Coffee Agroforestry for Climate Change Adaptation and Food Security in Gimbi District, West Wollega

Dissertation Submitted to Centre for Environment and Development, College of Development Studies

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To be presented in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Development Studies (Environment and Development)

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We the undersigned approve that dissertation composed by **Beshea Abdissa Chemeda**, entitled **"Coffee Agroforestry for Climate Change Adaptation and Food Security in West Wollega"** is submitted in partial fulfillment of the requirements for the degree of doctor of philosophy in **Development Studies (Environment and Development)** capitulate in completion of the prerequisites for the Degree of Doctor of Philosophy comply with the regulation of university and convenes the accepted standards concerning the originality, quality, and eminence.

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Declaration of Originality

I, the undersigned, declare that this is my original work, has never been presented in this or any other University, and that all the resources and materials used for the dissertation, have been fully acknowledged.

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Statement of Authorship

This dissertation is a thesis by publication in which Paper I, II III and IV are prepared as original research for publication. The PhD candidate, **Beshea Abdissa Chemeda**, was the corresponding author of these papers. The supervising team contributed to the papers discussing the structure and editing as co-authors. The list of papers below showed the details of each of the manuscript have been submitted and the current articles track status and publications. As the manuscripts are separate and submit to different journal publishers, the formatting of the articles or manuscripts as per the respective journal and publisher's requirements.

LIST OF PAPERS

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Dedication

This dissertation is dedicated to my wife, Abeba Sori Amesa, and my three children, Kana'ol Beshea, Mo'as Beshea, and Santanan Beshea, who have always supported me and cheerfully endured all of my absences from numerous family gatherings. It is also dedicated to my parents, Abdissa Chemeda and Bultu Dole, who emphasized the value of education and assisted me with my lessons throughout my life.

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List of Acronyms and Abbreviations

COREQ	Consolidated criteria for Reporting Qualitative research
CSA	Central Statistics Agency
DAs	Developmental Agents
DBH	Diameter at Breast Height
FAO	Food and Agriculture Organization
FGD	Focus Group Discussion
GDAOPC	Gimbi District Agricultural Office and personal communication
GPS	Global Positioning System
HDDS	The Household Dietary Diversity Scores
HFIAS	The Household Food Insecurity Access Scores
HHH	The Household Heads
IPCC	The Intergovernmental Panel on Climate Change
Kebele	The smallest administrative unit than district
KII	Key Informant Interview
M.a.s.l	Meter above Sea Level
MDG	The Millennium Development Goals
OCED	The Organization for Economic Cooperation and Development
NGOs	Non-Governmental Organizations
NMAE	The National Meteorological Agency of Ethiopia
UTM	The Universal Transverse Mercator
WWZANRO	West Wollega Zone Agriculture and Natural Resources Office

Table of Contents

List of tables

List of figures

Abstract

This study examined the role of coffee-based agroforestry for climate change adaptation, food security and tree diversity management in Gimbi district West Wollega. A household survey, focus group discussion, and key informant interviews were used to generate socioeconomic data. The sample plots of the forest survey of coffee-based agroforestry systems were also used to assess tree diversity and measure tree height and diameter to estimate the aboveground and belowground biomass. One-way ANOVA, binary logit model, ordered logit model and multinomial logit models were employed to analyze the perception and adaptation strategies, the role of crop diversification in improving food security of the households, and tree diversity and biomass carbon stock analysis along altitudinal gradients of coffee-based agroforestry systems in the sampled area. The comparison of tree diversity and biomass carbon stock analysis was conducted along the altitudinal gradients, which is locally classified as lowland, midland and highland respectively. This study revealed that farmers noted the signs of climate change included increasing temperature, erratic rainfall, late onset of rainfall, and early cessation of rainfall. Farmers used three distinct sets of climate adaption strategies: crop management, soil and water conservation and intensive farm management. The primary determinants of farmers' perceptions of climate change and adaptation techniques were household head age, education, soil fertility, market access, and agricultural training. Age, education, and soil fertility level were the characteristics that significantly impacted farmers' perspectives and coping mechanisms among the primary drivers evaluated in the area. The farmers consume a diversified diet having the average dietary diversity score of 4.4±1.27 household heads. About 19.69% of the sampled households had low HDDS, 55.79% had medium, and 24.51% had high dietary diversity. All farmers consumed cereal crops during the 24-hour recall period, followed by condiments, beans, and vegetables. In the middle altitude, there were more woody species (28) than in the top altitude. Aboveground biomass had a carbon stock of 32.22 C t ha^{-1}, whereas belowground biomass had a carbon stock of 8.38 C t ha^{-1}. The lower altitude biomass carbon stocks were substantially bigger than the upper altitude, which were 48.4 C t ha^{-1} and 25.67 C t ha^{-1}, respectively. With increasing altitude, the study found a statistically significant negative link between tree diversity and biomass carbon storage ($P<0.05$). Both socioeconomic and environmental factors have found to affect farmers' perceptions and adaptation to climate change and the farmers' food security improving intervention in the area. When implementing farm-based technologies, it is critical to assess farmers' level of awareness of climate change and their coping strategies, as well as the factors

limiting their ability to adapt to climate change. Further, to implement sustainable agriculture and improve food security in the area, it is important to focus on agroforestry practises.
Keywords: *Determinant, Climate change, Coffee agroforestry, Food security, Tree diversity*

CHAPTER ONE

1. GENERAL INTRODUCTION

1.1. Background

Agroforestry is a kind of land use that has been practiced since long in many parts of the world (Kumar *et al*., 2014). Farmers around the world have used agroforestry practices for thousands of years, however many countries incorporated it into their national agricultural and forestry agendas in the 1980s and 1990s. Agroforestry systems and practices have been defined by Nair (1993) as practices which involve "the deliberate integration of trees with agricultural crops and/or livestock either simultaneously or sequentially on the same unit of land". Hence, it increases productivity of land fulfilling environment and social aspects. In addition, the Rio Convention's Agenda 21 highlighted the significance of agroforestry systems on a global scale by mentioning it as an option for sustainable land management (Kumar *et al*., 2014).

Agroforestry is a feature of agriculture landscapes throughout the world, but the extent to which it is practiced varies from region to region (Lundgren, 1982). It is one of the most important projects for bettering land management that have been undertaken globally over the last few decades (Nair and Garrity, 2012). Today, an estimated total of 1.6 billion hectares of land worldwide; with roughly 78% in the tropics and 22% in the temperate regions; has the potential of areas under irregular stands of trees mixed with understory crops (Nair *et al*., 2021). At the global level, trees are integrated with crops into different forms in farming areas are economically important agroforestry systems, which have low tree canopy cover (Kumar *et al*., 2014). The Sahel's parkland systems and northern India's poplar-wheat-barley agroforestry systems serve as examples (Zomer *et al*., 2009).

According to a global assessment of agricultural land tree cover, 48 % of all agricultural land had at least 10% tree cover (Fahad *et al*., 2022). Furthermore, the FAO (Forest Resources Assessment Report) has included the assessment of trees outside of forests, which primarily consist of agroforestry systems and tree systems in urban areas, since 2000 (Tomar *et al*., 2021). In terms of potential, the current global area under agroforestry is 1,023 million ha (Dagar and Tewari, 2017). Agroforestry is currently active and cover 66.8% of global agricultural land, 72.9%, and 78.8% of such land with at least 10% and 30% tree cover, respectively (Noordwijk, 2019).

However, contradicting this, the combined effects of the changing climate on agricultural production and the pressures of a growing world population have increased the demand for more agricultural land (Benton *et al*., 2021). The demand to increase agricultural production is increasing deforestation, land degradation, unsustainable agricultural practices and biodiversity loss (Gomiero, 2016; Benton

et al., 2021). Such overexploitation of resources, in turn, has led to the threat of climate change and increased hunger, poverty and malnutrition (FAO, 2017; Leakey *et al*., 2005). As a result, farmers in various corners of the world have been suffering due to the worsening climate change and declining agricultural production (Arora, 2019; Muluneh, 2021).

Globally, agro-industrial expansion or monospecific plantations exploits a vast natural forest reduces biodiversity and increases releasing of carbon dioxide (Possu *et al*, 2018; Sistla *et al*., 2016). But compared to this, agroforestry practices combine relatively high biodiversity and sustainable economic benefits with apparently diversified and productive systems, while providing different produces to the farmers (Castle *et al*., 2022; Rolo, 2022). As a result, encouraging agroforestry practice has been considered as a means of combating climate change problems and a strategy that farmers use in different countries with different practices (Bajigo & Tadesse, 2015; Gwali *et al*., 2015). The practice is highly expanded in coffee and cocoa producing areas by smallholder farmers (Somarriba & Lopez-Sampson, 2018). Therefore, nowadays, the system has become an option for land-use to address many of these global challenges (Do & Gy, 2017; Kumar & Nair, 2011). Such systems play a vital role in conserving both crop and tree diversity, and sequestering huge amount of carbon stocks in the system (Kumar & Nair, 2011; Slusser *et al*., 2009). Agroforestry practice, among other virtues, can help address various dimensions of food insecurity through local production and market exchange, and supply non-food agricultural tree products while contributing to maintenance of environmental quality (Jemal *et al*., 2021; Noordwijk, 2021; Octavia *et al*., 2022).

Furthermore, the shade trees that agroforestry coffee farmers grow on their fields often contain species that increase coffee productivity without competition to the coffee (Koutouleas *et al*., 2022). This is mainly because of the versatile shade trees that are integrated with coffee and other crops in harmony and help maintain soil fertility, reduce the impact of climate change and produce essential products such as fruits, vegetables, firewood, and wood (Sheppard *et al*., 2020; Koutouleas *et al*., 2022). Such ecosystem goods and amenities work together to reduce production costs and increase the diversity of farm production (Worku & Dejene, 2017; Gwali *et al*., 2015). In support to this, since the Kyoto Protocol, agroforestry systems have gained more emphasis as a strategy to capture and store carbon (Tian *et al*., 2018). Furthermore, the IPCC reports that, “Agroforestry can both sequester carbon and produce a range of economic, environmental and socioeconomic benefits”. Consequently, integrating agroforestry into the landscape is regarded as one of the best "no regrets" measures for assisting communities in mitigating, adapting, and becoming resilient to the effects of the changing climate (Zoysa & Inoue, 2014; Possu *et al*., 2018).

In response to this, various countries have been preparing various adaptation strategies to deal with climate change (Sujakhu *et al*., 2020; Paudel *et al*., 2022). According to Calmon and Barberie (2019), farmers in Latin America, can adopt to climate change and generate income by integrating crop-livestock-forestry (plant agroforestry), rehabilitate degraded pasture, and pursue sustainable forestry. Akinnagbe & Irohibe (2015) addressed that most climate change coping strategies of most African farmers rely on crop and livestock integration whereby tree planting frequently seen as a main or complementary component. Such practices are common in Ethiopia, however, the types of intervention quietly varies from locality to localities (Belay *et al*., 2017; Zerssa *et al*., 2021).

Recently, the Ethiopian government sought to enthusiastically and iteratively pursue more incorporation of various adaptation strategies to the effects of climate change in developing policies and strategies as a complement to this over time. Ethiopia's climate resilient green economy (CRGE) is one of the national adaptation plans (NAP-ETH) (NAP, 2019). It concentrates on the industries that are most at risk, including those in agriculture, forestry, health, transportation, power, industry, water, and urban areas (NAP, 2019). Moreover, recently, an initiative, which is known as "the Green Legacy" is an indicator of Ethiopia's lasting commitment to a multifaceted response to the impacts of climate change and environmental degradation. The initiative encompasses agroforestry, greening and restoration of urban areas, forest sector development, and integrated soil and water management (UN, 2023). The main goal of these policies and strategies is to raise agricultural productivity, which directly contributes to increasing food security, while also considering its strategy to adapt to climate change and manage ecosystem sustainability (NAP, 2019; UN, 2023).

1.2. Statement of the problem

Various findings have indicated climate change is prevailing, productivity change is taking place, food conditions are changing, and insect and pest prevalence is higher than ever. Therefore, farmers perceptions and adaptation measures need to be addressed for better adjustment processes (Ricart *et al*., 2022). Coffee agroforestry adoption as an adaptation strategy to changing climate is important to address the impacts, but there are barriers and limiting factors. Despite researches on the need to adapt to climate change and the impacts of climate change on agricultural production, particular studies on the specific adaptation strategies to the coffee agroforestry systems are inadequate (Arora,s 2019; Gebru *et al*., 2020; Muluneh, 2021; Shukla *et al*., 2021). This research was, therefore, intended to identify perceptions of climate change and applicable adaptation strategies that coffee agroforestry farmers use to counter climate change and support farmers' adaptive capacity. In addition, it was to assess the role of coffee-based agroforestry practices for improving the food security levels of

households and their carbon storage capacity while conserving tree diversity in the agroforestry system of the study site.

In a country like Ethiopia with high multicultural and ecological diversity, one can expect local people to have developed their own indigenous adaptation mechanisms. These are, however, not fully explored, and the knowledge base on the factors governing farmers' decisions to adapt to climate change and the impact of these decisions on crop yield and productivity of their livestock is not formulated in the specific context. Developing knowledge and skills in these dimensions is particularly important for designing effective adaptation strategies to adapt to the potential impacts of climate change (Kpadonou *et al.*, 2012; Weldlul, 2016). In line with the above premise, diverse and critical questions can be raised in the context of the study area, viz., do the local communities perceive that there is climate change? How do rural communities adapt to calamities associated with climate change? What local knowledge and social capital have rural communities developed to adapt to the changing environment? Does the community perceive the changes in coffee yield due to climate change? Does the coffee-based farming system help the farm households produce diversified crops and access nutritious food to improve their household food security level? Do the coffee farmers understand the role of tree species diversity in coffee agroforestry productivity management? How do coffee farmers understand the role of woody species in carbon sequestration and maintain ecosystem sustainability?

As a general truth, many potential agricultural adaptation options have been suggested, representing measures or practices that might be adopted to alleviate the likely adverse impacts. They encompass a wide range of forms (technical, financial, managerial), scales (global, regional, local), and participants (governments, industries, farmers). Their applications have been influenced by phenomena of interest (biological, economic, social, etc.) and by time scale (instantaneous, month, years, centuries) (Giovannucci *et al*., 2012; OECD, 2001; Smit & Skinner, 2002). Most of these strategies represent only potential adaptation measures, rather than the ones actually adopted. Climate change impact analyses often assume certain adaptations in different parts of the world.

Various studies at both the government and non-government levels have been conducted concerning agricultural ecosystem management in relation to climate change adaptation. The research on climate change's impact on coffee production and coffee farmers' adaptation strategies in Ethiopia is still very limited. Similarly, the contribution of coffee based agroforestry as a coping strategy to climate change, food security, biodiversity conservation, and carbon sequestration is not well addressed. Thus, this study assessed coffee farmers' perceptions of climate change trends and adaptation strategies to climate change, the role of coffee based agroforestry management in

improving food security through crop diversification, tree species diversity, and carbon sequestration in the Gimbi district, west Wollega.

1.3. Objective of the study

1.3.1. General Objective

The overall objective of the study was to assess the role of coffee agroforestry for climate change adaptation, food security and tree diversity management in Gimbi district, west Wollega.

1.3.2. Specific Objectives of the study

The specific objectives of the study were to:

[1]. Evaluate coffee farmers' perception of climate change trends in Gimbi district.

[2]. Analyze determinants of adaptation strategies of coffee-based agroforestry farmers in Gimbi district.

[3]. Assess the contribution of crop diversification to improve household food security of coffee farmers in Gimbi district.

[4]. Analyze tree species diversity and biomass carbon stock along altitudinal gradients in coffee-based agroforestry systems in Gimbi district.

1.4. Significance of the Study

This study aimed to contribute to the existing body of knowledge in development theory and practice on the role of coffee-based agroforestry practices in relation to climate change, food security and tree diversity. This study aimed to analyze coffee farmers' perception of climate change and suggest the contribution of agroforestry as the best strategy to adapt to climate change, improve food security, and manage tree diversity. This will aid in comprehending the efficiency of climate change adaptation, the difficulties in managing food security and tree diversity, and the ways that governments and development actors can further maximize its potential. It will be advantageous for development planners to have a clear understanding of the community's perceptions and expectations in order to ensure food security through crop and tree diversification.

Moreover, respondents taking part in the research were brought together to further explore the challenges confronting them in practicing coffee-based agroforestry, addressing crop diversification, food security, and tree diversity. Collectively the reflection on practical steps, and initiating action aimed at improving adaptation strategies and food security through crop diversification and sustaining the environment through diversified tree management.

Therefore, the study is significant in that it generates findings, lessons, and recommendations on how coffee-based agroforestry can be harnessed by governments, researchers, and development agencies

to improve adaptation strategies, food security, and tree diversity management in households. It is hoped that this may influence programmatic approaches and interventions aimed at reducing poverty, improving incomes, and ensuring greater access to food for farmers. Further, local and regional governments use this research as a basis to better understand crop, food security, and tree diversity management. The findings can also assist policymakers in designing future policies and strategies for adapting to climate change, crop diversification, food security, and tree diversification. Lastly, the results of this study may be incorporated by non-governmental organizations (NGOs) when creating programs to improve farmers' abilities to comprehend and adapt to their environment, produce food, and manage their environment.

1.5. Literature Review

Origin and trends of agroforestry

Cultivating trees and agriculture crops/animals on the same unit of land is an ancient practice that has been practiced around the world for centuries. However, the traditional method has been replaced by intensive monoculture agriculture or forestry with the development of modern agriculture (Lovrić *et al*., 2018; Liu *et al*., 2019). Tropical deforestation, ecological degradation, and food situation deterioration promoted the general acceptance of agricultural diversity (Pacheco & Meyer, 2022). Agroforestry, which can resolve environmental problems and/or economic problems and provide benefits to producers and the public, was again recognized as a sustainable agricultural practice (Nair, 1993). Therefore, in 1970s, the International Council for Research in Agroforestry (ICRAF) was established and agroforestry became an independent discipline that received extensive attention (Liu *et al*., 2019).

There are various definitions of agroforestry. The ICRAF defines “agroforestry is the interaction of agriculture and trees, including the agricultural use of trees (Leakey, 2017). This includes trees on farms and contained in agricultural landscapes, farming in forests and along forest margins, and tree-crop production, including cocoa, coffee, rubber, and oil palm (Purwanto *et al*., 2020). Interactions between trees and other components of agriculture may be important at a range of scales: in fields (where trees and crops are grown together), on farms (where trees may provide fodder for livestock, fuel, food, shelter, or income from products, including timber), and landscapes (where agricultural and forest land uses combine in determining the provision of ecosystem services)” (Vira *et al*., 2015). The Food and Agriculture Organization of the United Nations (FAO) defines it as a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in

some form of spatial arrangement or temporal sequence (FAO, 2019). The United States Department of Agriculture (USAD) National Agroforestry Center (NAC) defines "agroforestry is the intentional integration of trees and shrubs into crop and animal farming systems to create environmental, economic, and social benefits" (NAC, 2019). In conclusion, the agroforestry system is a land use practice with productivity, sustainability, and adaptability (Nair, 1993).

Agroforestry has been shown to be a viable solution to many of the issues the world is currently facing by a large number of scientific research conducted over the last 50 years (Liu *et al*., 2019; Seghieri *et al*., 2021). Various governments and non-governmental organizations have taken note of the benefits of agroforestry and incorporated it into regional and governmental development plans (Bettles *et al*., 2021). This has led to a rapid globalization of the agroforestry system (Zome *et al*., 2009).Moreover, the extensive agroforestry practice, in turn, promotes the development of research. The rapid development of agroforestry research and practices led us to investigate what gaps are there, and where are there? My literature review and field observations led me to the hidden opportunity in coffee-based agroforestry research gaps, which I found very exciting. As a result, I concentrated on the importance of coffee agroforestry in my studies.

Impact of climate change on Coffee Sector

Coffee is the world's most important tropical export crop but recent studies predict severe climate change impacts on *Coffea arabica* (*C. arabica*) production (Kariuki, 2016). The predicted decrease in profitability and greater economic risk of coffee production may locally and temporarily have positive environmental impacts, but overall and over the longer term these impacts will likely be severe and negative (Schroth *et al*., 2009). According to Potts (2003), identified global coffee production and trades were under risk because of declining forest species, water contamination, diminishing biodiversity to persistently uncertain revenues and makes currently an imperfect market in action.

Many scientific justifications predicted coffee sectors are likely affected due to climate variation over the next forty years (Bakri *et al*., 2018; Killeen & Harper, 2016). The influence of this climate variation makes the farmers to be indebted, reduce ability to invest in production and reduce their income generation (Caswell *et al*., 2013). The climate variations affect coffee industry from production to export. About 70% of the world's coffee is produced by small-scale farmers, with over 20 million coffee farming family's equivalent to more than 100 million people depending on its production for their subsistence (Bento & DE Camargo, 2010; Neilson & Wang, 2018). Most suitable area becomes unsuitable because of climate variation (Jassogne *et al*., 2013; Laderach *et al*., 2008).

The reduction of land suitable for coffee production will influence the world coffee market and increase the price of coffee (Haggar & Schepp, 2012).

Coffee farmers' perception of and adaptation strategies to climate change

Measures to adapt coffee cultivation to climate change also contribute to reducing CO_2. Other environmental benefits include enhanced water storage, the regulation of local temperatures, and biodiversity conservation (Secretariat of the Convention on Biological Diversity, 2009; ITC, 2010). Changes in temperature and frequency of rains are associated positively and significantly with a higher probability to implement at least one adaptation strategy to climate change (Musa, 2016; Zuluaga *et al*., 2015). Proven approaches build on existing indigenous practices and knowledge to maximize benefits of climate change adaptation (Ebisa, 2017). As climate change becomes increasingly severe, an assessment of coffee producers' ability and willingness to adapt would be especially valuable to those hoping to create adaptation strategies and policies (Battiste, 2016). Good management practices that reduce soil erosion (e.g. cover crops and contour bunds) and increase water retention (mulching, shade) will further help farmers adapt to climate change and retain the more fertile topsoil (Jassogne *et al*., 2013; Temesgen *et al*., 2009). Scientists seem to agree that the best way to preserve A. coffee is through the use of shade trees (Ebisa, 2017). Shade trees planted near coffee plants have the ability to block out the sun's direct impact on the plants. They create lower temperature, reduce up to 4°C better suited for Arabica coffee plants.

Coffee agroforestry and food security

Agroforestry is a dynamic, ecologically based, natural resource management system that integrates trees into farms and other landscapes (Nair and Gordon, 2008). Integration of trees and annual crops with different rooting depths in time and space is believed to avoid competition for water and nutrients, resulting in increased crop yields (Stratton *et al*., 2021). In the same manner, agroforestry uses different elements of food as target products in the system in different seasons that help produce nearly all types of foods in the system (Galhena *et al*., 2013). Due to this, agroforestry practices can contribute a lot in the diversifying crops as diversification has been identified as an important agroecological strategy for rural development (Stratton *et al*., 2021).

In addition, forests and farm trees appear to be especially important for the rural poor (many of whom are women), as they frequently rely on off-farm employment opportunities and available forest resources to help meet their household need (Nair, 2001). Coffee and cacao are among the most widespread and economically important agroforestry crops worldwide. A diversified coffee cropping systems may also help to food supply while the expected demand for food and convenience products

continues to grow (Acosta-Alba *et al*., 2020). At the household level, the critical issue is to ensure sufficient access to food to all household members (Sarkar, 2022). Chronic food insecurity can be tackled most effectively through policies that promote agricultural productivity, rural income generation and food production (FAO, 2001; Kaini, 2020).

Coffee agroforestry and biodiversity conservation

Observed changes in climate already adversely affected biodiversity at the species and ecosystem level, and further changes in biodiversity are inevitable with further changes in climate (CBD, 2009). Davis *et al*. (2012) stated that the profoundly negative trend for the future distribution of indigenous Arabica coffee would be a 65% reduction in the number of bio-climatically suitable localities, and at worst (scenarios of almost 100% reduction, by the year 2080 under the influence of accelerated global climate change). Davis *et al*. (2012) also indicated that, a 90% reduction in area suitable for in situ conservation of coffee genetic resources was projected for the year 2080. The relationships between the climatic parameters and coffee production are quite complex, because it affects the growth and development of the plants at different growth stages (Bento & Camargo, 2010). As indicated in different findings, the predicted climate change is expected to increase mean temperatures and follows a change in precipitation regimes. And due to this reason, traditional coffee growing regions may disappear and new regions may appear (Laderach et al., 2017).

Rural landscapes that were once natural ecosystems have been transformed into mosaics containing a great variety of land uses. These include forests and other natural systems, a great diversity of agro-ecosystems, disturbed zones with or without tree cover, and areas of human settlement (Agnoletti & Santoro, 2018). The challenge to conserve biodiversity in these heterogeneous landscapes has resulted in a need to promote and manage conservation within anthropogenic ecosystems (Abdrabo *et al*., 2014).

Recent work in the tropics has demonstrated that agroforestry systems are among the most promising land uses for achieving both conservation goals and supporting human livelihoods at the landscape scale (Gobena *et al*., 2013; Mbow *et al*., 2014). For example, cacao agroforestry systems in Cameroon, include a diversity of shade trees that provide fruit and timber for income (Dawoe *et al.,* 2016; Rajab *et al*., 2016). The highly diverse agroforests tree species, also provide a variety of tree products to its managers (Gobena *et al*., 2013; Niehaus, 2011). In the Mesoamerican tropics, several studies have documented potential conservation scenarios in different types of tree-crop systems (Golicher *et al*,, 2011; Khoury *et al*., 2016).

Given its complex biophysical structure, shade coffee systems may have exceptional potential for biodiversity conservation of tropical plant and animal species (Faminow & Rodriguez, 2001 ; Peters

et al., 2016). Numerous studies on coffee based agroforestry systems have shown that a diversified and abundant canopy of shade trees enhances associated biodiversity of other plants and animals, including insects and birds and herbaceous plants and epiphytes (Gliessman *et al*., 2007; Harvey & Villalobos, 2011; Faminow & Rodriguez, 2001). However, most research on tree biodiversity in shade coffee agroecosystems has concentrated on documenting tree species richness and abundance (Niehaus, 2011; Soto-pinto & Aguirre-dávila, 2015; Gliessman *et al*., 2007). For coffee based agroforestry systems to contribute to the conservation of native trees, it is important that plantation management incorporates the value of conserving regionally vulnerable or threatened species, rather than focusing on exotic or domesticated species (Gliessman *et al*., 2007; Souza *et al*., 2010).

Coffee agroforestry and carbon storage

Coffee farming in Ethiopia has an exceptionally long history and helps maintain the highest genetic diversity of coffee on Earth, and that is recognized globally for its broader biodiversity value (Dereje, 2016). Ethiopia is where Coffea arabica, the coffee plant, originates. The plant is now grown in various parts of the world; Ethiopia itself accounts for around 3% of the global coffee market (Thomas et al., 2004). Sustainability of coffee is determined by the management system applied in the sector according to the livelihoods of coffee farmers and the environmental situation where the production is taking place. In Ethiopia there are about four coffee management systems like wild coffee, semi-forest coffee, garden coffee and plantation coffee (Schmitt & Grote, 2006). In the wild coffee system, coffee berries are directly harvested from wild plants in the natural forest, while semi-forest coffee (henceforth, SFC) refers to the coffee management system whereby the canopy trees are thinned, the ground vegetation is removed and empty spaces are enriched by transplanting naturally regenerating seedlings of coffee (IAEA, 2008; Schmitt & Grote, 2006). Nearly all cultivated Ethiopian coffee production system is considered as agroforestry systems.

Coffee based agroforestry systems help in managing environment by reducing human made impacts on ecosystems through wise utilization of existing resources. Deforestation and other unsuitable land use activities are considered as one of the major sources of anthropogenic CO_2 emissions (Matthews, 2013), and agroforestry systems seem to be an acceptable management of crop production, as well as for CO_2 mitigation through an increase in carbon stocks (Houghton *et al*., 2012). In agroforestry systems, trees or shrubs are grown around or among crops or pastureland (Nair, 1993), and the recognition of this system as a greenhouse gas mitigation strategy under the Kyoto Protocol has earned it the right to be part of the strategy for biological carbon sequestration (Jose & Bardhan, 2012; Ehrenbergerova *et al.*, 2016). Research on carbon sequestration in different types of land use provide

information for the Reduced Emissions from Deforestation and Forest Degradation (REDD) programs that would likely allow some countries to sell carbon credits to interested buyers or received financial support from funds (Francesco & Jian, 2005; Vangoidsenhoven, , 2011)Agroforestry systems help REDD by reducing pressure for further forest conversion to agriculture and by serving as a source of fuel-wood and construction material (Montagnini & Nair, 2012; Raimo *et al*., 2012). Such mechanisms have special importance because of their applicability in agricultural lands, as they have multifunctional roles like soil system modification, carbon sequestration and other ecosystem support services (Bünemanna *et al*., 2018; Finlayson *et al.*, 2007; Tittonell, 2014)).

Despite continuous crop exploitation, agroforestry production conserves the soil environment due to more closed nutrients and water turnover via tree cover producing litter and shading the soil surface, as well as sustaining the less eroded soil body (Choudhury, 2002; Ndoli, 2018). Moreover, in some studies, soil organic matter was found to have increased over 10 years by 16–42 Mg ha^{-1}) in the 0–45 cm layer, which is about 8–21 Mg C ha^{-1}) depending on the planted shading species and commodities (Ruan & Robertson, 2013; Zaia *et al*., 2012). On the other hand, soil organic matter dynamics are driven by many factors, in general by climate, soil type and land use management, which determine the physical, chemical and biological controls of soil carbon sequestration and turnover (Tian *et al.*, 2016; Zhao *et al.*, 2018). Therefore, different scholars have stated the role of coffee based agroforestry by measuring carbon stocks provided by agroforestry ecosystems under different shade trees as an additional ecosystem service.

