overall MPI (Fig. 3). Land and livestock ownership (20.2%) played a major role in determining household multidimensional poverty in these three sites, followed by health-care cost (18%). Conversely, asset ownership and housing material contributed little to the overall poverty index.

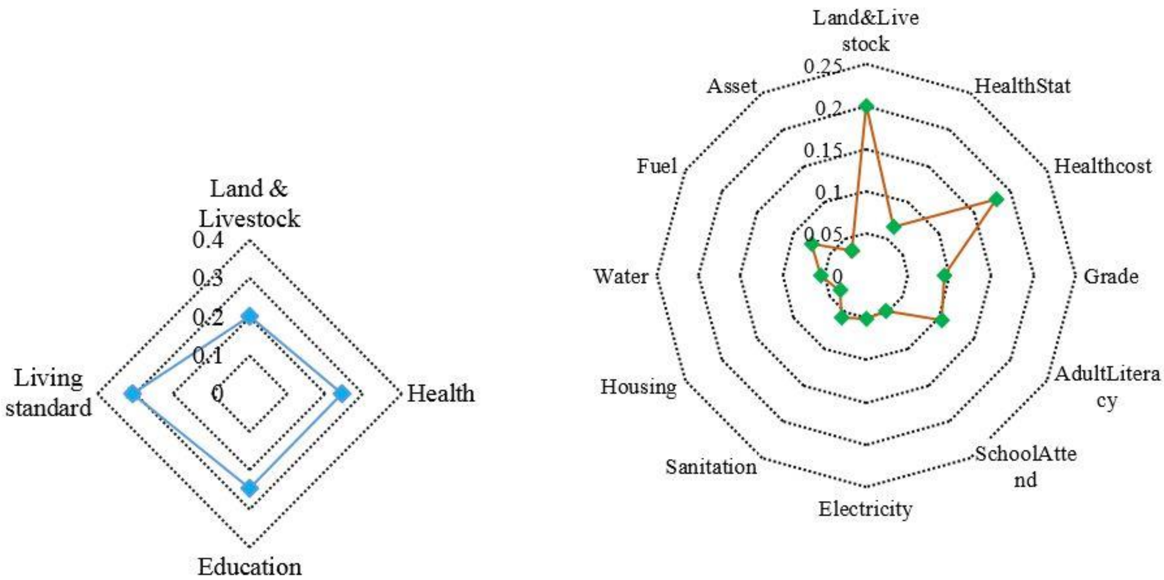

Figure 11 Dimensional (left) and indicator (right) contributions to MPI.

In terms of the dimensional contribution to overall poverty, living standard dominated the other three dimensions (Fig. 3). This result clearly signifies the importance of this dimension (a proxy for quality of life) in determining overall poverty. Similar findings have revealed that the basic elements in this dimension make substantial contributions to overall poverty in many parts of Ethiopia (Ambel 2015; Brück and Kebede 2013; OPHI 2018; Seff and Jolliffe 2017; Tigre 2018; UNDP 2014; University of Oxford 2016).

We present measures of multidimensional poverty for the Aba Gerima, Guder and Dibatie agro ecologically contrasting study sites in Table 4. The highest proportion of multidimensionally poor people reside in Aba Gerima, with 88% of the total sampled households experiencing multidimensional poverty. The incidence was also high in Guder (82%) and Dibatie (80%). For Ethiopia, a relatively similar multidimensional poverty incidence rate (88–90%) was estimated by OPHI (Alkire and Kanagaratnam 2018; OPHI 2015) and others (Seff & Jolliffe 2017; University of Oxford 2016). The values are also closely aligned with the more than 80% MPI estimated by a study of Ethiopian Rural Household Panel Data Survey for the Amhara and Benishangul-Gumuz national regional states (Tigre 2018). In the sampled households, M_o was about 45–46% in all three study sites whereas the University of Oxford (2016) estimated a much higher value (56%) for the entire country. In an assessment of the global MPI for Ethiopia, the Amhara and Benishangul-Gumuz regions (where the study sites are located) were estimated to have a higher MPI (59% and 58.4%, respectively) (OPHI 2015; University of Oxford 2016) (Oxford Poverty and Human Development Initiative, 2017). The measure *A* shows the breadth (or intensity) of poverty in the study areas. We did not observe a substantial difference in this measure; it was 56% at Dibatie as compared to 52% at Aba Gerima and 55% at Guder. In contrast, much higher breadth values were estimated by the University of Oxford (2016): 65.2% for Amhara and 65.1% for Benishangul-Gumuz.

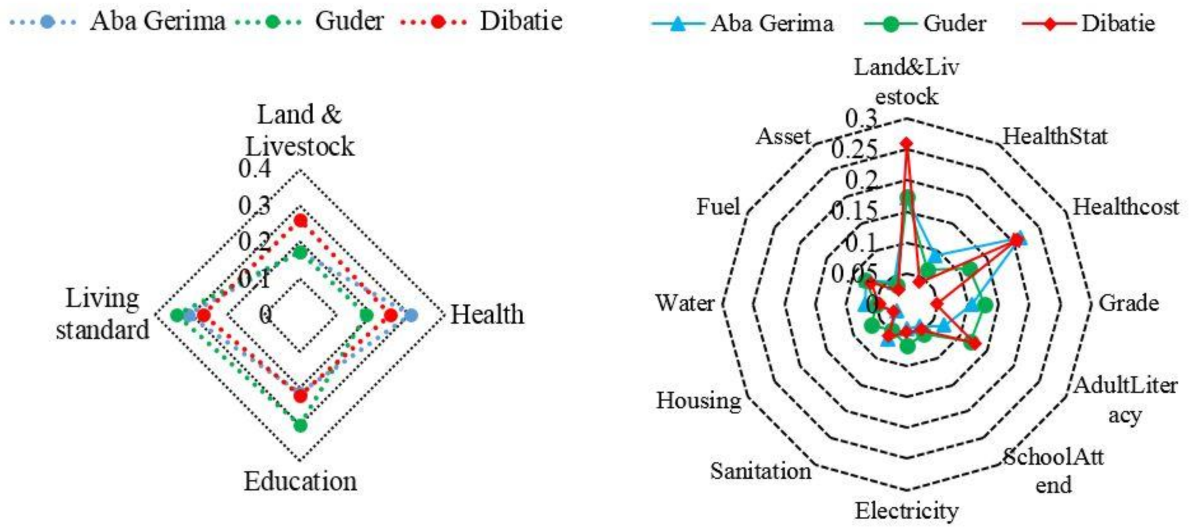

Figure 12 Dimensional (left) and indicator (right) contributions to MPI in the Aba Gerima, Guder and Dibatie study sites

We disaggregated the dimensional and indicator elements of the MPI for the three study areas (Fig. 4) to gain a better understanding of what drives the substantial difference in measures of multidimensional poverty in these locations. As can be seen in Fig. 4, the differences in multidimensional poverty are mostly derived from differences in the living standard dimension, which contributed about 34.3% and 31% for the Guder and Aba Gerima study areas, respectively, but only 27% in Dibatie. The opposite relationship was found for the land and livestock ownership dimension, where Dibatie had a notably higher rate than both of the other locations. A possible reason for the greater relative importance of land and livestock ownership in the Dibatie site might be related to its tenure system, in which 'non-indigenous ethnic groups' do not have land rights (Lavers 2018). The health domain was the second most important contributor in the Aba Gerima site (30.4%), whereas the education dimension (30.1%) was the second highest contributor in Guder. In a tripartite (global MPI) dimension study, several researchers in Ethiopia also found a very high contribution by living standard to overall multidimensional poverty (Ambel 2015; Brück and Kebede 2013; OPHI 2013 2015 2018; Seff and Jolliffe 2017; Tigre 2018; UNDP 2013 2014; University of Oxford 2016).

Fig. 4 also presents the contribution of each one of the 12 indicators. Health-care cost (21.4%) had the greatest contribution to overall multidimensional poverty in Aba Gerima and Dibatie (20.7%). Conversely, the value for this indicator was in about 12% in Guder, which clearly signifies that it is less important to the joint deprivation that households experience at this particular site. The health status indicator was lower in all three areas and varied from 9% in the Aba Gerima site to about 7% and 5% at Guder and Dibatie, respectively. Similar results were found for health indictors in Amhara and Benishangul-Gumuz (Heshmati and Yoon 2018; University of Oxford 2016). Among the education indicators, a much higher contribution was found from adult literacy in the Dibatie and Guder study sites (12.7% and 12%, respectively). Years of schooling was also important at the Guder site (12.6%) and in Aba Gerima (10.5%). With regard to the living standard indicators, access to cooking fuel had relatively equal contribution in Aba Gerima and Guder with 8%, whereas 7% in Dibatie. Electricity access also was a large contributor in Guder (7%). Similar studies in Ethiopia confirmed the relatively higher contribution of this indicator for overall MPI (Heshmati and Yoon 2018; University of Oxford 2016). As essential productive assets in these sites, livestock and land ownership are particularly important to the overall MPI. This indicator far outweighs other individual indicators at the Dibatie site, with a 26% contribution to average joint deprivation. As noted above, this difference might be a result of the land ownership system in Benishangul-Gumuz (Lavers 2018). This indicator also had a large relative contribution in Guder (17.3%) and in Aba Gerima (17.2%).

3.3.3 Inequality among the multidimensionally poor

After aggregating the deprivation levels, we calculated multidimensional poverty inequality measures among the poor in all study locations (Table 5). As far as we know, this has been ignored by almost all studies in Ethiopia. The state of not being multidimensionally unequal was also examined in the three agro ecologically contrasting study sites. Considerable differences in absolute inequality were evident among the multidimensionally poor households in the study sites. The overall gap in inequality was highest in Dibatie site (63%), followed by Guder 60%) whereas inequality was, in relative terms, lowest in Aba Gerima site with 53% of multidimensional poverty inequality. Despite the measures are different, our results are not in line with a national inequality average (37%) measured from relative consumption inequality indices (UNDP, 2014). For illustrative purpose, we also compared our findings with the CSPI, which uses a union approach to calculate the proportion of population who are multidimensionally poor. Hence, no substantial multidimensional poverty incidence difference was observed between the three sites (97–98%) (Table 5).

Table 7 Composite poverty indicators in three agro-ecological study areas

Index	Aba Gerima	Guder	Dibatie	Overall MPI
H	0.882	0.823	0.805	0.836
A	0.518	0.55	0.565	0.497
M_o	0.456	0.453	0.454	0.415
Iq	0.529	0.604	0.633	0.46
CSPI	0.98	0.98	0.97	

H= Average head count ratio, *A*= breadth of poverty, M_{o}=Adjusted head count ratio, or otherwise MPI, Iq= inequality, CSPI= Correlation Sensitive Poverty Index

In the household survey, we also collected income data so that we could compare that data with the estimated MPI values. We classified the income distribution into quartiles for all three sites (Table 6). The bottom quartile generated only 10% of the mean income (5197 ETB) in Dibatie, whereas the lowest contribution was in the fourth and third quartiles for Guder (12%) and Aba Gerima (21%), respectively. The bottom quartile in Guder averaged only 3622 ETB and included 49% of the sampled households, as compared to 12% of the households in the top quartile. The percentage of households in the bottom quartiles at Guder (49%) and Aba Gerima (39%) coincided with higher MPI values in poor households in these areas. Therefore, households with lower mean incomes were found to also be worse off in terms of the multidimensional poverty indices. A similar result was found in a study in Indonesia (Hanandita & Tampubolon 2016). However, this was not the case for Aba Gerima, where the high income quartiles were found to be relatively poorer as measured by the MPI (Table 6).

Table 8 Percentage of households identified as multidimensionally poor (Yi = 1) or otherwise (Yi = 0) placed in their respective income quartiles in all sites

Site	Quartile (*N*)	Mean income (*ETB*)	MPI status: N (%)	
			Poor	Non-poor
Aba Gerima	1 (39)	3169	30 (27)	2 (13)
	2 (29)	5756	28 (25)	4 (27)
	3 (21)	10610	26 (23)	6 (40)
	4 (38)	21562	28 (25)	3 (20)
Guder	1 (49)	3622	32 (30)	1 (4)
	2 (35)	4977	27 (25)	5 (22)
	3 (34)	7800	24 (22.5)	9 (39)
	4 (12)	17671	24 (22.5)	8(35)
Dibatie	1 (10)	5197	29 (27)	5 (19)
	2 (33)	8565	26 (24)	7 (27)
	3 (43)	12225	24 (23)	9 (35)
	4 (47)	19189	28 (26)	5 (19)

ETB=Ethiopian birr (currency); *N*= number of households

3.3.4 Gender differences in poverty

Relatively more female-headed households were found to be multidimensionally deprived (89.2%) as compared with their male counterparts (82.5%). Moreover, though not substantial, female-headed households were found to be more MPI poor (43% vs. 41%). A study of multidimensional poverty in Nicaragua found similar results (Espinoza-Delgado & Klasen 2018)

Figure 5 shows the dimensional and indicator results by gender. In terms of dimensional contribution, the living standard dimension had the highest contribution for both female- and male-headed households, but the contribution was slightly higher for female heads of household (34% vs. 30%). In contrast, the contribution from the land and livestock ownership dimension was somewhat higher for male-headed households (21% vs.15%). The contributions from the other two dimensions were almost the same. As far as indicators are concerned, the contributions of land and livestock (21.1%) and ability to pay for chronic illness (18.3%) were higher for male-headed households, but all of the other indicators were remarkably similar.