1.6. Conceptual framework

The promotion of agroforestry needs to identify the socio-economic conditions of households and the characteristics of their physical environment in order to meet local needs and preferences (Ndayambaje, 2013). Such a targeting will help create and promote locally acceptable and sustainable agroforestry systems. Many studies have focused on the socio-economic factors that motivate farmers to engage in the planting and conservation of trees in their fields (e.g. Salam *et al*., 2000; Mahapatra and Mitchell, 2001). The factors include household preferences, resource endowments, market incentives, biophysical factors, risk, and uncertainty. Furthermore, studies have shown that the age of the household head, education level, gender, household wealth, household size, farmland size and access to agricultural inputs all influence farmers' adoption of agroforestry technologies (Omuregbee, 1998; Ndayambaje, 2013). In a study of agroforestry in Ethiopia, Iiyama *et al*. (2017) found that favorable climatic conditions and institutional arrangements to control free grazing influence adoption. Jerneck and Olsson (2013) found that in Kenya, food-secure and opportunity-seeking

farmers are more likely to adopt agroforestry. Scherr (1992) found that in Kenya, a community-based approach to extension services is more suitable for local conditions than a commodity based approach. Achieving successful promotion and widespread adoption of innovative technologies regarding the retention of trees in cropping systems for food security improvement, biodiversity conservation and carbon sequestration requires paying particular attention to the perception and adaptation strategies (Buyinza and Ntakimanyire, 2008). Therefore, it is important to have a better understanding of farmers' decisions to adopt agroforestry technologies. The conceptual framework of this study relates to the factors that interact to influence farmers' decisions to undertake agroforestry implementation, considering the indirect effects on the livelihoods of farmers (Figure 1).

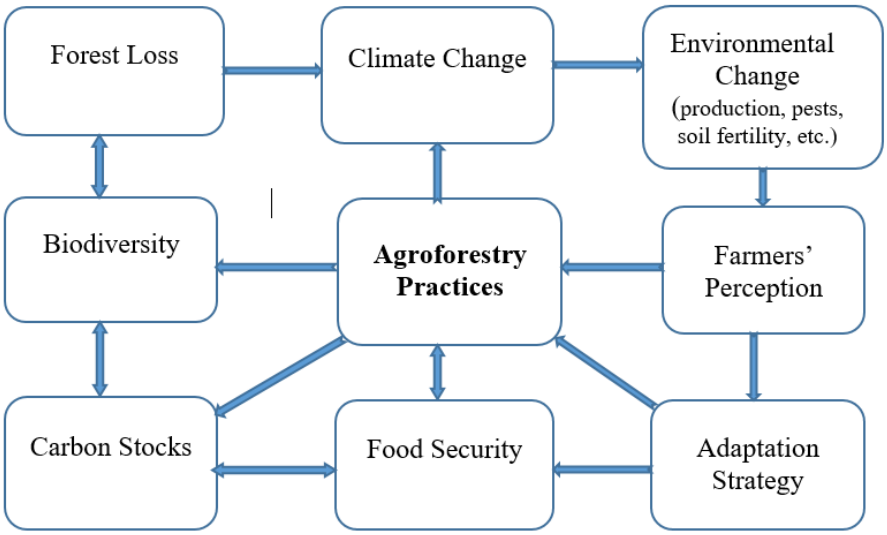

Figure 1 Conceptual framework for agroforestry systems

1.7. Materials and Methods

1.7.1. Description of the study area

The study was conducted in Gimbi district West Wollega Zone, Oromia National Regional State,Western Ethiopia. Administratively, the zone has 20 districts and three main municipalities, i.e. Gimbi, Nedjo and Mendi. Gimbi Town is a capital of the Zone and it is located between 142000 and 174000 E (UTM) and 993000 and 1029000 N (UTM) (Figure 2). The distric has an altitudinal range of 1200-2222-m.a.s.l. The study district is boarded Lalo Asabi in the west, Benishangul-Gumuz region in the north, and East Wollega Zone in the east. The district has 32 rural kebeles.

Climatic condition

The district has a mid-land climate condition. The mean minimum and maximum annual temperature of the area ranges between 10°C and 30°C. The mean annual rainfall is 1400-1800ml per year. According to the traditional agro-climate classification system, which only considers altitude, an area

is categorized as a *Kola* zone (elevation of below 1500 m a. s. l.), a *Weyna Dega* zone (elevation of 1500 to 2300 m a. s. l.) and a *Dega* zone (elevation above 2300 m. a. s. l.). Nevertheless, the classification systems has got such categories, the district encompasses only *Kola* (*Gammoojjii*) and *Weina Dega* (*Badda Daree*) zones (Zelalem *et al*., 2015).

The area consists of permanent and seasonal rivers and streams hence forming the major source of water used in the area. The district has a bimodal rainfall pattern. The major rainy season is during the months of June to September, which is the case for many Ethiopian highlands, and the season locally called *Ganna,* followed by a long dry spell that spans from October to April. The long drought season is locally called *Bona*, occurs from mid-October to April and sometimes to May (GDAOPC, 2018).

Population

Based on the 2021 Census conducted by the Central Statistical Agency of Ethiopia, West Wollega Zone has a total population of 1,350,415, of which 671,538 are men and 678,877 women. The zone has an area of 10,833.19 square kilometers. West Wollega has a population density of 124.66. While 146,672 or 7.39% are urban inhabitants, a further 2,578 or 0.19% are pastoralists. According to Central Statistical Agency (CSA, 2021), a total of 266,773 households were counted in this Zone, which results in an average of 5.06 persons to a household, and 250,473 housing units.

According to projection figures published by the Central Statistical Agency of Ethiopia in 2021, Gimbi District has an estimated total population of 147,701, of which 75,078 are men and 72,623 are women. Among this population, about 40,162 or 27.19% of them are urban dwellers, which is greater than the Zone average of 10.9%. With an estimated area of 1,183.44 square kilometers, the district has an estimated population density of 124.8 people per square kilometer, which is greater than the Zone average of 91.7 (CSA, 2021).

It is also stated that the total geographical area of the district comprises 1,129.69 km^2 of land. The average rural household has 1.2 hectare of land (compared to the national average of 1.01 hectare of land and an average of 1.14 for the Oromia Region) and the equivalent of 0.8 heads of livestock. A 20.7% of the population is in non-farm related jobs, compared to the national average of 25% and a Regional average of 24% (CSA, 2021).

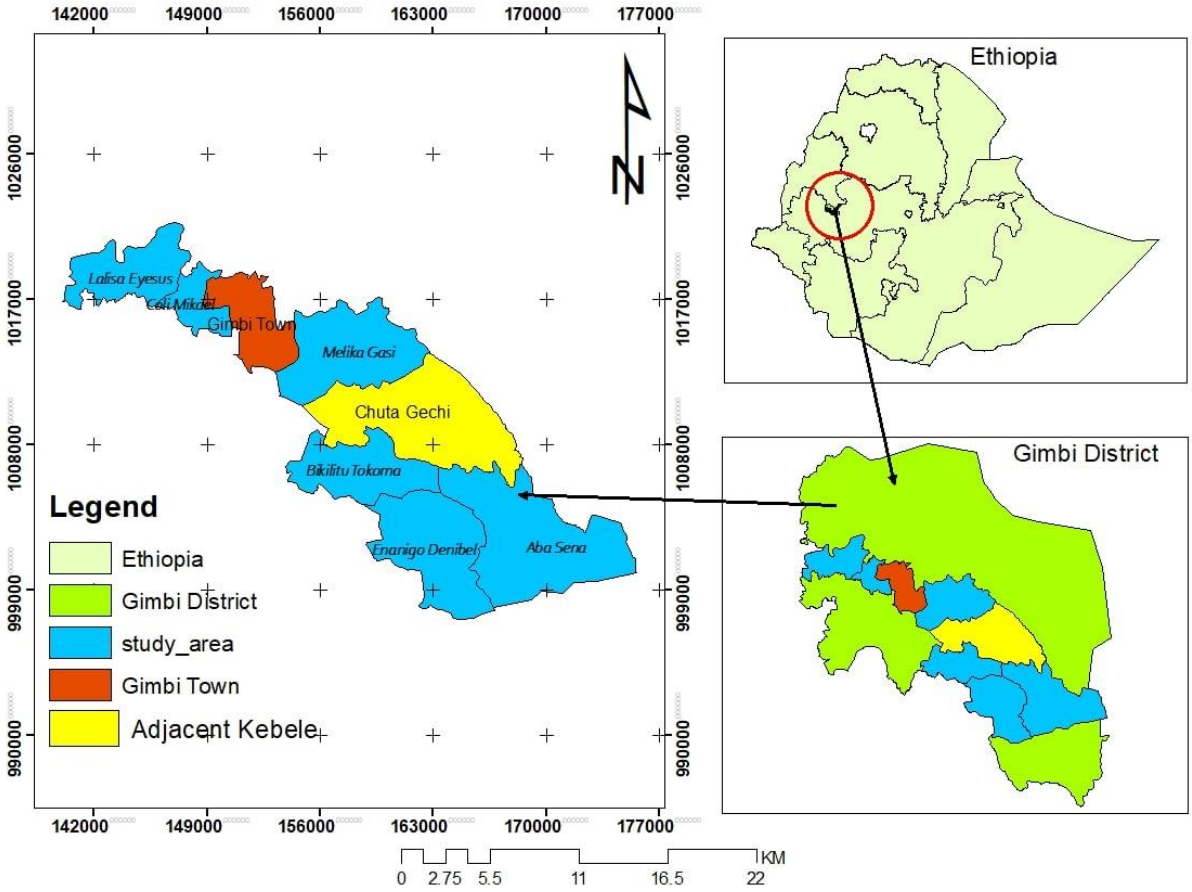

Figure 2 Map of the study area

Economic activities

The area has high potential for agriculture and it is predominantly small-scale farming of cash and food crops. The main crops cultivated include coffee, sesame, maize, beans, banana, pumpkins, fruits, sweet potato, cardamom and sugarcane as food and cash crops in the areas. Crop production is intensively carried out towards the northeastern parts, while coffee-agroforestry dominates the southwestern parts. Besides, it is rich in small ruminant animals, incense and gum resources. Except for the very small areas under vegetables and fruits, crops in all farms (commercial and smallholders) are grown under rain fed conditions. In the area, sesame, coffee, and maize are the most important cash crops, and account for 90% of the district's cultivated area.

Coffea arabica (Arabica coffee) is the dominant crop produced in this area. In most cases, coffee exists as part of forests and therefore assists in stabilizing local climate. In the district, most communities relies on coffee production for their subsistence. Furthermore, farmers in the study area are engaged in different activities for their livelihood. Fairly more than half 51.1% are engaged in mixed farming whereby farmers practice both crop production and animal husbandry on the same

plot of land (Chowdhury *et al.*, 2009). Among the remaining , about 37.4% practice crop production while the remaining smaller proportions are engaged in daily labor (5.2%), charcoal and firewood production (3.8%), and crafts work (2.5%).

1.7.2. Philosophical Groundworks

Theoretical stances, methodology, and methods all have a close relationship with one another (Saunders *et al*., 2009). The questions of what constitutes the ontological basis of social reality, is to know the epistemological basis of social reality, and how to investigate the methodological basis of social reality are all helped by this philosophical foundation (Scotland, 2012). According to Kivunja & Kuyini (2017), ontology, epistemology, methodology, and methods are all logically related. Research begins by relating what the researcher believes can be researched to what he or she already knows and how to obtain it. Furthermore, Kivunja & Kuyini, (2017) signified that the methodology of methods asserts that methodology is the science of studying methods and hypotheses about the modes of knowledge production. Such technique or process is used to choose, gather, organize, and analyze data (Williams, 2007).

Depending on whether reality exists outside of a person's mind or only within that person's mind, there are two main ontological positions. These are objectivism (also called realism), which asserts that social phenomena and their meanings exist independently of social actors, and constructivism (called subjectivism), which states that social phenomena and their meanings are continually constructed by social actors and thus in a constant state of revision (Saunders *et al*., 2009). The perspectives of the positivist and the constructivist or interpretivist contain two opposing epistemological positions as well. The first argues in favor of using natural science methods to study social reality and beyond. The second emphasizes the need for a strategy that respects the distinctions between people and objects in the natural sciences and, as a result, calls for a social scientist to have a thorough understanding of the subjective significance of social action (Ahmed, 2008; Saunders, 2009).

Aside from these, in 1878, an American philosopher by the name of Charles Sanders Peirce introduced another insight that supports pragmatism in philosophy (Ormerod, 2006). Instead of focusing on preexisting conditions and worries about applications and problem-solving strategies, pragmatic thinking is driven by events, circumstances, and outcomes. The researcher uses a pluralistic approach to understand the problem because it primarily addresses the problems rather than the methods use (Creswell, 2013). Pragmatists have two different perspectives on reality: first, they believe that there is an external world separate from our minds, which is consistent with the positivist

view of reality; and second, they "deny" that "truth" can be established for the last time. They also question the idea that one explanation of reality is superior to another (Frankenberry, 1991).

According to pragmatism, the ontology, epistemology, and methodology of the research are primarily determined by the demand for it, and it is possible to collaborate with both positivist and interpretivist positions (Saunders, 2009; Creswell, 2013). This unique feature of the pragmatic philosophy of research allows for the application of a variety of methodologies with various assumptions and worldviews, as well as various forms of data collection and analysis with the qualitative and quantitative techniques (Creswell, 2014).

1.7.3. Research Design

This study is positioned in the pragmatism philosophical assumption that applies mixed research methods in which researchers freely rely on quantitative and qualitative hypotheses. Pragmatism is results-oriented and is concerned with determining the meaning of things or focusing on the product of the research (Biesta, 2010; Antwi & Hamza, 2015). It is characterized by focusing on dialogue and cooperative meaning making to develop workable solutions to social issues. The research question is given priority in this statement. Pragmatism is predicted on the premise that theories are frequently both contextual and generalizable by examining them for "transferability" to a different situation.

A mixed-methods approach is a procedure for collecting and analyzing data by mixing both qualitative and quantitative data at different stages of the research process within a single study. The method encompasses a research problem more completely (Wisdom & Creswell, 2013; Creswell, 2014). The rationale for mixing both methods is that it helps investigate the complex role of agroforestry for a community whose livelihoods are directly dependent on agriculture. Numerous findings show that, when both methods are used in combination, they tend to complement each other and hence allow for analysis that is more complete. It also provides a better understanding of the issue at hand (Mathews, 2018; Odame, 2018). Correspondingly, Jick (1979) explicitly stated that the combination of qualitative and quantitative methods should be viewed as complementary rather than as competing camps. Other scholars also argued that to capture both biophysical realities, as well as the socio-political dimensions of the environment, it is important to utilize hybrid research methods in which a variety of perspectives play a role in dealing with the research problem (Galaz *et al*., 2008). Therefore, in this study, mixed methods (qualitative and quantitative research methods) were employed to analyze the perception and adaptation strategies of coffee agroforestry farmers, household food security, and their tree diversity management in Gimbi District, west Wollega.

Study site selection

The criteria to select the research site are centered on three factors. The first one bases itself on the potential of the district with its Arabica coffee production and the production variation across altitudinal gradients, which relates to the fact that impacts of climate change and variability vary from one traditional ecological zone to another traditional ecological zone. According to this approach, perception and adaptation to climate change were examined based on the agro-ecological zone classification.

The second factor is the proximity of the district, as most of the purposefully selected Kebeles lie along the main road from Addis Ababa to Nedjo-Mendi. This helps access all the representative traditional agro-ecologies within a set research work plan. The third factor is that the district has a large population compared to the remaining districts in West Wollega. According to the findings, the more densely populated an area is, the more vulnerable it is to deforestation, land degradation, overgrazing, dry land cultivation, and marginal areas, as well as intense competition for limited biomass among farmers and livestock. Such anthropogenic pressures pose environmental impacts and may lead communities to develop coping strategies to adapt to existing climate change that is complemented by adverse human impacts.

To achieve the research goal, the study area, which has an altitudinal range of 1200-2220 m.a.s.l., was stratified into three elevation zones: lowland (1450-1650 m.a.s.l.), midland (1650-1850 m.a.s.l.), and highland (1850-2050 m.a.s.l.) zones. This stratification helps capture and compare the views and perceptions of farmers on climate change and climate variability, adaptation strategies, and the associated limitations in agricultural adaptation to climate change. The study aimed for a broadly equal representation of participants from the lowland, midland, and highland zones. Hence, a total of 402 participants were identified, and their opinions and perceptions about the problem under study were captured and compared.

Data sources and methods of data collection

Data on perception and adaptation strategies of coffee farmers' and climate change impact assessment on coffee production trends (objective I), crop diversification impacts on Food Security (objective II), and were mainly collected using primary and secondary sources. Secondary data, such as climatic data like rainfall (mm) and temperature (°C) from 1990 to 2020 for West Wollega Zone, was obtained from the National Meteorological Agency of Ethiopia (NMAE).

Data on tree species diversity and carbon stock assessment (objective III) were directly collected from field measurements. For these measurements, parameters like tree height, tree diameter at breast

height (DBH), and tree species diversity were quantified and recorded at the plot level following transect lines selected as representative of the coffee-based agroforestry system.

Sampling procedures and Sample size determination

Sampling procedures

The sampling method for this study follows multistage sampling. The sampling procedure consisted of four steps. In the first stage, West Wollega zone was selected as the main study area. In the second stage, Gimbi district was selected out of the twenty districts found in the zone, and in the third stage, three representative agro ecological zones were purposefully selected. The district has a total of 32 kebeles with a 163,480-population size and 24,617 household heads (HHH). Accordingly, six kebeles were selected from the total kebeles in the district based on their altitudinal representatives and agricultural practices. In the fourth stage, the basic units of the study were the household heads. A comprehensive list of respondent households was randomly selected from lists of the names of household heads in the Kebeles using a computer-generated random number table. Hence, after identifying the participants from each kebeles, Key Informant Interview (KII), household survey questionnaires, Focus Group Discussion (FGD) were conducted according to questionnaires prepared for assessment. Thus, the vulnerability of farmers to climate change, their perceptions and coping strategies, and their food security status were assessed and evaluated to achieve the proposed objectives of the study.

After conducting the key informant interview and focus group discussion, transect walks were made to collect baseline information and observe woody species distribution in order to determine the number of transect lines and sample plots laid along the transect lines. The distance between the transect lines and the main plots was determined after the reconnaissance survey. Following the establishment of the first transect line, successive transects were established at uniform interval distances.

Once the number of transects and sample size is determined, the transect lines was laid out along altitudinal gradient. On the transect lines, quadrant plots of 40 m x 40 m size were established for trees' measurement in coffee based agroforestry and natural forest lands (Tadesse, 2003). During the transect walk, identification of tree species diversity and estimation of carbon sequestrated in the coffee based agroforestry was executed. Young plants (saplings and seedlings) were counted and used to estimate total biodiversity in the agroforestry system. These include, counting number of tree species and by measuring above ground and below ground tree biomass found in the systems. Following that, estimates of tree diversity and carbon sequestered in the systems were made to

determine which altitudinal gradients have the most tree diversity and sequester the most carbon for environmental sustainability.

All individuals of trees with diameter at breast height (DBH) greater than or equal to 5cm diameter and greater than or equal to 1.5 m bole length were measured in the 1,600m^2 quadrats. Diameter tape was used for diameter measurement while vertex was used for height measurements. Physical information on various aspects of the study area was recorded including the geographic location and elevation of each plot were taken from the center using GPS. Clinometer reading of the slope of each quadrat was also recorded.

Sample size determination

For determining the size of participants, a simplified formula provided by Yamane (1967) was used. According to this sample determination, the required sample size at 95% confidence level, 5% degree of variability and 8% level of precision were considered. Accordingly, 402 sample households was selected for inclusion in the data collection and analysis processes.

$$n = \frac{N}{(1 + Ne^2)}$$

Where,

N - Population size

n - Corrected sample size

e - Margin of error (MoE) or alpha level, i.e. = 0.05

Just to correct proportions for this study, the following formula is used.

$$n = \frac{no}{(1 + \frac{(no - 1)}{N})}$$

Where,

no - Sample size = 399.47, approximately = 400

N - Population size = 163,480

In order to check whether there is a difference between the predetermined sample size and the corrected sample size, the sample size correction factor was calculated and checked. Accordingly, the sample size was found to be 399.46, which is almost similar to the above calculated sample size. The sample was corrected to 402 and used for this study to make the sample size uniform for

Method of Data Analysis

After the data was collected from the sample respondents, both descriptive statistics and econometric models were employed in order to analyze and interpret the data and provide meaningful analysis. To

complement the quantitative data, the qualitative data was transcribed and analyzed to triangulate the quantitative data. For this analysis, Microsoft Excel, SPSS, and STATA version 12 were used. In this case, descriptive statistical tools such as percentages, tables, and figures were employed to strengthen the findings of econometric methods. A multinomial logit model (MNL) was employed to identify factors influencing perception and coping strategies in sampled households in response to climate change.

Similarly, the Binary Logit Model (BLM) and Ordered Logit Model (OLM) were used to analyze the contribution of coffee-based crop diversification to improving household food security through analyzing the Household Food Insecurity Access Score (HFIAS) and the Household Dietary Score (DDS). Additionally, the tree species diversity found in the system at the community level was measured using alpha (α) diversity and calculated. And then, the total number of species in a community, relative to the total number of all individuals in that community, was determined using Shannon diversity (H'). Evenness (E') indices were used as a measure to incorporate both species richness and species evenness, or heterogeneity. All measured tree species' woody biomass, both above ground and below ground, was estimated using a non-destructive allometric method. The species composition of the coffee-based agroforestry was calculated in terms of size, relative frequency, relative density, relative dominance, basal area, and an importance value index.

1.8. Structure of the thesis

The thesis is divided into five sections. The first chapter describes the background of the dissertation, which includes the background of the study, a statement of the problems, the objectives of the study, research questions, and the significance of the study, research methodology, and the scope and limitations of the study. The second chapter presents the synthesis of the dissertation, which includes the general summary, conclusions, and recommendations of the study. Chapter two to six (i.e., paper I, II, III & IV consecutively) present the findings of the field investigation conducted as part of this study. Accordingly, the first paper addresses the perception of coffee smallholder farmers' on trends of climate change, the second paper presents the determinants of perceptions of climate change and adaptation strategies of coffee-based agroforestry farmers. The third paper conceptualizes the role of crop diversification in improving household food security on coffee-based agroforestry practicing farmers. The fourth paper discusses tree diversity and carbon stock analysis along altitudinal gradients in the coffee agroforestry system of west Wollega.

CHAPTER TWO

2. Coffee farmers' perception of climate change trends in Gimbi district, west Wollega

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Abstract

This study looked at how smallholder farmers' perceptions of climate variability and change compared to actual meteorological data as well as how they responded to the impacts of climate change by adjusting their farming practices. Multistage sampling was employed to select four hundred two (402) rural farmers in Gimbi district located in West Wollega, Ethiopia. Data on monthly rainfall and temperature between 1990 and 2020 were compiled from the National Meteorology Agency of Ethiopia on an area-gridded surface. The results have shown that about 92 percent of coffee farmers perceived the change in rainfall amount during the period of analysis. About 70 perceived a decrease in both the annual and the main rainy season during the period of analysis. They also noted that there was seasonally unpredictable onset and cessation of rainfall. In addition, 94 percent of farmers perceived a variation in temperature. Among these, about 84 percent perceived an increase in temperature while 10 percent noticed a decrease in temperature. The modified Mann-Kendall trend test revealed that during the rainy season of the study period, rainfall decreased by 69 mm per decade. The farmers' perception is supported by the analysis, which found that the average annual temperature rose statistically significantly ($p<0.01$) by 0.41 degrees Celsius per decade. To reduce the noted impacts of climate change, farmers adopted various farm-level adaptation strategies like soil and water conservation, crop and livestock management practices. Thus, it is believed that the results of this study provide baseline data for regional governments, potential researchers, and policymakers in terms of farmers' perceptions of changing climates and the application of appropriate adaptation strategies.

Keywords: Climate change, Perception, Rainfall, Temperature, Coffee

2.1. INTRODUCTION

A significant impact of the changing climate has been felt globally on agricultural productivity (Alemu & Mengistu, 2019). A minimum increase in global temperatures (1-2 °C) will cause a 50% decline in agricultural output in developing countries, according to the climate change report of the Intergovernmental Panel (IPCC) (2014). Due to its agriculture's dependence on rainfall and its limited capacity for adaptation, Sub-Saharan Africa is particularly vulnerable to the consequences of climate change and variability (Matewos, 2019). The main victims of this change's negative impact are the local agrarian communities' means of subsistence (Kalele *et al*., 2021). The biggest challenge to food security and agricultural implementation in Sub-Saharan Africa continues to be climate change (Arora, 2019).

Smallholder farmers in the region, who rely heavily on rain-fed crops as their main source of income, are especially vulnerable to the effects of climate change (FAO, 2013). There is a growing question on whether climate unpredictability and change result in serious challenges to the development issues in Ethiopia (Deressa *et al*., 2009). This is because the main economic activity of the country is rain-fed agriculture, which is heavily sensitive to changing climate and its variability (Zhai and Zhuang, 2009). The nation is experiencing the changing patterns of rainfall, increasing of temperatures which is leading to elevated evaporation rates and flooding. It also will in turn lead to greater levels of land degradation, transmission of infectious disease, prevalence of pests and loss of surface and ground water potential. The poor subsistence farmers are the first to suffer from the effects of climate change, as they typically account for 98% of the total area under crops and more than 90% of the total agricultural output (Deressa *et al*., 2008; EEA, 2008). The country's susceptibility to climate change is a reflection of the significant regional differences that exist. For instance, increased temperatures and protracted droughts could have an impact on livestock rearing in the lowlands. Higher temperatures combined with more intense and erratic rainfall in the highlands can cause erosion, which lowers overall agricultural output. This could make some areas more vulnerable to food insecurity, especially as the population grows.

Ethiopia, like many other African countries, is extremely vulnerable to climate change and unpredictability (Asrat & Simane, 2017). The majority of the population depends on agriculture for food, employment, and finances. As an illustration, the agriculture sector is responsible for about 40% of the GDP, 75% of the jobs, and 80% of exports (USAID, 2021). Ethiopia's agriculture sector, despite its significant economic contribution, is currently extremely vulnerable to climate-related disasters like drought (Mekonnin *et al*., 2021). In addition, data show that Ethiopian agriculture is renowned

for having little reliance on outside inputs, making it vulnerable to changes in the climate or other related factors (Shukla et al., 2021; Zerssa et al., 2021).

It is unclear whether agricultural producers in developing countries will be able to adapt quickly enough to lessen the negative effects of the rapidly changing global climate (FAO, 2017). Farmers must therefore consider the existence of a changing climate condition or how it might change in the future in order to implement adaptation strategies. They must also give this belief enough weight to justify taking action (Asrat & Simane, 2018; Marie *et al*., 2020). As a result, according to numerous studies, public perceptions and awareness of climate change vary between nations and have changed over time (Capstick *et al*., 2019). It is attested that most findings on climate change conducted in the country have mainly focused on food production and soil fertility management. However, the assessment of coffee farmers' perceptions on climate change remain limited. Therefore, the objective of this study is to examine rural coffee farmers' perceptions of climate change comparing with the observed metrological data of rainfall and temperature. Besides, it assesses the adaptation strategies in response to the perceived impacts of climate change in Gimbi district, west Wollega.

2.2. MATERIALS AND METHODS

2.2.1. Description of the study area

The study area is located in Oromia National Regional State, west Wollega, is majorly a midland climate zone which is characterized by a heavy rainy season (June to August), a small rainy season (March to May), and a major dry season (October to March) (WWZANRO, 2020). Geographically, the district is located between 142000 and 174000 E (UTM) and 993000 and 1029000 N (UTM) (Figure 2). Despite the fact that the area has an altitudinal range of 1200–2222 m a.s.l., and includes the lowland and midland altitudinal zones, local duelers classify it as lowland, midland, and highland mainly based on its suitability for coffee production. Haru borders the district to the south, west by Lalo Asabi, north by Gumuz, and east by the East Wollega Zone. It has 32 rural kebeles. The area's typical annual minimum and maximum temperatures range from 10 °C to 30 °C, with an annual rainfall range from 1400-1800 mm.

The total population of the district was estimated to be 163,480 (WWZANRO, 2020). It consisted of approximately 83,099 men and 80,381 women. The total area of the district covers nearly 1,183.44 km^2 with 124.8 inhabitants per km^2. The typical rural land holding size is approximately 1.2 ha and 0.8 head of livestock. Approximately 21% of the population is engaged in jobs that are unrelated to agriculture. The rivers and streams flow year-round and seasonally throughout the study area. The rainfall has a bimodal pattern, lasting from June to September, followed by a dry period from October

to April. A prolonged drought season, known locally as Bona, lasts from mid-October to April, and sometimes into May (data obtained from the district agricultural office and personal communication, March 2020).

A large portion of the area is endowed with potential agricultural production that is mainly used for small-scale farming. The principal crops grown are coffee, sesame, corn, beans, bananas, pumpkins, fruit, sweet potatoes, cardamom, and sugarcane. Coffee farming predominates in the district's southwest, while other crop products dominate in the northeast. It is also rich in small ruminant animals, incense, and gum resources. Nearly all crops, whether grown commercially or by small farmers, are cultivated using rainwater, except for a few places that are used for vegetables and fruits. Approximately 90% of the district's land is agricultural, and coffee, sesame, and corn are the most popular marketable goods.

2.2.2. Sampling and data collection

A multi-stage sampling procedure was used in the actual data collection. First, west Wollega was chosen as the primary study area. Second, among the 20 districts in the zone, the Gimbi District was selected since both its coffee productivity potentials and diverse ecological zones, socioeconomic conditions, and occurrences of frequent extreme weather events. Third, out of 32 kebeles in the district, six kebeles were selected based on their altitudinal representatives and agricultural practices. Accordingly, the Enango Dembel and Aba Sena Kebeles from the lowlands, Choli Mikael and Melka Gasi Kebeles from the midlands, and Bikiltu Tokuma and Lelisa Yesus Kebeles from the highlands were selected. The total households (n) that were sampled in each kebele were determined using a proportionate to size sampling strategy using a study sample that was received from the pertinent agricultural sectors.

The survey was conducted between March and May 2020, administered by trained experts who speak the local language, from relevant sectors in the study districts. Moreover, to compare farmers' perceptions of climate change with the actual meteorological data monthly maximum, minimum temperatures and monthly total rainfall data were collected. The data are based on the National Meteorology Agency of Ethiopia over the period between 1990 and 2020. A satellite rainfall and temperature estimates from European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) and the US National Aeronautics and Space Administration (NASA) were combined with station gauge data by National Meteorological Services Agency to confirm the decreasing or increasing of climate variables.

The total sample size from the district was computed using the following standard formula:

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

where, N = total population of the sample kebele, n = sample size to be computed, and e^2 = acceptable error (level of precision), which is assigned a value of 5 percent (0.05).

The primary data were collected from the households, such as from community elders, youth, and females, Development Agents (DAs), and different experts in the district and the zone. The questionnaire for the study was prepared based on literature from prior research and a preliminary survey conducted a month before the study. Before starting the actual data collection, the questionnaire was pre-tested (piloted). In addition, the reliability and validity of the questionnaire were attested. Based on the pretest results, the necessary modifications were made to the questionnaire.

Focus group discussions (FGDs) were also conducted. During the study period, there have been security concerns in the area. Due to this, it was impossible to move from village to village to get participants at their homes. As a result, once the sampling was determined, it was decided to approach the participants face-to-face in public places such as kebele offices, farmer training centers (FTC), health centers (HC), traditional local institutional (TLI) (e.g., Idir and Afosha), and ritual places. There was no anybody else present besides the participants and researchers during the discussions. Based on this, a farm household survey with interviews and six focus group discussions with 72 participants was conducted regardless of gender, farm size, or wealth level. The six focus group discussion topics were classified into three themes separately to address the intended perception and adaptation strategies. The discussion was topic guided to get views of the participants and identify their experiences of the climate change perceptions and adaptation strategies.

Information on farmers' understanding of and adaptation measures for the changing climate and its impact on crop production was considered as the main study factor. Soil management, crop production and livestock management practices were found to be main clasters of the adapatation strategies that farmers used. The assessment principally evaluated tree planting, soil and water conservation, agroforestry, fertilizer application, improved crop variety, shifting planting dates, crop diversification, drought resistant crop, small-scale irrigation and livestock adjustment. The information sources that farmers use to adapt to climate change were considered. Accordingly, field notes were taken during the focus group discussion and used for data analysis after transcribing the discussion points. For these discussions, the average time taken was 150 minutes.

Trend Analysis Methods

Parametric and nonparametric methods are groups of tests for the detection of significant trends in climatologic time series (Kocsis *et al*., 2017). The temporal trends of temperature and rainfall were examined using the coefficient of variation (CV), the standardized rainfall anomaly (SRA), and the nonparametric methods of Mann-Kendall's test and Sen's slope estimator. CV is a widely used technique to analyze inter-annual variability of rainfall computed as the ratio of standard deviation to mean value over the given period (Sanjay *et al*., 2018). A rainfall amount with a CV less than 0.20 is less variable, that with a CV between 0.20 and 0.30 is moderately variable, and that with a CV greater than 0.30 is highly variable (Alemayehu *et al*., 2020). SRA is calculated as the difference between long-term mean annual rainfall and observed annual rainfall to the ratio of standard deviation assuming that the observations are normally distributed (Longobardi & Boulariah, 2022). This computation helps examine the pattern of rainfall that exhibits dry and wet years over time and the negative anomaly of rainfall at 25% and 50% refers to dry and very dry conditions, respectively (Kocsis *et al*., 2017).

Mann–Kendall's Trend Test

The Mann-Kendall (MKT) trend test is designed to compare random series ordered against nonrandom series over time (Hamed, 2009). The test is useful to identify the direction and magnitude of significant trends because of its low sensitivity to abrupt breaks and permitted missing values, as well as not significantly affected by single data errors or outliers (Ay *et al*., 2018). Furthermore, serial independence, which results in unreliable results, must not exist in the data. The modified Mann-Kendall (MMK) test was used to avoid the impact of serial autocorrelation in the event that it occurred (Hu *et al*., 2020). Therefore, the lag 1 autocorrelation for the temperature and rainfall time series was checked using the autocorrelation function before beginning a monotonic trend test. Numerous researchers who have used the same application have applied the test (Bari *et al*., 2016; Hu *et al*., 2020).

The MKT test method primarily involves the standardized test statistic Z and Sen's slope β parameters. It computes the difference between the later measured values and all early measured values for a time series of interest over time. If a data value from a later time-period is higher than a data value from an earlier time-period, the statistic S is incremented by 1. On the contrary, if the data value from a later time-period is lower than a data value sampled earlier, S is decremented by1. The net result of all such increments and decrements yields the final value of S using the following formula:

$$S = \sum_{k=1}^{n-1} \sum_{j=i+1}^{n} sgn\,(x_j - x_i), \tag{2}$$

where n denotes the length of a dataset and x_j and x_i are the sequential data values at times *j and i (j>i)*:

$$sgn(x_j - x_i) = \begin{cases} +1, & if(x_j - x_i) > 0, \\ 0, & if(x_j - x_i) = 0, \\ -1, & if(x_j - x_i) < 0, \end{cases} \tag{3}$$

where sgn denotes the sign function that takes the values 1, 0, or - 1 if *x j >xi*, *xj = xi,* or *xj<xi*, respectively. Positive *S* values indicate an increasing (upward) trend, and negative values of *S* reveal a decreasing (downward) trend in the time series data.

For samples, n≥10, the S statistic is approximately normally distributed with mean and variance as follows (Helsel *et al*., 2020).

$$E(S) = 0$$

$$\sigma^2 = \frac{1}{18}[n(n-1)(2n+5)], \tag{4}$$

If there is a tie in the data, then the variance (σ^2) statistic is given as:

$$\sigma^2 = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)\right], \tag{5}$$

where m is the number of tied groups and t_i is the number of observations in the i^{th} group. The standardized MK test statistic Z_{MK} that follows the standard normal distribution with mean zero and variance one is as follows:

$$Z_{MK} = \begin{cases} \frac{s-1}{\sqrt{\delta^2}}, & if s > 0, \\ 0, & if s = 0, \\ \frac{s+1}{\sqrt{\delta^2}}, & if s < 0, \end{cases} \tag{6}$$

A positive (negative) value of S indicates an increasing (decreasing) trend for the period. 'e trend is insignificant if Z_{MK} is less than the standard normal variate $Z_{\alpha/2}$, where α is the significance level. Testing trends is done at the specific α significance level. When $|Z_s| > Z_{1-\alpha/2}$, the null hypothesis is rejected and a significant trend exists in the time series.

The parameter β (the trend magnitude), indicating the variation rate within the time series, given by Sen's slope estimation test computes both the slope and intercept. A positive value of β indicates an "upward trend" (increasing values with time), while a negative value of β indicates a "downward

trend." In general, the slope between any two values of a time series x can be estimated from the following formula:

$$\beta = median\left[\frac{X_j - X_k}{j-k}\right], \quad (7)$$

where X_j and k are data values at times j and k ($j > k$), respectively. Tau measures the strength of the monotonic relationship between x and y (Kendall, 1948). Therefore, Kendall's tau correlation coefficient is given by:

$$\tau = \frac{S}{n(n-1)/2}, \quad (8)$$

A positive value of τ indicates an increasing trend, and vice versa. The summation of the Mann–Kendall test statistic (S) indicates how strong the trend of temperature and precipitation is and whether it is increasing or decreasing. The final analyses of the socioeconomic data and MKT tests were carried out using SPSS and XLSTAT statistical software packages.

2.3. RESULT AND DISCUSSION

2.3.1. Sample Household Characteristic

According to self-reported subjective measurement of climate information indicated that household heads received access to weather information from various media outlets and rural local institutions. About 35% of the respondents were aware of the changing climate and its impacts from their life experiences and external information sources (Figure 3). Respondents also stated that informal communication increased public understanding of climate change. External information sources commonly used by smallholder farmers include the mass media, agricultural extension agents, and seminars (Figure 3). These information sources helped farmers understand their environment in terms of climate change, and see how their farm productivity is changing over time. Farmers perceived that climate change had caused an intermittent condition that resulted in a shift in crop production due to a high prevalence of pests and diseases and reduced crop and livestock productivity in the area. In order to tackle the problems climate change, coffee farmers have adopted various adaptation strategies like soil and water conservation, crop and livestock management practices in the study site.

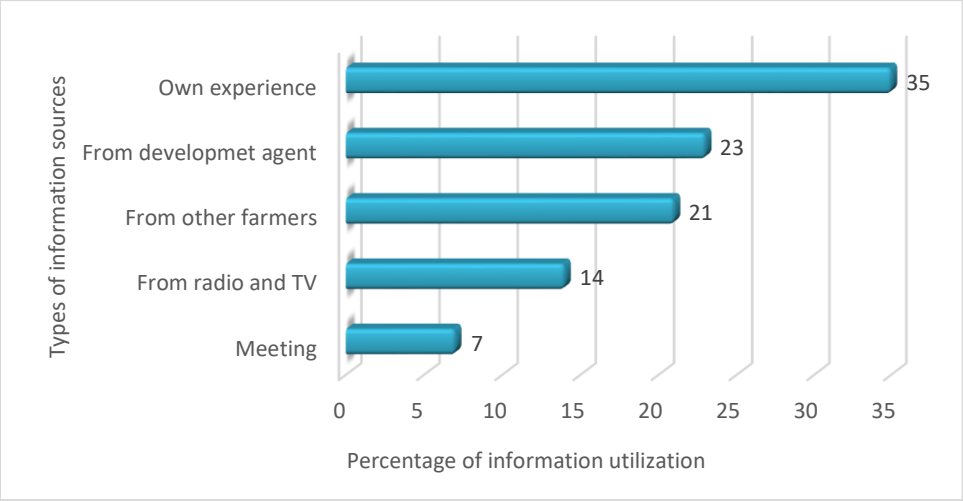

Figure 3 Information sources used by farmers to perceive and adapt to the changing climate

2.3.2. Farmers' Perceptions of Climate Change and Variability

Farmers' Perception of Rainfall Variability

The households' perception of climate change and variability in terms of rainfall distribution, amounts, and increasing temperatures over the last twenty years was analyzed (Table 1). According to interviews and focus group discussions, 20 years ago, rainfall in the district was more predictable and had a more regular pattern. During those periods, there was usually sufficient rainfall throughout the season for agricultural production. Out of the total households, 93% perceived that climatic

patterns have changed over the last two decades. Only 7 % did not detect any changes in climatic characteristics. In addition to perceiving the decreased rainfall in the study area, almost 89 percent and 92 percent of households believed that unpredictability of rainfall onset and cessation time of rainfall is more in the last two decades, respectively.

Moreover, around 88 percent of households in the districts noted that the poor distribution of rainfall. Nonetheless, few households suggested that even when it rains, the intensity of rainfall is increased. Furthermore, almost 57 percent of the households understood that the occurrence of drought frequency was increased. In addition, around 67 percent of households witnessed that there was flooding frequency following intermittent rainfall (Table 1*Table 1*). Apart from this, about 87 percent of household understood that the occurrence of repeated incidence of pests & diseases in the area (Table 1). Planning for agriculture that incorporates appropriate adaptation strategies and trustworthy scientific climate information to adapt to climatic changes was hampered by the inadequate rainfall and unreliable raining times.

Farmers' Perception of Temperature Variability

The study report indicated that about 83 percent of households perceived that temperature increased, and 10 percent believed that temperature decreased in the last two decades, while the remaining 7 percent perceived there was no change. Moreover, about 73 percent of households perceived an increase in hot days, and about 3 perceived an increase in warm nights, while 6 percent noted the decrease of coldness in cold seasons (Table 1). Generally, the majority of households are aware about the presence of climate change and variability. They revealed their local experience of climate change and variability or unpredictability of rainfall onset and cessation time of the rainy season, the decreased number of rainy days, a raise of drought severity, and the increased number of hot days.

2.3.3. Actual Variability and Trends of Rainfall and Temperature

Variability of Rainfall.

An average of monthly rainfall values was used to determine the district's seasonal rainfall. Seasons were defined using the standard meteorological definition: winter (December, January, and February), spring (March, April, and May), summer (June, July, and August), and autumn (September, October, and November), which is consistent with the study conducted by Orke & Li (2021).

Table 1 Farmers' perceptions of indicators and impacts of climate change and variability

Indicators and impacts of climate change	**Perceptions**						**Change**			
	Yes	No	Ch-Square	Increased	Decreased	No change	Early	Late	No change	Ch-square
Indicators										
Temperature variability	93.53	6.47	<0.001	83.53	10	6.47	—	—	—	<0.0001
✓ Increased number of hot days	72.74	—	—	—	—	—	—	—	—	<0.0001
✓ Increased number of warm nights	4.40	—	—	—	—	—	—	—	—	<0.0001
✓ Decreased coldness in cold seasons	6.39	—	—	—	—	—	—	—	—	<0.0001
Change in rainfall amount	92.29	7.71	<0.001	22.29	70	7.71	—	—	—	<0.0001
Unpredictability of rainfall onset	89.55	10.45	<0.001	—	—	—	38.55	51	10.45	<0.0001
Unpredictability of rainfall cessation	92.24	7.76	<0.001	—	—	—	79.24	13	7.76	<0.0001
Poor distribution of rainfall	88.06	11.94	<0.001	81.2	6.86	11.94	—	—	—	<0.0001
Strong wind	6.97	93.03	<0.001	5.97	1	93.03	—	—	—	<0.0001
Flooding frequency	66.92	33.08	<0.001	57.92	9	33.08	—	—	—	<0.0001
Frequent drought occurrence	57.2	42.8	<0.001	45.2	12	42.8	—	—	—	<0.0001
Repeated Incidence of pests & diseases	87.17	12.83	<0.001	85.17	2	12.83	—	—	—	<0.0001

During the analysis period, the long-term mean annual rainfall averaged out to be about 1819.53 mm, which is consistent with the country's southwest rainfall (Alemu & Desta, 2017) (Table 2). Ofgeha & Abshire, (2021) found greater than 2000 mm as maxima and less than 300 mm as minima mean annual rainfall of southwestern and northwestern of Ethiopia. The main rainy season, which is summer, and the relatively short rainy season, which is spring, each contribute roughly 57% and 27% of the district's mean annual rainfall, respectively. As a result, during the analysis period, the two seasons account for about 84% of the total annual rainfall. In western Ethiopia, the seasonal pattern is dominated by summer rainfall, though spring likely makes up a sizable portion of the yearly total (Gemeda *et al*., 2021).

Table 2 Mean (μ), standard deviation (σ), and CV (%) of rainfall (mm) during 1990-2020

Annual and seasonal	**μ**	**σ**	**CV**
Annual	1819.53	268.04	32.26
Spring	495.15	109.26	42.18
Summer	1032.73	159.02	38.03
Autumn	277.76	34.17	47.49
Winter	13.89	14.38	66.34

Trends of Rainfall

The Mann-Kendall trend test was used to analyze the monotonic trend of temperature and rainfall time series, presuming there was no serial correlation in the dataset. The most widely applied test for detecting serial correlation is the Durbin–Watson statistic that is defined as the ratio of the sum of squared differences in successive residuals to the residual sum of squares (Gujarati, 2009). Prior to the Mann–Kendall test, a serial correlation analysis for rainfall and temperature was assessing the Durbin–Watson d statistic. The estimated Durbin–Watson d statistic values were above 1 and less than 2, hence not rejecting the null hypothesis suggesting that there is statistically significant evidence of positive autocorrelation in the residuals.

Therefore, the modified Mann–Kendall (MMK) test was used in order to analyze the true trend value. The trend test or annual and seasonal rainfall did not show statistically significant results for the district (Figure 4). However, negative trends are evident in the main rainfall season while it is a positive trend observed in annual rainfall during the period of analysis. In the area, annual rainfall has been decreasing by about 69 mm per decade. Similarly, the main rainy season rainfall was decreasing by 132.7 mm per decade while the annual rainfall increased by 107.2 mm, in the period of analysis (Figure 4). This result agreed with the study by Amare (2022) that indicated no statistically significant

trends with a blend of positive and negative trends annual rainfall, over the period of 1990 to 2015. Between 1987 and 2017, Osena & Ujulu (2022) observed a negligible trend in Kersa district annual and seasonal rainfall measurements. Assefa & Mengistu's (2023) findings also revealed a non-significant trend in annual and seasonal rainfall in western Oromia, Ethiopia.

Table 3 Annual and seasonal rainfall trends of Gimbi district in 1990-2020

Rainfall modalities	Kendall's tau	S	P-value	Sen's slope
Annual rainfall (mm)	0.242	28	0.916	2.326
Main rainy season (mm)	-0.062	-18	0.285	-0.274
Spring season (mm)	0.524	32	0.995	0.285

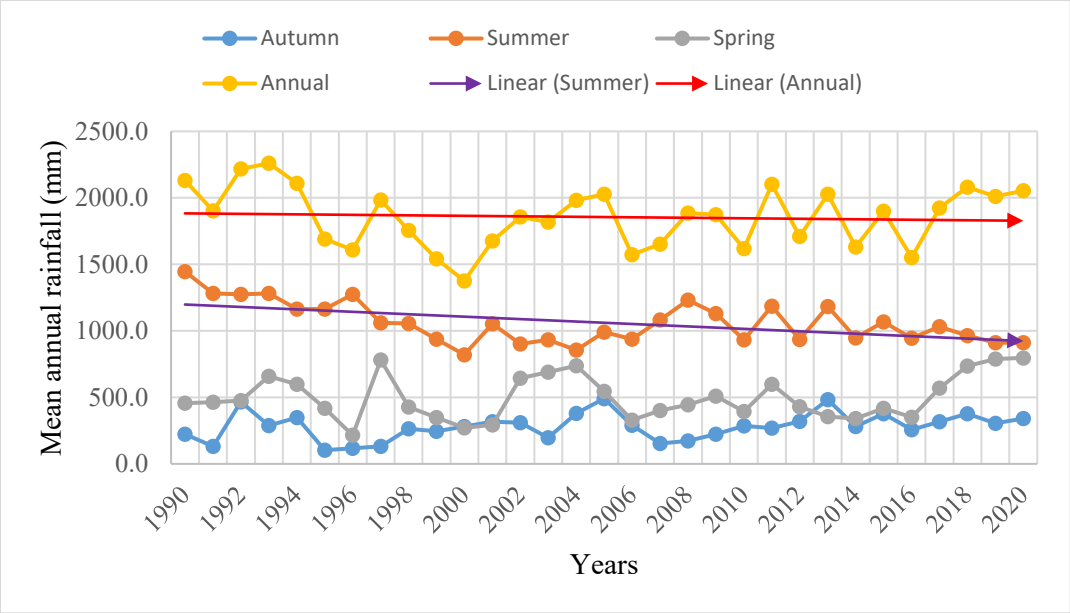

Figure 4 Mean annual rainfall trends of Gimbi district during 1990-2020

Variability of Temperature

The average annual temperature data were computed as an average of the obtained maximum and minimum temperatures. Mean and standard deviation values of temperature during the study period of analysis are presented in (Table 4 and Table 5). The mean maxima (T_{max}), minima (T_{min}), and annual (T_{mean}) temperatures was 25.63°C, 14.00°C, and 19.82°C for the district over the period of analysis (Table 4). The recorded maximum and minimum temperatures in 1996 and 2017 suggest that temperatures in the districts have recently risen. In the district, winter and summer were the hottest and coldest seasons that reported 21.33°C±0.94σ and 18. 40±0.66σ.

Table 4 Mean maximum, minimum, and annual temperatures (°C) in the Gimbi district

	T_{max} (°C)		T_{min} (°C)		T_{mean} (°C)	
Annual and seasonal	**μ**	**σ**	**μ**	**σ**	**μ**	**σ**
Annual	25.63	0.72	14.0	0.60	19.82	0.66
Spring	27.46	1.02	15.2	0.86	21.33	0.94
Summer	23.3	0.68	13.5	0.64	18.4	0.66
Autumn	24.9	0.84	13.6	0.78	19.25	0.81
Winter	27.48	0.92	13.6	0.82	20.54	0.87

Trends of Temperature

A statistically significant level of warming trends in the district's annual maximum and mean temperatures was noted ($p<0.001$). Maximum and mean annual temperature trends in the area over the analysis period showed warming trends of 0.49°C and 0.32°C per decade, respectively. In general, during the analysis period, the mean annual temperature trend increased by roughly 0.64°C (Table 5 and Figure 5). Furthermore, for the districts, the maximum temperature increased faster than the minimum temperature. However, Kahsay *et al*. (2019) discovered that between 1971 and 2013, in the Tigray region of northern Ethiopia, the average annual minimum temperature (0.40°C) increased more quickly than the average annual maximum temperature (0.65°C) per decade.

Table 5 Annual and seasonal temperature trend analysis by the MKT test for the Gimbi district in 1990-2020

Temperature modality	**Kendall's tau**	**S**	**P value**	**Sen's slope**
T_{max} (°C)	0.675	328	0.001	0.062
T_{min} (°C)	0.193	92	0.152	0.031
T_{mean} (°C)	0.495	231	0.001	0.044

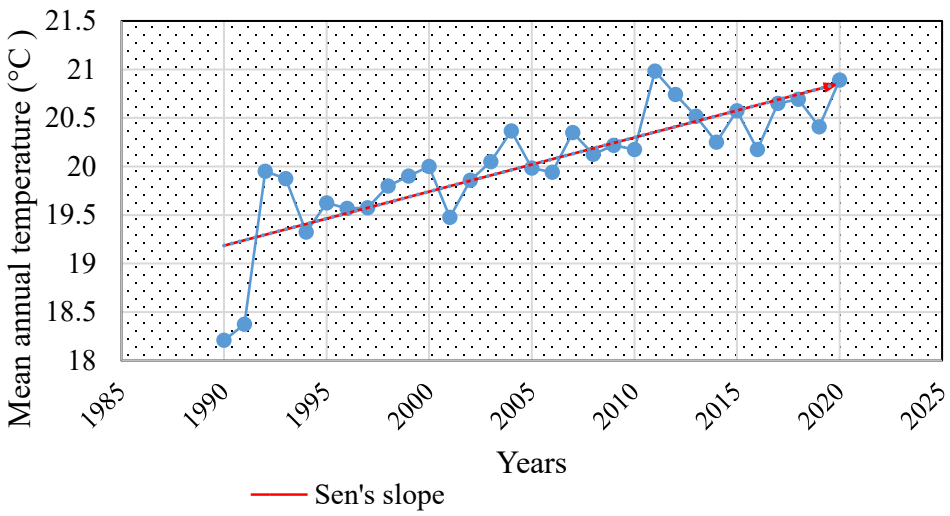

Figure 5 Mean annual temperature trends of Gimbi district during 1990-2020

2.4. Farmers' Perceptions of Climate Change versus Meteorological Data.

Farmers' self-reported perceptions of the climate are insufficient to draw general conclusions about trends in climate change and variability. Their understanding of climate change is very site-specific, highly subjective, and influenced by a variety of factors (Niles & Mueller, 2016). The majority of farmers thought that over the previous twenty years, summer season rainfall had decreased in their localities while there was an intermittent increase in rainfall in the spring and autumn seasons (Table 1). Meteorological rainfall data analysis was also consistent with farmers' perceptions of rainfall decline in the main rainy season in the districts. It has shown decreasing tends in the main rainy season and increasing in the spring and autumn seasons. The study by Ayal *et al*. (2018) attested that the annual and *Bega* rainfalls show increasing trends. Farmers' perceptions of rising temperatures and changes in rainfall amount and distribution corresponded to meteorological records of mean temperature trends in their areas (Table 3). Previous studies have also supported the accord between farmers' perceptions of a rising temperature trend and meteorological results (Ayal *et al*., 2018; Ricart *et al*., 2022).

2.5. Conclusion and Policy Implications

Integrating coffee farmers' perceptions with the observed meteorological to identify how coffee farmers notice their environment has not been comprehensively studied. The principal objective of the study was to scrutinize farmers' perceptions of rainfall and temperature to compare with the observed metrological data. The multistage sampling method was employed to select 402 rural farmers in Gimbi district, west Wollega. The areal gridded data on rainfall and temperature were collected from National Meteorology Agency of Ethiopia.

Access to sources of climate information has had a positive impact on coffee farmers' perceptions in the study area in addition to their own experiences. The majority of farmers had noticed weather extremes and climate change in their region over the previous 20 years. More specifically, about 70 percent of coffee farmers noticed a decrease of rainfall and 22 percent perceived an increase, whereas 8 perceived no change during the main rainy season in the district. Farmers recognized the manifestation of rainfall variability in terms of oscillations in the commencement and cessation of the rainy season, unexpected rainfall distribution, decreased number of rainy days, and increased intensity.

The actual meteorological data are consistent with farmers' experiences of climate change and variability, which show a decrease in the primary rainy season and yearly rainfall with increasing temperatures. The updated MKT test revealed that annual rainfall reduced by 107.2 mm and primary rainy season rainfall decreased by 132.7 mm per decade. Furthermore, during the analysis period, the mean annual temperature had been declining by around 0.31°C each decade.

Our findings indicated that the coffee farmers have perceived that the climate is changing and as response, they adopted different strategies to lessen impact of the changing climate risks. Thus, the results of the findings provide valued information to policy-makers and extension works. Primary, an increase in local weather station sites improves access to weather information, thereby advancing various strategies against adverse climate change impacts. In addition, since farmers get information about climate change from different media and social networks during meetings, government should strengthen social networks' capacity and develop a link with local public institutions. Furthermore, the government required to disseminate and present weather information that represent specific local weather variabilities in newspapers and Internet to promote the capacity of rural agricultural extension workers and farmers.

CHAPTER THREE

3. Determinants of adaptation strategies of coffee-based agroforestry farmers in Gimbi district, west Wollega

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Abstract

A range of local social and environmental factors has an impact on farmers' views of climate change and choices on the use of coping mechanisms. This study examines the factors that are limiting farmers' perceptions of climate change and their coping mechanisms in Gimbi district, Western Ethiopia. A household survey and focus group discussion were employed to collect relevant data. A total of 402 randomly selected households and six focus group discussions containing 72 participants were used to gather data. Binary logit models were used to analyze the collected data. Farmers noted that some of the signs of climate change included increasing temperature, erratic rainfall, late onset of rainfall, and early cessation of rainfall. We discovered that there are three distinct sets of climate adaption strategies used by farmers: crop management, soil and water conservation and intensive farm management. The primary determinants of farmers' perceptions of climate change and adaptation techniques were household head age, education, soil fertility, market access, and agricultural training. Age, education, and soil fertility level were the characteristics that significantly impacted farmers' perspectives and coping mechanisms among the primary drivers evaluated in the area. Use of Agroforestry, shifting planting dates, and fertilizer application were all essential farming practices used as climate adaptation measures. Both socioeconomic and environmental factors have found to affect farmers' perceptions of climate change in the area. The existing socioeconomic and environmental factors, in turn, affect their choice of strategies to adapt to climate change. When implementing climate change adaption strategies, it is critical to assess farmers' level of awareness of climate change and their coping strategies, as well as the factors limiting their ability to adapt to climate change.

Keywords: *Determinant, Adoption, Climate change, Coffee*

3.1. INTRODUCTION

The earth's climate is changing quickly, according to scientific data, as a result of rising greenhouse gas emissions (Jarraud & Steiner, 2012). The increased concentration of greenhouse gases has raised the average temperature and altered the amount and distribution of rainfall globally (McNutt & Ramakrishnan, 2021). For example, in Sub-Saharan Africa, warming is expected to be greater than the global average and in parts of the region, rainfall will decline (Serdeczny *et al*., 2017). There is growing evidence that extreme events, such as droughts and floods, have been common incidences (Clarke *et al*., 2022). These have affected smallholder farmers in developing countries who heavily depend on rainfed agriculture for their livelihoods (Zerssa *et al*., 2021). In Africa, climate change has affected both the natural and social systems (Ofori *et al*., 2021; Maino & Emrullahu, 2022). Impacts of climate change are felt more severely in semi-arid and arid areas (Raza *et al*., 2019; Sitati *et al*., 2021). The world is now concerned with how to lessen the consequences of a changing climate and its adaptation measures (Eriksen et al., 2021).

Farmers use adaptive strategies to respond to the effects of climate change. Socioeconomic conditions and local environments play a significant role in the success of adaptation strategies in different parts of the region (Chersich & Wright, 2019; McKinley *et al.*, 2021). Various environmental and social factors affect farmers' perceptions of climate change and their decisions to use particular adaptation strategies (Wondimu *et al.*, 2022; Yoosefi Lebni *et al.*, 2020). For instance, owing to climatic changes, smallholder farmers may change domestic crop cultivation to new and more adaptable crop types, but doing so may reduce their productivity (Belay *et al*., 2017). Consequently, the effectiveness of an adaptation strategy depends on the participation of numerous stakeholders (Wamsler, 2017; Prutsch *et al.*, 2018).

Evidently, it is crucial to investigate adaptation measures to reduce the anticipated adverse impacts of climate variation (Raza *et al.*, 2019; Fawzy *et al.*, 2020). As a strategy to help smallholder farmers lessen the existing outcome of a fluctuating environment, it has been acknowledged that having the capacity to adapt to the changing climate is commonly endorsed as a policy priority (Belay *et al.*, 2017; Raza *et al.*, 2019). Various studies have been conducted to examine and identify the factors influencing farmers' adaptation decisions to address the main problems caused by climate change and to recommend the best adaptation mechanism choices. The findings of such studies were largely aimed at agricultural productivity changes and/or suggested adaptation measures towards the changing climate. This is a serious drawback because a range of factors affects farmers' responses to changing environmental factors and their coping techniques.

The impacts of climate change and the variables influencing the selection of adaptation in African agricultural systems have been analyzed using various methods (Marie *et al.*, 2020; Mwinkom *et al.*, 2021). Owing to the diversity of the countries studied, it is extremely difficult for collective research to offer insights into identifying country-specific impacts and adaptation possibilities (Eriksen *et al.*, 2021; Sitati *et al.*, 2021). As a result, these studies did not address socioeconomic and environmental issues or agro-ecological aspects within each explicit area. In other words, the adoption of adaptation strategies to adapt to a changing climate is specific to the environment, and it limits the role of adaptation measures across different localities.

As verified, most findings on climate change conducted in the country related to agriculture have mainly focused on food production and soil fertility management. However, despite the level of knowledge about coffee farmers' adaptation strategies to climate change, the determinants of their strategies remain limited. Hence, this study has focused on (1) assessing farmers' adaptation strategies to the changing climate and (2) investigating the determinants of coffee farmers' adoption of adaptation strategies in Gimbi district, West Wollega.