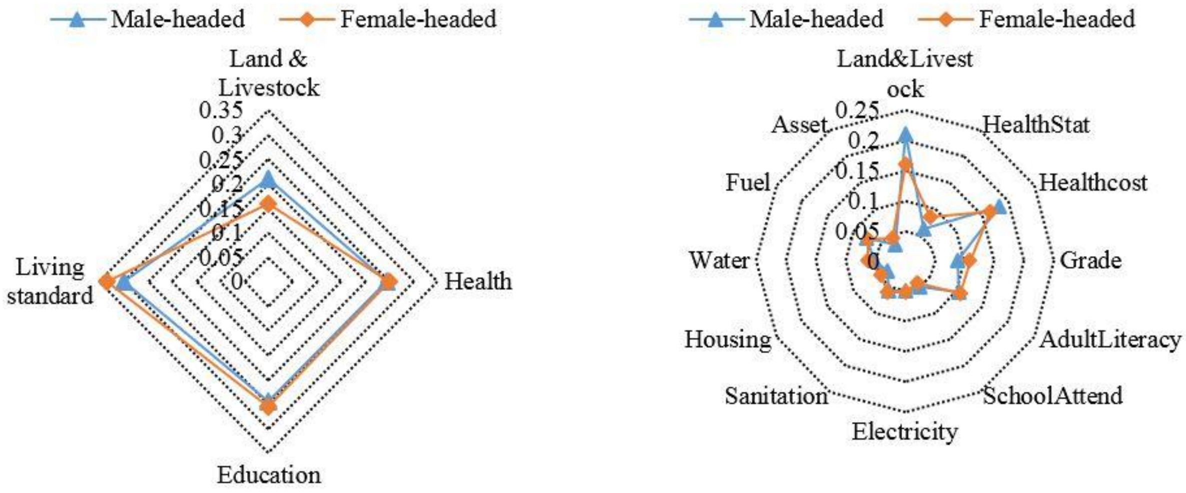

Figure 13 Dimensional (left) and indicator (right) contribution to overall MPI by gender

3.3.5 Vulnerability and severity of multidimensional poverty

Vulnerability to multidimensional poverty, which specifically refer to the percentage of the population that experiences 20–33.33% of weighted deprivations were also estimated. In this particular study, we present the proportion of the population that is vulnerable to poverty in each locations. Even though Aba Gerima had the highest percentage of multidimensionally poor population, only 9% of the population was identified as vulnerable, whereas 14% and 16% of households were found to be vulnerable to poverty in Dibatie and Guder, respectively. We also calculated the proportion of the population who are deprived in 50% or more of the indicators (which is technically called severe poverty). Although Guder had the highest percentage of multidimensionally poor vulnerable households when the poverty severity cut-off was set at 50%, it showed lower percentage of population in severe situation. Whereas, Dibatie with the lower proportion of population who are multidmensionally poor population turned out to have more severe population with 44%. Moreover, in Aba Gerima 40% of sampled households were found to suffer from severe multidimensional poverty.

Our results revealed that fewer female-headed households were vulnerable (17%) as compared to male ones (27%). Female-headed households are generally thought to be poorer for a variety of reasons, including shortage of labour, social discrimination and lack of education. A similar study in Nicaragua found that multidimensional poverty is not feminized as expected (Espinoza-Delgado & Klasen, 2018). Similarly, female headed households were found to be less vulnerable to shocks and stable in consumption compared to their counterparts in Thailand

and Vietnam (Klasen et al. 2010). A possible explanation for this could be when measuring poverty in multiple dimensions, for instance in housing conditions and assets ownership, they were found to be less vulnerable (Rajaram 2009; World Bank 2004; Yuka 2004). Similarly, a lower proportion of male-headed households (27.7%) were in severe multidimensional poverty as compared with female-headed households (43%).

3.3.6 Robustness and sensitivity analysis

Before running the calculations for our MPI, we checked for associations between indicators by using a Spearman's rank correlation matrix and found only very weak correlations between the indicators considered in our analysis (Supplementary Table S1). As it can be seen in the Table S1, we found no to very weak correlation between education and all other deprivation indicators. This could possibly be associated with the return they expect from education at large and also partly be due to the fact that they might have poor academic back ground from their parents (Espinoza-Delgado & López-Laborda, 2017) and their level of education (Belzil & Hansen 2003). Moreover, land and livestock holding was weakly related to other indicators; this might be due to that the fact that it would uniquely contribute to the overall deprivation households in these sites.

Overall, we justified that the candidate variables could contribute uniquely. In addition, we conducted robustness tests to assess how sensitive the ranking of study sites are by MPI are, ceteris paribus, to changes in key parameters (Supplementary Table S2).

The measures of multidimensional poverty and inequality were quite sensitive to modifications in the weighting schemes (Supplementary Table S3). However, the results still shows that how important some new indicators like land livestock holding are important for the study sites. We can also conclude that the relative weight attached to each scheme clearly changes the poverty rankings of the study sites. However, we could still provide concluding evidence that living standard and land livestock ownership were key indicators for explaining the multidimensional poverty in the study sites. Moreover, we carried out a poverty cut-off sensitivity analysis by varying the identification function (Alkire & Seth 2009). Table S2 presents the results of the robustness analysis for the different poverty cut-offs for K-values from 1 to 12 on incidence (H), intensity (A) and MPI and each of the 12 indicators of multidimensional poverty used in this study. As the K value increased, H and MPI each decreased. We therefore concluded that the results for H and MPI are robust as indices of multidimensional poverty conditions in the study area given the chosen identification function. However, the individual deprivation indicators showed little change with increasing *K*-values, signifying that the selected indicators are stable. At *K*=11, MPI was 0, which indicates that there are no more than 11 indicators of typical household deprivation. The findings generally showed small changes in each indicator's contribution as *K* increased. School attendance values were stable up to *K*=6 and then showed a decreasing trend. The ability to pay for chronic illness was also very stable as compared to all the other indicators. Livestock and land ownership and household's ability to pay for chronic illness were consistently the two most important contributors, which is consistent with the results of this study.

3.4 Conclusions and Implications

Poverty analysis in Ethiopia has paid little attention to its multidimensional nature. In this study, we applied the A–F method to understand poverty conditions in three different agro-ecological settings in the upper Blue Nile basin, Ethiopia. We contributed to the existing literature on multidimensional poverty by measuring multiple dimensions at a small scale. This micro-scale study made use of context-specific MPI analysis, which included incidence and intensity of poverty, overall MPI, inequality and contributing factors to MPI. Poverty indicators were selected through a participatory exercise and a literature review. To verify our estimates of multidimensional poverty, we also applied the CSPI well-being measure comparison.

Overall, multidimensional poverty incidence, and inequality were significantly different between agro ecological environments ($P<0.001$). The greatest proportion of multidimensionally poor people was found in Aba Gerima (88%), followed by Guder (82%) and Dibatie (80%). The adjusted head count ratio (M_o), which refers to the proportion of the population who are poor and the degree to which they are deprived for the given set of deprivation indicators, was quite similar in all three areas (45–46%). We also did not observe substantial differences in the intensity (breadth) of poverty: Dibatie (56%), Guder (55%) and Aba Gerima (52%). Results indicated that differences in the incidence, intensity and inequality of poverty in the three study areas were mostly driven by differences in the living standard dimension, which contributed about 34% and 31% in the Guder and Aba Gerima study locations, respectively. A substantially lower contribution was observed at the Dibatie location (27%). For the first time in Ethiopia, multidimensional poverty inequality was also evaluated and considerable differences in absolute inequality were seen in the deprivation scores among the multidimensionally poor households in the study sites. Overall inequality was highest in Dibatie site (63%), Guder (60%) and relatively low in Aba Gerima (53%). We also compared our findings of MPI with those generated with the CSPI approach and found significant differences in terms of the head count multidimensional poverty poor households.

Female-headed households had a higher multidimensional poverty head count as compared to their male counterparts. However, female-headed households were found to be less vulnerable to multidimensional poverty under the highest severity conditions as compared to male-headed households.

Our results vividly show the importance of including long-term welfare indicators, such as those included in our MPI, when analysing poverty to complement conventional poverty measures to better understand poverty and its drivers. More particularly, this study showed that agricultural land and livestock ownership are the most important endowments for small scale farmers in Ethiopia (e.g in our study area) to determine the status of their multidimensional poverty. Hence, given that the global MPI indicators are related to basic services, bringing up some such locally relevant indicators could provide information that can help initiating in-depth studies at local and regional levels for evidence-based and effective policy and program planning. When trying to understand and design anti-poverty interventions, policymakers and researchers should take into account smaller scale contextualised indicators and agro-ecological differences.

CHAPTER FOUR

Exploring drivers of livelihood diversification and its effect on adoption of sustainable land management practices in the upper blue nile basin, ethiopia

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Chapter 4. Exploring drivers of livelihood diversification and its effect on adoption of sustainable land management practices in the upper blue nile basin, ethiopia

4.1 Introduction

Globally, agriculture accounts for 67% of employment, 39.4% of national gross domestic product, and 43% of export goods (FAO, 2015). This sector can continue to be a major source of the world's food and fiber if ecosystem balance is maintained. The world's population continues to grow and is forecast to reach 9.7 billion by 2050 (UN, 2015); the demand for food and livelihood security is therefore a pressing concern of development planners and researchers. This is especially true in Sub-Saharan African countries, where more than three-fourths of the population is essentially dependent on rain-fed agriculture and land degradation is the principal cause of the reduction in production and productivity (Rosegrant, Cai, Cline, & Nakagawa, 2002).

In rural areas of developing countries, households combine diverse portfolios of activities in their pursuit of alleviating poverty and improving living standards (Alobo Loison, 2015; Ellis, 2000b). As defined by Ellis (1998), livelihood diversification refers to the process by which households pool a wide range of activities and social support systems to deal with shocks and improve their welfare. It is recognized as a way to confront the various idiosyncratic risks and shocks that people face (Alobo Loison, 2015). For most smallholder farmers in developing countries, diversification away from agriculture accounts for 30–40% of their overall incomes (Alobo Loison, 2015; Ellis, 1998). A more specific study carried out in Ghana pointed out that livelihood diversification by smallholder farmers prioritize less viable livelihoods attributable to their current food demand, availability of livelihood alternatives and level of entry barriers (Gideon Baffoe & Matsuda, 2017). Diversifying livelihood activities may affect the environment and the natural resource base (Assan & Beyene, 2013; Cordingley, Snyder, Rosendahl, Kizito, & Bossio, 2015; G. W. Kassie, 2017). The use of natural resource-based livelihood sources to increase income and reduce poverty has a two-way cause–effect association with environmental depletion (Cordingley et al., 2015; Daregot, Ayalneh, Belay, & Degnet, 2015; M. Kassie, Jaleta, Shiferaw, Mmbando, & Mekuria, 2013; Kelly and Huo, 2013; Lee, 2005). Rural households' engagement in livelihood activities that increase income, and thus reduce poverty, could have varied effects on the environment (Liu & Lan, 2015). A positive effect could be through the decision to allocate labor away from livelihood activities that exploit natural resources to other, less exploitative, livelihood options. Rural households' engagement in these latter activities may induce less environmental degradation (Ellis, 2000b; Liu & Lan, 2015). On the other hand, although such livelihood diversification could increase the income of the rural poor, it is possible that some related activities could have a degrading effect on the environment, and poor households could end up living in worse conditions (Harcourt & Sayer, 1996; Salafsky & Wollenberg, 2000).

Previous studies related to livelihood diversification focused mainly on identifying its extent and determinants, and examining dominant income sources among sets of livelihood activities (Alobo Loison, 2015; Babatunde, Olagunju, Fakayode, & Adejobi, 2010; G Baffoe & Matsuda, 2015; Gideon Baffoe, Matsuda, Nagao, & Akiyama, 2014; Ellis, 2000a; G. W. Kassie, Kim, & Fellizar Jr, 2017; Martin & Lorenzen, 2016; Rahut, Ali, Kassie, Marenya, & Basnet, 2014). Some of these studies have identified two main types of livelihood diversification: distressed diversification, in which poor households are motivated to address the shocks they are facing (Alobo Loison, 2015; Ellis, 1998; Martin & Lorenzen, 2016; Riithi, Irungu, & Munei, 2015), and progressive diversification, which is mostly regarded as an ex-ante strategy implemented by relatively well-off households (Gideon Baffoe & Matsuda, 2017; Martin & Lorenzen, 2016). According to these studies, livelihood diversification could be motivated by asset ownership, market accessibility, credit accessibility, education, and income, among other factors (Alobo Loison, 2015; Ellis, 1998; Martin & Lorenzen, 2016; Rahut et al., 2014).

In Ethiopia, rural households combine a broad array of livelihood activities, most of which are depend mainly on the exploitation of natural resources and subsistence farming systems (Alobo Loison, 2015; Dercon & Krishnan, 1996; Woldehanna, 2002). In studies conducted in different parts of the country, high population growth, land scarcity among youth, and lack of agricultural inputs and the associated low productivity have all been reported to drive diversification away from agriculture (Asfaw, Simane, Hassen, & Bantider, 2017; Bezu & Holden, 2014; Carswell, 2002; Davis, Di Giuseppe, & Zezza, 2017; G. W. Kassie, 2018). On the other hand, evidence has shown that land degradation in Ethiopia has been profoundly associated with an insufficient regulatory environment, weak institutions, population increase and high population density, the land tenure system (land right to the state), and lack of participation from the local community. Moreover, the proximate causes are believed to be unsustainable agricultural practices, uneven topography, and high fuel-wood consumption (Belay & Bewket, 2013; Deininger & Jin, 2006; Holden & Shiferaw, 2004; Jagger & Pender, 2003; Pender & Gebremedhin, 2007). Therefore, in the context of land degradation and food security problems, the essential role of livelihood diversification in Ethiopia has focused on addressing shocks and enhancing household coping strategies (Berhanu, Colman, & Fayissa, 2007; Block & Webb, 2001; Canali & Slaviero, 2010; Vaitla, Tesfay, Rounseville, & Maxwell, 2012).