3.2. Methods

Description of the study area

Gimbi is located in Oromia National Regional State, Ethiopia, between 142000 and 174000 E (UTM) and 993000 and 1029000 N (UTM). The area has an altitudinal range of 1200-2222-m a.s.l. and includes the lowland and midland altitudinal zones. Haru borders the district to the south, west by Lalo Asabi, north by Gumuz, and east by the East Wollega Zone. It has 32 rural kebeles. The area's typical annual minimum and maximum temperatures range from 10 °C to 30 °C, with an average annual rainfall of 1400-1800 mm.

The total population of the district was estimated to be 163,480 (WWZANRO, 2020). About 83,099 were men and 80,381 were women. It covers 1,183.44 km2 with 124.8 inhabitants per km^2. The typical rural land holding size is approximately 1.2 ha and 0.8 head of livestock. Approximately 21% of the population is engaged in jobs that are unrelated to agriculture. The rivers and streams flow year-round and seasonally throughout the study area. The rainfall has a bimodal pattern, lasting from June to September, followed by a long dry period from October to April. A prolonged drought season, known locally as Bona, lasts from mid-October to April, and sometimes into May (data obtained from the district agricultural office and personal communication, March 2020).

A large portion of the area is endowed with potential agricultural production that is mainly used for small-scale farming. The principal crops grown are coffee, sesame, corn, beans, bananas, pumpkins, fruit, sweet potatoes, cardamom, and sugarcane. Coffee farming predominates in the district's southwest, while other crop products dominate in the northeast. It is also rich in small ruminant animals, incense, and gum resources. Nearly all crops, whether grown commercially or by small farmers, are cultivated using rainwater, except for a few places that are used for vegetables and fruits. Approximately 90% of the district's land is agricultural, and coffee, sesame, and corn are the most popular marketable goods.

Sampling techniques

A multi-stage sampling procedure was used in the actual data collection. First, west Wollega was chosen as the primary study area. Second, of the 20 districts in the zone, the Gimbi District was selected. Third, out of 32 kebeles in the district, six kebeles were selected based on their altitudinal representatives and agricultural practices. Accordingly, the Enango Dembel and Aba Sena Kebeles from the lowlands, Choli Mikael and Melka Gasi Kebeles from the midlands, and Bikiltu Tokuma and Lelisa Yesus Kebeles from the highlands were selected. The total households (n) that were

sampled in each kebele were determined using a proportionate to size sampling strategy using a study sample that was received from the pertinent agricultural sectors.

The primary data were collected from the households, such as from community elders, youth, and females, Development Agents (DAs), and different experts in the district and the zone. The questionnaire for the study was prepared based on literature from prior research and a preliminary survey conducted a month before the study. Before starting the actual data collection, the questionnaire was pre-tested (piloted). In addition, the reliability and validity of the questionnaire were attested. Based on the pretest results, the necessary modifications were made to the questionnaire.

Focus group discussions (FGDs) were also conducted. During the study period, there have been security concerns in the area. Due to this, it was impossible to move from village to village to get participants at their homes. As a result, once the sampling was determined, it was decided to approach the participants face-to-face in public places such as kebele offices, farmer training centers (FTC), health centers (HC), traditional local institutional (TLI) (e.g., Idir and Afosha), and ritual places. There was no anybody else present besides the participants and researchers during the discussions. Based on this, a farm household survey with 402 interviews and six focus group discussions with 72 participants was conducted regardless of gender, farm size, or wealth level (Table 6). The six focus group discussion topics were classified into three themes separately to address the intended perception, adaptation strategies, and determinant factors investigations. The discussion was topic guided to get views of the participants and identify their experiences of the climate change perceptions and adaptation strategies.

Information on farmers' understanding of and adaptation measures for the changing climate and its impact on crop production was considered the main study factor. Soil management techniques, crop production and livestock management practices were evaluated. The assessment principally included tree planting, soil and water conservation, agroforestry, fertilizer application, improved crop variety, shifting planting dates, crop diversification, drought resistant crop, small-scale irrigation and livestock adjustment. The information sources that farmers use to adapt to climate change were considered. Accordingly, field notes were taken during the focus group discussion and used for data analysis after transcribing the discussion points. For these discussions, the average time taken was 150 minutes.

Data analysis

In this study, demographic and socioeconomic data were summarized and presented using descriptive statistics such as frequency, percentage, graphs, figures, and tables. In addition, t-tests and Chi-square tests were used in order to compare the difference among groups for different socioeconomic and demographic variables. This test is mainly employed to know whether the difference is statistically significant or not.

The descriptive statistics were used to analyze categorical variables, including education, gender, and marital status. Similarly, other categorical parameters were analyzed, including credit access, agricultural training, and extension services. The t-test statistical analysis was employed for the continuous variables including age, farming experience, household size, farm income, farmland size, tropical livestock unit (TLU), market access, and distance to farmland (Table 6).

As indicated by Kpadonou *et al.* (2017) and Mairura *et al.* (2021), although multivariate probit modeling has been employed in different studies to examine the factors that influence a farmer's decision to adopt a variety of technologies, this was inappropriate because the study's main focus was on the farmer's individual strategic choices. Therefore, we employed the binary logistic models to assess the variables affecting smallholder perceptions and coping strategies. For this analysis, Microsoft Excel, SPSS and STATA version 12 were used.

$$\ln\left[\frac{P}{1-P}\right] = \beta_0 + \beta_1 x_1 + \beta_2 x_{2+\dots+} + \beta_j x_j \quad \text{(1)}$$

where, *p* represents the possibility of adopting a coping measure, 1-*p* is the possibility of not adopting a coping measure. β_0 was the intercept, β_1, β_2 … β_j were the regression coefficients of determinants, and X_1, X_2 … X_j represented the social and environmental explanatory variables.

Table 6 Variables used to assess perceptions and adaptation strategies of smallholder farmers

Variable	Description	Ex. Sign
Gender	1 if male and 0 if female (Dummy)	-
Education	1 if obtained a minimum of primary education, 0 otherwise (Dummy)	+
Marital status	1 if married with a couple, 0 otherwise (Dummy)	±
Age	age in years (Continuous)	±
Farming experience	farming experience in years (Continuous)	+
Size of household	no of individuals in the HH (Continuous)	+
Occupation	1 if farming, 0 otherwise (Dummy)	+
Off-farm activities	1 if engaged in off-farm, 0 otherwise (Dummy)	-
Income from farm	Total income from farm activities (Continuous)	+
Income from non-farm	Total income from non-farm activities(Continuous)	±
Size of farmland	Total farm size in hectares (Continuous)	+
TLU	Reference total tropical livestock units (unit less number) (Continuous)	+
Market access	Distance to input markets (km) (Continuous)	-
Farmland distance	Distance to output markets (km) (Continuous)	-
Credit access	1 if accessed credit, 0 otherwise (Dummy)	+
Agricultural training	1 if accessed training, 0 otherwise (Dummy)	+
Extension services	1 if accessed extension, 0 otherwise (Dummy)	+

Source: Mairura et al. (2021)

3.3. Results and discussion

Socioeconomic and demographic aspects

The study identified that the average age of coffee smallholder farmers, participated both in interviews and in focus group discussions (FGDs), in Gimbi district was 47 years. The minimum and maximum ages were 20 and 90, respectively. During the study period, 23% were under 35 years of age, 69% were in the range of 36-65 years, and 8% were above 65 years, while the age and education level of the focus group were different from those of surveyed households across the agroecological zones (Table 7). All kebeles had different year of farm experiences (29 years on average) and household dependency ratios (0.3). The average TLU was 1.32, with the lowest at 0.78 and the highest at 1.88. The landholding size of the farmers ranged from 0.125 ha to 6 hectares. In terms of soil fertility, 39% of cultivable land was prone to erosion, 50% was moderately sensitive, and 11% was unaffected.

Climate change impact on agriculture in the study area

Farmers have addressed that the present farming system is different from the trends of the past two decades due to climate change. The main farming system mentioned by the participants was mixed farming, which was mostly rain-fed. They cultivate different types of crops, which are dominated by coffee and the rearing of animals. They also identified the major crops that are planted in the long rainy season and the short rainy season. Both cash crops and others are produced in the area. Participants responded that the productivity of several crops is declining from time to time compared to those that were produced two decades ago. A few crop types are not produced, and other crops replace them. For instance, previously the area used to produce peas and beans, but now corn and coffee replace them.

Table 7 Focus group discussion participants' socio-economic characteristics by study area base with their respective kebeles.

AB = Aba Sena, ED = Enango Dembel, BT = Bikiltu Tokuma, MG = Melka Gasi, LY = Lelisa Yesus, CM = Choli Mikael

Farmers characteristics		Categories of the farmers	**Study area base**						Total
			Lowland		**Midland**		**Highland**		
			AB	ED	BT	MG	LY	CM	
Gender		Male	8	7	8	7	9	9	48
		Female	4	5	4	5	3	3	24
Age		35 and below	2	1	2	3	1	2	11
		36-50	5	5	3	5	7	6	31
		51-65	2	4	6	3	1	4	20
		Above 65	3	2	1	1	3	0	10
Education	Illiterate	Can't read & write	1	0	0	0	2	0	3
	Literate	Primary school	9	8	10	9	7	7	50
		Secondary school	2	3	1	3	2	3	14
		High school	0	1	1	0	1	2	5
Occupation		Farming alone	8	10	9	11	8	7	63
		Farming and off-farm	4	2	3	1	4	5	19
		Total	12	12	12	12	12	12	72

"I think the farming system I am following is problematic because the types of crops I am cultivating are inadequate due to environmental limitations. Formerly, I could produce different crops, including peas and beans, but now I cannot produce them in the period two decades ago. Additionally, the land I manage is getting infertile, and I am looking for additional land for cultivation, but I could not get that. My cattle do not have enough grass to graze as there is no free land available, and as a result, their productivity is decreasing. I am selling these and using the proceeds to buy food." (Participant-1)

Due to this, the farmers ought to cultivate additional land by removing forests to increase production. However, they are facing problems with forest cover and biodiversity reduction, which result in soil fertility decline and increased fertilizer costs. Throughout the conversation, each person has articulated his or her individual point of view. Few of the participants who did not perceive the presence of climate change think differently. They believe that the drying of rivers, the reduction of forest cover, extreme weather conditions, the prevalence of diseases, the reduction of crop production, etc. are the punishment of the creator that came to them because of the evil deeds of people.

"Well, I guess that the shortening of rainfall seasons and intermittently unseasonal rainfall shows the changing of climate. I perceive that the temperature is increasing while the rainfall amount is decreasing. Droughts, disasters, floods, and pests and diseases are all becoming more common on our farm." (Participant-2)

"... it is obvious that our area was known for its forest coverage and coffee production. Now everything has changed following the forest cover change. Biological diversity is changing, soil fertility is unable to recover, rivers are drying, and irrigation farms are being depleted. I think we are cursed." (Participant-3)

"I think the crop variety and productivity reduction will continue as our village population is increasing. The rainfall reduction is affecting the rain-fed farming. Our forest cover is declining from time to time. Since it is because of our unwise resource usage and population growth, the agricultural productivity reduction will be worse than ever before." (Participant-4)

"... you know that our livelihoods depend on agriculture, and the current situation is getting worse because our land is not producing sufficient food. The types of crops we produce are being reduced, and some crop types are replaced them. Even with fertilizer,

rainfall is insufficient to cultivate what we require. I tend to plant coffee crops while integrating some other complementary crops. "But still, I am unable to stop cutting trees and maintain forests as fuelwood and charcoal making are part of my livelihood." (Participant-5)

This study confirmed that the trends of crop and production in the area have changed over time following the occurrence of climate change. This was due to the increasing temperature and reduction of the normal distribution of rainfall, together with the unpredictability of its onset and cessation. Findings reported most African nations have seen an increase in the yearly average temperature over the past few decades owing to human-induced greenhouse gas emissions (Almazroui *et al*., 2020). This adversely affects the region's agricultural productivity. Other findings also stated that climate change is likely to reduce Ethiopian crop production, in particular coffee production, by up to 40% in the 2090s, including the potential loss of suitable planting regions (Chemura *et al*., 2021). In order to tackle those problems, farmers have adopted different adaptation strategies. The adopted strategies vary among farming communities from local to local.

Adaptation strategies

According to the survey and focus group discussions, farmers adopted different strategies to adapt to the changing climate in the area. Despite the fact several adaptation strategies have been noticed in the study area, we categorized them into three main parts using principal components like soil and water management, crop management, and intensive farm management. The most common practices farmers used to alleviate the effects of climate change, particularly in the lowlands, were agroforestry and improved crop varieties, followed by soil and water conservation strategies. Most farmers in the midland used conservation of soil and water resources, agroforestry, and fertilizer application at the optimum level and at the same rate (Figure 6). Highland farmers primarily used conserving soil and water, fertilizer application, and tree planting as resilient mechanisms for climate change adaptation**.** As a general truth, agroforestry is the main land use system that farmers have used for several decades. The intensity of using the system varies among farming communities across the zones. The reason for the difference is that coffee is the most important cash crop produced in the area that was integrated with tree management, particularly forest resource conservation. Coffee production was previously well known in the lowlands and partially in the midlands, according to farmers. This is inconsistent with the findings of Asrat & Simane (2018); Ahmed *et al*. (2021).

"I could understand my environment from my observation, through training obtained from a development agent, from radio, and from different meetings held to discuss on climate change issues in my kebele. I mainly cultivate coffee crops and other integrated seasonal crops. As a result, I like to plant trees, conserve soil and water, and protect multipurpose trees on my farm that are used for fruits, fodder, fencing, and fuelwood. This helped me adjust myself and my family to living and working in the area." (Participant-6)

Farmers stated that crop type or variety shifting taking place because of rising temperatures and erratic rainfall. For instance, coffee has become the main crop type that is substituting practically everywhere in the area, with various levels in different agroecological systems. Farmers have adapted to appropriate coffee crop management by conserving the various tree species that comprise the agroforestry system. They had largely practiced tree planting and integrated coffee with shade trees over time, eventually progressing to incorporating other crop types into the system. As a result, agroforestry has now spread widely from the lowlands and midlands to the highlands. Most farmers cultivate crops compatible with coffee agroforestry systems, and at the same time, they opt to produce climate change-resistant varieties. As a result, agroforestry has spread widely from the lowland and midlands to the highlands. Consequently, teff, corn, sorghum, and various spices make up the main crops cultivated in the region after coffee.

"... I guess that I would continue adjusting to the changing climate by tree planting with coffee, using crop diversification, improved crop varieties, and drought resistant crops. I have observed my environment through my life experiences, as I have lived on a farm for many years, and several factors affect crop productivity. I managed the land fertility problem by diversifying crops on a plot of land, mixing nitrogen-fixing types, rotating crops, and integrating drought-resistant species. What drove me to look for such measures was what I perceived in my surroundings. I noticed a decrease in rainfall, an increase in temperature, floods, and the prevalence of pests and diseases. I also followed the advice of developmental agents and the information I got from other farmers. In addition to crop management, I believe we should plant trees to conserve soil and water." (Participant-7)

Other adaptation options include boosting agricultural productivity by using additional inputs, particularly fertilizer per unit area, small-scale irrigation, and supplementary irrigation. The farmers

also seek for better alternative adaptation strategies that can solve the problem of the changing climate sustainably (Figure 6). This is consistent with previous research reported by Kumawat *et al.* (2020), Kuyah *et al.* (2021) and Zerssa *et al.* (2021). Farmers use different adaptation strategies based on their local conditions. This is study agree with the findings of Belay *et al*. (2017) that states farmers adopt different coping methods to climate change impacts.

> *"In our kebele, the majority of farmers rear animals and cultivate crops using intensive fertilizer applications. Animal rearing has become based on the advice of developmental workers and information obtained from different sources like TV, meetings, and other farmers. Crop production is also supported in a similar fashion to animal rearing. We adopted these practices from our fathers, but we improved on them to adapt to the changing climate. I believe that these adaptation strategies alone would not make our lives better and more sustainable. We have to practice other coping mechanisms to adapt better to the environment." (Participant-8)*

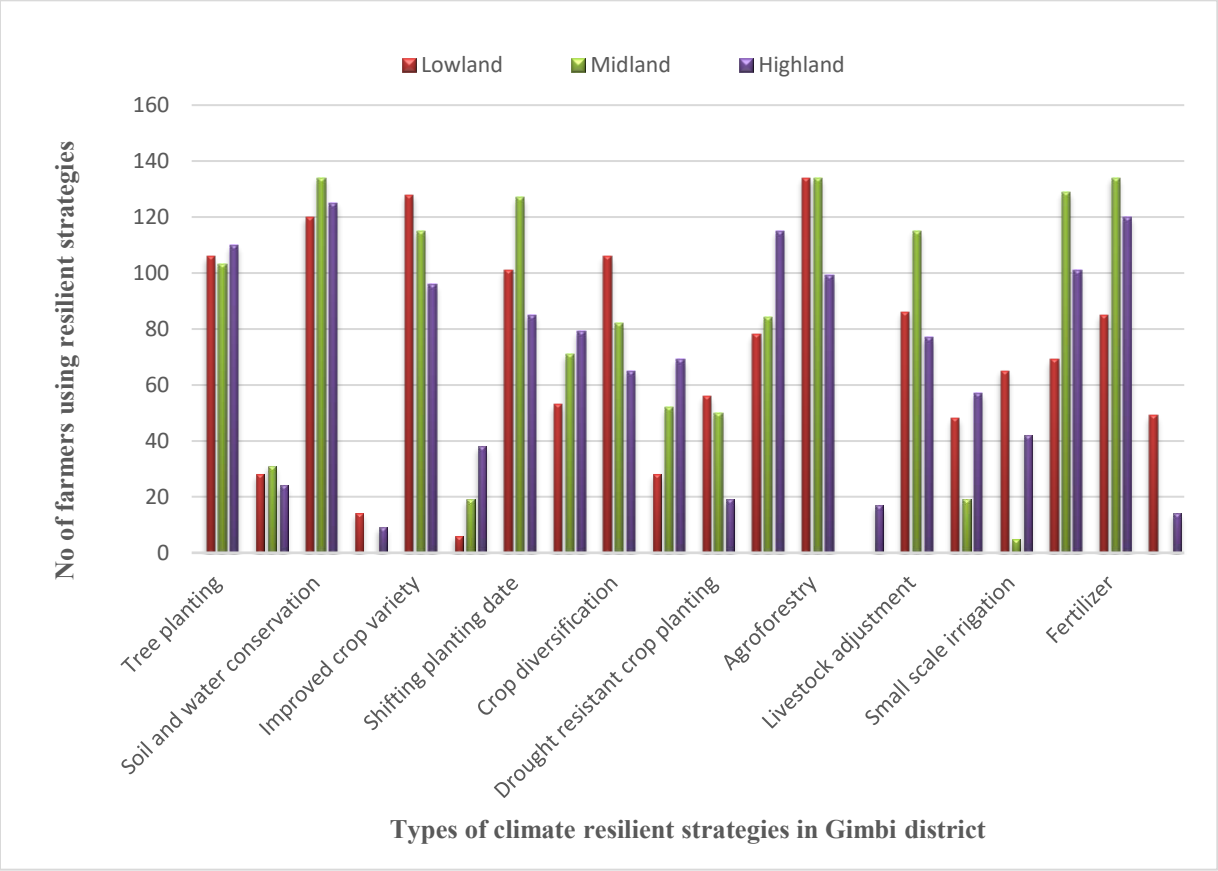

Figure 6 Types of adaptation strategy option used by the farmers

Determinants of adaptation strategies

Farmers used various strategies, but the factors that influenced their decision to use a particular measure varied (Table 8). For example, tree planting and agroforestry, which determine soil and water management strategies, differed significantly across the determinants, except in land holding size. This result agrees with other findings in different regions (Belay *et al.*, 2017; Hundera *et al.*, 2020; Mairura *et al.*, 2021).

This study's finding revealed that having a male as the head of the family boosted the likelihood of greater agricultural diversity and variety as adaptation strategies. The odds of employing improved crop variety, crop diversification, and agroforestry as climate change adaptation techniques increased by 22%, 36%, and 6%, respectively, when the household head was a male (Table 8). By this, Wondimu *et al.*, (2022) and Yoosefi Lebni *et al.* (2020) contend that male household heads have more opportunities than female household heads to put adaptation measures into practice.

Contrary to the usual assumption, the age of the household has negatively affected the decision to use some adaptation techniques while having a positive influence on others (Table 8). The likelihood of employing adaptation techniques like tree planting, increased crop variety, crop type diversification, agroforestry, and small-scale irrigation drops by 2.7%, 3.6%, 3.7%, 2.1%, 3.4%, and 4.1%, respectively, as the household head's age rises by one year from the average. Similarly, previous studies have reached a variety of conclusions on how to adopt certain soil and water protection measures (Yifru and Miheretu, 2022).

> *"I am a farmer concerned about coping with the changing climate. In comparison to the farmer's holdings in my kebele, my plot of land is average in size. I am trying to manage the production of sufficient food for my family and supply it to the market so I can buy other complementary foods. However, as I got older, I was unable to produce food using intensive farming, and as a result, I preferred to plant trees and raise some animals. I also cannot go to the market to buy agricultural inputs or sell my produce. Market access affected my adaptation choices to adapt to the changing climate." (Participant-9)*

According to current finding we obtained the use of tree planting, agroforestry, shifting planting dates, drought resistant crops, and fertilizer application were not impacted by education when tested at a 5% significant level (Table 8; Table 10). This conclusion is consistent with past findings indicating that education has a positive impact on farmers' decisions to implement soil and water preservation, improved crop variety, livestock adjustment, and small-scale irrigation (Gebru *et al.*, 2020; Negera *et al.*, 2022).

Like other variables, the income obtained from non-farming negatively influenced practices like livestock adjustment, and small-scale irrigation (Table 8). The study revealed that the greater the farmers' non-farm income options, the more they can afford to conserve soil, irrigate the land, engage in agroforestry, promote crop diversity, cultivate drought-resistant crops, and use less fertilizer. Therefore, with every unit income increase from non-farm sources, crop diversity increased by 0.001% (Table 8). According to previous studies, non-farm activities positively influence the adoption of technologies such as tree planting, agroforestry, using improved crop varieties, and conservation of soil and water (Jha *et al.*, 2021; Tolera & Fekadu, 2021).

Regarding the landholdings, our findings showed that they have a positive association with all adaptation techniques. In this situation, the probability of employing all approaches increases by at least 18.6% for each unit increase in cultivated land. According to other studies, farmers in diverse agricultural regions are more likely to use strategies that enable them to adapt to climate change (Vo *et al*., 2021). This fact may have given farmers the assurance they needed to put adaptation strategies in place to lessen the effects of climate change. Therefore, due to the size of the farm, the possibility of a successful and meaningful adaptation to climate change has increased (Destaw & Fenta, 2021; Sorvali *et al.*, 2021). In a similar vein, additional research has demonstrated that households with small farmland are more likely to choose conventional crop varieties because of the costs associated with new crop types (Mutanyagwa *et al.*, 2018; Noack & Larsen, 2019).

Small-scale irrigation and fertilizer application were the practices positively impacted by livestock ownership in TLU. As a result, it addressed the fact that per unit increases in animal ownership, small-scale irrigation, and fertilizer use increased by 18.2% and 1.3%, respectively (Table 8). The relationship between farmers' decisions to adapt to the changing climate and the number of cattle has been the subject of contested studies (Belachew & Ababu, 2021; Zeleke *et al.*, 2022). According to Amare and Simane (2017), diversifying sources of income is inversely connected with owning cattle. In contrast to what was previously stated, our findings support the findings of Saguye (2017), who found that smallholder farmers were more likely to employ sustainable farming techniques in the West Shoa Jeldu district. Because of this, it is challenging to estimate how livestock holding would affect conservation choices.

Table 8 Marginal effects of the model

Variables	Soil and water management			Crop management				Intensive farm management		
	TP	SWC	AF	ICV	SPD	CD	DRC	LA	SSI	FA
Gender	0.487	0.301	0.062*	0.223*	-0.692	0.357*	-0.41	-0.241	-0.209	0.023
	-1.01	-1.12	-0.58	-0.29	(-1.54)	(0.24)	(-0.57)	(-0.51)	(-0.44)	-1.01
Age	-0.027**	0.0022	-0.034**	-0.036**	-0.00829	-0.0373***	0.0206*	0.0164	-0.0410***	0.0413*
	(-2.82)	-0.13	(-3.00)	(-2.71)	(-0.94)	(-3.76)	-2.04	-1.89	(-3.51)	-2.01
Family size	0.186	-0.662	0.054	-0.0665	0.230	0.078	0.124	-0.105	0.127	-0.113
	-2.28	(-3.86)	-0.59	(-0.71)	-3.7	-1.19	-1.63	(-1.66)	-2.16	(-1.06)
Education	0.206	0.662*	0.056	0.065*	0.237	0.079	0.118	-0.105	0.132	0.113**
	-2.18	-1.84	-0.61	-0.68	-3.7	-1.14	-1.09	(-1.72)	-2.11	-1.02
Farm income	0.0003	0.0006	0.012***	0.0005**	0.00933	0.00148	0.019***	0.0047*	0.0193**	0.011**
	-1.28	-1.39	-2.28	-2.13	-3.60	-0.35	-1.51	-2.02	-1.18	-1.26
Non-farm income	-0.00006	0.0002	-0.0002***	-0.0001*	-0.00008**	0.000145*	-0.0002***	2.69E-05	1.97E-05	-8.3E-05
	(-1.54)	-1.49	(-3.98)	(-3.10)	(-3.01)	-2.52	(-3.72)	-0.93	-0.8	(-1.23)
Farm size	0.830***	1.96***	0.520**	2.795***	0.436***	0.697***	0.948***	0.68***	0.186*	0.764**
	-4.79	-3.89	-2.78	-4.67	-4.37	-5.49	-7.75	-5.48	-2.03	-2.94
TLU	0.421	-0.628	0.246	0.084	0.272	0.079	0.518	-0.305	0.182**	0.013***
	-1.12	(-1.24)	-0.61	-0.68	-1.7	-1.14	-1.09	(-1.72)	-1.11	-1.92
Soil fertility	1.094***	0.121	-0.81***	-0.423	-0.183	0.00909	0.12	0.57***	0.0169	-1.09***
	-4.85	-0.43	(-4.19)	(-1.89)	(-1.39)	-0.07	-0.82	-3.82	-0.12	(-5.09)
Farmland distance	-0.0134*	-0.0016	0.0290*	0.005	-0.019***	0.00279	-0.025***	-0.004	-0.0051	-8.7E-05
	(-2.29)	(-0.12)	-2.25	-0.45	(-3.62)	-0.51	(-3.59)	(-0.80)	(-1.04)	(-0.01)
Market access	-0.009***	0.001	0.008*	0.02***	0.01***	0.00472*	0.0108***	-0.0014	0.00746***	-0.01***
	(-3.60)	-0.35	-2.47	-3.56	-5.26	-2.26	-4.67	(-0.31)	-3.66	(-3.46)
Credit access	0.312	0.24	0.056	0.0051*	0.431	0.079	0.118	-0.105	0.132*	0.113**
	-1.18	-1.84	-0.61	-1.68	-2.1	-1.14	-1.09	(-1.72)	-2.11	-1.02
Extension services	0.811	0.48	-3.13**	1.024	1.94	1.024	-2.95***	0.24	0.019	0.116*
	-1.29	-0.51	(-3.25)	-1.61	-0.01	-1.61	(-2.87)	-0.36	-0.03	-1.01
Agricultural training	-0.0945	-0.306	-1.083	-1.208*	1.901	-1.208*	1.497*	-0.136	0.688	0.042**
	(-0.17)	(-0.37)	(-1.21)	(-2.00)	(-0.01)	(-2.00)	-2.87	(-0.23)	-1.1	-1.92
_cons	-1.491	3.991*	4.147***	3.153*	-0.683	0.53	-4.214***	-1.630*	-0.615	5.3***
	(-1.66)	-2.32	-3.94	-2.29	(-0.94)	-0.68	(-4.16)	(-2.18)	(-0.81)	-3.46
N	402	402	402	402	402	402	402	402	402	402

****, **, * significant level (at 1%, 5% and 10%, respectively), TP= Tree planting, SWC = Soil & water conservation, AF = Agroforestry, ICV = Improved crop management, SPD = Shifting planting dates, CD = Crop diversity, DRC = Drought-resistant crop, LA = Livestock adjustment, SSI = Small-scale irrigation, FA= Fertilizer application.*

"I believe it will be difficult to continue life with the current farming system unless I devise a new mechanism to accommodate the changing environmental conditions. My parents are farmers who raised a large family. The size of the farm they shared with us is small, and on top of that, its fertility is highly declining. I have been producing with intensive farming for a few years now. However, the soil became aggregated over time and was no longer capable of producing. Developmental agents advised me to use lime to reduce its acidity and plant multipurpose trees that are used for compost and as food sources. But, I'm doing it in such a way that I won't get the expected result until the tree grows and produces compostable leaves and edible fruits." (Participant-10)

Results also revealed that soil fertility status significantly and positively influenced tree planting and livestock adjustment, whereas it significantly and negatively influenced agroforestry and fertilizer application (Table 9). The availability of credit affects farmers' choices to invest in resource-intensive practices or purchase farm inputs, according to Moahid and Maharjan (2020). As a result, labor-intensive technology could make it unfavorable to use improved crop varieties through loan access. Credit-using farmers preferred labor-intensive strategies, which affected small-scale irrigation and fertilizer application.

"There are some things that I never considered before: I have ample land resources, which include crop land, grazing land, and forestland. I was considering having large amounts of farmland as the only resource to enrich my life. Now that I have heard what farmers with small plots of land produce, I knew it is far superior to what I produce each year. My land's resources, such as its forest cover, are dwindling, its soil fertility is declining, and the crop types I grow are shifting. What I realized is that I didn't pay attention to the advice of developmental agents and ignored other sources of information." (Participant-11)

For market availability, the study has shown a positive association with the application of small-scale irrigation, drought-resistant crops, and crop variety. Contradicting this, it had negatively affected the adoption of tree planting and fertilizer application. Smallholder farmers must choose an adaptation depending on those methods' alleged advantages. A finding by Fisher *et al.* (2015) demonstrated that a farmer's preferred techniques were altering planting dates and switching to crop varieties less susceptible to climate stress, supported by market access. According to Mango *et al.* (2018), the

implementation of sustainable intensive farming considerably lessens the negative effects associated with climatic unpredictability and change.

Table 9 Sets of factors affecting farmers' perceptions of climate change in Gimbi district

Variables	Coef. (β)	Std. err.	z	P>|z
Gender	-0.03	0.04	-0.67	0.505
Age	0.01	0.00	4.86	0.000***
Family size	-0.01	0.01	-1.84	0.066
Education	0.21	0.04	5.35	0.001**
Farm income	0.01	0.00	0.63	0.532
Non-farm income	0.01	0.00	0.1	0.919
Farmland size	-0.01	0.02	-0.84	0.398
TLU	0.01	0.00	1.9	0.057
Soil fertility status	-0.09	0.02	-5.23	0.000***
Farmland distance	0.00	0.00	-0.1	0.920
Market access	0.00	0.00	-2.1	0.035*
Credit access	0.06	0.04	1.44	0.151
Extension services	-0.11	0.07	-1.72	0.086
Agricultural training	0.24	0.06	3.85	0.001***

****, **, * Significant level (at 1, 5, and 10% respectively)*

Additionally, different factors have affected farmers' decisions to adjust to the changing climate to manage soil and water, crops, and intensive farms (Table 9). For instance, the impact of predictor variables' adoption of agroforestry, tree planting, and soil and water conservation varied. Other variables had no noticeable effect on the adoption method. Education and farm family size were the only predictors that had a substantial positive impact on soil and water conservation. Gender, farm income, farmland size, market access, and farm distance were all positive predictors of agroforestry adoption strategy. Non-farm income, soil fertility, and extension services were all negative predictors (Table 9). These findings also suggest that farmers' adaptation strategies are dependent on their localities (Atube *et al.*, 2021; Sorvali *et al.*, 2021).

3.4. Conclusion

This study's primary goals were to assess how farmers responded to climate change and identify the determinant factors that affect coffee-based agroforestry farmers' adoption of adaptive measures. Our findings investigated that farmers face several climate change-related issues, including lower agricultural production, a loss of natural forest cover, a decline in soil fertility, and soil erosion increment. In response to the changing climate, coffee smallholder farmers have developed various adaptation techniques.

Three categories of adaptation strategies: soil and water management, crop management, and intensive farm management were identified. However, the farmers have used various adaptation strategies in response to climate change, and different factors have affected their responses to the change. Accordingly, socioeconomic and environmental factors, such as the age of household heads, education, market access, and level of agricultural training, affected the farmers' knowledge of the changing climate. Similarly, farmer's perceptions and the existing socioeconomic and environmental factors, in turn, affected the choice of strategies compatible with climate change. Based on this finding, crop management strategies were more significantly associated with farmers' perceptions of climate change than the management of soil and water, as well as intensive farm practices.

This study revealed that different socioeconomic and environmental factors limit the choice of particular adaptation techniques. For instance, farmers' agricultural training determined how they perceived climate change and responded to it. We concluded that the adoption of coping strategies to adapt to a changing climate is specific to an environment, as it limits the role of adaptation measures across different localities. Therefore, authorities should focus on farmers' capacity enhancement priorities to adjust to climate change. Furthermore, when advocating for the deployment of climate change adaptations, it is critical to consider local environmental characteristics such as market accessibility and soil fertility for the viability of adaptation measures in a certain area.

Table 10 Parameters estimates of binary logit model for climate change adaptation decisions

Variables	Soil and water management			Crop management				Intensive farm management		
	TP	SWC	AF	ICV	SPD	CD	DRC	LA	SSI	FA
Socioeconomic Factors										
Gender	0.00186	0.014	0.0018	1.084*	0.262	-1.059*	0.699	-0.505	0.0187	-1.09
	0.02	-0.04	-0.002	-2	-0.69	(-2.48)	-1.19	(-1.24)	-0.04	(-1.48)
Age	-0.027**	-0.00511	-0.029**	-0.045***	-0.0142	-0.0343***	0.0196	0.0158	-0.0383**	-0.034
	(-2.85)	(-0.30)	(-2.59)	(-3.42)	(-1.61)	(-3.50)	-1.92	-1.83	(-3.24)	(-3.50)
Family size	0.109	-0.663	0.210	-0.0186	0.238	0.0791	0.0919	-0.141	0.128	0.079
	-1.49	(-3.77)	-2.23	(-0.19)	-3.95	-1.21	-1.23	(-2.25)	-2.19	-1.24
Education	0.0328	0.712**	0.0154	0.437**	0.0163	-0.00505	0.0111	0.139**	0.125**	0.0866
	(0.61)	-2.62	-021	-2.99	-0.46	(-0.12)	-0.21	(-3.25)	-2.91	-0.92
Farm	0.00003	0.00068*	0.00019*	0.002***	0.00004	0.0002***	0.0002***	-2.7E-05	-0.0001	-0.00003
income	-1.08	-2.07	-2.5	-4.8	-1.94	-4.03	-5.52	(-1.19)	(-2.24)	(-0.74)
Non-farm	-0.0001*	0.0002	-0.0002***	-0.001*	-0.0001**	0.0001*	-0.0002***	1.31E-05	2.61E-05	0.0040*
income	(-2.33)	-1.56	(-4.32)	(-2.48)	(-2.61)	-2.33	(-3.68)	-0.47	-1.05	-2.33
Farm size	0.832***	1.820***	0.546**	3.320***	0.443***	0.655***	0.989***	0.669***	0.266**	0.65***
	-4.84	-3.8	-2.99	-4.79	-4.46	-5.18	-8.05	-5.24	-2.8	-5.18
TLU	0.651	0.879	0.891	0.622	1.582	0.111**	0.514	0.712	1.022	-0.13**
	-0.49	-0.69	-0.57	-0.41	-1.71	-2.81	-0.39	-0.41	-1.71	(-1.01)
Environmental Factors										
Soil fertility	0.00977	-1.328	0.0067	0.598	-0.336	-0.338	0.596	0.0501	1.294***	-0.338
	-0.02	(-1.81)	-0.048	-0.69	(-0.88)	(-0.85)	-1.36	-0.12	-3.35	(-0.85)
	-0.03***	-0.00475	0.053***	0.0351**	-0.0130**	-0.000791	-0.0228***	-0.0110*	-0.00168	-0.0008

Farmland distance	(-4.92)	(-0.37)	-3.43	-2.64	(-2.77)	(-0.16)	(-3.38)	(-2.40)	(-0.35)	(-0.16)
Market	-0.0012	0.00445	-0.00269	0.00562	0.0075***	0.0071***	0.0093***	0.0038*	0.0048*	0.006***
access	(-0.92)	-1.03	(-0.89)	-1.81	-4.24	-3.76	-4.22	-2.05	-2.5	-3.68
Institutional Factors										
Credit	0.027	-0.024	-0.504	-0.076	0.024	1.028**	-0.062	0.004	-0.209	1.208*
access	-0.04	1.02	1.42	(-0.08)	-1.63	-0.39	1.38	-1.13	(-0.64)	-1.48
Extension	0.811	0.48	-3.13**	1.024	1.94	1.024	-2.95***	0.24	0.019	0.116*
services	-1.29	-0.51	(-3.25)	-1.61	-0.01	-1.61	(-2.87)	-0.36	-0.03	-1.01
Agricultural	-0.0945	-0.306	-1.083	-1.208*	1.901	-1.208*	1.497*	-0.136	0.688	0.042**
training	(-0.17)	(-0.37)	(-1.21)	(-2.00)	(-0.01)	(-2.00)	-2.87	(-0.23)	-1.1	-1.92
_cons-	2.037*	6.130***	0.922	-0.691	-1.422	1.425	-5.388***	0.255	-2.357**	1.425
	-2.28	-3.32	-1.23	(-0.54)	(-1.88)	-1.76	(-5.35)	-0.34	(-2.90)	-1.76
N	402	402	402	402	402	402	402	402	402	402

****, **, * significant level (at 1%, 5% and 10%, respectively, TP= Tree planting, SWC = Soil & water conservation, AF = Agroforestry, ICV = Improved crop management, SPD = Shifting planting dates, CD = Crop diversity, DRC = Drought-resistant crop, LA = Livestock adjustment, SSI = Small-scale irrigation, FA= Fertilizer application.*

CHAPTER FOUR

4. The role of crop diversification in improving household food security of coffee-based rural households in west Wollega

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Abstract

The main objective of this study was to examine the role of crop diversification to improve household food security of coffee farmers using household dietary diversity score (HDDS) and household food insecurity access score (HFIAS) in western Ethiopia. The study uses a multistage sampling procedure to select four hundred two (402) sample households. Data were collected using a household survey, a focus group discussant (FGD), and key informant interviews. The dietary diversity score consumed over a 24-hour period and food insecurity access score of the households were used as measures of improved food security. Descriptive statistics and econometric models were used for data analysis. Ordinary least squares regression (OLS), ordered logit model and multinomial logistic regression model were used to analyze the collected data. The farmers consume a diversified diet. Typically, the average DDS of the household heads was 4.4±1.27. From smaple households, about 19.69% of them had low HDDS, 55.79% had medium, and 24.51% had high dietary diversity. All farmers consumed cereal crops during the 24-hour recall period, followed by condiments, beans, and vegetables. The household head's age, education, annual income, agroforestry practices, and tropical livestock units influenced the household's dietary diversity positively and significantly. In contrast, dietary diversity was negatively correlated with the distance to the closest market. Adequate education, improved agroforestry practice, implementing feasible rural technologies that help advance TLU, irrigation, and road infrastructures to improve market access are important interventions to improve food security of farmers who are dependent on coffee-based agroforestry.

Keywords: *Food security, dietary diversity, household, coffee, agroforestry.*

4.1. INTRODUCTION

Food security has been a major issue around the world, particularly in Africa (Giller, 2020). Evidences indicate that hunger has affected 702 to 828 million people worldwide in 2021, depending on the report of food security and nutrition (FAO *et al*., 2021). According to the Global Report on Food Crises 2022, the number of people facing acute hunger that was 155 million in 2020 has increased to nearly 193 million in 2021 (FAO *et al*., 2021). Song *et al*. (2020) also stated that undernourishment now affects every country in the world, however, it was dropped over the first decade of the 2000s, but now it is subsequently rising again since then. Other indicators highlight the tragic scope of the developing crisis, and the 2022 global hunger index (GHI) score demonstrates that the fight against hunger has largely come to a standstill (Grebmer *et al*., 2022). As a result, in 2022, there were more people who were undernourished. Moreover, many smallholder farmers are facing slowdowns in economic development. When there is a crisis, there is frequently a negative impact on food diversity due to the increased emphasis on producing cheap, nutrient-poor staple foods that are high in energy. This results in increased food insecurity and inadequate nutrition (FAO *et al*., 2021).

Nutritional adequacy is the consumption of sufficient dietary diversity to maintain a balanced diet and meet daily nutrient demands (Chen *et al*., 2021; Mekonnen *et al*., 2021). Dietary diversity is a good alternative measure of the nutritional adequacy and food security (Sambo *et al*., 2022). When everyone has constant access to enough wholesome food that meets their dietary needs and preferences and promotes an active as well as healthy lifestyle, this is known as food security (Peng & Berry, 2018; El Bilali *et al*., 2019). Food security is realized, in addition to dietary diversity, when every person has stable and continuous access to quality, safe, affordable, and available foods in sufficient amounts (UNCTD, 2017; FAO *et al*., 2021). A sizable portion of the population is food insecure and suffers from micronutrient deficiencies despite growing national and international commitment to the food and nutrition problem.

Food insecurity and lack of nutritional diversity are frequent in Sub-Saharan Africa. These problems have adverse implications for growth and development, notably for young children (Harper *et al*., 2022). Ethiopia has the highest proportion of food insecure households among the East African nations (20.3 million), followed by Sudan (15.6 million) (WFP, 2022). Findings indicate that poverty and food insecurity continue to be serious obstacles to Ethiopia's economic development (Mulugeta *et al*., 2018). According to FAO (2021), in Ethiopia, the occurrence of malnutrition was 18.2 million between 2018 and 2020.

In Ethiopia, the main cause of food insecurity is a reliance on undiversified livelihoods based on low output rain-fed agriculture (Abegaz, 2017). The difficulties traced back, among other things, to inadequate infrastructure, declining soil fertility, problem of farming system (e.g. mono-cropping), and climate change (Mengistu *et al*., 2021). As a result, depending on their localities, smallholder farmers in the district employ a variety of strategies to address issues with food security and ensure the sustainability of their operations (Zerssa *et al*., 2021). For instance, forest tree planting, soil and water conservation, climate-smart agriculture and adopting different farming systems (Mosissa, 2019; World Bank, 2020).

A finding by Adjimoti & Kwadzo (2018) indicated that the quantity of crops grown significantly affects the dietary variety and food security of households. Crop diversification has two main benefits: it significantly affects household diets and, when all other factors remain constant, it increases agricultural income Mango *et al*. (2018) also stated that compared to households that specialize in crop production, families that grow a variety of crops are less likely to be poor. Furthermore, Tigre & Heshmati (2022) emphasized that growing a variety of crop species can assist smallholder farmers in minimizing their exposure to price and production risk.

Similar to other parts of the country, the district has been experiencing household food insecurity due to climate hazards and land degradations. According to WWZANRO (2020), out of the 32 rural kebeles in the district, 18 of them were supported by the productive safety net program (PSNP). To alleviate their food stocks and earnings, farmers in the area were applying a coffee-based crop diversification. Despite the fact that food security is the main problem, no research has been done to address the problem in the district. In light of this, the study has scrutinized the role of cultivating different crops to improve food security in households engaged in coffee-based farming systems.

Crop diversification, according to WWZANRO (2020), is the means of growing more than one type of crop from the same or a different species year-round in a specific area. Correspondingly, FAO (2017) describes crop diversification as a method of creating a robust system of agricultural production, particularly in areas where communities heavily rely on agricultural food production for their livelihood. In this study, the analysis mainly applied the FAO definitions and methods of analysis used by different researchers for food security. To examine the status of household food security, the household food access and dietary diversity were considered as indicator variables. Thus, this study has attempted to contribute to address the gap.

Therefore, this study aimed at examining the status of food security of the district by using household dietary diversity score (HDDS) and household food insecurity access score (HFIAS) of coffee-based

farmers. It attempted to show the gaps by answering the subsequent research questions: 1) What was the factor prompted farmers to adopt coffee farming system? (2) Does coffee-based farming system help the farm households produce diversified crops and access nutritious food? (3) Do the farmers sustainably produce and access diversified food resources from the exiting coffee farming system? (4) What are the factors affecting the household's dietary diversity and access?

4.2. Materials and Methods

4.2.1. Description of the study area

Gimbi is located in Oromia National Regional State, Western Ethiopia, between 142000 and 174000 E (UTM) and 993000 and 1029000 N (UTM). The area has an altitudinal range of 1200-2222 m a.s.l. and includes the lowland and midland altitudinal zones. Haru borders the district to the south, west by Lalo Asabi, north by Gumuz, and east by the East Wollega Zone. It has 32 rural kebeles. The area's typical annual minimum and maximum temperatures range from 10 °C to 30 °C, with an average annual rainfall of 1400-1800 mm.

The total population of the district was estimated to be 163,480 (WWZANRO, 2020). About 83,099 were men and 80,381 were women. It covers 1,183.44 km2 with 124.8 inhabitants per km^2. The typical rural land holding size is approximately 1.2 ha and 0.8 head of livestock. Approximately 21% of the population is engaged in jobs that are unrelated to agriculture.

The rivers and streams flow year-round and seasonally throughout the study area. The rainfall has a bimodal pattern, lasting from June to September, followed by a long dry period from October to April. A prolonged drought season, known locally as Bona, lasts from mid-October to April, and sometimes into May (data obtained from the district agricultural office and personal communication, March 2020).

A large portion of the area is endowed with potential agricultural production that is mainly used for small-scale farming. The principal crops grown are coffee, sesame, corn, beans, bananas, pumpkins, fruit, sweet potatoes, cardamom, and sugarcane. Coffee farming predominates in the district's southwest, while other crop products dominate in the northeast. It is also rich in small ruminant animals, incense, and gum resources. Nearly all crops, whether grown commercially or by small farmers, are cultivated using rainwater, except for a few places that are used for vegetables and fruits. Approximately 90% of the district's land is agricultural, and coffee, sesame, and corn are the most popular marketable goods.

4. 2.2. Sampling techniques

A multi-stage sampling procedure was employed to select rural farm households in the study area. Accordingly, first, the West Wollega zone was selected as the main study area based on well-referenced literature for the diverse agricultural activities in the area (Daba, 2018). Second, the Gimbi district was chosen because it is one of the districts in the zone were disputing ideas where reported on the food security circumstances among the coffee-based agroforestry farmers. Third, out of 32 villages in the district, six (6) villages were purposefully selected based on their food security situation and farming systems, which is coffee-based agroforestry practices representatives in order to analyze the status of their food security, by using the dietary diversity scores. Accordingly, Enango Dembel and Aba Sena kebeles selected from the lowlands, Choli Mikael and Melka Gasi kebeles from midlands, and Bikiltu Tokuma and Lelisa Yesus kebeles from the highland altitudes zones were selected.

In order to obtain a representative sample size, the study employed the sample size determination formula given by (Yamane, 1967).

$$n = \frac{N}{1 + N(e^2)} = \frac{32696}{1 + 32696(0.05^2)} = 402$$

where *n* is the sample size*, N* is the population size (total households in the six kebeles, which is 32,696) and *e* is the level of precision. The sample size, which was obtained using the formula, was approximated at 402 in order to make a uniform sample size representation for each agroecological zone as they have nearly the same number of households.

Prior to the data collection, field training was given to six enumerators on the objective of the farmers' household survey. The field training included interpretation of questions, data types and quality, research ethics, probing and triangulation before collecting data under the close supervision of the researcher. Pre-testing of the questionnaire was performed to avoid missing any important information using 12 households in Enango Dembel and Bikiltu Tokuma kebeles, after which the households were excluded from the main survey. Primary data were gathered from households, key informants such as community elders, health extensions, development agents (DAs), and researchers. Participants were selected from lists of the names of household heads in the kebeles using a computer-generated random number table. Accordingly, the formula described above, four hundred two (402) participants and six focus group discussions (FGDs) each comprising of 12 participants for each kebele. The FGDs were conducted to obtain important qualitative data on the issues related to economic activities, food security, farm household consumption behavior, and the factors that affect

the household's dietary diversity and access. During the interview and FGDs, a translated local language was used to properly get the required information from the participants.

4.2.3. Data analysis

The survey data were coded, organized, summarized, and analyzed using descriptive and econometric model analysis. STATA version 12.0 was used to aid data analysis. While the qualitative data were analyzed using narration and conceptual explanation, quantitative data were analyzed using Ordinary least square (OLS), ordered logit model and multinomial logit models. The independent variables did not exhibit multicollinearity.

Crop diversification in coffee-based farming systems

The concept of crop diversification implies production of multiple crops on the farm throughout the year by households. In this study crop diversification is the main variable of interest. The Herfindahl index (HI) is used as a measure for crop diversification or specialization. In other words, the Herfindahl index is calculated for each farm separately to measure the degree of diversification. The index captures the degree or extent of diversification for an individual farm household using an equation as:

$$P_i = \frac{A_i}{\sum_{i=1}^{n} A_i} \quad \text{.....(2)}$$

where, *Pi*=proportion of i^{th} crop, *Ai*=area under i^{th} crop (ha), $\sum_{i=1}^{n} A_i$ total cropland (ha) and i = 1, 2, 3 . . . , n (number of crop).

$$\text{Herfindahl Index} = (\text{HI}) = \sum_{i=1}^{n} P_i^{\,2} \quad \text{.....(3)}$$

$$\text{Crop diversification index} = \text{CDI} = 1 - \text{HI} \quad \text{.....(4)}$$

Food security analysis

Food security can be attained when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. It relies on four main dimensions: physical availability of food, economic and physical access to food, food utilization and stability of the other three dimensions over time (World Bank, 1996). However, the four dimensions are central points for food security; this study was fixed to assess the status of food security of coffee farmers using the Dietary Diversity scale and the Household Food Security Access Score (HFIAS) as measures of household food security, in the study area.

Table 11 Variables used to assess household food security status of smallholder farmers

Variables	Description	Sign
Dependent variables		
HDDS	Continuous	
HFIAS	Continuous	
Explanatory variables		
CDI	Continuous	+
Education	1 if obtained a minimum of primary education, 0 otherwise (Dummy)	+
Marital status	1 if married with a couple, 0 otherwise (Dummy)	±
Age	Age in years (Continuous)	±
Family size	No of individuals in the HH (Continuous)	+
Annual income	Total annual income (Continuous)	+
Farmland size	Total farm size in hectares (Continuous)	+
Fertilizer	1 if used, 0 otherwise	+
TLU	Reference total tropical livestock units (unit less number) (Continuous)	+
Market access	Distance to input markets (km) (Continuous)	-
Credit access	1 if accessed credit, 0 otherwise (Dummy)	+
Agricultural training	1 if accessed training, 0 otherwise (Dummy)	+
Extension services	1 if accessed extension, 0 otherwise (Dummy)	+

Household Dietary Diversity Score (HDDS)

A dietary diversity questionnaire can be used to collect data from households or individuals (Arimond *et al*., 2010). According to FAO's guidelines for assessing household dietary diversity, the population of interest should be chosen prior to the start of the data collection. Because it helps to adapt the questionnaire to the local survey context (Sichoongwe *et al*., 2014). The method used to collect

information is determined by the survey's goal and objective. If the purpose and objective of the survey are to determine nutrition, assessing household dietary diversity would be the best approach (Arimond *et al*., 2010).

The Household Dietary Diversity (HDD) was assessed using a 24-h recall of food types eaten by members of the household as either a shared meal in the home or as food made at home to be eaten by household members outside the home, as suggested by Swindale & Bilinsky (2006).

Similarly, the HDDS in this study was based on 12 food groups, using the guidelines for measuring HDD developed by INDEX Project (2018). The 12 food groups included cereals, tubers, vegetables, fruits, meat, eggs, fish, beans, dairy products, fats/oils, sugar/honey and condiments. If the food group was consumed, one point was provided; if the food group was not consumed during the reference period, no points were given. The sum of all the points for each household was then computed.
The factors that were significantly associated with the dietary diversity of the households were found by fitting the ordered logistic regression model to the data. The equation of the ordered logit model regression is specified as:

$$Y^* = \sum_{k=1}^{k} \beta_k X_k + \varepsilon, \quad (1)$$

Where Y^* is unobserved, X_k is a vector of independent variables, β denotes coefficients to be estimated and ε denotes a random error term.

From the above model, the observed or defined categorical variable Yi is determined as follows:

$Y = 0$ if $Y^* \leq 0$

$Y = 1$ if $0 < Y^* \leq \mu_1$

$Y = 2$ if $\mu_1 < Y^* \leq \mu_2$

$Y = j$ if $\mu_{j-1} \leq Y^*$

In case y is observed in j number of ordered categories, μs are unknown threshold parameters differentiating the adjacent categories to be assessed with βs; then μ1, μ2 and μ3 represent the different levels of the HDDS that are to be estimated. The general form for the probability that the observed y falls into category j and the μs and the βs are to be estimated with an ordered logit model i

$$Prob(Y = j) = 1 - L\left(\mu_{j-1} - \sum_{k=1}^{k} \beta_k X_k\right), \quad (2)$$

where, L (·) represents cumulative logistic distribution.

Household Food Insecurity Access Score (HFIAS)

Apart from HDDS, HFIAS was employed to analyze the food security status of farm households. The HFIAS is a continuous measure of the degree of food insecurity in the household in the past 30 days. It asks nine questions about household access to food and household members' experiences and perceptions of hunger. Despite the limits of all measures, the HFIAS has been found to be comprehensible and appropriate in a variety of scenarios (Devereux & Tavener-Smith, 2019). Each question has four response options: never, rarely, sometimes and often, which are coded 0, 1, 2 and 3 in order of increasing frequency. Responses to these nine questions are summed to construct a food insecurity score, with a maximum score of 27 indicating most food insecure households (Ballard *et al*., 2011).

The HFIAS represents three common categories of household food insecurity: worry about household food insecurity, insufficient food quality, and insufficient food quantity (Ballard *et al*., 2013). According to Castell *et al*., (2015), this indicator reflects the household's attitude toward their diet, regardless of its nutritional composition. The minimum score of HFIAS is zero when a household head responds 'no' to all questions. Alternatively, 27 is the maximum score of HFIAS. It is obtained when a family responds yes to all inquiries and 'often' as the frequency of occurrence to all nine items. HFIAS (0-27) at a higher value present that a household is food insecure. Simultaneously, a low score indicates that the family is less vulnerable to food insecurity

The HFIAS was computed as follows. The results of the HFIAS analysis were used as supplementary data, as the main discussion part was mainly based on the dietary diversity score variable.

HFIAS (0−27) = Q1a*F1 + Q2a*F2 + Q3a*F3 + Q4a*F4 +

Q5a*F5 + Q6a*F6 + Q7a*F7 + Q8a*F8 + Q9a*F9 …….…… (3)

Effects of crop diversification on household food security

In the analysis of the relation between crop diversification and food security, the study used an ordinary least squares (OLS) regression. Crop diversification index (a continuous variable) and food security outcomes HDDS and HFIAS are taken as dependent variables (all continuous variables) that, we decided to use OLS regression. According to FAO (2010), it is appropriate to use OLS to ascertain influence of a continuous variable on another continuous variable similar to the current study. The OLS model is specified as:

$$Y_i = \beta_0 + \beta_i X_{i1} + \beta_2 X_{i2} \ldots + \beta_n X_{in} + \mathrm{e} \quad (4)$$

where Y_i = household food security outcome (either DDS or HFIAS), X_{i1} = crop diversification index, X_{i2} = sex of household head, X_{i3} = age of household head (in year), X_{i4} = education level of household head, X_{i5} = household size, X_{i6} = farm land size, …., β_0 = intercept, β_1 to β_n are coefficients, and e is the error term. Food security analysis

Food security can be attained when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. It relies on four main dimensions: physical availability of food, economic and physical access to food, food utilization and stability of the other three dimensions over time (World Bank, 1996). However, the four dimensions are central points for food security; this study was fixed to assess the status of food security of coffee farmers using the Dietary Diversity scale and the Household Food Security Access Score (HFIAS) as measures of household food security, in the study area. Table 11 shows the description of variables used in the analysis.

4.3. Result and discussions

Socioeconomic and demographic aspects

The average age of households was 47 years (

Table 12). The ages of the participants ranged from 20 to 90. About 23% of the households were under the age of 35, 69% were between the ages of 36 and 65, and 8% were beyond the age of 65. The average Tropical livestock unit (TLU) was 1.32, with the lowest at 0.78 and the highest at 1.88. The average landholding size of the households was 2.6 hectares, while the average annual income of the households was 26,278 Ethiopian Birr (ETB). The average distance taken to travel from home to the nearest market place was 5.1 km. The average number of contacts with the agricultural extension agent for training was 7.5 times per year (

Table 12). The one-way revealed that the age of the household head, education level of the head, household size, and farmland and livestock holdings of the households had a significant mean difference among household dietary diversity groups (

Table 12).

The findings revealed a considerable difference in income, distance to market, and agricultural extension connections amongst HDD categories. Most of the cultivated crops are rain fed near to residential areas and only 12% of heads of the households had access to irrigation. Approximately 23.4% of families had access to credit and used the services. Nearly 80.6% of respondents were aware

of the importance of dietary diversity obtained from their farm for a balanced diet and household health (Table 13).

The findings indicate that, except for dairy products, the intake of foods rich in animal sources was significantly low in terms of frequency in the sample. For instance, the proportion of fish consumption was only about 3.7%, followed by egg and meat consumption of the households, which accounted for only 18.4% and 38.3%, respectively (Figure 8).

The households with high household dietary diversity consumed majorly cereals (100%), condiments (94.2%), tubers (80.2%), dairy products (76.2%), sugar and honey (67.4%), and vegetables (61.6%), while those with medium household dietary diversity consumed mainly cereals (100%), vegetables (79.3%), tubers (73.6%), condiments (62.6%), and fats/oils (53.7%). Except for cereal crops, the low household dietary diversity consumed primarily fats and oils (91.4%), beans (88.6%), and vegetables (85.7%). None of the households in the low dietary diversity households consumed fish. This variation in dietary diversity consumption across levels could be attributed to high income, which allowed people to purchase expensive food items such as meat, eggs, and fruits (Figure 8; Table 12). This was because the gap between the average low and high annual income of household heads was found to be quite large (11,708 and 42,342 ETB respectively). This shows that low and medium-income households may have limited purchasing power and are unable to afford expensive goods like meat (Table 12). This finding is in agreement with the results of a previous investigation (Kuma *et al*., 2019; Urmale *et al*., 2020; Aliyo *et al*., 2022). Motuma *et al*. (2019) have reported similar findings that fish was not consumed at all among other dietary diversity scores. This could be due to its economic or environmental inaccessibility. The same holds true, as only certain households with medium- and high-dietary diversity and none with low-dietary diversity consumed fish.

Furthermore, participants have stated that practicing agroforestry management enabled them to cultivate diversified crops in agroforestry systems. Accordingly, the findings of this study revealed that households with higher crop diversification intensities are more likely to have diversity in terms of food crops. The diversified agroforestry crops can be consumed within the household and have justified the positive relationship that indicates crop diversification has improved dietary diversification. It is also proved that the crop diversification in the system reduces the severity of food insecurity in the district. It implies that households with higher crop diversification intensities are more likely to diversify in terms of food crops. This indicates crop diversification improves dietary diversification in the study area. In other words, households that participate in multiple cropping in agroforestry systems are distributing the possible risk of a particular crop failure in a season.

Households that cultivate multiple crops are better assured of food availability and access than households that practice mono-cropping.