Despite the inseparable and practical links between livelihood diversification and sustainability of the farming system in Ethiopia (García-Fajardo, Orozco-Hernández, McDonagh, Álvarez-Arteaga, & Mireles-Lezama, 2016; World bank, 2008), few studies have sought to understand the linkage between these interdependent goals. As in other developing countries, rural households in Ethiopia have been undergoing considerable socioeconomic and environmental transitions in recent years, and this has brought both opportunities and challenges in terms of livelihoods (Escobal, 2001; Kowalski et al., 2016; Vaitla et al., 2012; Woldehanna, 2002; Yona & Mathewos, 2017). As a result, rural households are trying to diversify their household economies to either survive or generate additional income to secure their livelihoods, regardless of the impacts on the natural resource base (Asfaw et al., 2017; Assan & Beyene, 2013; Bezu & Holden, 2014; Carswell, 2000; Davis et al., 2017; G. W. Kassie, 2018). Despite decades of land rehabilitation efforts by governmental and non-governmental organizations that have addressed land degradation and the associated loss of production and productivity, as well as improving rural livelihoods, the efficiency and adoption rates of promoted land management practices have shown mixed results (Adgo, Teshome, & Mati, 2013; D'souza, Cyphers, & Phipps, 1993; Haregeweyn et al., 2015; Schmidt & Zemadim, 2015; Teklewold, Kassie, & Shiferaw, 2013).

Many studies related to sustainable land management (SLM) practices and livelihood diversification have focused either on processes at the farm level (D'souza et al., 1993; Nigussie et al., 2017b; Teklewold et al., 2013) or the extent of adoption as influenced by socioeconomic and behavioral factors (Adimassu, Kessler, & Hengsdijk, 2012; Nigussie et al., 2017b; Schmidt & Zemadim, 2015). With a growing number of alternative non- and off-farm livelihood activities in rural economies, like those available in Ethiopia, little is known about the relationship between livelihood diversification efforts and the extent of adoption of SLM practices. Moreover, some efforts at livelihood diversification seem to have had a deagrarianization effect in some parts of Ethiopia (Bezu, Barrett, & Holden, 2012; WorldBank, 2007). We, therefore, think that looking at the relationship between livelihood diversification and uptake of SLM practices is imperative, because engaging in diverse livelihood activities could be associated more with earning additional income than with sustainable agriculture.

Hence, the main purpose of this study was to elucidate both the motivations that drive rural households to diversify livelihood activities and their probable links with the implementation of SLM practices in the Upper Blue Nile basin of Ethiopia. The specific objectives were to: (1) explore the extent and determinants of household livelihood diversification and (2) investigate the relationship between livelihood diversification and adoption intensity of SLM practices. On the basis of household survey data collected in November and December 2017 from three rural watersheds located in different agro-ecological zones, we analyzed the extent of livelihood diversification by using the Herfindahl–Simpson index and applied a multivariate probit model to estimate the probability of choosing certain livelihood activities. Moreover, an ordered probit model was estimated to determine the effects of livelihood diversification on intensity of adoption of SLM practices.

The rest of the paper proceeds as follows. Section 2 presents details of the methods used and describes the data and summary statistics of the explanatory variables. Our main results and discussion about livelihood diversification and its effect on SLM adoption are presented in Section 3. Concluding remarks and policy implications are discussed in Section 4.

4.2 Materials and Methods

4.2.1 Study Area

This study was carried out in three watersheds of the Amhara and Benishangul-Gumuz national regional states of Ethiopia, in the Upper Blue Nile basin (Figure 1). People in the three study communities in the watersheds, Aba Gerima (in the Bahir Dar Zuria district), Guder (in the Fagita Lekoma district), and Dibatie (in the Dibatie district), primarily make their livelihoods from a mixed crop–livestock production system. The study area ranged from 1479 to 2900 m above sea level and from the highland to lowland climatic zones representing three different agro-ecological regions (Dega, Woyena Dega, and Kolla) of the Upper Blue Nile basin (Nigussie et al., 2017b). The major crops grown are barley (*Hordeum vulgare* L.), teff (*Eragrostis tef* Zucc.), wheat (*Triticum aestivum* L.), and potato (*Solanum tuberosum* L.) (Nigussie et al., 2017b). Cattle, sheep, goats, donkeys, and horses are the dominant livestock raised.

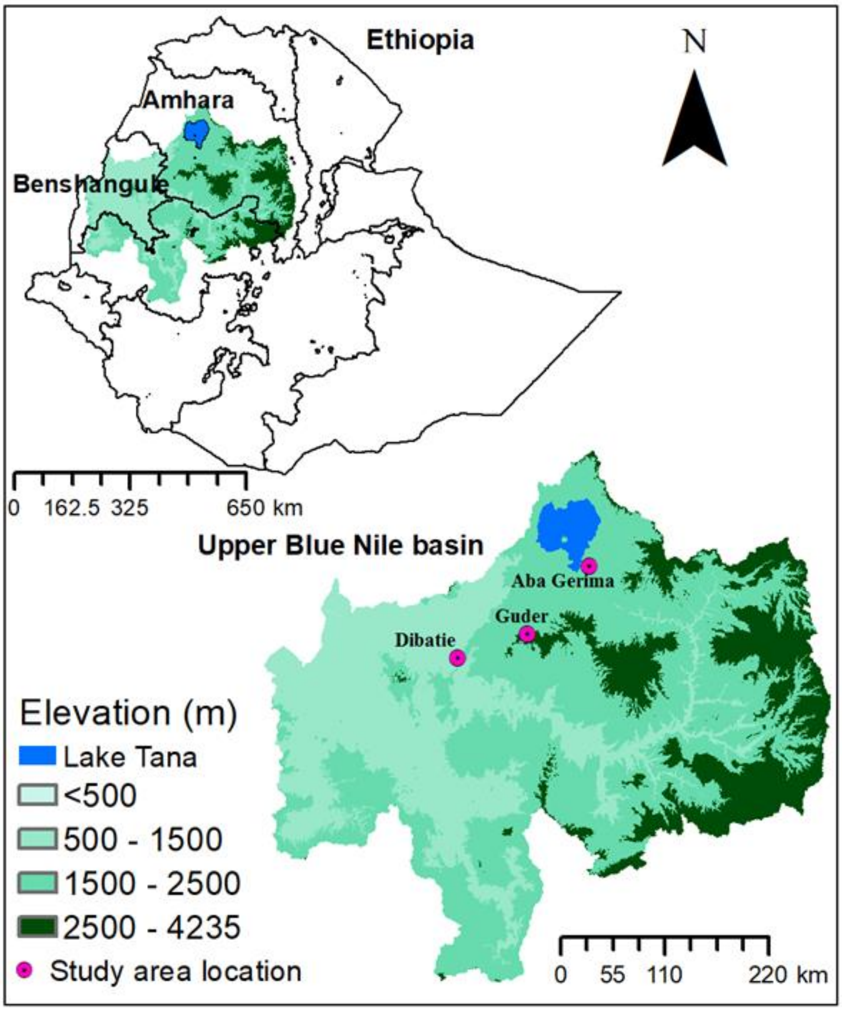

Figure 14 Location map of the study area.

The Aba Gerima watershed is categorized as humid sub-tropical with an annual rainfall of 895–2037 mm; Guder is moist tropical with an annual rainfall of 1951–3424 mm, and Dibatie is tropical hot humid with an annual rainfall of 850–1200 mm (Ebabu et al., 2018; Nigussie et al., 2017b; Sultan et al., 2018). The Swiss Development Cooperation Water and Land Resource Centre in Aba Gerima and the Sustainable Land Management Programme in Guder are notable SLM-related projects in the study areas (Nigussie et al., 2017b). In these watersheds, the majority of farmers have subsistence-based livelihoods with additional sources of non- and off-farm income. In the past decade, most farmers in Guder and Aba Gerima have shifted from growing food crops to growing green wattle (*Acacia decurrens*) and khat (*Catha edulis*), respectively (Nigussie et al., 2017b).

4.2.2 Data Collection

Primary data were obtained from the sampled respondents by using a structured questionnaire to generate quantitative data on household characteristics, socioeconomic parameters, market access, community institutions, and educational levels of farmers through in-person interviews conducted in November and December 2017. The household was the unit of analysis. Sampling procedures are discussed in the next section.

4.2.3 Sampling Procedure, Data, and Data Analysis

To select sample households for the study, we used a two-stage sampling procedure. First, on the basis of their specific experiences with SLM practices and varied biophysical and socio-economic characteristics, three watersheds representing different agro-ecological settings were selected: Guder (highland), Aba Gerima (midland), and Dibatie (lowland). Second, household respondents from each watershed were selected randomly by using a probability proportional to size sampling procedure. To gain a better understanding of SLM practices and socioeconomic conditions in these areas, we held a participatory rural appraisal in which we were able to understand the collective dynamics of socio-economic conditions, livelihood shifts and available opportunities in the watersheds. Before the main survey, 15 questionnaires were administered (five in each watershed) in October 2017 to examine the appropriateness of the predesigned set of questions in the selected watersheds. Finally, the household survey was administered to 270 households. The household survey collected detailed information on key socioeconomic and other parameters such as household demographic characteristics, education, asset holdings, livelihoods, income, shock/stress experience, implemented SLM practices, and membership of formal or informal organizations (Table 1). Data management and analyses were performed by using Stata ver. 14.1 (Stata Corp LP, College Station, TX, USA).

Table 9 Description of the independent variables used in the analysis.

Explanatory Variable	Definition/Description	Scale	Hypothesized Relationship with Livelihood Strategies	Hypothesized Relationship with Adoption of SLM Practices	References
Gender	Gender of household head	Binomial, 1 if male	–	+	(Ellis, 2000a; Nigussie et al., 2017b)
Age	Age of household head	Metric, in years	+	+/−	(Ellis, 2000a; Teklewold et al., 2013)
Grade	Education level of household head	Metric, in years of schooling	+	+	(Ellis, 2000a; Teklewold et al., 2013)
Household size	Number of individuals in household	Metric, in person	+	+/–	(Ellis, 2000a, 2000b; Teklewold et al., 2013)
Dependency ratio	Ratio of household members aged 0–14 and 65+ years to those aged 15–64 years	Metric, in person	+	+	(Ellis, 2000a; G. W. Kassie, 2017)
Distance to market	Distance from home to nearest district market	Metric, in km	+/−	–	(Ellis, 2000a; Teklewold et al., 2013)
Land size	Land size operated by household	Metric, in ha	+/−	+	(Ellis, 2000a; Nigussie et al., 2017b; Woldehanna, 2002)
Tenure	Land ownership or tenure type	Binomial, 1 if owned by farmer	+/−	+	(Bezu & Holden, 2014; Ellis, 2000a; M. Kassie

					et al., 2013; Nigussie et al., 2017b)
Land for food security	Perception of and's contribution to household's food security	Binomial, 1 if yes	−	+	(Bezu & Holden, 2014; Dedehouanou, Araar, Ousseini, Harouna, & Jabir, 2018)
Access to credit	Household received credit	Binomial, 1 if yes	+	+/−	(G Baffoe & Matsuda, 2015; Gideon Baffoe et al., 2014; Ellis, 2000a; Paudel Khatiwada et al., 2017; Teklewold et al., 2013)
Access to extension service	Household received agricultural and non-agricultural extension service	Binomial, 1 if yes	+/−	+/−	(Ellis, 2000a; M. Kassie et al., 2013)
Membership in CBOs	Household is member of local level community-based organizations	Binomial, 1 if member	+	+	(Ellis, 2000a; M. Kassie et al., 2013; Teklewold et al., 2013)
Household income	Total income obtained by household	Metric, in ETB	+/−	+/−	(Ellis, 2000a; Teklewold et al., 2013)
Asset value	Total monetary value of assets owned by household	Metric, in ETB	+	+	(Ellis, 2000a; M. Kassie et al., 2013)
Aggregate stress/shock	Extent of severity of shocks experienced by household during the last 6 years	Metric, in number	−	+/−	(Ellis, 2000a; M. Kassie et al., 2013; WorldBank, 2007)

Livestock size	Livestock size owned by household	Metric, in tropical livestock unit	+/−	+/−	(Ellis, 2000a; Woldehanna, 2002)
Intensification	Intensification achieved by household during the year	Binomial, 1if high	+/−	+/−	(Gideon Baffoe et al., 2014; Ellis, 2000a; Mutyasira, Hoag, Pendell, & Manning, 2018)
Agro-ecology	Study location (agro-ecological zones representing high-, mid-, and lowlands)	Binomial, 1 if Aba Gerima; 1 if Guder; 1 if Dibatie	+/−	+/−	(Ellis, 2000a; Teklewold et al., 2013)

4.2.4 Empirical Model

Respondents were asked to indicate the household's major livelihood activities according to six categories; crop production, livestock production, charcoaling, khat cultivation and daily labor. A related question on the amount of income derived from each livelihood activity over the past 1 year gave us additional means to understand livelihood structures at the household level. In accordance with past studies (Berjan et al., 2013; Ellis, 1998; G. W. Kassie et al., 2017), we classified livelihood activities as on-farm livelihood activities comprising crop and livestock production, off-farm activities (which included earning wages for work on other farms), non-farm activities where income was earned from non-agricultural sources, and self-employment. We also included petty (minor) trading, beverage making, charcoal making, housing rental, and formal and informal transfers. We then calculated the income share of each livelihood activity carried out by the household in a given year, as follows:

$$S_i = \frac{q_i}{\sum_{i=1}^{n} q_i} \quad i = 1,2,\dots,n \tag{1}$$

where n represents the number of livelihood activities, q_i is household income from activity i, and S_i is the share of livelihood activity i in a given household in 1 year.

To identify the most remunerative livelihood strategies, we evaluated the variabilities in returns from various livelihood strategies by using stochastic dominance analysis (Buckley, 1986). In addition, the cumulative per capita annual income densities for major livelihood strategies were plotted to approximate the income distribution of households engaged in each livelihood strategy. As noted by Buckley (1986), a typical livelihood strategy first-order stochastically dominates another livelihood strategy when it has a lower cumulative density, thereby proving that households are drawing higher incomes from that strategy. Hence, taking each livelihood activity's income distribution, we were able to test for stochastic dominance. One Way Analysis of Variance (ANOVA) was used to test the differences in livelihood income shares. Moreover, the chi-squared test was used for understanding the difference in households livelihood opportunity choices.