Agroforestry crop diversification can reduce risks in a season where one particular crop fails to give much yield; other crops may be better off, which farmers may rely on for survival. Thus, farmers who increase crop diversification outperform their counterparts because diversification is related to dietary diversification and, negatively, to food insecurity. This is mainly due to the advantages of crop diversification, which include increased farm productivity and income as well as reduced production and price risks. The current finding is consistent with previous similar findings, which demonstrated a positive relationship between crop diversification and household food security (Mugendi, 2013; Ch *et al*., 2016). Kissoly *et al*. (2020) found that farm production diversity was consistently and positively associated with household dietary diversity. Fahad *et al*. (2022) also stated that agroforestry systems promote crop diversification, increase farmland production, increase fodder yields, and minimize soil erosion. Moreover, Ghosh-Jerath *et al*. (2021) found that agroforestry improves access to and utilization of traditional foods.

Status of Household's Dietary diversity (HDDS)

The study results showed that from 402 of households, 138 (34.33%) participants consumed up to three food groups (low dietary diversity), 184 (45.77%) consumed four to six food groups (medium dietary diversity), and 80 (19.9%) participants consumed seven or more food groups (high dietary diversity) in their diet during the preceding 24 hours. The household dietary diversity scores ranged from 2 to11 food groups with the mean of 4.4±1.27 standard deviation. Majority of the households had medium dietary diversity scores (Figure 7). The result is consistent with Motuma *et al*. (2019); Fufa & Laloto (2021); Madlala *et al*. (2022).

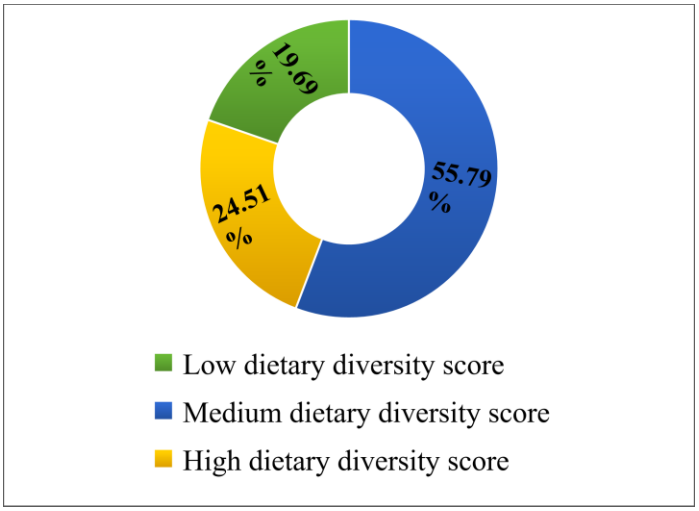

Figure 7 Dietary diversity scores of coffee-based agroforestry farmers

Groups of food consumed by households

All participants consumed cereals in everyday meal (Figure 8). Cereals were the mainstay of the households' diet. Studies have reported that cereal crop consumption has shown dominance over other diets (Motuma *et al*., 2019; Ali *et al*., 2022; Sambo *et al*., 2022). In the previous 24 hours, vegetables and tubers were found as part of meals in 76.6% and 72.6% of households, respectively. Similarly, 68.7% and 62.7% of households consumed condiments and fats/oils as meals, respectively. Our finding concurs with previous similar studies reported before (Kuma *et al*., 2019; Motuma *et al*., 2019). Fruit was consumed by around 22.1% of the sampled households; 41.9% of the high household dietary diversity category consumed it, while only a small number of the low and medium household dietary diversity categories consumed fruits.

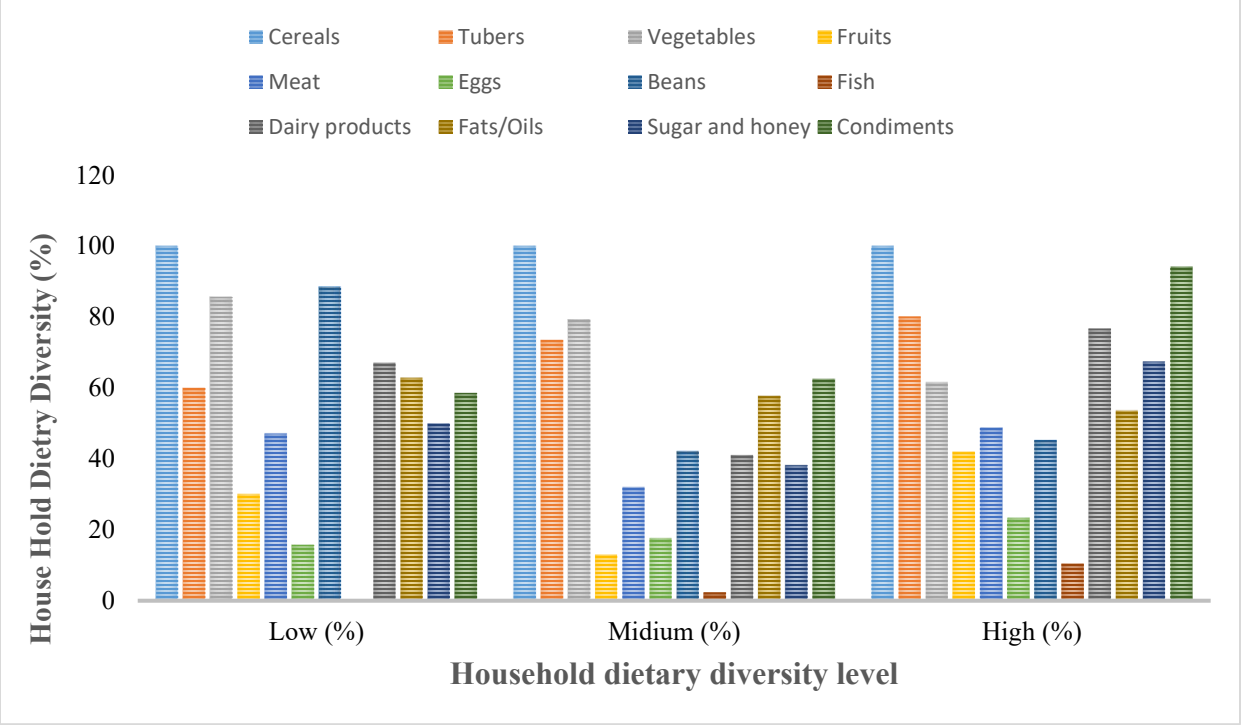

Figure 8 Food groups of households consumed by coffee-based agroforestry farmers

The findings indicate that, except for dairy products, the intake of foods rich in animal sources was significantly low in terms of frequency in the sample. For instance, the proportion of fish consumption was only about 3.7%, followed by egg and meat consumption of the households, which accounted for only 18.4% and 38.3%, respectively (Figure 8).

Table 12 Household dietary diversity categories (continuous explanatory variables)

Variables	Household dietary diversity category								
	Low		Medium		High		Total		F
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Age	38.4	6.8	53.0	6.2	49.6	7.1	47.0	6.2	12.53**
Educational level	0.7	1.4	2.2	2.4	6.5	1.8	3.1	2.9	21.62***
Family size	4.6	1.3	5.8	1.4	6.2	1.7	5.3	1.5	6.78***
Farmland size	1.2	0.7	2.6	1.3	3.8	2.5	2.6	1.4	10.10***
TLU	0.9	1.0	1.3	1.4	1.7	2.4	1.3	1.7	8.28***
Annual Income	11708	8626	24380	25398	42342	71364	26278	41260	13.56**
Market distance	6.5	1.4	5.8	1.4	3.2	1.1	5.1	1.3	9.23***
Extension service	3.0	6.6	8.6	10.4	12.0	12.6	7.5	10.4	6.82***

Source: Own survey, 2020

The households with high household dietary diversity consumed majorly cereals (100%), condiments (94.2%), tubers (80.2%), dairy products (76.2%), sugar and honey (67.4%), and vegetables (61.6%), while those with medium household dietary diversity consumed mainly cereals (100%), vegetables (79.3%), tubers (73.6%), condiments (62.6%), and fats/oils (53.7%). Except for cereal crops, the low household dietary diversity consumed primarily fats and oils (91.4%), beans (88.6%), and vegetables (85.7%). None of the households in the low dietary diversity households consumed fish. This variation in dietary diversity consumption across levels could be attributed to high income, which allowed people to purchase expensive food items such as meat, eggs, and fruits (Figure 8;

Table 12). This was because the gap between the average low and high annual income of household heads was found to be quite large (11,708 and 42,342 ETB respectively). This shows that low and medium-income households may have limited purchasing power and are unable to afford expensive goods like meat (

Table 12). This finding is in agreement with the results of a previous investigation (Kuma *et al*., 2019; Urmale *et al*., 2020; Aliyo *et al*., 2022). Motuma *et al*. (2019) have reported similar findings that fish was not consumed at all among other dietary diversity scores. This could be due to its economic or environmental inaccessibility. The same holds true, as only certain households with medium- and high-dietary diversity and none with low-dietary diversity consumed fish.

Furthermore, participants have stated that practicing agroforestry management enabled them to cultivate diversified crops in agroforestry systems. Accordingly, the findings of this study revealed that households with higher crop diversification intensities are more likely to have diversity in terms of food crops. It is also proved that the crop diversification in the system reduces the severity of food insecurity in the district. It implies that households with higher crop diversification intensities are

more likely to diversify in terms of food crops. This indicates crop diversification improves dietary diversification in the study area. In other words, households that participate in multiple cropping in agroforestry systems are distributing the possible risk of a particular crop failure in a season. Households that cultivate multiple crops are better assured of food availability and access than households that practice mono-cropping.

Agroforestry crop diversification can reduce risks in a season where one particular crop fails to give much yield; other crops may be better off, which farmers may rely on for survival. Thus, farmers who increase crop diversification outperform their counterparts because diversification is related to dietary diversification and, negatively, to food insecurity. According to respondents, only about 5 percent of the rural community often worries about food in the area (Table 15). This is mainly due to the advantages of crop diversification, which include increased farm productivity and income as well as reduced production and price risks. This might be because farmers have easier access to informational resources like agricultural training (Table 13). The current finding is consistent with previous similar findings, which demonstrated a positive relationship between crop diversification and household food security (Mugendi, 2013; Ch *et al*., 2016). Kissoly *et al*. (2020) found that farm production diversity was consistently and positively associated with household dietary diversity. Fahad *et al*. (2022) also stated that agroforestry systems promote crop diversification, increase farmland production, increase fodder yields, and minimize soil erosion. Moreover, Ghosh-Jerath *et al*. (2021) found that agroforestry improves access to and utilization of traditional foods.

Table 13 Household dietary diversity categories (dummy explanatory variables)

Variables		**Household dietary diversity category**								χ^2
		Low		**Medium**		**High**		**Total**		
		N	**%**	**N**	**%**	**N**	**%**	**N**	**%**	
Gender	Female	5	5.8	26	12.2	13	12.7	44	10.9	15.2
	Male	82	94.2	187	87.8	102	87.3	358	89.1	86**
Marital status	Yes	54	62.1	174	81.7	92	90.2	320	79.6	22.6
	No	33	37.9	39	18.3	10	9.8	82	20.4	28**
Credit access	Yes	18	21.4	50	26.3	26	20.3	94	23.4	2.10
	No	66	78.6	140	73,7	102	79.7	308	76.6	4
Agricultural	Yes	62	75.6	98	76.0	164	85.9	324	80.6	29.20
training	No	20	24.4	31	24.0	27	14.1	78	19.4	6***

*** & ** are significance level (at 1% and 5% respectively).*

Table 14 Parameter estimates of ordinal logistic regression

Variables	Coefficients	SE	Wald	P-value	Odds ratio
Age	0.304	0.081	13.412	0.000***	1.302
Education	0.962	0.088	18.001	0.000***	1.642
Annual income	0.178	0.060	8.204	0.001**	1.104
Marital status	-0.145	0.372	0.231	0.634	0.746
Family size	0.124	0.139	0.632	0.501	1.201
Farmland size	0.224	0.168	1.544	0.203	1.196
Livestock own in TLU	0.322	0.128	4.89	0.021**	1.296
Market distance	-0.462	0.140	6.029	0.001***	0.586
Credit access	0.004	0.018	0.064	0.821	1.003
Agricultural training	0.176	0.781	0.135	0.697	0.838
Extension services	0.039	0.021	0.048	0.784	1.004

***, **, * *significance level (at 1%, 5% and 10%, respectively).*

Table 15 Distribution of households by HFIAS condition

HFIAS	Rarely		Sometimes		Often	
	N	%	N	%	N	%
Worry about food	141	73.06	30	15.54	22	11.40
Unable to eat preferred foods	200	52.49	112	29.40	69	18.11
Eat just few kinds of foods	102	31.10	92	28.05	134	40.85
Eat foods they really do not want to eat	52	13.83	99	26.33	225	59.84
Eat smaller meal	106	49.77	79	37.09	28	13.15
Eat fewer meals in a day	91	70.00	22	16.92	17	13.08
No food of any kind in the household	29	72.50	7	17.50	4	10.00
Go to sleep hungry	22	95.65	0	0	1	4.35
Go a whole day and night eating	3	100	0	0	0	0

Hints to the severity status: (1) Rarely (once or twice in the past 4 weeks); (2) Sometimes (three to ten times in the past 4 weeks); (3) Often (more than ten times in the past 4 weeks).

Table 16 Multinomial logit model

Variables	Food secure			Moderately food insecure			Severely food insecure		
	Coefficient	Standard Error	Marginal Effect	Coefficient	Standard Error	Marginal Effect	Coefficient	Standard Error	Marginal Effect
Gender	0.652	0.498	0.083	0.283	0.512	0.079	0.280	0.502	0.018
Age	-0.027**	0.002	-0.048	0.008	0.019	0.019	0.021	0.018	0.029
Education	0.485**	0.210	0.081	0.078	0.210	0.032	0.003	0.218	0.015
Marital status	1.329**	0.802	0.122	1.312	0.780	0.116	1.020	0.793	0.042
Family size	-0.013	0.081	-0.006	0.080	0.072	0.011	0.061	0.085	0.039
Annual income	0.120	0.203	0.059	-0.220	0.215	-0.016	-0.790*	0.281	-0.082
Farmland size	0.007	0.120	0.010	0.005	0.097	0.009	-0.092	0.134	-0.020
TLU	0.015	0.004	0.006	-0.076**	0.041	-0.018	0.030	0.040	0.005
Market access	0.003	0.002	0.018	-0.004	0.017	-0.005	0.005	0.002	0.011
Credit access	0.879**	0.450	0.100	0.300	0.471	-0.021	0.772	0.550	0.061
Agri_training	0.260	0.452	-0.017	-0.512	0.410	0.089	-0.830***	0.453	0.050
Extension services	0.370	0.532	-0.021	-0.480	0.420	0.049	-0.364	0.518	0.032
_cons	-2.710	1.623		-2.362	1.474		-4.981	1.608	
Log likelihood = - 442.867			Number of observation =					402	

****, **, * significant level (at 1%, 5% and 10%, respectively).*

Determinants to the household food insecurity

Econometric model has shown the statistical relationship that is thought to exist between several economic parameters relevant to the variables used in this study. The variables assumed to have influence on household dietary diversity were tested in the model and out of 12 variables entered into the model five of them were found to be significant while seven of them were not found to be statistically significant (Motuma *et al*., 2019).

Age of household head:

The age of the household head is a proxy for farming experience, on the assumption that the household's knowledge of dietary diversity issues will increase, as the household head gets older and more experienced. Similarly, the result of this finding confirmed that the older the household heads, the more they consume diverse diet (Table 14). As most studies confirmed, the age of the household head increase, the household acquires more farming experience, becomes more risk averse, and diversifies its production (Gebre *et al*., 2021). Households headed by older people are thus more likely to diversify their dietary than those with younger heads. In contrast, Mengistu *et al*. (2021) shows that as the age of the household head increases, households become less productive and rely more on specialized crops. Hence households with older heads are more likely to be food insecure than those with younger heads.

Educational level of household head:

As education increases the knowledge and skill of the people in a society, it has been hypothesized to have a positive relationship with household dietary diversity. As expected, education level of household head had a positive influence on the household dietary diversity. By holding the influence of other variables constant, a one unit increase in household head education level, the odds ratio in favor of high category with household dietary diversity increased by the factor of 1.642 (Table 14). This indicates that education improves knowledge on nutritious diet and one of the most important predictors of dietary diversity intake. Educated household heads could have better understanding on health benefits of consuming nutritious food so that they spent a higher amount of their food budget on diversified diet than uneducated ones (

Table 12). Education of the household head plays a positive role for household dietary diversity (Bandyopadhyay *et al*., 2021; Kundu *et al*., 2021). The more households are educated, the more they are likely to attain a higher dietary diversity. Additionally, Aserese *et al*. (2020) stated that a well-educated household head is nearly twice as likely to produce vitamin A-rich fruits and vegetables for eating. Khandoker *et al*. (2022) and Motuma *et al*. (2019) observed that independent of the greater

income, educational achievements in the household boost intake of non-alcoholic beverages such as fluids, milk, and yoghurt.

Annual income:

When compared to the base category, a negative relationship has been observed between the households' annual income and their levels of food security. Income assumes a positive relationship for household dietary diversity because it is an important and significant indicator of a household's overall economic well-being. The fact that this variable has a positive relationship with income suggests that wealthier households are more likely than poorer ones to diversify their diet. The odds ratio in favour of a high category with dietary diversity in the household increases by a factor of 1.202 for every unit increase in household income when the effects of other variables were held constant (Table 14). The result concurs with the previous findings conducted by Bandyopadhyay *et al*. (2021). It states that a household with more money can purchase more food with better nutrition, increasing dietary diversity at the household level. In addition, Mengistu *et al*. (2021) indicated that a household's likelihood of consuming a varied diet is significantly positively correlated with higher agricultural revenue. Furthermore, Rajendran *et al*. (2017) has also addressed that the level of consumption in a household is determined by income.

Livestock owned in TLU:

Livestock ownership of households' significantly and positively influenced household dietary diversity. The model output indicates that keeping other variables constant, a unit increase in livestock ownership leads the odd ratio in favor of high category with household dietary diversity increase by a factor of 1.296. The relationship between livestock ownership and household food security is positive, which is explained by the fact that livestock size is a proxy for rural household resource endowment and asset accumulation. Owners of large livestock are therefore more likely to experience income growth (Table 14). The result supports the findings of other studies that found a relationship between owning livestock and a varied diet (De Jager *et al*., 2018; Motuma *et al*., 2019; Taruvinga *et al*., 2022). Moreover, Milner *et al*. (2022) and Sambo *et al*. (2022) described that rural households that own livestock are more likely to transition from a medium to a high dietary diversity status.

Market distance:

The number of kilometers farmers must travel to the next market to sell their produce is referred to as the "market distance." The result of our finding indicates that distance to market had significant and negative influence on household dietary diversity at $\alpha=0.05$. Farmers who live close to markets have better access to food than their competitors do. A one-unit increase in market distance leads the

odds ratio in favor of high category household dietary diversity to decrease by a factor of 0.586 (Table 14). When examined using a multinomial logit model, market distance did not exhibit a significant positive or negative influence (Table 16). This agrees with the findings of Mengistu *et al*. (2021) and Mudzielwana *et al*. (2022) who reported strong relationship between remoteness from markets and household dietary diversity. Furthermore, other findings also addressed that increased dietary diversity may be facilitated by improved market access through shorter travel distances (Gupta *et al*., 2020; Usman & Callo-Concha, 2021).

4.4. Conclusion

The principal goal of the study was to analyze the role of agroforestry systems for crop diversification to improve household food security for coffee-based farmers and identify socioeconomic factors affecting food security. The household dietary diversity score and the household food insecurity access score measured food security. The result of the ordered logit model revealed that the age of the household heads, education levels of the household heads, implementing agroforestry practices, annual income, and livestock holding in TLU all positively influenced household food security conditions via dietary diversity. Conversely, distance to the nearest market negatively affected household food security.

Farm households with better systems for dietary diversification are more secure in their food supplies and income and can therefore meet their households' needs for food. As it is assessed, the coffee based agroforestry systems enabled farmers to get better availability, access to, and utilization of food resources in the study area. Accordingly, it is implied that dietary diversity increases food security in terms of quantity and variety, as well as income from the sale of crops made from a variety of crops grown, which in turn improves household consumption trends. Thus, to improve the farmers' level of food security, agroforestry practices need to be promoted to encourage farm households to diversify their crop production in order to improve their food security status.

Additionally, the level of education in the household had a significant impact on food security. Therefore, capacity building through training and basic education must be emphasized in interventions designed to support households by governmental and non-governmental organizations. Lastly, the distance from the nearest market to a household had a significant and unfavorable impact on food security. Therefore, enhancing rural infrastructural development, such as roads, market centers, and market information, helps rural residents have better food security.

CHAPTER FIVE

5. Tree diversity and biomass carbon stock analysis along altitudinal gradients in coffee-based agroforestry system of West Wollega

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Abstract

Agroforestry systems are thought to reconcile biodiversity protection with food production and as a means of climate change adaptation and mitigation options. The contribution of a coffee-based agroforestry system to tree diversity and carbon stock along altitudinal gradients in West Wollega was assessed. At 100-meter intervals, six transect lines were methodically set up throughout the altitudinal gradient. There were made a total of 60 sample plots, each measuring 40 m by 40 m. A total of 34 woody species were identified. Biomass carbon stocks and tree diversity were quantified across altitudinal gradients. In the middle altitude, there were more woody species (28) than in the top altitude, where there were only a few species (16). The tree plants stored around 40.6 t ha^{-1} of biomass carbon on average. Aboveground biomass had a carbon stock of 32.22 C t ha^{-1}, whereas belowground biomass had a carbon stock of 8.38 C t ha^{-1}. The lower altitude biomass carbon stocks were substantially bigger than the upper altitude, which were 48.4 C t ha^{-1} and 25.67 C t ha^{-1}, respectively. With increasing altitude, the study found a statistically significant negative link between tree diversity and biomass carbon storage ($P<0.05$). The negative link between biomass carbon stock and altitude was that tree parameters that determine the amount of biomass carbon sequestered in a plant, such as basal area, tree diversity, and density, decreased as altitude increased. Despite differences along altitudinal gradients, the systems supported a diverse range of tree species and biomass carbon stocks.

Keywords*: Agroforestry, Carbon, Coffee, Tree diversity, Altitudinal gradient*

5.1. INTRODUCTION

Agriculture has become the most vulnerable to the effects of climate change (K. Mekonnen & Gebreyesus, 2011). As a result, human communities all over the world have devised a wide range of complex tactics for coping with climatic change and the natural environment (Gizachew & Shimelis, 2014). Understanding the true dynamics of climate change consequences at the local level, such as farm households and communities, is crucial (Tadesse *et al*., 2009). Smallholder farmers in a country like Ethiopia, which has a high level of ecological and cultural diversity, such as language, beliefs, and indigenous knowledge of conserving natural resources, are likely to have developed their own indigenous adaption mechanisms (Nair, 1993; Lin, 2020). To combat climate change, preserve biodiversity, and increase food production, subsistence farmers in various regions of the country have developed and adopted the practice of agroforestry (Jamnadass *et al*., 2013; Reppin *et al*., 2020).

Agroforestry is an old practice that involves growing trees or shrubs near or amid pastureland or crops in order to benefit from the subsequent ecological and economic interactions (Nair, 1993; Mkonda & He, 2017). They are specific local examples of methods that are relevant to a certain habitat, plant species, arrangement, management, and socioeconomic function, e.g. Coffee-based home-garden. Home-garden is specific due to its distinctive environment, plant species, arrangement and management, social and economic functions (Nair, 1993).

The likely importance of agroforestry is designated differently. As a result, due to the locality-specific nature of each agroforestry practice, they have evolved differently across the world. In Ethiopia, where arabica coffee originated, coffee-based agroforestry grows naturally as an understory shrub in native woods (Tadesse *et al*., 2014). It is also grown throughout a wide management gradient, but exclusively under shade (Zewdie *et al*., 2022). The practice is abundantly found in the southwestern and western parts of the country, where a large proportion of the country's forest cover is found. As coffee shrubs are perennial crops, coffee-based agroforestry practices are believed to form a better biodiversity and biomass carbon sequestration system than other agroforestry practices (Hylander *et al*., 2013; Buechley *et al*., 2015; Tesfay *et al*., 2022). Another benefit of coffee-based agroforestry management is that it slows the rate at which ecosystems with trees are being converted to open agricultural landscapes (Hylander *et al*., 2013).

Due to the composition of trees and shrubs, the system sequesters a high amount of biomass carbon. It also contributes to maintaining food and nutrition security, helps diversify household income, provides fiber and energy to local communities (Jamnadass *et al*., 2013). Agroforestry systems have a high potential to offset greenhouse gas emissions compared to land resources converted to other

more intensive forms of land uses owing to the carbon storage in trees, shrubs, and soils. In the case of traditional coffee farming, retaining a high degree of the canopy increases the capacity of the system to store more carbon in the tree and perennial crop components (Olsson *et al*., 2019).

In a wide range of ecological settings, the practices maintain biodiversity and provide ecosystem resilience in addition to biomass carbon stocking (Santos *et al*., 2022). Tropical and subtropical ecological zones are home to the majority of agroforestry systems (Nair, 1993). According to different researches, many tropical forests are under severe anthropogenic pressure and require management interventions to maintain overall biodiversity, productivity, and sustainability (Kurnar *et al*., 2006). Despite the fact that species composition often varied widely, examples from around the world demonstrate that tropical agroforestry systems can support high levels of biodiversity, often similar to native forest (Tscharntke *et al*., 2011). In such regions, subsistence farmers who care for a diverse range of trees to support their families might hearten carbon storage and tree diversity, which will benefit ecosystems (Sistla *et al*., 2016).

Understanding the places of convergence between carbon storage and biodiversity protection is one of the primary concerns at the intersection of climate change and ecosystem science (Mulatu & Hunde, 2020). Nonetheless, higher carbon storage potential is related to its co-existence with biodiversity conservation, which varies with the type of agroforestry practices (Santos *et al*., 2022).

Though carbon stocks and biodiversity in Ethiopian agroforestry systems have been researched (Eshetu *et al*. 2021; Manaye *et al*. 2021), there has been no research on coffee-based agroforestry systems across altitudinal gradients in West Wollega. The majority of studies on agroforestry systems have mostly focused on food production and soil fertility management (Gebrewahid *et al*. 2019; Lameso and Bekele 2020; Mulatu and Hunde 2020; Mebrate *et al*. 2022). However, the impact of coffee-based agroforestry systems to carbon stocks and biodiversity conservation remains unexplored. For that reason, there is a limitation in addressing the contribution of coffee-based agroforestry systems towards tree diversity conservation and carbon sequestration across agro-ecological differences (Tschoraf and Cherubini 2020).

Therefore, the specific objectives of this study were to analyze tree species diversity in coffee-based agroforestry systems, quantify biomass carbon stock in tree species, and assess the effect of tree diversity on biomass carbon stock along altitudinal gradients. In the study area, the farmers were mostly coffee producers, but they also raise cattle. In addition, population density was varying across the ranges of the altitudinal gradients. The population of the upper land was higher, so they raise many cattle and tend to the production of other grains besides coffee to support the population density.

On the other hand, as the altitude increased, the weather variables of the area was varying and decreased at the upper altitude. Therefore, due to these two reasons, we hypothesized that biomass carbon and tree diversity would change amongst the three gradients of coffee-based agroforestry systems. In addition, because of a projected weather variable-related drop with elevation ascent, the high biomass carbon stock would be recorded at lower altitudes and associated to tree diversity; and, as a result, both biomass carbon stock and tree diversity would decrease with elevation.

5.2. Material and Methods

5.2.1. Study area description

The study was conducted in the Gimbi district in the West Wollega Zone of Oromia National Regional State. The district is located between 142000 - 174000 UTM E and 99300-1029000 UTM N. Gimbi district has a Weina Dega climate condition. The mean minimum and maximum annual temperature of the area was between 10°C and 30°C. The mean annual rainfall is 1400-1800 ml per year (Abera *et al*., 2015). In the Gimbi district, June, July, and August are the summer months similar to most of the country's annual seasons. It lies at an altitudinal range of 1200-2222m.

Every location in Ethiopia is categorized as lowland, midland, or highland depending on its altitude: below 1500 m. a. s. l., between 1500 and 2300 m. a. s. l., and beyond 2300 m. a. s. l. In this categorization, only altitudinal gradients are taken into consideration. Gimbi district only has lowland and midland altitudinal gradients because it is located between 1200 and 2222 meters above sea level.

5.2.1. Sampling Techniques

First, we identified classifications of coffee landscapes based on the farmer's perceptions and experts. They classified the landscapes into three altitudinal gradients namely lower land (1451-1650m. a. s. l.), mid-land (1651-1850m. a. s. l.) and upper land (1851-2050m. a. s. l.). Then, we adopted this classification scheme for our study. We identified three altitudinal gradients of coffee-based agroforestry systems, with an area of 3.2 ha, for each gradient. Across the three-altitudinal gradients, an area of 9.6 ha was identified using Google Earth. In each altitudinal classification, a 1 km long transect was established. Generally, six transects were established across the whole altitudinal gradients over six kebeles (the smallest administrative unit in Ethiopia) in the district.

5.2.2. Sampling Design

Data was collected from February 2020 to May 2020. Tree species diversity and biomass carbon stock assessment were carried out using areas of 40m x 40m sample plots, along the altitudinal gradients classification. Square plots were selected as they tend to include more of the within-plot heterogeneity and; thus be more representative than circular plots of the same area. A total of 60 sample plots were

used for tree parameter measurements. In each plot, tree species diversity, tree height, and tree diameter at breast height (DBH) were recorded following the transect lines.

The coffee farm chosen for the purpose of the study has been producing for a long time, so the trees on the farm were large in height and diameter. During the inventory, the height of most of the trees was > 2 m and their thickness was > 5 cm. However, a limited number of trees with a height of < 2 m and a diameter of < 5 cm observed occasionally. Since the number of trees (h < 2m and d < 5 cm) was small, they have not been included in the estimation of biomass carbon stocks.

Hence, trees with a height $\geq$ 2m and $\geq$ 5 cm in diameter at breast height (DBH) were measured. Trees height and diameter were measured using a vertex, diameter tape, and caliper respectively. Branched trees at 1.3 m were measured at the smallest point below 1.3 m, where the stem assumes a nearly cylindrical shape. A woody plant with multiple stems or forked below 1.3 m height was treated as a single individual. Plant identification was done in the field using their local name and useful trees and shrubs for Ethiopia (Bekele-Tesemma, 2007). Nomenclature follows the Flora of Ethiopia and Eritrea (Vol 1-8). To quantify the tree diversity of the coffee-based agroforestry systems, the number and names of tree species (both seedling and sapling) were recorded.