To understand the extent of livelihood diversification, we adopted the Herfindahl–Simpson diversity index, which is commonly applied in ecological and marketing research (Johny, Wichmann, & Swallow, 2017; Nagendra, 2002). Although there are many different diversity index methods, this measure of index enable us to use the degree of diversification as a measure of the size of each livelihood activity in relation to its containing groups (in our case, a household's total income), while assessing the activity's diversification and dominance at the same time (Ellis, 1998, 2000a; Khatun & Roy, 2016). In accordance with the methods of Djido and Shiferaw (2018), the indices were calculated by using the following formula:

$$HHI_i = 1 - \sum_{i=1}^{n} S_i^2 \tag{2}$$

where HHI_i is the Herfindahl–Simpson diversity index, S^2_i is the squared income share from each livelihood activity, i is the activity and n is the number of livelihood activities. As stated by Smith and Wilson (1996), to address limitations related to evenness and dominance characteristics, we used the total number of livelihood activities to normalize the Herfindahl–Simpson diversity index:

$$NHHI_i = 1 - \frac{HHI_i - \left(\frac{1}{n}\right)}{1 - \left(\frac{1}{n}\right)} \tag{3}$$

where HHI_i refers to the normalized Herfindahl–Simpson diversification index, which ranges from zero (specialization in one activity) to one (full or complete diversification). As stated by Djido and Shiferaw (2018) and Brezina, Pekár, Čičková, and Reiff (2016), higher normalized index values indicate a greater amount of diversification.

For the three simultaneous livelihood choices (i.e., on-farm, off-farm, and non-farm livelihood activities) we estimated a multivariate probit model. The model adopted in this particular study has been used extensively in studies of technology adoption, information and knowledge transfer, labor-related decisions for on- and off-farm employment, and participation in agro-environmental programs (Kau & Hill, 1973; Velandia, Rejesus, Knight, & Sherrick, 2009).

We first modeled a random utility for the decision to pursue any livelihood activity. In the utility function, we assumed that households decide to implement a certain livelihood strategy on the basis of maximizing utility, i.e., $U*_j - U_o > 0$. Hence, in the utility function, the net benefit of a livelihood activity ($B*_{ij}$) could be fit as follows;

$$B_{ij}^* = x_i'\beta_j + \mu_i \quad (j = on - farm, off - farm \,\&non - farm\; activities, i = 1,2, \dots, n) \tag{4}$$

where $B*_{ij}$ is the household's net benefit, which is indicated as a function of a vector of exogenous household variables x_i; β refers to parameter estimates; n is the number of households; and u_i is the error term. Therefore, a typical household would choose a given livelihood strategy in the pursuit of gaining higher household income. Hence, a general multivariate probit model could be specified as follows:

$$B_{ij} = x'_{ij}\beta_j + \mu_{ij},$$

$$B_{ij} = \begin{cases} 1 \; if \; y^*_{ij} > 0 \\ 0 \; Otherwise \end{cases} \qquad (j = on - farm, off - farm \; \& non - farm) \tag{5}$$

where B_{ij} (j = 1, …, m) is a vector of livelihood activities (in our case m = 3) performed by the ith household, x'_{ij} is vector of observed variables that affect the decision to choose any type of livelihood activity, β_j is vector of unknown parameters, and μ_i is the error term.

As indicated by Greene (2003), the multivariate probit model follows a series of independent probit models for each alternative livelihood activity j. Note that rural households are likely to undertake multiple livelihood activities simultaneously; thus, it is likely that the decisions among choices are correlated. As a result, the unobserved error terms for the estimated probit models would not be independent. If we were to ignore this characteristic of the outcome variables, the result would be a biased estimate of the probabilities and parameters. In the multivariate probit approach to estimating the unknown parameters in Equation (5), the error terms (across j = 1, …, m alternatives) of the latent equation are assumed to have multivariate normal distributions, and this results in a model with a mean vector equal to zero and a covariance matrix R with diagonal elements equal to one.

With the assumption of multivariate normality, the unknown parameters in Equation (5) can be estimated by using maximum likelihood procedures. The probabilities were computed by using the Geweke–Hajivassiliou–Keane simulation procedure (Cappellari & Jenkins, 2003).

To model the association between livelihood diversification and implemented SLM practices, reported practices were taken as outcome variables. The respondents were asked about a total of 18 of SLM practices, including soil fertility management, soil and water conservation, and gully rehabilitation. We summarized the results and took the 10 most frequently practiced SLMs as outcome variables for the model estimation. We estimated an ordered probit regression model (D'souza et al., 1993; Teklewold et al., 2013; Wollni, Lee, & Thies, 2010), which was suitable for count data like ours.

In analyses of the adoption of some technologies, it is essential to note that they will be implemented to different extents by different farmers. In this study, the outcome variable adoption of SLM practices could take values ranging from 0 to 10. The households are heterogeneous because of differences in socio-economic, community, education, and other factors, so the likelihood of any household adopting the first SLM practice might vary from that of other households. In accordance with the method of Wollni et al. (2010), the model is specified as:

$$y^* = \beta' X + \mu, \tag{6}$$

where y^* is the latent variable (number of SLM practice) and takes the values 1 through 10, β' is a vector of unknown parameters to be estimated, X is a vector of explanatory variables, and μ is the error term, which is assumed to be normally distributed with zero mean and a variance of one. The number of observed technologies (y) used is related to the underlying latent variable y^* through the threshold μ_n (n = 1, …,10) and the probability that any given number of technologies (y) is used is calculated as follows:

$$prob(y = n) = \varphi(\mu_n - \beta' X) - (\mu_{n-1}\beta' X). \forall_n = 1, \dots, 10 \tag{7}$$

The ordered probit estimation will give the threshold μ and vector parameter β. The threshold μ shows the range of the normal distribution associated with the specific values of the response variables. The remaining parameters (β) represent the effect of changes in explanatory variables on the underlying scale.

When estimating the effect of livelihood diversification and adoption of SLM technologies, a potential endogeneity problem may arise. In our case, it may occur when an explanatory variable of choosing a certain livelihood strategy is jointly determined by the decision to adopt in the SLM adoption specification (Abdulai & Huffman, 2014). To address this problem, we tested for it in accordance with the method of Rivers and Vuong (1988) by using a two-stage linear regression, and we confirmed that there was no endogeneity problem between livelihood diversification and adoption of a specific SLM technology.

4.3 Results and Discussion

4.3.1 Summary of Socioeconomic Variables

Table 2 summarizes the socio-economic characteristics of the survey respondents (see Table 1 for a description of the variables). For the entire sample, the average age of the household head was 49 years, the dependency ratio was 71%, the average household size was 5.4, and more than 80% of the study households were headed by males. Family size was significantly larger at Dibatie than Aba Gerima and Guder ($p < 0.001$). Most households in the watersheds are characterized as smallholdings, with an average of 1.03 ha of land (which sustains an average household size of about 5.4 people) and an average livestock holding of 3.97 TLUs. The average land holding was somewhat smaller than the national average farm (1.22 ha) [74]. Farmers in Aba Gerima held significantly more land than famers in Guder and Dibatie, while Dibatie farmers owned more livestock compared to Aba Gerima and Guder ($p < 0.05$) More

Table 10 Descriptive statistics of socio-economic characteristics, by watershed (n = 270).

Explanatory Variables	Whole Sample	Aba Gerima	Guder	Dibatie	Test
Gender	0.811(0.41)	79 (11)	60 (30)	79 (11)	b ***
Age	49 (12.9)	47 (11.5)	51 (12.3)	50 (14.3)	a *
Grade	1.3 (2.9)	0.53 (1.56)	1.6 (3.20)	1.76 (3.47)	a **
Household size	5.38 (2.34)	4.65 (2.61)	5.55 (2.08)	5.92 (2.11)	a ***
Dependency ratio	71.19 (12.79)	72.67 (11.87)	70.42 (13.33)	70.46 (13.11)	
Distance to market	9.5 (6.7)	14.33 (5)	6.84 (4.40)	7.37 (7.35))	a ***
Land size	1.03 (0.76)	1.25 (0.70)	0.91(0.58)	0.93 (0.92)	a ***
Tenure	0.77 (0.42)	76 (14)	78 (12)	55 (35)	b ***
Land for food security	0.59 (0.49)	69 (21)	67 (23)	68 (22)	b ***
Access to credit	0.56 (0.50)	55 (35)	53 (37)	42 (28)	
Access to extension service	0.70 (0.46)	76 (14)	48 (42)	64 (26)	b ***
Membership in CBOs	0.51 (0.50)	54 (36)	63 (27)	20 (70)	b ***
Household Income	10,758 (13,021)	9109 (8502)	12,425 (18,649)	10,742 (9321)	a **
Asset value	1919 (4191)	2771 (4224)	1598 (3638)	1389.58 (4572)	a ***
Aggregate stress/shock	0.52 (0.20)	0.60 (0.14)	0.45 (0.23)	0.51 (0.18)	a ***
Livestock size	3.97 (0.49)	3.84 (2.20)	3.52 (2.38)	4.52 (2.67)	a **
Intensification	0.42 (0.50)	0.69 (0.47)	0.21 (0.41)	0.37 (0.41)	b ***

Note: * Significant at 10%, ** significant at 5%, *** significant at 1%; standard deviations in parentheses;

[a] non-parametric two-sample test: Wilcoxon's rank-sum test, [b] Chi-squared test.

than half (52%) of the sampled households reported having experienced anthropogenic (e.g., price inflation, poor access to social services) and naturally driven (e.g., drought, pest infestation, soil erosion, animal disease) stresses. Experience of these types of stressors differed significantly between watersheds with households in Aba Gerima reporting significantly more stress than Guder and Dibatie (p < 0.001).

4.3.2 Livelihoods in the Study Areas

The majority (81%) of surveyed households were engaged in crop and livestock production (Figure 2). The result is closely in line with a report showing that an average of 79% of Ethiopian rural smallholding farmers earn income from agriculture (FAO, 2012). In addition to engaging in their mixed crop–livestock farming system, a considerable number of households engage in off-farm and non-farm livelihood activities. Moreover, there was a statistically significant difference of mean income across watersheds as determined by one-way ANOVA ($p < 0.001$) for charcoal production ($F(2, 270) = 13.03$, $p = 0.000$), khat plantation income ($F(2, 270) = 39.96$, $p = 0.000$) and crop production ($F(2, 270) = 7.50$, $p = 0.0007$)

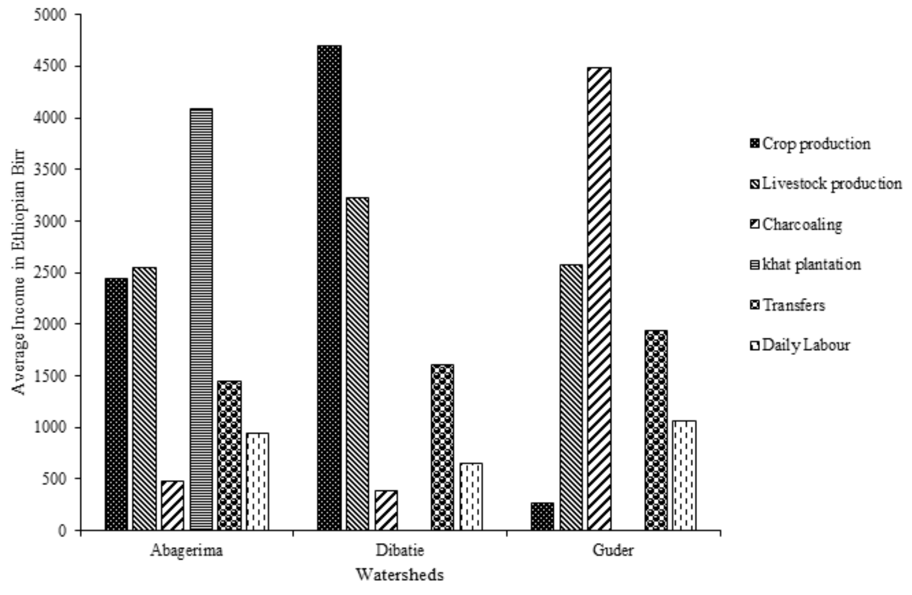

Figure 15 Average annual income from major livelihood activities in the study watersheds.

High-value cash crops such as khat in Aba Gerima and *Acacia decurrens* for charcoaling in Guder are the dominant household livelihood activities in those watersheds. Because of increasing demand, khat cultivation has become a notable remunerative income source for households in the Aba Gerima watershed. Similar studies have shown that, despite its controversial social significance, khat makes a substantial contribution to the country's national income (Alemu, 2015; Dachew, Bifftu, & Tiruneh, 2015). *Acacia decurrens* was the dominant cash crop in the Guder watershed, where the charcoal is usually destined for markets (Nigussie et al., 2017a). In Dibatie, crop and livestock farming made a higher contribution to overall income.

Households were asked to mention the opportunities that were available to them to improve their livelihoods. Five opportunities were noted, but three of these are agriculture related, suggesting that there is little diversification beyond farming in rural Ethiopia. Except establishing retailing business, there was significant difference ($p < 0.001$) on the household's choices of existing livelihood opportunities across watersheds. The majority of the households reported that, if initial investment capital or credit were made available, they would prefer to invest the money in livestock fattening (92% of households in Guder, 72% in Aba Gerima, and 37% in Dibatie) (Figure 3). A possible explanation for this could be, alike other parts of the rural Ethiopia, farmers' limited entrepreneurial competence would not be able to allow them to pursue other lucrative opportunities than livestock rearing, or it may be related to its multipurpose role to livelihoods of farmers through provision of food and income from products, employment, insurance against drought, fuel for cooking, manure for crops, and draught power for farming. On the other hand, it could also be related to their perception that livestock rearing outweighs others because of its capacity to optimally use available resources (e.g., crop residue, grass) that could not otherwise be utilized by them.