5.2.3. Data analysis

Tree species diversity

For this study, we have used different diversity indices. The weaver indices of the sampled coffee-based agroforestry systems were calculated by using Shannon diversity which is a very widely used index for comparing diversity between various habitats (Okpiliya, 2012). The evenness of a population was estimated following the Shannon-Wiener index. Additionally, Simpson's diversity index was used. Simpson's diversity index is the most sensitive to changes in more abundant species and hence places more weight on the most abundant species in the community. The Simpson's diversity index is derived from probability theory and it is the probability of picking two organisms at random which are of different species (Magurran, 1988).

The Sorensen similarity coefficient was used to estimate the similarity/dissimilarity of species between altitudinal gradients. The Sorensen similarity coefficient was widely deployed as it gives more weight to the species that are common to the samples rather than to those that only occur in either sample (Gotelli & Chao, 2013).

The IVI of a species was used to express the relative ecological significance of the species in the forest ecosystem. It was calculated by summing up the relative dominance, relative density, and

relative frequency of the species It indicates the significance of species in the system (B. Mengistu & Asfaw, 2016).

Tree carbon estimation

In this study, the non-destructive allometric equation which is described by Chave *et al*. (2014) was used to estimate both the aboveground and belowground biomass (ton). This method is applied to the global forest type. It helps calculate the aboveground and belowground biomass contained within each tree that is given as a function of height (m), DBH (cm), and wood density (g/cm^{-3}).

The aboveground biomass of trees and shrubs in the coffee-based agroforestry was calculated using the formula in Eq. (1).

$$AGB = 0.0673X(\rho D^2 H)^{0.976}, \quad \ldots\ldots (1)$$

Where, AGB = above ground biomass

ρ = wood density (g/cm^{-3})

D = diameter at breast height (1.3m above ground) (cm)

H = tree height (m)

Aboveground live carbon (AGC) was estimated at 50% of AGB, while belowground biomass carbon estimated by multiplying the aboveground biomass by 0.26 as conversion factor (Chave *et al*., 2014; Manickam *et al*., 2014). Wood-specific gravity was obtained at the species level from the Global Wood Density Database (Chave *et al*., 2009). For example, one of the studied trees species (*Albizia gummifera*) from plot1 in the coffee-based agroforestry system has a height of 28 m and DBH of 65 cm. The wood density of this tree species is 0.580. Therefore, the aboveground biomass of the tree was calculated as follow.

$$AGB = 0.0673X(\rho D^2 H)^{0.976},$$

$$AGB = 0.0673X(0.580 * 0.65^2 * 28)^{0.976},$$

$$AGB = 0.441t$$

Aboveground biomass (AGB) of this *Albizia gummifera* (Fabaceae) was 0.441t. From (Pearson & Brown, 2005), the follow equation is used to determine the amount of carbon stock of the tree:

$$C(t) = \frac{AGB}{2} \quad \ldots\ldots (2)$$

Therefore, the carbon stock estimation of this tree was 0.221 t.

Where, T = ton

C = Carbon

AGB = Aboveground biomass

In order to estimate the total carbon sequestered in the agroforestry system, it was necessary to calculate the belowground biomass carbon stock. Therefore, the belowground biomass carbon (BGBC), was calculated by multiplying AGB taking 0.26 as the root to shoot ratio used by Sudha *et al*. (2007). And subsequently, the carbon stock of belowground biomass was calculated by using the equation developed by Manickam *et al*. (2014).

$$\text{BGB } (\text{tha}^{-1}) = \text{AGB } (\text{tha}^{-1})\ x\ 0.26 \quad \text{..... (3)}$$

$$\text{Total Biomass} = AGB + \text{BGB} \quad \text{..... (4)}$$

Furthermore, the formula developed by several scholars is what is used to transform biomass into carbon stock. According to the premise that living biomass (tissues) contains 47% carbon, the carbon stock for both trees and shrubs/bushes was calculated to be 0.47 times the amount of woody biomass (Chave *et al*., 2005). In other words, the biomass has a carbon content of roughly 47% by dry weight and the carbon stock in the biomass was estimated using the formula in Eq. (5).

$$\text{Total Carbon estimation} = Total\ Biomass\ x\ 0.47 \quad \text{..... (5)}$$

Statistical analysis

The data which was collected from the field inventory was organized and recorded in Microsoft excel 2010 datasheet. The altitudinal gradients were the independent variables while density, basal area, species richness, species evenness, and species diversities were considered as dependent variables. Vegetation data were analyzed using univariate analysis. Variables were compared using one-way analysis of variance (ANOVA) following the linear model (GLM) procedure at $P < 0.05$ with the help of the R software for Window versions 3.6.1 with statistical significance difference were observed ($P < 0.05$), Tukey's HSD test were used to separate the means. To investigate the effect of tree diversity on carbon stock across altitudinal gradients, repeated analyses of Variance was performed and the relationship between tree diversity and tree and coffee shrubs biomass were analyzed.

5.3. Results

Floristic composition

A total of 36 tree species were recorded from coffee-based agroforestry systems (CBAS). Out of this, 27 species were recorded from the 1451-1650m altitudinal range and 29 were from the 1651-1850m altitude, while 17 species were from the 1851-2050m altitude respectively. The entire recorded species were belonging to 34 genus and 23 families (Table 17). Fabaceae are represented by 7 species (19.44%) followed by Boraginaceae, Combretaceae, Euphorbiaceae, Loganiaceae, Moraceae, Myrsinaceae, Rubiaceae families collectively representing 38.92% (Figure 9). The remaining 15 families altogether accounted for 41.7% of the total species composition each family represented by 1 species (Table 18). Overall, 3,231 tree individuals and 36,424 coffee stems were counted (Table 19).

Table 17 Total number of tree families, genera, and species recorded in coffee-based agroforestry

Altitude gradient (m. a. s. l.)	**Family**	**Genus**	**Species**
1451-1650	17	26	27
1651-1850	19	28	29
1851-2050	16	17	17
Overall	23	34	36

Species richness, Evenness (E), Shannon-Wiener Diversity Index (H'), and Simpson Diversity (1-D) were significantly different along an altitudinal gradient (Table 18). The mean species richness, which measures the number of species present per plot, ranged from 3.60 to 7.40. The highest species richness (S=7.40) was measured in the 1651-1850m altitudinal gradients while the lowest (S=3.60) was recorded in the 1851-2050m altitudinal gradient. Shannon evenness index was also highest (J = 0.88) at the 1651-1850m altitudinal gradient and lowest (E = 0.60) at 1851-2050m altitudinal gradient (Table 18). The highest Shannon-Wiener diversity index (H') was recorded from 1651-1850m altitudinal gradient while the lowest was recorded in 1851-2050m altitudinal gradient (Table 18). The highest and lowest Simpson's diversity index for each study site is similar to that of Shannon-Wiener diversity index (H') across the altitudinal gradients.

Table 18 Tree diversity indices in coffee-based agroforestry system across altitudinal gradients

Indices	**Altitudinal Gradients (m. a. s. l.)**		
	1451-1650	1651-1850	1851-2050

Species richness (S) (Mean ± S.E.)	6.00(0.39) [ab]	7.40(0.83) [a]	3.60(0.82) [c*]
Evenness Index (E)(Mean ± S.E.)	0.86(0.02) [a]	0.88(0.02) [a]	0.60(0.13) [b]
Shannon Diversity Index (H')(Mean ± S.E.)	1.51(0.05) [ab]	1.75(0.12) [a]	0.88(0.24) [c]
Simpson Diversity (1-D)(Mean ± S.E.)	0.14(0.04) [b]	0.14(0.03) [b]	0.41(0.11) [a]

* (a, b, c) Means followed by a different superscript (a, b, c) are significantly different at the 0.05 level; S.E.: Standard error

Species dominance varies across the three-altitudinal gradients. In the 1451-1650m altitudinal range, *Albizia gummifera* (49.95), *Terminalia laxiflora* (35.54), *Combretum molle* (27.99), *Croton macrostachyus* (26.83), *Maesa lanceolata* (20.97) and *Ficus vasta* (11.59) were the six most dominant species. In the 1651-1850m altitude, *Albizia gummifera* (52.27), *Terminalia laxiflora* (38.73), *Croton macrostachyus* (25.6), *Combretum molle* (22.21), *Maesa lanceolata* (14.91), and *Vernonia amygdalina* (12.37) were recorded as a top dominant species. Whereas, the 1851-2050m altitude was uniquely dominated by *Sapiumellipticum* (48.15), *Croton macrostachyus* (36.94), *Celtis africana* (30.05), *Premnaschimperi* (28.25), *Strychnos spinosa* (27.17), and *Oncoba spinosa* (24) species. Of all species, *Albizia gummifera* was the top ranking in 1451-1650m and 1651-1850m altitudes while *Sapiumellipticum* was found to be the top ranking in 1851-2050m altitude.

The mean density of the entire tree species recorded along altitudinal gradients in the coffee-based agroforestry systems was 13 individuals per 1600m^2. Tree species density showed a significant difference ($F = 5.144$; $P < 0.05$) along altitudinal gradient. It was significantly highest (17 individuals per sample plot) in the 1451-1650m altitude and lowest in 1851-2050m altitudes (10 individuals per sample plot). In the 1451-1650m altitude, the dense species were *Albizia gummifera* (8 individuals per sample plot), *Croton macrostachyus* (8 individuals per sample plot), *Terminalia laxiflora* (7 individuals per sample plot), and *Combretum molle* (6 individuals per sample plot). The abundance of these four tree species alone covers 40.45% of the total population of tree species in the 1451-1650m altitudinal range. *Albizia gummifera* (10 individuals per sample plot), *Croton macrostachyus* (9 individuals per sample plot), *Terminalia laxiflora* (8 individuals per sample plot), and *Combretum molle* (5 individuals per sample plot) were the most abundant in the 1651-1850m altitude. Unlike the former two altitudinal gradients, *Strychnos spinosa* (7 individuals per sample plot), *Sapiumellipticum* (7 individuals per sample plot), *Croton macrostachyus* (6 individuals per sample plot), *Oncoba spinosa* (6 individuals

per sample plot), and *Premnaschimperi* (5 individuals per sample plot) were the most abundant in the 1851-2050m altitudinal range; and account for 60% of the total density.

Table 19 Tree density and basal area in coffee-based agroforestry systems along different altitudinal gradients

Altitudinal gradient (m. a. s. l.)	**No. of Tree species**	**No. of tree individual**	**No. of Coffee individuals**	**Density (plot $^{-1}$)**	**Basal Area (m2 plot $^{-1}$)**
1451-1650	26	1197	17240	11.44(1.27)^{ab}	3.67(0.64)^{a}
1651-1850	28	1055	11288	16.60(2.22)^{a}	2.18(0.33)^{ab}
1851-2050	16	979	7896	10.10(0.59)^{c}	1.82(0.13)^{c}

The standard error (±SE) mean is shown in parenthesis.

Note; one-way ANOVA was conducted to see the mean difference between groups and followed by a post hoc test for multiple comparisons. A similar letter indicates have no significant difference but a different letter shows the statistically significant difference between altitudinal gradient at $p < 0.05$

Likewise tree species density, the basal area has also shown a significant difference ($F = 5.349$, $P < 0.05$) along the altitudinal gradient. Lower altitude showed a higher mean basal area (3.67 m^2 per sample plot) of tree species and the lowest mean basal area was found at 1851-2050m altitude (1.82m^2 per sample plot) (Table 19).

Carbon stock

The pattern of aboveground and belowground carbon stocks distribution varies across altitudinal gradients. The differences in tree carbon stock, both aboveground and belowground, showed a slight increase from 1451-1650m altitude to 1651-1850m while it was decreasing from 1651-1850m to higher 1851-2050m altitude in the coffee-based agroforestry system (Table 20).

Table 20 Mean (± standard error; n = 20) aboveground and belowground biomass (Tons/ha) for each of the three altitudinal gradients and results of one-way ANOVA (at $\alpha = 0.05$, significant differences between the altitudinal gradient of the biomass carbon stocks).

Total biomass carbon*	Altitudinal Gradients (m. a. s. l.)			Mean	Pr(>F)
	1451-1650	1651-1850	1850-2050		
AGC (trees)	34.66 (4.2)^{a}	36.03 (4.4)^{a}	19.49 (1.6)^{b}	29.91	**
BGC (trees)	9.01 (1.1)^{a}	9.37 (1.1)^{a}	5.07 (0.6)^{b}	8.77	**
AGC (coffee)	3.75 (0.26)^{a}	1.86 (0.13)^{b}	0.88 (0.05)^{c}	2.16	**
BGC (coffee)	0.98 (0.07)^{a}	0.48 (0.03)^{b}	0.23 (0.01)^{c}	0.56	**
Total Carbon	48.4 (5.3)^{a}	47.74 (5.4)^{a}	25.67 (2.0)^{b}	41.4	**

* AGC-Aboveground carbon; BGC-Belowground carbon

The pattern of aboveground and belowground biomass carbon stock in coffee shrub across altitudinal gradients was significantly different along the altitudinal gradients. It was monotonically decreasing as altitude increased. The maximum aboveground and belowground biomass carbon recorded in coffee shrubs were 4.73 tons per ha and the minimum was 1.11 tons per ha respectively (Table 20).

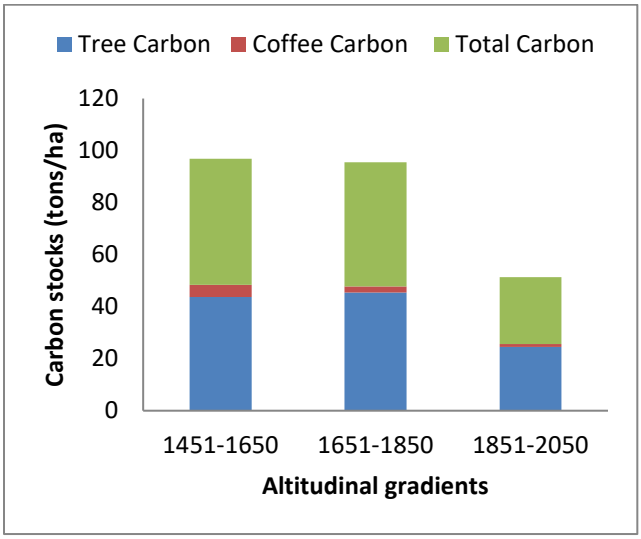

Figure 9 Tree species and coffee-shrub biomass carbon in coffee-based agroforestry systems

The highest BGC for tree species was recorded in the 1651-1850m altitudinal class (tons ha−1) followed by 1451-1650m altitudinal range (9.01 tons ha−1). Similarly, the variation of carbon stock in coffee shrubs along the altitudinal gradient was statistically significant ($F = 6.0408$, $P < 0.001$). Overall, the highest carbon stock was observed in the 1451-1650m altitudinal range while the lowest was found in the 1851-2050m altitudinal scale (Figure 9).

Total carbon stocks and tree diversity relationships

The carbon stock in the study area was influenced by the variation in tree species diversity, abundance, and dominance of trees across the altitudinal gradients in the coffee-based agroforestry system (Table 20; Figure 9). The largest carbon stock was contributed by the tree species which accounted for 93.3% % of the system for the three altitudinal gradients while the remaining was contributed by coffee shrubs (Table 20). The mean tree carbon stock was calculated to be 38.68 tons per ha, and the average coffee shrub carbon stock was estimated to be 2.73 tons per ha (Table 20). The overall mean carbon stock stored in the system was estimated to be 41.4 tons per ha (Table 20).

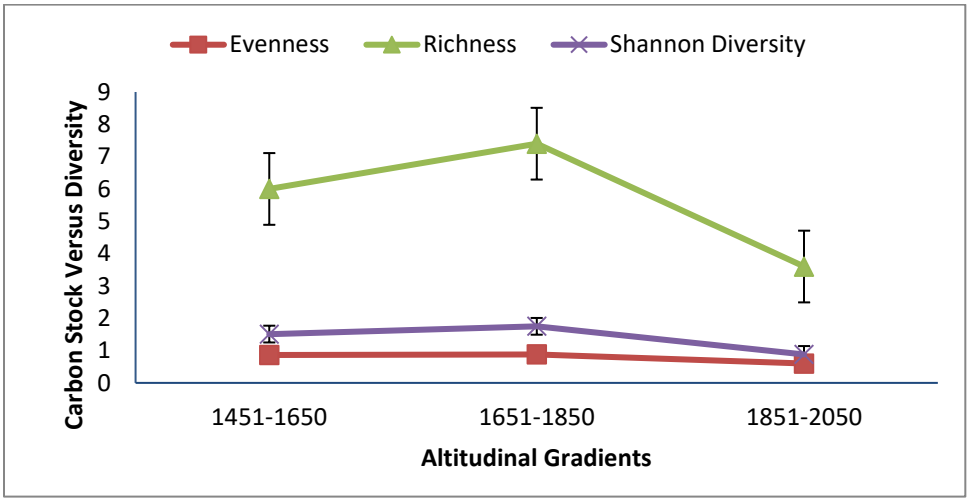

Figure 10 Tree diversity indices across altitudinal gradient

5.4. Discussion

Floristic composition

Floristic composition and variety were found to be highest in the 1651-1850m height, followed by the 1451-1650m altitude, and lower in the 1851-2050m altitude. Desalegn and Beierkuhnlein (2010) found a similar trend of species richness and pattern. They discovered that woody species richness follows a trend that begins with an increase and peaks about 2000 meters, then begins to fall and level off at elevations over 2500 meters. Altitudes and slopes, according to Eilu and Ofbua (2005), influence tree species richness and dispersion behavior. As reported by Sharma *et al*. (2017), tree species richness was found to be highest at a lower altitude, followed by middle altitude, and lowest at a higher altitude. They also reported that tree species richness (including genera and family richness) shows a similar pattern, reaching a maximum at intermediate elevations in the subtropical Andes of Argentina.

Several studies have shown that species richness patterns can show a monotonic reduction (Sharma *et al*. 2017; Gebrehiwot *et al*. 2019). Ali and Yan (2017) and Gebrehiwot *et al*. (2019) have found a monotonic increase along altitudinal gradient. In contrast, some researchers have discovered that species richness is lowest at mid-elevations, resulting in an inverted hump-shape (Nanda *et al*., 2018), while others have discovered no apparent association between species richness and elevation. According to Toledo-Garibaldi and Williams-Linera (2014), species, genus, and family richness decreased in a unimodal fashion along the entire elevation gradient, while diversity decreased monotonically.

Several researchers conclude that there is no general pattern along elevation gradients; however, particular patterns, such as the unimodal hump-shaped and monotonic reduction, do exist. Due to a

multitude of rules driving the general ecology of forest ecosystems (Lawton, 1999) and the existence of a wide variety of strategies and ways developed by species to adapt to environmental stresses (Grime, 1977). However, there is no general conclusion on the correlation between species distribution and altitude, the fact that tree species show variation along altitudinal gradients. Pausas and Austin (2001) affirmed that the distribution of species richness over any wide area is likely to be influenced by two or more environmental factors.

In the 1851-2050m altitudinal range, Shannon-index Weiner's values ranged from 0.88 to 1.75 and dropped. Our findings are consistent with those found in other temperate woods (Sharma *et al*., 2009). Similarly, the important value indexes differed throughout elevation gradients, and different tree species predominated at various altitudes. In this study, *Albizia gummifera* was the major tree species in the coffee-based agroforestry systems at altitudes of 1451-1650m and 1651-1850m, respectively, whereas Croton macrostachyus was the dominating tree species at elevations of 1851-2050m. According to Curtis and Mcintosh (1950), the highest important value index obtained for a given woody species indicates that it is the dominating species among other plant species in the same area.

According to Nemera *et al*. (2018), a species' ecological dominance may be linked to pathogen resistance or competition, adaptability to growth in the shade, least preferred by browsing animals, pollinator attraction, and diversity of seed predators that facilitated seed dispersal within the existing environmental conditions. Environmental factors and selective human use of the available species, on the other hand, may be due to the woody species with the least important value.

Tree dominance varies with variation in the coffee-based agroforestry systems across elevation. Simpson's index value was 0.14 in the 1451-1650m and 1651-1850m gradients, which gradually increased and reached finally up to 0.41 for the tree species in the 1851-2050m gradients. This was due to the tolerance-based dominance of only a few tree species under severe environmental conditions. The high importance value index (IVI) of species between 1651-1850m altitudes indicated their dominance and ecological success, good power of regeneration, and ecological amplitude. Similar observations were also recorded by Sharma *et al*. (2017) and Gebrewahid *et al*. (2019).

Tree diversity and carbon stocks along altitudinal gradients

The mean above and below ground biomass carbon stocks of both trees and coffee shrubs decreased with increasing altitude, which could be attributable to the absence of large trees with maximum DBH, a decrease in tree species diversity, and a decrease in the number of coffee shrubs in the upper altitude. Because tree species richness decreased as altitude increased from 1851 to 2050, relatively small trees (low DBH) with low diversity became dominant. This could be the result of anthropogenic influences

in the study area. The farmers did raise animals and grow other crops, but they mostly grew coffee. The population density fluctuated along the altitudinal gradients' ranges as well. For instance, the population of the upper land increased along with the number of cattle and crops produced which displaced coffee production and transformed the land into open agriculture, according to agricultural office report.

On the other hand, in the lower altitudes, farmers cut trees for charcoal making and wood selling. Furthermore, as altitude increased, the weather variables of the area varied with a pattern of decreasing at the upper altitude. Because of these factors, lower and higher tree diversity were observed at lower and upper altitudes, respectively. The study's findings were similar to those of Esubalew *et al*. (2019) and Tesfaye and Seifu (2016). According to them, the variations in the parameters could be due to a variety of factors that change with altitude. The elements that caused the variation could have been soil humidity or temperature, as well as a study site's dissimilarity.

Similar research has found that a number of factors influence the variability of tree variety, which affects both above and belowground carbon reserves in a forest ecosystem. Because of good species diversity, environmental conditions, and soil characteristics in the mid-altitudinal gradient, Eshetu and Hailu (2020) reported that the pattern of total carbon stock in their study had a humped shape with altitudinal gradient and formed a peak carbon stock at the mid-altitude. Yohannes *et al*. (2015) discovered a declining trend in soil organic carbon stock as elevation increased, which they attribute to canopy cover, litter biomass accumulation, and species diversity. Another reason, as Gedefaw *et al*. (2014) point out, is that climatic conditions can influence forest carbon stock along an elevation gradient. Farm size, management, socioeconomic needs, species diversity, tree age, local climate, and tree spacing among agroforestry systems could all have a role in carbon stock variation (B. Mohan Kumar, 2011). A continual removal of falling litter, deadwood, and twigs, as well as unlawful cutting for charcoal production, construction, agriculture, and livestock grazing, were also discovered to have an impact on the forest carbon stock balance (Gedefaw *et al*., 2014). The highest amount of carbon was stored in coffee shrubs at 1451-1650m, followed by 1651-1850m, and the lowest at 1851-2050m. That might be because the upper land forest, which located in the 1851-2050m altitudinal gradient, is dominated by natural forest, while the 1651-1850m altitude is mixed, and the 1451-1650m altitude is dominated by planting because of farmers' shade tree preference intervention.

This research provides valuable information on tree diversity, coffee shrub density, biomass, and carbon stock in coffee-based agroforestry ecosystems over an altitudinal gradient in the study area. The impact of human intervention on tree species variety and coffee shrub density throughout an altitudinal

gradient is also highlighted in our research. In comparison to the 1451-1650m and 1651-1850m systems, the agroforestry system in the 1851-2050m altitudinal range is frequently subjected to more intense human disturbance and has a lower density of huge trees, according to local experts. The agroforestry systems in the altitudinal ranges of 1451-1650m and 1651-1850m sustained more large trees due to long-term management of larger trees by coffee producers. The 1851-2050m altitude, which mainly comprises natural forest, was found to contribute low accumulations of carbon stocks as compared to the 1451-1650m and 1651-1850m altitudes. The more coffee shrubs, large tree diversity, and high carbon storage potential of 1451-1650m and 1651-1850m altitudes show that the two sites are more productive and have more sustainable ecosystems compared to the 1851-2050m altitude, which has lower coffee shrubs density and small size and less diversity tree with less carbon stock potential.

Thus, comparing these species diversity and carbon storages phenomena, coffee-based agroforestry systems can be seen as an agroecosystem function that is directly interrelated to biodiversity conservation and carbon storage. However, the effect of species diversity on biomass carbon storage depends on management practices, species, and site factors.

5.5. Conclusion

This study highlights coffee-based agroforestry systems are important for conserving Ethiopian tree species that are either indigenous or highly endangered. In cosmparison, the system has a high proportion of native woody species equal to some unmanaged natural forests. Farmers typically establish or keep nearly multipurpose indigenous trees in the coffee-based agroforestry system. Our finding revealed that the system considerably improves native tree conservation.

Compared to the coffee shrubs, shade trees significantly stored large carbon stocks across the altitudinal gradients. Higher carbon stock and large trees with diverse species recorded in the lower and mid-altitudinal gradients indicate that plant density and diversity can actively influence total carbon stock in agroforestry systems than elevation gradients. This shows that the system is vital for carbon sequestration and help in alleviating climate change issues.

The system contributes to the augmentation of productivity of the area by providing food and assisting the community's livelihoods, protecting soil and watersheds. Hence, coffee-based agroforestry systems were found to be vital for biodiversity conservation, carbon sequestration, and ecosystem services that can lead to sustainable ecosystem management.

CHAPTER SIX

6. SYNTHESIS

Agroforestry is a time-honored practice that involves growing trees or shrubs near or amid pastureland or crops in order to benefit from the subsequent ecological and economic interactions (Mkonda & He, 2017). Due to the diversity of species and products, the practices protect farmers from socioeconomic shocks, spreading risks and providing adequate protection in the occurrence of extreme events (Mukhlis *et al*., 2022). Agroforestry practice, among other virtues (Noordwijk, 2021), can help address various dimensions of food insecurity through local production and market exchange, and supply non-food agricultural tree products while contributing to maintenance of environmental quality (Jemal *et al*., 2021; Octavia *et al*., 2022).

In a wide range of ecological settings, agroforestry systems can maintain biodiversity and provide ecosystem resilience in addition to carbon stocking (Santos *et al*., 2022). According to Nair (1993), the majority of agroforestry systems are found in tropical and subtropical ecological zones. In addition, various studies have examined how tropical forests are under severe anthropogenic stress and require management interventions to maintain overall biodiversity, productivity, and sustainability (Kurnar *et al*., 2006). Tscharntke *et al*. (2011) also added, despite the fact that species composition often varied widely, examples from around the world demonstrate that tropical agroforestry systems can support high levels of biodiversity, often similar to native forest. In such regions, subsistence farmers who care for a diverse range of trees to support their families might hearten carbon storage and tree diversity, which will benefit ecosystems (Sistla *et al*., 2016).

Accordingly, our study tried to address the connection of farmers' perception towards the existing climate change and the strategies that farmers use to adapt to the change. Climate change has become one of the most devastating environmental threats (Alemu & Desta, 2017), its impact on cropland degradation is expected to compromise households' livelihood and the gross domestic production of many developing countries (Balasha *et al*., 2023). Therefore, understanding farmers' perceptions about climate change and adaptation strategies can help support their efforts and develop interventions more suited to the local context (Likinaw *et al*., 2022).

The result of this study addresses that coffee farmers have perceived the presence of climate change and indicated the extreme temperatures and the unpredictable onset or cessation of rainy seasons in the study area. They indicated that temperature is raising and rainfall amount and its distribution is declining. In order to compare the farmers' perceptions of climate change, meteorological data was

used to analyze the annual rainfall and temperature condition of the study area. The meteorological data analysis revealed that temperature of the study area has shown a significant increasing while the rainfall insignificantly decreasing during the period of analysis. The annual rainfall has been decreasing by about 69 mm per decade while the mean annual temperature trend has been increasing by about 0.64°C in the period of analysis. Therefore, the perception of the farmers is consistent with the meteorological data, as both their understanding and the obtained climate data approve the decreasing of annual rainfall and increasing of annual temperature. Farmers' perception was positively influenced by their own experience, information sources they obtained from neighbors, media and different institutions.

Based on their perceptions, farmers have adopted different strategies to live with the changing climate. The most common adaptation strategies that farmers use to modify the environment by conserving soil and water resources, protecting existing forest resources by supporting with tree plantation, planting drought resistant crop types, establishing agroforestry systems, etc. Despite various factors influencing the adaptation strategies of the farmers, they could able to keep their productivity with in the changing climate. Agroforestry systems was the best strategy that helped the farmers to integrate different adaptation measures to diversify food produces in order to improve food security.

The combination of different crops/plants in agroforestry system not only enabled more effective agroecological process utilization, but also added variety to the farmers' diets and increased household income, enabled the purchase of alternative foods. Therefore, incorporating a wider variety of plant species into production and consumption practises could significantly improve their livelihoods, household food security and ecological sustainability.

Apart from the diversified production of food crops in the area, agroforestry systems have largely helped coffee producers to manage a large number of multifunctional trees in the system. In such away, the system could support high tree diversity that sequesters large amount of carbon in the above and belowground biomass during the period of production that contribute to climate change mitigation. Thus, the study clearly indicates that agroforestry plays a key role in climate change adaptation and contributes to improving food security while conserving ecological systems.

Conclusion and Recommendation

Empirical evidence revealed that the Gimbi district has been suffering from land degradation, decreased rainfall and distribution, decreased production, the occurrence of pests and diseases, decreased biodiversity, and human and animal health problems. The findings of this study, which drew on the participants' extensive prior knowledge of the subject as well as information from the media, agricultural education, and other farmers, demonstrated that farmers are aware of the existence of climate change. Additionally, farmers have been utilizing various adaptation techniques to lessen the impact of these problems and adapt to climate change.