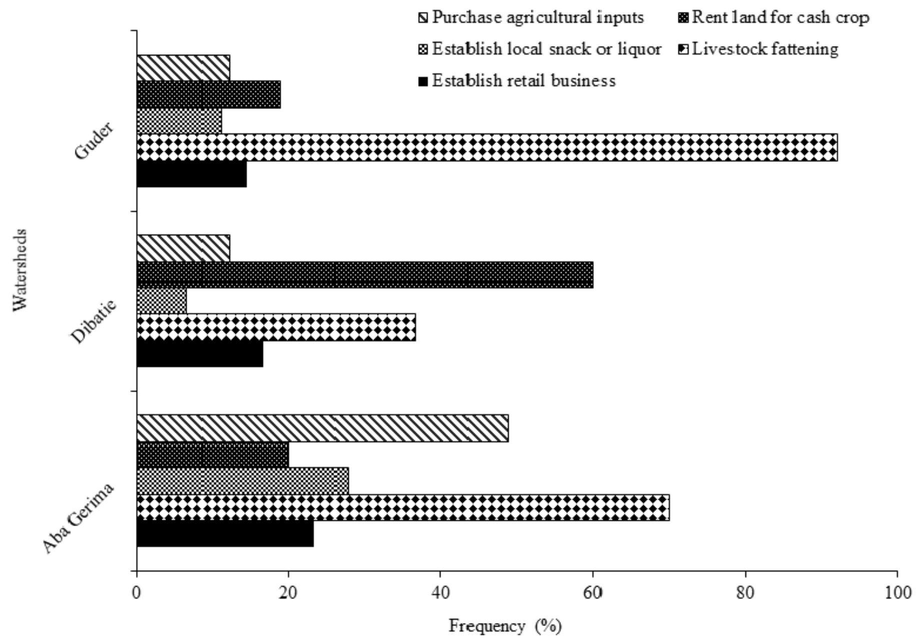

Figure 16 Household livelihood opportunity preferences in the study watersheds.

4.3.3 Remunerative Livelihood Activities in the Study Areas

On the basis of the stochastic dominance criterion, khat production was the first-order stochastically dominant activity in Aba Gerima (Figure 4). In Dibatie, crop production was dominant and livestock production was the second most dominant. In Guder, growing *Acacia decurrens* for charcoaling was the dominant remunerative livelihood strategy. According to Achamyeleh (2015), in comparison with other on-farm sources, acacia plantations made a very high contribution to the overall income of households in Guder. Similarly, Nigussie et al. (2017a) indicated that 84.6% of households reported income as their major motivation to plant *Acacia decurrens*. In addition, our findings showed that charcoaling and khat production were the most inferior (i.e., least lucrative) of the six livelihood strategies in Aba Gerima and Dibatie, respectively.

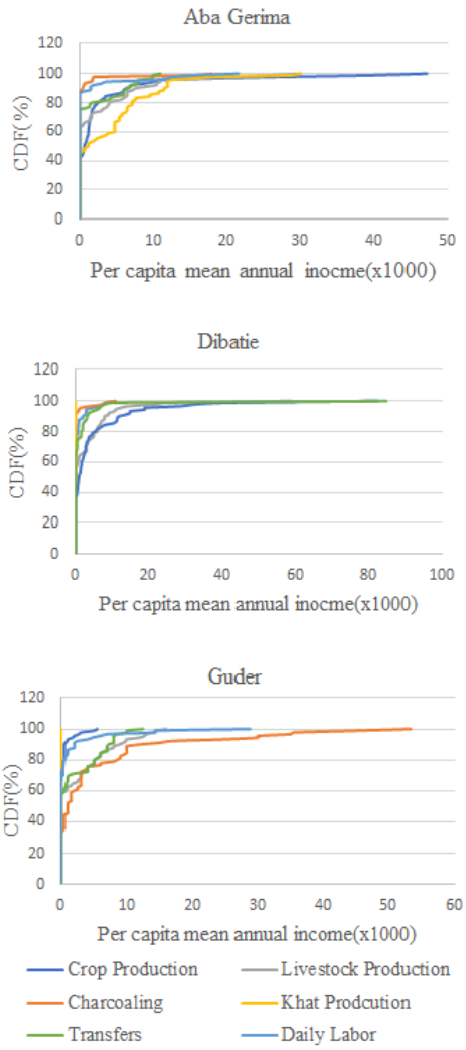

Figure 17 Cumulative density curve (CDV) for major livelihood activities in the study watersheds.

4.3.4 SLM Practices in the Watersheds

Among the surveyed SLM practices, the most commonly reported SLM technologies included crop rotation, chemical fertilizer use, gabion check dams, wooden check dam, gully filling, fencing, residue management, traditional terracing, soil bunds, diversion channels, and waterways. Crop rotation, fertilizer application, use of soil bunds, traditional terracing, and residue management were reported to be the most extensively applied SLM practices. Aba Gerima watershed had the highest percentage of households implementing SLM activities (Figure 5). Similar results were reported by Nigussie et al. (2017b), who reported that agroforestry, drainages, and application of manure and fertilizers were commonly implemented in Aba Gerima. In this study, fencing, gabion check dams, and gully filling were the least used SLM practices. Note, however, that the abovementioned technologies are community-wide practices, and households were asked for their participation in these operations.

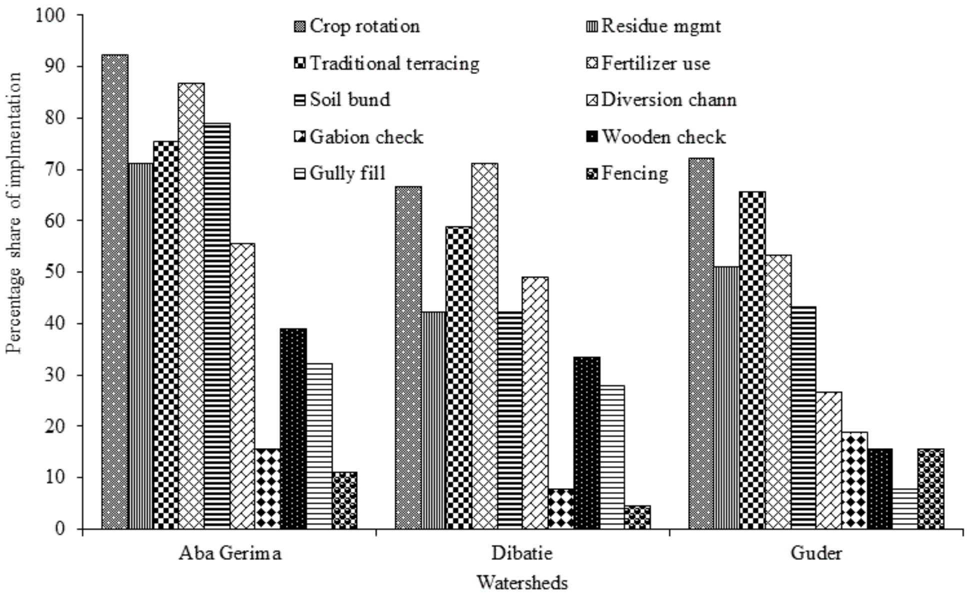

Figure 18 Major sustainable land management (SLM) practices in the study watersheds.

4.3.5 Drivers of Livelihood Diversification

We used a multivariate probit model to analyze the likelihoods of households engaged in a certain livelihood activity associated with a set of factors related to household, socioeconomic, location, and asset features. On-farm activity was negatively correlated with both off- and non-farm activities, indicating that households that diversified into with in on-farm activity may not have had a chance to engage in the other activities. Conversely, off-farm activity was positively correlated with non-farm activity, implying that households that had engaged in wage employment activities may also have engaged in non-farm activities ($\rho 32$ in Table 3).The likelihood ratio test of the independence of the error terms of the various livelihood activity equations was strongly rejected (χ^2 (3) = 46.9552, $p < 0.001$) (Table 4). We therefore adopted the alternative hypothesis of mutual interdependence among livelihood strategies.

Table 11 Pair-wise correlation coefficients across livelihood strategies.

Livelihood Strategy	**Coefficient**	**Standard Error**	***p*-Value**
ρ21	−0.588	0.097	0.000
ρ31	−0.704	0.085	0.000
ρ32	0.233	0.148	0.034

Note: ρ21 = ρ(off-farm, on-farm), ρ31 = ρ(non-farm, on-farm), ρ32 = ρ(non-farm, off-farm).

Gender of the household head significantly influenced the probability of adopting certain livelihood strategies (Table 4), and males were more likely to participate in on-farm livelihood activities ($p < 0.05$). Our result is in line with that of Ragasa, Berhane, Tadesse, and Taffesse (2013), who also reported that male-headed households have more productive labor and asset ownership than their female counterparts when it comes to on-farm activities. Female-headed households can be characterized by a lack of access to asset ownership and adequate labor to pursue on-farm activities. The probability of participation in non-farm livelihood activities decreased with increasing household size ($p < 0.05$), perhaps because larger households had more dependents. Likewise, Babatunde et al. (2010) reported that the larger the household, the less likely it was to support activities other than agriculture. As expected, the dependency ratio significantly influenced all livelihood diversification choices. A negative effect was observed with on-farm livelihood activities ($p < 0.01$); this may indicate that households with more dependents were less likely to choose on-farm activities because of a shortage of active working labor. Eswaran and Kotwal (1986) reported that households with more active working labor yielded higher levels of productivity for smallholder farmers. Conversely, households with more dependents tended to choose off-farm ($p < 0.01$) and non-farm ($p < 0.05$) livelihood activities. A possible explanation for this could be that a larger household could shift available labor to alternative off- and non-farm livelihood activities.

Table 12 Multivariate probit regression results.

	Outcome Variables		
Variables	On-farm	Off-farm	Non-farm
Gender	0.557 ** (0.281)	0.191 (0.284)	–0.252 (0.245)
Age	0.006 (0.008)	0.008 (0.008)	–0.005 (0.007)
Grade	–0.045 (0.033)	0.056 (0.035)	0.030 (0.031)
Household size	0.033 (0.050)	0.021 (0.050)	–0.083 * (0.044)
Dependency ratio	–0.040 *** (0.009)	0.027 *** (0.008)	0.020 ** (0.008)
Distance to market	–0.136 (0.122)	–0.275 ** (0.114)	0.205 ** (0.102)
Land size	–0.124 (0.140)	–0.232 (0.149)	–0.102 (0.136)
Tenure	0.118 (0.259)	–0.049 (0.236)	0.090 (0.214)
Land for food security	–0.0271 (0.241)	0.200 (0.220)	–0.225 (0.200)
Access to credit	0.480 ** (0.195)	–0.133 (0.188)	–0.036 (0.178)
Access to extension services	–0.262 (0.214)	0.442 ** (0.216)	–0.056 (0.204)
Membership in CBOs	0.251 (0.214)	–0.188 (0.204)	0.700 *** (0.206)
Household income	0.185 * (0.103)	–0.106 (0.097)	–0.221 ** (0.090)
Asset value	0.002 (0.105)	–0.080 (0.103)	–0.002 (0.100)
Aggregate stress/shock	–0.164 (0.552)	0.956 ** (0.502)	–0.655 (0.468)
Livestock size	–0.029 (0.045)	0.005 (0.046)	0.096 ** (0.045)
Intensification	0.536 ** (0.253)	–0.231 (0.207)	–0.156 (0.202)
Aba Gerima	–0.393 (0.361)	0.614 ** (0.301)	0.591 ** (0.294)
Dibatie	–0.010 (0.340)	–0.216 (0.302)	1.253 *** (0.291)
Constant	1.762 (1.350)	–2.187 * (1.303)	–0.352 (1.192)
Wald χ^2 (*df*)	134.44 (400)		
Prob. > χ^2	<0.001		
n	270		

Note: Standard errors are given in parentheses. Likelihood ratio test of overall error terms correlation: ρ21 (off-farm, on-farm) = ρ31 (non-farm, on-farm) = ρ32 (non-farm, off-farm) = 0: χ^2 (3) = 47.8868, Prob > χ^2 < 0.001. Significance levels are indicated as follows: * 10%, ** 5%, *** 1%.

Market distance significantly affected the choices of off-farm ($p < 0.05$) and non-farm ($p < 0.05$) livelihood activities, but in opposite directions (Table 4). The regression result had a negative value for the choice of off-farm activity, which may suggest that, as the labor market distance increased, households were less likely to choose this option. Our finding that market distance affected off-farm income is well substantiated by Ellis and Bahiigwa (2003), but differs from the results of Kung and Lee (2001). In contrast, market distance had a positive influence on the choice of non-farm activities. In our discussion with the residents of Aba Gerima and Guder, we learned that when some products, such as khat and charcoal, were directly sold at distant marketplaces they might have achieved higher prices than could have been obtained from local buyers. In addition, demand for these products might have been higher in distant markets than in closer ones. Using panel data, Jiao, Pouliot, and Walelign (2017) revealed that access to infrastructure would help households to diversify to more remunerative strategies.

Contrary to our initial expectation, access to credit showed a significant effect only for on-farm activities ($p < 0.05$) (Table 4). These results could be related to targeting and efficiency issues related to the credit service. It is also possible that the sampled households may have used this credit for on-farm inputs, such as fertilizers, improved seeds, or consumption smoothing. A more profound study done in Ghana revealed a similar result, which indicated that households who received credit found to be effective in terms of improving agricultural productivity and it also helped them to diversify their livelihoods (Gideon Baffoe et al., 2014). This idea is in line with the work of Mulwa, Marenya, and Kassie (2017), who found that access to credit allowed households to adopt soil and water conservation activities that help them to invest more in agricultural inputs. Credit users also may not use the financing for the intended purpose of diversifying their income sources (Carswell, 2000). A similar result was found in rural Niger, where access to financial institutions in the community seemed to negatively affect the probability of participating in businesses activities (Dedehouanou et al., 2018). In contrast, Mentamo and Geda (2016) reported that credit access increased the extent of livelihood diversification in Kadida Gamela district, Ethiopia.

Access to extension services had a significant positive effect on the choice of off-farm livelihood activities ($p < 0.05$) (Table 4). A similar result was also reported by Chikobola and Sibusenga (2016). Extension services customarily help households increase production and productivity within the farming system itself (Carswell, 2000; G. W. Kassie et al., 2017; Rahut et al., 2014). However, the present findings could be attributed to the fact that these services may include small-scale employment opportunities (e.g., off-farm activities). For example, in northern Ethiopia, agricultural extension programs that made use of public employment schemes such as "food for work" helped farmers to shift to off-farm livelihood sources (Woldehanna, 2002).

As anticipated, membership in rural cooperatives had a significant positive effect on diversification to non-farm livelihood activities ($p < 0.01$). This finding underscores the importance attached to the entry barrier households face in terms of initial capital, because these cooperatives might help them to access credit (Dercon & Krishnan, 1996). Previous studies have also reported that membership in formal and informal community organizations can help smallholder farmers to address financial constraints, gain social cohesion and skills, and increase their market networking in selling and buying products (Alobo Loison & Bignebat, 2017; Ellis & Bahiigwa, 2003; Escobal, 2001; G. W. Kassie et al., 2017; Riithi et al., 2015; Sallawu, Tanko, Nmadu, & Ndanitsa, 2016).

Household income had a significant positive effect on the choice of on-farm activities ($p < 0.1$), but it had a significant negative influence on non-farm livelihood activities ($p < 0.01$) (Table 4). This finding may suggest that, despite the increased income, these households still do not have a strong incentive to diversify their livelihood sources. As discussed earlier, access to credit also seemed to make households focus on on-farm livelihood activities. A similar finding was reported by Ellis and Bahiigwa (2003), who found that a greater income may aid in the timely purchase of farm inputs, such as fertilizers, improved seeds, or the ability to hire wage labor, leading to enhanced cultivation practices and higher productivity.

The aggregate stress/shock index had a significant positive affect on a household's decision to participate in off-farm livelihood activities ($p < 0.05$). For example, exposure to seasonal rainfall may force households to look for short-term solutions, such as engaging in daily labor. In a study carried out in Zambia, Gautam and Andersen (2016) argued that households tended to choose livelihoods related to short-term gains when they experience shocks like the lack of seasonal rainfall. Moreover, our result supports the theory of distress-driven livelihood diversification, as opposed to progressive-driven diversification, in the region (Dercon, 2002; Ellis, 2000a; Ellis & Bahiigwa, 2003; Kasie, Adgo, Botella, & García, 2018; Martin & Lorenzen, 2016). Woldehanna (2002), Kasie et al. (2018), Dercon (2002), and Block and Webb (2001) reported a similar result in Ethiopia, where the amount and variability of rainfall had a significant effect on the decision by households to engage in any type of off-farm work. Likewise, studies conducted in Uganda (Kijima, Matsumoto, &

Yamano, 2006) and in Indonesia (Newhouse, 2005) confirmed that rural household labor adjustment decisions serve as a coping mechanism in response to agricultural shocks.

Livestock holding had a significant positive effect on the choice of non-farm livelihood activities ($p < 0.05$). Similarly, Ellis (2000a) and G. W. Kassie et al. (2017) found that increasing livestock holding is an essential financial safeguard to starting a new livelihood and helps farmers to diversify both within and outside agriculture. In addition, higher agricultural intensification had a significant positive effect on the choice of on-farm livelihood activities ($p < 0.05$). This could mean that, as more households adopt agricultural technologies and inputs, more will stay on the farm. This result is in line with that of Sanders and McKay (2014)and Verkaart, Orr, Harris, and Claessens (2017), who reported that households with greater agricultural intensification and productivity were less likely to be driven to diversify to other sources of income. In terms of study locations, significant differences were observed in the probability of adopting non-farm and off-farm livelihoods among the different agro-ecological areas (Table 4). Despite the fact that most households in the watersheds practice crop–livestock mixed farming, a substantial difference was observed in activities such as khat and charcoal production (Figure 3). Similarly, Tesfaye, Roos, Campbell, and Bohlin (2011), Ellis (2000a) and Peng, Zheng, Robinson, Li, and Wang (2017) indicated that geographical locations, and policies related to ecologies determines the choices of livelihood strategies.

4.3.6 Effects of Extent of Livelihood Diversification on SLM Practices

The livelihood diversification index had a mean of 0.10 and a standard deviation of 0.18, indicating that households tended to be relatively concentrated in their main sources of income. The maximum estimation was 0.64 and the minimum was 0. A relatively high diversification was found in Dibatie (0.13), whereas in Guder it was lower (0.07). The values of livelihood diversification were roughly similar in studies carried out in different parts of Ethiopia (Amare, 2018; Block & Webb, 2001; Carswell, 2000; G. W. Kassie et al., 2017; Robaa & Tolossa, 2016; Tesfaye et al., 2011). Conversely, a higher extent of livelihood diversification was revealed in studies conducted in Tigray and Gamebella (Addisu, 2017; Gebrehiwot, 2018).

We also estimated an ordered probit model to investigate the marginal effect of each covariate on the probability of adopting SLM practices by the respective households. The joint test of all slope coefficients proved that our null hypothesis was rejected (Table 5).

Overall, the results showed that livelihood diversification had a positive effect on a small number of SLM practices, but there was a negative relationship when the number SLMs increased (Table 5).

As shown in Table 5, an increase in a household's livelihood diversification status increases the probability of selecting zero, one, two, or three SLM practices by 3% ($p < 0.1$), 5.3% ($p < 0.05$), 7.3% ($p < 0.05$), and 9.3% ($p < 0.05$), respectively. Conversely, an increase in the livelihood diversification status decreases the probability of adopting five, six, seven, or eight SLM practices by 7.3% ($p < 0.05$), 5.6% ($p < 0.05$), 9% ($p < 0.05$), and 2.6% ($p < 0.1$), respectively. Generally, livelihood diversification shows mixed results in that it favors a lower level of SLM adoption intensity and disfavors higher level of adoption of SLM. These results clearly show the complementary nature of having diversified livelihood strategies and carrying out SLM activities in these watersheds for a relatively low number of SLM adoptions. A slightly similar result was revealed in Gozamin district, Ethiopia (G. W. Kassie et al., 2017) where livelihood diversification was positively associated with farmland management strategies. Compared with the case when the household head has any level of education, the probability of adopting five, six, seven, and eight SLM practices was higher by 0.6 ($p < 0.05$), 0.5 ($p < 0.05$), 0.7 ($p < 0.05$), and 0.2 ($p < 0.1$) percentage points, respectively, among household heads of higher education levels (Table 5). Similar studies in the study watersheds and elsewhere in Ethiopia have revealed that more educated heads of households have a higher probability of adopting SLM practices (Nigussie et al., 2017b; Pender & Gebremedhin, 2007).

Table 13 Estimates of the ordered probit model and marginal effects.

SLM Intensity	**Marginal Effects for Each Outcome**											**Coeff**
	Pr(Y = 0/X)	**Pr(Y = 1/X)**	**Pr(Y = 2/X)**	**Pr(Y = 3/X)**	**Pr(Y = 4/X)**	**Pr(Y = 5/X)**	**Pr(Y = 6/X)**	**Pr(Y = 7/X)**	**Pr(Y = 8/X)**	**Pr(Y = 9/X)**	**Pr(Y = 10/X)**	
Livelihood diversity	0.030 *	0.053 **	0.073 **	0.093 **	0.024	−0.073 **	−0.056 **	−0.090 **	−0.026 *	−0.007	−0.010	−0.701 **
	(0.020)	(0.028)	(0.037)	(0.045)	(0.018)	(0.036)	(0.029)	(0.044)	(0.016)	(0.006)	(0.008)	(0.332)
Gender	−0.017 *	−0.032 *	−0.044 *	−0.056 **	−0.014	0.044 *	0.034 **	0.054 **	0.015 *	0.004	0.006	0.424 **
	(0.010)	(0.017)	(0.024)	(0.030)	(0.0116)	(0.024)	(0.018)	(0.028)	(0.009)	(0.004)	(0.005)	(0.211)
Age	−0.000	−0.000	−0.000	−0.000	−0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.005)
Grade	−0.002 **	−0.004 **	−0.006 **	−0.008 **	−0.002	0.006 **	0.005 **	0.007 **	0.002 *	0.001	0.001	0.057 **
	(0.001)	(0.002)	(0.003)	(0.003)	(0.001)	(0.003)	(0.002)	(0.003)	(0.001)	(0.000)	(0.001)	(0.025)
Household size	−0.003 *	−0.005 **	−0.007 **	−0.009 **	−0.002	0.007 **	0.005 **	0.009 **	0.002	0.001	0.001	0.067 **
	(0.002)	(0.003)	(0.003)	(0.004)	(0.002)	(0.003)	(0.003)	(0.004)	(0.002)	(0.001)	(0.001)	(0.031
Dependency ratio	0.000	0.000	0.001	0.001	0.000	−0.001	−0.000	−0.001	−0.000	−0.000	−0.000	−0.005
	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.005)
Distance to market	0.004	0.008	0.011	0.013	0.003	−0.011	−0.008	−0.013	−0.004	−0.001	−0.001	−0.101
	(0.003)	(0.006)	(0.008)	(0.011)	(0.003)	(0.008)	(0.006)	(0.010)	(0.003)	(0.001)	(0.001)	(0.077)
Land size	−0.002	−0.003	−0.005	−0.006	−0.002	0.005	0.004	0.006	0.002	0.000	0.001	0.047
	(0.004)	(0.007)	(0.010)	(0.013)	(0.003)	(0.010)	(0.008)	(0.012)	(0.003)	(0.001)	(0.002)	(0.095
Tenure	0.010	0.018	0.026	0.033	0.008	−0.026	−0.020	−0.031	−0.009	−0.002	−0.004	−0.246
	(0.008)	(0.013)	(0.018)	(0.023)	(0.008)	(0.018)	(0.014)	(0.022)	(0.007)	(0.002)	(0.003)	(0.167)
Land for food security	−0.001	−0.001	−0.002	−0.002	−0.001	0.002	0.001	0.002	0.001	0.000	0.000	0.018
	(0.007)	(0.012)	(0.017)	(0.022)	(0.006)	(0.017)	(0.013)	(0.021)	(0.006)	(0.002)	(0.002)	(0.164)
Access to credit	−0.016 **	−0.030 **	−0.041 **	−0.053 ***	−0.014	0.041 **	0.032 **	0.051 **	0.015 **	0.004	0.006	0.398 ***
	(0.009)	(0.012)	(0.016)	(0.020)	(0.010)	(0.016)	(0.013)	(0.020)	(0.008)	(0.003)	(0.004)	(0.14)
Access to extension services	−0.006	−0.011	−0.016	−0.020	−0.005	0.016	0.012	0.019	0.005	0.001	0.002	0.151
	(0.007)	(0.011)	(0.016)	(0.020)	(0.006)	(0.016)	(0.012)	(0.019)	(0.006)	(0.002)	(0.003)	(0.149)
Membership in CBOs	−0.004	−0.008	−0.011	−0.014	−0.004	0.011	0.009	0.014	0.004	0.001	0.002	0.108
	(0.006)	(0.011)	(0.015)	(0.019)	(0.005)	(0.015)	(0.011)	(0.018)	(0.005)	(0.002)	(0.002)	(0.14)
Household income	0.004	0.007	0.009	0.012	0.003	−0.009	−0.007	−0.011	−0.003	−0.001	−0.001	−0.088
	(0.003)	(0.005)	(0.008)	(0.010)	(0.003)	(0.008)	(0.006)	(0.009)	(0.003)	(0.001)	(0.001)	(0.072)
Asset value	0.002	0.004	0.006	0.008	0.002	−0.006	−0.005	−0.008	−0.002	−0.001	−0.001	−0.06
	(0.003)	(0.005)	(0.007)	(0.009)	(0.003)	(0.007)	(0.005)	(0.008)	(0.002)	(0.001)	(0.001)	(0.065)
Aggregate stress/shock	−0.046 **	−0.083 **	−0.116 **	−0.147 **	−0.038	0.116 **	0.089 **	0.142 **	0.041 **	0.011	0.016	1.113 ***
	(0.018)	(0.037)	(0.050)	(0.063)	(0.028)	(0.050)	(0.040)	(0.056)	(0.021)	(0.008)	(0.011)	(0.422)
Livestock size	−0.002	−0.004 *	−0.006 *	−0.008 *	−0.002	0.006 *	0.005 **	0.007 **	0.002	0.001	0.001	0.057 *
	(0.001)	(0.002)	(0.003)	(0.004)	(0.002)	(0.003)	(0.003)	(0.004)	(0.001)	(0.000)	(0.001)	(0.03)
Aba Gerima	−0.023 **	−0.043 **	−0.059 **	−0.075 **	−0.019	0.059 **	0.046 **	0.073 **	0.021 *	0.006	0.008	0.568 **
	(0.011)	(0.021)	(0.029)	(0.035)	(0.014)	(0.028)	(0.022)	(0.033)	(0.011)	(0.005)	(0.006)	(0.247)
Dibatie	−0.025 **	−0.046 **	−0.064 **	−0.081 **	−0.021	0.064 **	0.049 **	0.0780 **	0.022 **	0.006	0.009	0.611 ***
	(0.011)	(0.020)	(0.026)	(0.031)	(0.014)	(0.027)	(0.021)	(0.030)	(0.010)	(0.005)	(0.006)	(0.217)

n = 270; Wald $\chi^2(20) = 113.92$; Prob > $\chi^2 < 0.001$; Pseudo $R^2 = 0.0888$; Robust standard errors are given in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Marginal effects (dy/dx) are calculated at the mean for continuous variables and for a discrete change from 0 to 1 for dummy variables.

Access to credit was found to have a positive effect on adopting a higher number of SLM practices. Compared with the case when respondents had no access to credit, the probability of adopting five, six, seven, or eight SLM practices was higher by 4.1 ($p < 0.05$), 3.2 ($p < 0.05$), 5.1 ($p < 0.05$), and 1.5 ($p < 0.05$) percentage points, respectively, for respondents who had access to credit. This could possibly be associated with owning more livestock, as it is a liquid asset and provide financial safe guarding (DFID, 1999). Likewise, in India, Aryal et al. (2018) revealed that more ownership of livestock showed a higher intensity of adoption of climate-smart agricultural practices. These findings are in line with those of Nigussie et al. (2017b), who reported that credit access could encourage the adoption of manure application.

With regard to the shock index, the more severe its impact, the lower adoption intensity for greater intensity level of SLM adoption. For example, the probability of adopting five, six, seven, and eight practices was higher by 11.6 ($p < 0.05$), 8.9 ($p < 0.05$), 14.2 ($p < 0.05$), and 4.1 ($p < 0.05$) percentage points, respectively, for those who experienced a lower shock. Likewise, in their comparative study of Thailand and Vietnam, Nguyen, Nguyen, Lippe, and Grote (2017) revealed that farmers' experience with weather shocks affected their decision priorities relative to what type of land management practices they should engage in. Nigussie et al. (2017b) revealed that a higher erosion risk promoted the adoption of SLM practices in a similar area in the Upper Blue Nile basin. This clearly indicates that, when there are few or no shocks, rural households will have more time and labor to invest in SLM practices instead of looking for coping mechanisms to deal with a crisis. Overall, these results showed the varied magnitude and effect of the explanatory variables on the different SLM adoption intensities.

4.4 Conclusions and Implications

In the Northwestern part of Ethiopia, despite efforts to improve livelihoods of smallholder farmers through promoting their uptake of SLM practices, there is still marked inadequacies of the level of adoption of these strategies and their effect on the sustainability of livelihoods. Rural households always try to diversify their sources of income within and outside of agriculture, and this could be associated with the decision and extent of adopting of certain SLM measures on their farms. There has been a wealth of research evidence available in terms of looking at livelihood diversification and adoption of SLM practices, treating them as separate research topics. However, earlier research works have paid little attention to the links of these two research domains. As a result, this particular study was conducted to be able to extend existing knowledge on this issue.

We used data obtained from a cross-sectional household survey to examine the extent and drivers of livelihoods diversification in the Upper Blue Nile basin of Ethiopia, as well as the effects of diversification on the adoption intensity of SLM practices. In the study sites, for majority of the smallholder farmers, non-farm and off-farm livelihood activities were accounted as supplementary sources to the on-farm livelihoods. The study revealed that crop production, livestock production, charcoaling, khat plantation, transfers, and less capital-intensive activities such as casual daily labor are the most prominent livelihood activities. With more dependents, households tend to choose off-farm and non-farm livelihood strategies. In addition, households' access to credit was found to favor the probability of selecting on-farm livelihoods. Owning more livestock and being a member of community-based organizations increase the probability of participating in non-farm livelihood strategies. Therefore, for more diversified livelihood strategies, it is important to focus on policies and programs that enhances household's livestock production and degree of participation in community-based organizations; and for those who opted to stay in agriculture, facilitating financial supports could contribute to sustaining their agricultural livelihood. Better-off households preferred to stay in on-farm, while poor farmers opted for non-farm livelihoods. The results clearly showed the complementary nature of having diversified livelihood strategies and carrying out SLM activities in the study watersheds for a relatively low number of SLM adoptions. While there is heterogeneity of factors which influence the adoption intensity of any of the 10 SLM practices, findings of this study underscore the importance of higher level of education, better access to credit, shock/stress experience, and more livestock wealth on higher adoption intensity of SLM practices. Likewise, agro-ecological heterogeneity also found to have an influence for higher adoption rate in Aba Gerima (mid land) and Dibatie (low land) watersheds.

Overall, the following important conclusions can be drawn. First, despite the availability of few different livelihood activities in the study areas, diversification as such does not contribute to higher overall income. More important is a household's ability to engage into lucrative sectors with better returns into its livelihood portfolio (e.g., khat production in Aba Gerima and *Acacia decurrens* charcoal production in Guder). Second, decisions to diversify to another livelihood activity are dependent on the gender of the household head, distance to markets, access to credit and extension services, membership in community-based organizations, dependency ratio, level of income, agro-ecological setting, household size, exposure to shocks, livestock holding, and agricultural intensification. Third, a higher extent of livelihood diversification favors a lower level of adoption of SLM practices, whereas the reverse is true for a higher level of SLM adoption. A prospective look at livelihoods in the context of these factors would likely help households to be able to exploit new economic opportunities more effectively in the future. Experiencing stress/shocks tended to push households toward earning short-term economic gains; this can be seen as a coping strategy, but it is not a sustainable way of promoting livelihoods in these watersheds.

Results have implications for development planners in the Upper Blue Nile basin and elsewhere in the country where rain fed agriculture is predominantly make up the livelihoods of the majority of its population there by diversifying livelihood sources is essentially needed to sustain and promote livelihoods. More emphasis should be given to remunerative livelihoods like *Acacia decurrens* and khat plantations while not disregarding their environmental and social feasibility. Sustainable livelihood initiatives that focus on increasing access to financial support mechanisms, improved livestock production, quality extension services, and shock/stress resilience mechanisms, while also accounting for agro-ecological differences, are much needed. In this regard, livelihood transformations to cash crops like *Acacia decurrens* in Guder and khat plantation in Aba Gerima should profoundly be studied as to how they are ecologically, socially and economically feasible. Strengthening policies that encourage positive interplay between diversifying livelihood strategies and SLM practices could help in the attempt to achieve a sustainable agriculture system. This cross-sectional study contributes to the literature of the nexus between rural livelihoods and management of natural resources using three selected watersheds of Upper Blue Nile basin. Hence, further lines of research on a broader location, dynamic links between livelihood diversification and adoption intensity of SLM practices, and economic benefits of SLM practices will be helpful.

CHAPTER FIVE

General conclusins and recommendations

Chapter 5. General conclusions and recommendations

5.1 Conclusions

In Ethiopia, subsistence agriculture remains to be a pivotal sector. It will continue to deicide the country's all rounded effort to reducing poverty and increase GDP. However, climate variability/change and land degradation are the major threats. Moreover, the deep-rooted rural poverty substantially contributes to the vulnerability to climate variability. In literatures, it has been widely indicated that sustainable agriculture comprising climate change adaptation schemes and sustainable livelihood are the way forward to addressing the challenges. In this regard, the motivation and interface to increasing income and environmental sustainability should also get due attention.

In essence, the overall objective of this thesis is to gain better understanding of the socio-economic, institutional and biophysical factors that contribute to livelihood vulnerability to climate variability, multidimensional poverty status and thereby suggest the potential areas of intervention and livelihood coping strategies. The following section discusses the specific objectives in outlined with their summarized methods and major findings, contribution of the study, limitation and further research recommendations;

Objective 3: To analyse the livelihood vulnerability of households to climate variability

Evidences have shown that climate change exacerbates the recurrent drought situation and presents a daunting challenge to predominantly rain-fed agricultural livelihoods. The aim of this study was to analyse the extent and sources of smallholder famers' livelihood vulnerability to climate change/variability in the Upper Blue Nile basin. We conducted a household survey (n=391) across three distinct agro ecological communities and a formative composite index of livelihood vulnerability (LVI) was constructed. The Mann–Kendall test and the standard precipitation index (SPI) were employed to analyze trends of rainfall, temperature, and drought prevalence for the period 1982-2016. The communities across watersheds showed a relative difference in the overall livelihood vulnerability index. Aba Gerima (midland) was found to be more vulnerable with a score of 0.37, while Guder (highland) had relatively lower LVI with 0.34 index score. Given similar exposure to climate variability and drought episodes, communities' livelihood vulnerability was mainly attributed to their low adaptive capacity and higher sensitivity indicators. Adaptive capacity was largely constrained by lack of participation in community-based organizations and lack of income diversification. This specific study will have practical implications to policy development in heterogeneous agro ecological regions for sustainable livelihood development and climate change adaptation programs.

Objective 2: To explore multidimensional poverty status of households

This study explored multidimensional poverty in three different drought-prone agroecological settings of the Upper Blue Nile basin, Ethiopia. A preliminary participatory exercise was carried out at the study sites to select important indicators and then a structured survey was administered to systematically and randomly selected households. The Alkire–Foster method was used to analyse multidimensional poverty and verified it with Correlation Sensitive Poverty Index (CSPI). Multidimensional poverty incidence adjusted head count ratio and inequality were significantly different between study sites ($P<0.001$). Results indicated a high incidence (88%, 82% and 80%), intensity (52%, 55% and 56%), MPI (46%, 45% and 45%) and inequality (53%, 60% and 63%) of poverty in Aba Gerima, Guder and Dibatie study sites, respectively. The living standard and land and livestock ownership dimensions contributed the most to MPI. The case study signifies the importance of inclusion of land and livestock indicators for the national MPI. Besides, it implies that researchers and policymakers need to account for smaller scale contextualised indicators and location differences when studying and designing anti-poverty interventions

Objective 3: To identify the existing coping strategies of households in the face of climate variability.

This specific objective tries to address the extent and drivers of livelihood diversification and households' actual adoption SLM intensity. Using household level data from three contrasting agroecological environments of the Upper Blue Nile basin, we tried to model the extent of livelihood diversification by multivariate probit model as affected by different socio-economic and demographic variables. Moreover, an ordered probit model was estimated to examine the effect of livelihood diversification on the adoption intensity of SLM practices.

In addition to mixed cropping and livestock production, the production of emerging cash crops (e.g., Acacia decurrens for charcoal, and khat) dominated the overall income generation of most farmers. Stress/shock experience, extent of agricultural intensification, and agro-ecology significantly affected the probability of choosing certain livelihood strategies. Livelihood diversification at the household level was significantly associated with the dependency ratio, market distance, credit access, extension services, membership in community organizations, level of income, and livestock ownership. A greater extent of livelihood diversification had a significant negative effect on adopting a greater number of SLM practices, whereas it had a positive effect on lower SLM adoption intensity. Overall, we found evidence that having greater livelihood diversification could prompt households not to adopt more SLM practices. Livelihood initiatives that focus on increasing shock resilience, access to financial support mechanisms, improving livestock production, and providing quality extension services, while also considering agro-ecological differences, are needed. In addition, development planners should consider the livelihood portfolios of rural households when trying to implement SLM policies and programs.

5.2 Recommendations

This study made use local level measure of livelihood vulnerability, multidimensional poverty and coping strategies where different stakeholders could benefit from; as the impacts of climate variability are felt at local level, the findings of these studies could help to inform an insight on what to plan for to deal with the adverse consequences. For instance, enhancing adaptive capacity of households is more important compared to other dimensions of livelihood vulnerability. In addition, addressing the effects of climate variability is should be integrated with the reducing the proximate causes of multidimensional poverty in the study areas and elsewhere where there is similar contexts. Appropriate land use management and livestock production improvement could be recommended and hence decision makers and famers would have their own fair contribution. In addition, enhancing famers degree of participation in CBOs and FBOs so that they can be benefited in terms of building their adaptive/coping capacity. They would also focus on livelihood diversification as a way out from vulnerability and poverty situation.

The study also provides insight for decision makers (or policymakers) and development practitioners to sharpen their awareness of multidimensional poverty issues. For example, they can learn and understand the importance of inclusion of livestock ownership and land ownership in national multidimensional poverty studies. In turn, this could inspire them to prepare suitable strategies to livestock development and sustainable land management activities in Ethiopia or elsewhere, whereby the specific contexts allow in. We have also contributed that there shouldn't be high number of SLM measures be introduced to famers by campaign, as the showed no interest of higher adoption for larger number of SLM practices. Moreover, our findings showed the livelihood vulnerability to climate variability by agroecology, where intervention can directly be benefited from. Famers should be encouraged to invest in alternative off-farm and non-farm livelihood portfolio options so that they could be resilient against the climate related shocks. The livelihood strategies should also be carefully planned as to how much could it be remunerative in helping the household achieve economic gain.

Finally, the results are useful inputs for concerned development actors to accommodate pro climate change adaptation and multidimensional poverty index in preparing specific strategies, and to promote sustainable development through livelihood diversification as a means to move away from poverty, conserve the natural resource base in a sustainable way and other holdings.

Suggestions for further research

We suggest that studies on livelihood vulnerability to climate variability and multidimensional poverty should consider more locally based indicators so that the definition of both constructs be well be captured. The Ethiopian government is also advised to have the country focused MPI indicators and this study would be a stepping stone for more sound and comprehensive study.

Future research studies are needed that are used a more representative sample size with separate sustainable land management practices, wider geographical coverage across different and incorporating time-variant aspects to increase our understanding of the subject matter and allow us to design specific interventions of coping strategies to motivate farmers to adopt climate smart practices, and thereby create positive effects on poverty reduction and the ecology. Moreover, to better capture local adaptive capacity of communities and households, further studies on the livelihood-based analysis in all agroecological contexts can be suggested.

To better capture the changes on the farm households with regard to livelihood vulnerability to climate variability and change, their multidimensional poverty and adoption of climate smart SLM, the present dataset can be used to complement future research on the same farm households and communities to build up a panel dataset.

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SUMMARY

In Ethiopia, agriculture employs 80% of workforce, contributes to 44% of the country's GDP, and accounts for 70% of the export revenue. As such, it is unarguably the mainstay of the economy. Ethiopian smallholder farmers produce 90–95% of the country's agricultural output. However, Ethiopia's smallholder farmers are over reliant on rain-fed agriculture and only cover half of rural households' annual food intake requirements. The productivity and sustainability of the smallholder farming sector is vulnerable to the adverse effects of climate variability and land degradation. To tackle this long-standing problem, the government and its partners have put in place policies and programs thus, billions of dollars have been outlaid. Despite all these efforts, poverty is still prevalent in the country. Evidences in Ethiopia have shown that livelihood vulnerability to climate variability often has resulted in prolonged poverty. Although climate variability is a shared global phenomenon, it could substantially be felt by the most vulnerable ones (smallholder farmers). Given the fact that the manifestations of poverty and vulnerability are context-specific, local adaptive or coping measures should be advised. However, little attention has been given to the smaller scale lived experiences of rural villages with climate variability/change, their coping capacity-or lack thereof. Moreover, albeit poverty has been well-studied in the country, efforts to measure from multidimensional perspective and making the indicators locally relevant is still lacking.

Owing to the above facts and to support efforts of addressing the negative effects of climate variability thereby reducing poverty and bringing out sustainable development, this study aimed to achieve the following objectives: First, this study analysed the livelihood vulnerability of households to climate variability; Second, it explored multidimensional poverty status of households as explained by multifaceted livelihood asset endowments and finally, it examined the covariates that shape rural livelihood coping strategies. The study was conducted in three rural villages with contrasting agro-ecologies (i.e. Dibatie [lowland]), Aba Gerima [midland], and Guder [highland]) of the northwestern part of Ethiopia. The study used the data collected during the period from 2017 to 2018 and combining household survey, focus group discussion, key informant interview and field observation. It uses the Sustainable Livelihood Approach (SLA) to conceptually build the interaction between vulnerability, climate variability and multiple dimensions of poverty.

This doctoral thesis is a compilation of 5 chapters where chapter one presents the backgrounds, introductory contexts, problem justification, objectives, conceptual framework and outline of the doctoral thesis.

Chapter two analyses the extent and sources of smallholder farmers' livelihood vulnerability to climate variability in the Upper Blue Nile basin. We conducted a household survey (n=391) across three distinct agroecological communities, and a formative composite index of livelihood vulnerability (LVI) was constructed. Indicators evaluation was carried out by the Shannon Entropy procedure as a function of IPCC constructs; adaptive capacity, sensitivity and exposure. The Mann–Kendall test and the standard precipitation index (SPI) were employed to analyse trends of rainfall, temperature and drought prevalence for the period 1982-2016. The communities across watersheds showed a relative difference in the overall livelihood

vulnerability to the effects of climate variability. Aba Gerima (midland) was found to be more vulnerable with a score of 0.37, while Guder (highland) had relatively lower LVI with 0.34 index score. Given similar exposure to climate variability and drought episodes, communities' livelihood vulnerability was mainly attributed to their low adaptive capacity and higher sensitivity indicators. Adaptive capacity was largely constrained by lack of participation in community-based organizations and lack of income diversification. This study will have practical implications to policy development in heterogeneous agroecological regions for sustainable livelihood development and climate change adaptation programs.

Chapter three analyses multidimensional poverty and inequality in three different agroecological settings of the Upper Blue Nile basin, Ethiopia. A participatory indicators selection and a structured survey were administered to 390 systematically and randomly selected households. The Alkire–Foster method was used to analyse multidimensional poverty. Multidimensional poverty incidence adjusted head count ratio and inequality were significantly different between study sites (P<0.001). Results indicated a high incidence (88%, 82% and 80%), intensity (52%, 55% and 56%), MPI (46%, 45% and 45%) and inequality (53%, 60% and 63%) of poverty in Aba Gerima, Guder and Dibatie study sites, respectively. The living standard and land and livestock ownership dimensions contributed the most to MPI. The case study signifies the importance of inclusion of land and livestock indicators for the national MPI. Besides, it implies that researchers and policymakers need to account for smaller scale contextualized indicators and location differences when studying and designing anti-poverty and climate vulnerability interventions and broader sustainable livelihood improvement programs.

Chapter four explores the covariates that shape rural livelihood diversification as climate variability coping strategies. Household-level data were collected from 270 households in three rural located in northwestern Ethiopia. We used the Herfindahl–Simpson diversity index to explore the extent of livelihood diversification. A stochastic dominance ordering was also employed to identify remunerative livelihood coping strategies. A multivariate probit model was employed to estimate the probability of choosing simultaneous livelihood coping strategies, and an ordered probit model was estimated to examine the effect of livelihood diversification on the adoption intensity of climate smart SLM practices. In addition to mixed cropping and livestock production, the production of emerging cash crops (e.g., Acacia decurrens for charcoal and khat) dominated the overall income generation of most farmers. Livelihood diversification at the household level was significantly associated with the dependency ratio, market distance, credit access, extension services, membership in community organizations, level of income, agroecology, shock experience and livestock ownership. We found evidence that having greater extent of livelihood diversification could prompt households not to adopt more climate smart SLM practices. Livelihood initiatives that focus on increasing climate related shock resilience, access to financial support mechanisms, improving livestock production, and providing quality extension services, while also considering agro-ecological differences, are needed. In addition, development planners should consider the livelihood portfolios of rural households when trying to implement SLM policies and programs.

The final chapter presents general conclusions, based on the main findings, and draws policy implications, which may help decision-makers and development practitioners. Some limitations and future research points are also reported. The findings from this study indicated that small scale farmers livelihoods are vulnerable to the negative effects of climate variability, mainly associated with their poor adaptive capacity and sensitivity and showed a remarkably high joint deprivation of wellbeing capability indicators. Their livelihoods portfolio entails significant diversification, but selected activities were remunerative (e.g. Acacia decurrence and Khat) and showed mixed relationship with climate smart SLM adoption. This study calls for integrated focus on climate resilient rural livelihood improvement to reducing poverty and vulnerability through sustainable coping measures.

概要

エチオピアでは、農業は労働力の 80%を雇用し、国の GDP の 44%に貢献し、輸出収入の 70%を占めており、農業はエチオピア経済の柱となっている。エチオピアの小規模農家は、国の農業生産の 90～95%を生産している。しかし、エチオピアの小規模農家は天水農業に過度に依存しており、農村部の世帯の年間食物摂取要件の半分しか充足させていない。小規模農家農業部門の生産性と持続可能性は、気候変動と土地劣化の悪影響に対して脆弱である。この長年の問題に取り組むために、政府と関連機関は政策とプログラムを導入し、数十億ドルが支出されてきた。これらのすべての努力にもかかわらず、貧困は依然として農村部に蔓延している。エチオピアでの調査から、気候変動に対する生計の脆弱性がしばしば長期的な貧困をもたらすことが示されている。気候変動は世界共通の現象であるが、最も脆弱な集団（小規模農家）にとってもっとも実質的な問題である。貧困と脆弱性の兆候は状況固有であるという事実を考えると、地域に応じた適応策または対処策が助言されるべきである。しかし、気候の変動/変化、対処能力、またはその欠如のある農村の小規模な生活体験にはほとんど注意が払われていない。さらに、エチオピアでは貧困がよく研究されているが、多次元の観点から貧困を測定し、指標を地域に適合させる努力がいまだに不足している。

上記の事実と、気候変動の悪影響に対処し、それによって貧困を削減し、持続可能な開発をもたらす努力を支援するために、本研究は、以下の目的を達成することを目的とした。第一に、気候変動に対する家計の生計脆弱性を分析し、第二に、多面的な生計資産によって説明されるように、世帯の多次元的な貧困状態を定量化し、第三に、農村の生計対処戦略を形作る共変量を明らかにした。本研究は、エチオピアの北西部の対照的な農業生態学である 3 つの農村（すなわち、Dibatie [低地]）、Aba Gerima [中間地]、および Guder [高地]）で実施した。本研究では、2017 年から 2018 年までの期間に収集されたデータを使用し、世帯調査、フォーカスグループディスカッション、重要な情報提供者のインタビュー、現場観察を組み合わせた。持続可能な生計アプローチ（SLA）を使用して、脆弱性、気候の変動性、貧困の複数の側面間の相互作用を概念的に構築した。

本学位論文は、5 つの章から成り、第 1 章では、背景、導入コンテキスト、問題の正当化、目的、概念フレームワーク、および博士論文の概要を紹介する。第 2 章では、青ナイル川上流域の気候変動に対する小規模農家の生計脆弱性の範囲と原因を分析する。3 つの異なる農業生態学的コミュニティで世帯調査（n = 391）を実施し、生計脆弱性（LVI）の形成複合指数を構築した。指標評価は、IPCC コンストラクトの関数としてシャノンエントロピー手順によって実行した。適応能力、感度、露出。 Mann–Kendall テストと標準降水指数（SPI）を使用して、1982 年から 2016 年までの期間の降雨、気温、および干ばつの発生率の傾向を分析した。流域全体のコミュニティは、気候変動の影響に対する全体的な生計脆弱性の相対的な違いを示した。Aba Gerima（中間地）は 0.37 のスコアでより脆弱であることが示された。一方、Guder（高地）は 0.34 の指標値で LVI が比較的低かった。気候変動と干ばつエピソードへの同様の暴露を考えると、コミュニティの生計脆弱性は、主に適応能力が低く、感度指標が高いことに起因していると考えられた。適応能力は、コミュニティベースの組織への参加の欠如と所得の多様化の欠如によって大きく制約されていた。本研究は、持続可能な生計開発と気候変動適応プログラムのための不均質な農業生態学的地域の政策開発に実際的な意味を持つと期待される。

第 3 章では、エチオピアの青ナイル川上流域の 3 つの異なる農業生態系における多次元の貧困と不平等を分析した。390 の体系的かつランダムに選択された世帯に参加型指標の選択と構造化された調査を実施した。 Alkire–Foster 法によって、多次元の貧困を分析した。多次元貧困発生率調整ヘッドカウント比と不平等は、研究サイト間で有意差があった（Pt; 0.001）。この結果、Aba Gerima、Guder、Dibatie の各研究サイトでの貧困について、高い発生率（88%、82%および 80%）、強度（52%、55%および 56%）、MPI（46%、45%および 45%）および不平等（53%、60%および 63%）を示した。MPI に最も寄与したのは、生活水準と土地と家畜の所有形態である。この事例研究から、国の MPI に土地および家畜の指標を含めることの重要性が示された。加えて、研究者と政策立案者は、貧困対策と気候脆弱性への介入とより広範な持続可能な生計向上プログラムを研究および設計する際に、小規模なコンテキスト指標と場所の違いを考慮する必要があることが示唆された。

第 4 章では、気候変動への対処戦略として農村生活の多様化を形成する共変量について解析した。世帯レベルのデータは、エチオピア北西部に位置する 3 つの農村の 270 世帯から収集された。Herfindahl–Simpson 多様性指数を用いて、生計の多様化の程度を定量化した。確率的支配の順序を用いて報酬の生計対処戦略を識別した。多変量プロビットモデルを採用して同時生計対処戦略を選択する確率を推定し、順序付きプロビットモデルを推定して、気候変動適応型 SLM 技術の採用強度に対する生計の多様化の影響を調べた。耕畜連携農業に加えて、新興の換金作物（例えば、木炭生産のためのアカシア・デカレンスおよびチャット）の生産は、ほとんどの農家の全体的な収入の生成を支配していた。世帯レベルでの生計の多様化は、依存率、市場への距離、クレジットアクセス、技術普及サービス、コミュニティ組織のメンバーシップ、収入のレベル、農業生態系、気候変動へのショック経験、および家畜の所有に大きく関連していた。生計の多様化の程度が大きいと、家庭がより多くの気候変動適応型 SLM 技術を採用しないよう促すことができることが示唆された。気候関連のレジリエンスの向上、財政支援メカニズムへのアクセス、家畜生産の改善、および質の拡張サービスの提供に焦点を合わせ、農業生態系の違いも考慮した生計イニシアチブが必要である。さらに、開発計画者は、SLM のポリシーとプログラムを実装する際に、農村部の世帯の生計ポートフォリオを考慮する必要が指摘された。

第 5 章では、上記の研究結果に基づいて一般的な結論を示し、意思決定者および開発実務者に役立つ可能性のあるポリシーの意味を導出した。いくつかの制限と将来の研究課題を示した。本研究結果から、小規模農家の生計が気候変動の負の影響に対して脆弱であり、主に適応能力と感度が低いことに関連しており、幸福能力指標の著しく高い共同剥奪を示した。彼らの生計ポートフォリオは大幅な多様化を必要とするが、選択された活動は報酬的であり（たとえばアカシア・デカレンスやチャット）、気候変動適応型 SLM の採用との混合関係が示された。本研究から、持続可能な対処策を通じて貧困と脆弱性を減らすために、気候変動に強い農村部の生活改善に焦点を合わせることの必要性が指摘された。

LIST OF PUBLICATIONS

1. Abeje, M.T., Tsunekawa, A., Adgo, E., Haregeweyn., N., Nigussie, Z., Ayalew, Z., Elias, A., Molla, D. and Berihun, D. (2019). Exploring Drivers of Livelihood Diversification and Its Effect on Adoption of Sustainable Land Management Practices in the Upper Blue Nile Basin, Ethiopia. *Sustainability*, *11*(10), 2991. (Published, this article covers Chapter 3 in the thesis)
2. Abeje, M.T., Tsunekawa, A., Haregeweyn., N., Nigussie, Z., Adgo, E., Ayalew,Z., Tsubo, M., Elias, A., Berihun, D., Quandt, A., Berihun, M.L. and Masunaga, T. (2019). Communities' Livelihood Vulnerability to Climate Variability in Ethiopia. Sustainability, 11(22), 6302. (Published, this article covers Chapter 4 in the thesis)