The research investigated three categories of adaptation strategies: soil and water management, crop management, and intensive farm management. However, the farmers have used various adaptation strategies in response to climate change, and different factors have affected their perceptions and responses to the change. Accordingly, socioeconomic and environmental factors, such as the age of household heads, education, market access, and level of agricultural training, affected the farmers' perceptions toward the changing climate. Similarly, farmer's perceptions and the existing socioeconomic and environmental factors, in turn, affected the choice of strategies compatible with climate change. Based on this finding, crop management strategies were more significantly associated with farmers' perceptions of climate change than the management of soil and water, as well as intensive farm practices.

This finding also revealed that different socioeconomic and environmental factors limit the choice of particular adaptation techniques. For instance, farmers' agricultural training determined how they perceived climate change and responded to it. We concluded that the adoption of coping strategies to adapt to a changing climate is specific to an environment, as it limits the role of adaptation measures across different localities. Despite the fact that the area has limiting factors for adaptation methods, coffee-based agroforestry farmers can usually use diversified crop integrations with coffee crops and form good agroforestry practices. The agroforestry practices result in better production in a sustainable way than the monocropping that they had been practicing before adopting agroforestry systems. Therefore, crop diversification in coffee-based agroforestry showed great promise for improving the food security of households by improving food availability, accessibility, and utilization.

Apart from improving food security, this study revealed that coffee-based agroforestry systems are important for conserving Ethiopian tree species that are either indigenous or highly endangered. In comparison, the system has a high proportion of native woody species, equal to some unmanaged

natural forests. Farmers typically establish or keep nearly multipurpose indigenous trees in the coffee-based agroforestry system. Our findings revealed that the system considerably improves native tree conservation.

Compared to the coffee shrubs, shade trees significantly stored large carbon stocks across the altitudinal gradients. Higher carbon stock and large trees with diverse species recorded in the lower and mid-altitudinal gradients indicate that plant density and diversity can actively influence total carbon stock in agroforestry systems more than elevation gradients. This shows that the system is vital for carbon sequestration and helps alleviate climate change issues. Hence, coffee-based agroforestry systems were found to be vital for food security improvement through crop diversification, biodiversity conservation, carbon sequestration, and ecosystem services that can lead to sustainable ecosystem management.

Based on the study findings, the following recommendations were made to lessen the negative consequences of climate change on the livelihoods of farm households via agroforestry practices that are integrated with crop diversification, which in turn improve food security, biodiversity, and carbon stocking to attain sustainable environmental management.

1. Assessing and taking into account farmers' levels of climate change awareness as well as their adaptation mechanisms will be crucial in the future when implementing climate change adaptation strategies.
2. To determine whether adaptation measures will be effective in a particular area, it is crucial to take into account regional environmental factors when advocating for the implementation of climate change adaptations.
3. Future studies should compare how coffee-based agroforestry and a nearby agricultural land differ in terms of enhancing food security.
4. The connection between coffee-based agroforestry in the region as a strategy for food security, sustainable development, and climate adaptation needs more study.

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Annexes

Annex 1 Parameters estimates of binary logit model for climate change adaptation decisions

Variables	Soil and water management			Crop management				Intensive farm management		
	TP	SWC	AF	ICV	SPD	CD	DRC	LA	SSI	FA
Socioeconomic Factors										
Gender	0.00186	0.014	0.0018	1.084*	0.262	-1.059*	0.699	-0.505	0.0187	-1.09
	0.02	-0.04	-0.002	-2	-0.69	(-2.48)	-1.19	(-1.24)	-0.04	(-1.48)
Age	-0.027**	-0.00511	-0.029**	-0.045***	-0.0142	-0.0343***	0.0196	0.0158	-0.0383**	-0.034
	(-2.85)	(-0.30)	(-2.59)	(-3.42)	(-1.61)	(-3.50)	-1.92	-1.83	(-3.24)	(-3.50)
Family size	0.109	-0.663	0.210	-0.0186	0.238	0.0791	0.0919	-0.141	0.128	0.079
	-1.49	(-3.77)	-2.23	(-0.19)	-3.95	-1.21	-1.23	(-2.25)	-2.19	-1.24
Education	0.0328	0.712**	0.0154	0.437**	0.0163	-0.00505	0.0111	0.139**	0.125**	0.0866
	(0.61)	-2.62	-021	-2.99	-0.46	(-0.12)	-0.21	(-3.25)	-2.91	-0.92
Farm income	0.00003	0.00068*	0.00019*	0.002***	0.00004	0.0002***	0.0002***	-2.7E-05	-0.0001*	-0.00003
	-1.08	-2.07	-2.5	-4.8	-1.94	-4.03	-5.52	(-1.19)	(-2.24)	(-0.74)
Non-farm income	-0.0001*	0.0002	-0.0002***	-0.001*	-0.0001**	0.0001*	-0.0002***	1.31E-05	2.61E-05	0.0040*
	(-2.33)	-1.56	(-4.32)	(-2.48)	(-2.61)	-2.33	(-3.68)	-0.47	-1.05	-2.33
Farm size	0.832***	1.820***	0.546**	3.320***	0.443***	0.655***	0.989***	0.669***	0.266**	0.65***
	-4.84	-3.8	-2.99	-4.79	-4.46	-5.18	-8.05	-5.24	-2.8	-5.18
TLU	0.651	0.879	0.891	0.622	1.582	0.111**	0.514	0.712	1.022	-0.13**
	-0.49	-0.69	-0.57	-0.41	-1.71	-2.81	-0.39	-0.41	-1.71	(-1.01)
Environmental Factors										
Soil fertility	0.00977	-1.328	0.0067	0.598	-0.336	-0.338	0.596	0.0501	1.294***	-0.338
	-0.02	(-1.81)	-0.048	-0.69	(-0.88)	(-0.85)	-1.36	-0.12	-3.35	(-0.85)
Farmland distance	-0.03***	-0.00475	0.053***	0.0351**	-0.0130**	-0.000791	-0.0228***	-0.0110*	-0.00168	-0.0008
	(-4.92)	(-0.37)	-3.43	-2.64	(-2.77)	(-0.16)	(-3.38)	(-2.40)	(-0.35)	(-0.16)
Market access	-0.0012	0.00445	-0.00269	0.00562	0.0075***	0.0071***	0.0093***	0.0038*	0.0048*	0.006***
	(-0.92)	-1.03	(-0.89)	-1.81	-4.24	-3.76	-4.22	-2.05	-2.5	-3.68
Institutional Factors										

Credit	0.027	-0.024	-0.504	-0.076	0.024	1.028**	-0.062	0.004	-0.209	1.208*
access	-0.04	1.02	1.42	(-0.08)	-1.63	-0.39	1.38	-1.13	(-0.64)	-1.48
Extension	0.811	0.48	-3.13**	1.024	1.94	1.024	-2.95***	0.24	0.019	0.116*
services	-1.29	-0.51	(-3.25)	-1.61	-0.01	-1.61	(-2.87)	-0.36	-0.03	-1.01
Agricultural	-0.0945	-0.306	-1.083	-1.208*	1.901	-1.208*	1.497*	-0.136	0.688	0.042**
training	(-0.17)	(-0.37)	(-1.21)	(-2.00)	(-0.01)	(-2.00)	-2.87	(-0.23)	-1.1	-1.92
_cons-	2.037*	6.130***	0.922	-0.691	-1.422	1.425	-5.388***	0.255	-2.357**	1.425
	-2.28	-3.32	-1.23	(-0.54)	(-1.88)	-1.76	(-5.35)	-0.34	(-2.90)	-1.76
N	402	402	402	402	402	402	402	402	402	402

****, **, * significant level (at 1%, 5% and 10%, respectively, TP= Tree planting, SWC = Soil & water conservation, AF = Agroforestry, ICV = Improved crop management, SPD = Shifting planting dates, CD = Crop diversity, DRC = Drought-resistant crop, LA = Livestock adjustment, SSI = Small-scale irrigation, FA= Fertilizer application.*

Annex 2 Crop diversification for improving food security of coffee-based rural households in Gimbi district, western Ethiopia. Questions for constructing Households Dietary Diversity Score (HDDS)

No	Food Groups	Examples	Yes (1)	No (0)
1	Cereals	bread, noodles, biscuits, cookies or any other foods made from millet, sorghum, maize, rice, wheat like *injera or kita* plus+ *local foods porridge*		
2	Vitamin A rich vegetables and tubers	pumpkin, carrots, squash, or sweet potatoes that are yellow or orange inside + *other locally available vitamin-A rich vegetables*		
3	White tubers and roots	White potatoes, white yams, or foods made from roots.		
4	Dark green leafy vegetables	sweet pepper, dark green/leafy vegetables, cabbages including wild ones +		
5	Other vegetables	other vegetables, including wild vegetables		
6	Vitamin A rich fruits	ripe mangoes, papayas, Bananas or *other locally available vitamin A- rich*		
7	Other fruits	other fruits, including wild fruits		
8	Meat	beef, lamb, goat, wild game, chicken, or		
9	Eggs	Chicken egg or wild		
10	Fish	fresh or dried fish or shellfish		
11	Legumes, nuts & Seeds	beans, peas, lentils, nuts, seeds or foods made from these		
12	Milk and milk Products	milk, cheese, yogurt or other milk products		
13	Oils and fats	milk, cheese, yogurt or butter other milk products		
14	Sweets	sugar, honey, sweetened soda or sugary foods such as chocolates, sweets or		
15	Spices and caffeine or alcoholic beverages	Spices, coffee, tea, alcoholic beverages or *local beverages like tela etc...*		
Did you or anyone in your household eat anything (meal or snack) OUTSIDE of the Home yesterday?			Yes(1)	No(0)

Annex 3 Tree parameters along altitudinal gradients

Table A1. Plant species recorded from coffee-based agroforestry system of the study area, Gimbi District, western Ethiopia

S/N	Scientific Name	Family	Local Name	Habitat
1	*Acacia lahai* (Steud. & Hochst. ex Benth.) Kyal. & Boatwr	Fabaceae	Laaftoo	Tree
2	*Albizia gummifera* (J.F.Gmel.) C.A.Sm	Fabaceae	Muka Arbaa	Tree
3	*Bersama abyssinica* Fresen.	Melianthaceae	Lolchiisaa	Tree
4	*Buddleia polystachya* Fresen.	Loganiaceae	Qawwisa	Shrub or Small Tree
5	*Celtis africana* Burm.	Ulmaceae	Cayii	Tree
6	*Combretum molle* R. Br. ex G. Don.	Combretaceae	Dhandhansa	Tree
7	*Cordia africana* Lam.	Boraginaceae	Waddeessa	Tree
8	*Croton macrostachyus* Hochst. ex Delile	Euphorbiaceae	Bakkaniisa	Tree
9	*Ehretia cymosa* Thonn.	Boraginaceae	Ulaagaa	Shrub or Tree
10	*Entada abyssinica* Steud. ex A. Rich.	Fabaceae	Ambaltaa	Tree
11	*Erythrina abyssinica* Lam. ex DC.	Fabaceae	Waleensuu	Tree
12	*Erythrina brucei* Schweinf.	Fabaceae	Waleensuu	Tree
13	*Fagaropsis angolensis* (Engl.) Dale	Rutaceae	Mukee	Tree
14	*Ficus thonningii* Blume	Moraceae	Dambii	Shrub or Tree
15	*Ficus vasta* Forssk	Moraceae	Qilxuu	Tree
16	*Gardenia volkensii* K. Schum. subsp. volkensii var. volkensii	Rubiaceae	Gambeelloo	Small tree or Shrub
17	*Grewia bicolor* Juss.	Tiliaceae	Arooressa	Shrub or Tree
18	*Hypericum revolutum* Vohl	Hypericaceae	Muka Foonii	Shrub or Tree
19	*Juniperus procera* Hochst. ex Endl.	Cupressaceae	Gaattiraa	Tree

20	*Maesa lanceolata* Forssk.	Myrsinaceae	Abbayyii	Shrub or Tree
21	*Maytenus arbutifolia* (A. Rich.) Wilczek	Celastraceae	Kombolcha	Usually shrub or small tree
22	*Millettia ferruginea* (Hochst.) Bak.	Fabaceae	Sootalloo	Tree
23	*Oncoba spinosa* Forssk.	Flacourtiaceae	Akuukkuu	Shrub or small tree
24	*Piliostigma thonningii* (Schumach.) Milne-Redh.	Fabaceae	Liilluu	Tree/occasionally climbing
25	*Podocarpus falcatus* (Thunb.) Mirb.	Podocarpaceae	Birbirsa	Tree
26	*Premna schimperi* Engl.	Verbenaceae	Urgeessaa	Shrub or Tree
27	*Prunus Africana* (Hook.f.) Kalkm.	Rosaceae	Hoomii	Tree
28	*Sapium ellipticum* (Krauss) Pax	Euphorbiaceae	Bosoqa	Tree
29	*Stereospermum kunthianum* Cham.	Bignoniaceae	Botoroo	Tree
30	*Strychnos spinosa* Lam.	Loganiaceae	Baddeessaa	Tree
31	*Syzygium guineense* (Wild.) DC.	Myrtaceae	Goosuu	Tree
32	*Terminalia laxiflora* Engl. & Diels.	Combretaceae	Dabaqqaa	Tree
33	*Trichilia dregeana* Sond.	Meliaceae	Diimoo/Koonuu	Tree
34	*Vernonia amygdalina* Del.	Asteraceae	Eebicha	Shrub/sometimes tree

Table A2. Value for the different phytosociological parameters measured for different tree species of Coffee-based Agroforestry System in 1451-1650 m.a.s.l. altitudinal range

No	Scientific name	Family	Local Name	F	D	BA	RF	RD	RBA	IVI
1	*Albizia gummifera*	Fabaceae	Muka Arbaa	65	7.20	46.76	14.44	14.71	20.79	49.95
2	*Terminalia laxiflora*	Combretaceae	Dabaqqaa	40	7.00	27.76	8.89	14.30	12.35	35.54
3	*Combretum molle*	Combretaceae	Dhandhansa	35	5.60	19.73	7.78	11.44	8.77	27.99
4	*Croton macrostachyus*	Euphorbiaceae	Bakkaniisa	50	3.60	18.81	11.11	7.35	8.36	26.83
5	*Maesa lanceolata*	Myrsinaceae	Abbayyii	30	4.00	13.80	6.67	8.17	6.14	20.97
6	*Ficus vasta*	Moraceae	Qilxuu	15	1.60	11.21	3.33	3.27	4.98	11.59
7	*Vernonia amygdalina*	Asteraceae	Eebicha	25	1.60	2.61	5.56	3.27	1.16	9.98
8	*Ehretia cymosa*	Boraginaceae	Ulaagaa	10	2.40	4.07	2.22	4.90	1.81	8.93
9	*Acacia lahai*	Fabaceae	Laaftoo	15	1.00	7.70	3.33	2.04	3.42	8.80
10	*Syzygium guineense*	Myrtaceae	Goosuu	10	1.30	8.56	2.22	2.66	3.81	8.69
11	*Piliostigma thonningii*	Fabaceae	Liilluu	10	0.80	9.73	2.22	1.63	4.33	8.18
12	*Premna schimperi*	Verbenaceae	Urgeessaa	15	1.60	3.15	3.33	3.27	1.40	8.00
13	*Millettia ferruginea*	Fabaceae	Sootalloo	15	1.00	5.81	3.33	2.04	2.58	7.96
14	*Ficus thonningii*	Moraceae	Dambii	10	0.90	8.71	2.22	1.84	3.87	7.93
15	*Strychnos spinosa*	Loganiaceae	Baddeessaa	5	1.00	9.85	1.11	2.04	4.38	7.54
16	*Grewia bicolor*	Tiliaceae	Arooressa	5	1.60	4.33	1.11	3.27	1.92	6.30
17	*Buddleia polystachya*	Loganiaceae	Qawwisa	10	0.95	3.81	2.22	1.94	1.69	5.86
18	*Cordia africana*	Boraginaceae	Waddeessa	10	0.55	4.88	2.22	1.12	2.17	5.52
19	*Gardenia volkensii*	Rubiaceae	Gambeelloo	15	0.80	1.21	3.33	1.63	0.54	5.50
20	*Stereospermum kunthianum*	Bignoniaceae	Botoroo	15	0.60	1.56	3.33	1.23	0.69	5.25
21	*Trichilia dregeana*	Meliaceae	Diimoo	10	0.90	2.15	2.22	1.84	0.96	5.02
22	*Bersama abyssinica*	Melianthaceae	Lolchiisaa	15	0.70	0.41	3.33	1.43	0.18	4.95
23	*Sapium ellipticum*	Euphorbiaceae	Bosoqa	5	0.40	4.12	1.11	0.82	1.83	3.76
24	*Erythrina brucei*	Fabaceae	Waleensuu	5	0.70	2.64	1.11	1.43	1.17	3.72
25	*Celtis Africana*	Ulmaceae	Cayii/Amalaqa	5	0.60	1.06	1.11	1.23	0.47	2.81
26	*Hypericum revolutum*	Hypericaceae	Muka Foonii	5	0.55	0.46	1.11	1.12	0.20	2.44
							100.00	100.00	100.00	300.00

F= Frequency, D= Density, A= Abundance, RF= Relative Frequency, RD=Relative Density, BA= Basal Area, RBA= Relative Basal Area, IVI= Importance Value Index

Table A3. Value for the different phytosociological parameters measured for different tree species of Coffee Based Agroforestry System in 1651-1850 m.a.s.l. altitudinal range

No	Species	Family	Local Name	F	D	BA	RF	RD	RBA	IVI
1	*Albizia gummifera*	Fabaceae	Muka Arbaa	75	9.6	44.20	14.85	18.20	19.22	52.27
2	*Terminalia laxiflora*	Combretaceae	Dabaqqaa	35	7.6	40.01	6.93	14.41	17.39	38.73
3	*Croton macrostachyus*	Euphorbiaceae	Bakkaniisa	50	4	18.99	9.90	7.49	8.26	25.60
4	*Combretum molle*	Combretaceae	Dhandhansa	35	4.6	15.08	6.93	8.72	6.56	22.21
5	*Maesa lanceolata*	Myrsinaceae	Abbayyii	30	3.2	6.67	5.94	6.07	2.90	14.91
6	*Vernonia amygdalina*	Asteraceae	Eebicha	30	2.4	4.31	5.94	4.55	1.88	12.37
7	*Syzygium guineense*	Myrtaceae	Goosuu	20	1.7	11.20	3.96	3.22	4.87	12.05
8	*Ficus thonningii*	Moraceae	Dambii	20	1.7	11.03	3.96	3.13	4.80	11.89
9	*Millettia ferruginea*	Fabaceae	Sootalloo	25	1.8	7.73	4.95	3.41	3.36	11.73
10	*Ficus vasta*	Moraceae	Qilxuu	15	1.2	11.07	2.97	2.27	4.80	10.06
11	*Ehretia cymosa*	Boraginaceae	Ulaagaa	15	2.4	4.82	2.97	4.55	2.10	9.62
12	*Strychnos spinosa*	Loganiaceae	Baddeessaa	10	1	9.85	1.98	1.90	4.28	8.16
13	*Acacia lahai*	Fabaceae	Laaftoo	15	1.1	6.32	2.97	2.09	2.75	7.81
14	*Cordia africana*	Boraginaceae	Waddeessa	10	1.1	6.48	1.98	1.99	2.82	6.79
15	*Premna schimperi*	Verbenaceae	Urgeessaa	15	1.6	1.52	2.97	3.03	0.66	6.66
16	*Fagaropsis angolensis*	Rutaceae	Mukee	5	0.8	9.29	0.99	1.52	4.04	6.55
17	*Stereospermum kunthianum*	Bignoniaceae	Botoroo	15	0.6	3.32	2.97	1.14	1.40	5.55
18	*Grewia bicolor*	Tiliaceae	Arooressa	5	1.5	3.88	0.99	2.75	1.69	5.42
19	*Gardenia volkensii*	Rubiaceae	Gambeelloo	10	1.4	1.52	1.98	2.56	0.66	5.20
20	*Bersama abyssinica*	Melianthaceae	Lolchiisaa	15	0.6	0.47	2.97	1.14	0.20	4.31
21	*Piliostigma thonningii*	Fabaceae	Liilluu	5	0.5	5.47	0.99	0.85	2.38	4.22
22	*Celtis Africana*	Ulmaceae	Cayii/Amalaqa	10	0.5	0.71	1.98	0.95	0.31	3.24
23	*Buddleia polystachya*	Loganiaceae	Qawwisa	10	0.4	0.88	1.98	0.66	0.38	3.03
24	*Trichilia dregeana*	Meliaceae	Diimoo	10	0.4	0.84	1.98	0.66	0.36	3.01
25	*Entada abyssinica*	Fabaceae	Ambaltaa	5	0.4	1.90	0.99	0.76	0.83	2.57
26	*Sapium ellipticum*	Euphorbiaceae	Bosoqa	5	0.4	1.43	0.99	0.66	0.62	2.28
27	*Hypericum revolutum*	Hypericaceae	Muka Foonii	5	0.5	0.42	0.99	0.95	0.18	2.12
28	*Erythrinas abyssinica*	Fabaceae	Waleensuu	5	0.2	0.69	0.99	0.38	0.30	1.67
							100.00	100.00	100.00	300.00

F= Frequency, D= Density, A= Abundance, RF= Relative Frequency, RD=Relative Density, BA= Basal Area, RBA= Relative Basal Area, IVI= Importance Value Index

Table A4. Value for the different phytosociological parameters measured for different tree species of Coffee Based Agroforestry System in 1851-2050 m.a.s.l. altitudinal range

No	Species	Family	Local name	F	D	BA	RF	RD	RBA	IVI
1	*Sapium ellipticum*	Euphorbiaceae	Bosoqa	40	6.35	59.23	7.48	12.7	27.98	48.15
2	*Croton macrostachyus*	Euphorbiaceae	Bakkaniisa	70	5.975	25.21	13.08	11.95	11.91	36.94
3	*Celtis Africana*	Ulmaceae	Cayii/Amalaqa	60	4.345	21.48	11.21	8.69	10.15	30.05
4	*Premna schimperi*	Verbenaceae	Urgeessaa	50	5.39	17.2	9.35	10.78	8.12	28.25
5	*Strychnos spinosa*	Loganiaceae	Baddeessaa	35	6.64	15.55	6.54	13.28	7.35	27.17
6	*Oncoba spinosa*	Flacourtiaceae	Akuukkuu	65	5.68	1.04	12.15	11.36	0.49	24
7	*Cordia africana*	Boraginaceae	Waddeessa	30	3.01	24.39	5.61	6.02	11.52	23.14
8	*Syzygium guineense*	Myrtaceae	Goosuu	35	3.175	13.48	6.54	6.35	6.37	19.26
9	*Bersama abyssinica*	Melianthaceae	Lolchiisaa	50	2.715	5.21	9.35	5.43	2.46	17.24
10	*Albizia gummifera*	Fabaceae	Muka Arbaa	40	1.965	12.29	7.48	3.93	5.8	17.21
11	*Juniperus procera*	Cupressaceae	Gaattiraa	10	2.965	7.45	1.87	5.93	3.52	11.32
12	*Embelia schimperi*	Myrsinaceae	Hanquu	10	0.46	2.81	1.87	0.92	1.33	4.11
13	*Prunus Africana*	Rosaceae	Hoomii	10	0.335	2.7	1.87	0.67	1.27	3.81
14	*Ekebergia capensis*	Meliaceae	Somboo	10	0.335	2.22	1.87	0.67	1.05	3.59
15	*Podocarpus falcatus*	Podocarpaceae	Birbirsa	10	0.375	1.25	1.87	0.75	0.59	3.21
16	*Maytenus arbutifolia*	Celastraceae	Kombolcha	10	0.29	0.22	1.87	0.58	0.1	2.56
							100	100	100	300

F= Frequency, D= Density, A= Abundance, RF= Relative Frequency, RD=Relative Density, BA= Basal Area, RBA= Relative Basal Area, IVI= Importance Value Index

Annex 4 Survey Questionnaire

This questionnaire is prepared to collect data for the research proposal entitled "The contribution of coffee based agroforestry for biodiversity and climate change mitigation in Western Ethiopia" in partial fulfillment for PhD in Environment and Development. The objective of this study is to assess smallholder coffee farmers' perceptions on trends of climate change and identify the coping strategies that the farmers use to adapt to climate change. Confidently this research has a significant contribution in an effort to reduce the climate change relate problems of the farmers of this area. Therefore, your valid contribution by giving accurate information is highly valuable in achieving the objective of this research. The information we collect from you will serve only the academic purpose and it will be kept confidential. Therefore, please feel free to convey the required information honestly.

Thank you in advance for your cooperation.

General Directions

Put (x) marks in space provided for closed-ended questions and write your response on space provided for open ended questions.

Part I. Supportive Information

i. Name of interviewer: _____ Code: _____

ii. Date: _____/_____/_____. Time spent for interview: From: _____ to _____

iii. Name of respondent: _____ ID.code: _____

iv. Name of Kebele: _____

v. Agro-ecological Zone: Kola: Woina-dega: Dega:

Part II. Questions on Household Head Demographic Characteristics

1. Gender of the household head: Male: Female:

2. Age of the household head (in years): _____

3. Marital status: a) Married: b) Single; c) divorced: d) widowed: e) Other (specify)_____

4. Educational level of household head: Illiterate: Literate:

5. The highest level of formal education completed, if the household head is literate: _____

6. Number of total family members: Male: _____ Female: _____

7. Number of active household members aged between 15-64 years, Male: ____ Female:___

8. Farm experience of household head: _____

Part III. Questions on Household Head Socio-economic Characteristics

9. Farming system you follow currently

i. Coffee crop production only iii. Mixed farming

ii. Livestock rearing only iv. Others (please specify).....

10. How much income can you generate from your farming activities during last production year (i.e., 2010 E.C.?) Please specify in Birr:

I. From coffee production..... III. Selling of fruits and vegetables....

II. From selling livestock and livestock products IV. Others (please specify).....

11. Do you/any members of your family has any sources of non-farm income i.e. income from remittance, petty trade, employment in government or private enterprise, etc.? Yes: No:

12. If yes to the above question, how much money you/your family make during last production year from off-farm activity? Please specify in Birr: .....

13. How much is your total expenditure during last production year? Please specify in Birr: .....

14. Total farm land operated including any grazing land (including rented land and excluding rented out land) during last production year (in hectares)_____

Size of land rented in _____ Size of land rented out_____

15. Do you have certificate for your land? Yes: No:

16. What are the physical characteristics of your farm, in terms of its exposure to erosion?

Susceptible to erosion: Moderately susceptible to erosion:

Not susceptible at all:

17. How is the fertility of the soil of your farm in general?

Very fertile..... Moderate..... Poor/ infertile

If you have more than one plot, answer the following questions

a. plot 1: (a) Highly fertile ___ (b) Fertile ____ (c) medium____ (d) low ____

b. Plot 2: a) Highly fertile ____(b) Fertile ____ (c) medium ____ (d) low____

c. Plot 3: a) Highly fertile ____ (b) Fertile ____ (c) medium ____(d) low ____

18. How long does it take to reach your farm from your home? In case you have more than one plots take its average distance and/or time. (Specify one way only):

Distance (in KM)..... In terms of time it takes (in min).....

19. How many quintals of yield have you harvested per hectare in 2010 E. C

Coffee..... Maize..... Wheat..... Teff.....

Barley..... Bean/pea..... Others (specify if any).....

20. Do you have any communication devices like TV, radio, mobile phone, so on?

Yes: No:

21. If your answer for question 20 is "Yes" what types of communication devices you have?

TV: Mobile: Phone: Radio others specify.....

Part IV. Questions on Institutional Factors

22. How far the market where you buy your agricultural inputs is (e.g. seeds, fertilizers, pesticides, insecticides, etc)?

Distance in KM.....…… In terms of time it takes (in hour).....

23. How far is the market where you sell your agricultural outputs?

Distance in KM..... In terms of time it takes (in hour).....

24. In undertaking your usual farming activities have ever faced shortage of finance? For example to purchase agricultural inputs like fertilizer, oxen, and others. Yes: No:

25. Do you have access to any formal credits (DCSI) in time face shortage of money? Yes: No:

26. Do you have access to any informal credits (from neighbors, friends, relatives etc.)? Yes: No:

27. If yes to '25 &26' where you look for credit to fill your financial constraints? More than one choice is possible. From: Relatives: Friends: Non-formal money lenders: Microfinance Institutes:

28. Do you have access to agricultural extension services in your kebele?

Yes: No:

29. Do you receive any support from agricultural extension which could help improve your farming activities?

Yes: No: If, yes mention them ……

30. Have you ever got any kind of formal training which helps improve your farm productivity? This might be how to (protect soil from erosion, conserve rain water, use modern agricultural inputs, reduce post harvest loss, etc)

Yes: No:

31. Did you have non-formal training of the above kind from farmers or did you give training to other farmers in your locality? (Farmers-to-farmers extension services).

Yes: No:

32. If yes to '30 & 31' how do you find it in terms of its contribution to improve your farming income?

Very important: important: Has no effect:

Part V. Climate Change Perception Assessment and Adaptation Methods Employed

33. Is today's weather the same as the weather conditions that were 30 years from now?

Yes: No:

34. If Q 33 is No, what are the major indicators?

Climatic variable	***Yes***	***No***
Rainfall amount has increased		Poor distribution of rainfall
Rainfall amount has decreased		Frequent high volume flood
Rainfall amount is the same		High temperature
Early onset of rainfall		Strong wind
Late onset of rainfal		Other
Early cessation of rainfall		

35. How do you evaluate the trend of the climatic variables change over the last ten years?

1. The change has become severe 2. Slow change

3. No visible difference has been observed 4. No change at all

36. What problems have you faced due to climatic variability? Mention them;

37. Which local indicators do you use to evaluate the temperature trend in the area? (Please support your choice with example)

i. Prevalence of human and animal diseases that are not familiar to the area (malaria etc).

ii. Introduction of plant and animal species that were not popular in the area (goat in highland not common).

iii. Observation of physical structures and societal clothing styles (frost damage become uncommon, drying up of rivers streams, swampy areas, lakes, dressing light cloths etc.).

iv. Other specify …….

38. What do you say about the trend of rainfall over the last 30 years?

i. Increased

ii. Not changed

iii. Decreased

iv. Change in times of raining

v. Increase in frequency of drought 6. I don't know 7. Other (specify)……..

39. What are the local coping mechanisms used to reduce current climate impact and adapt to the future climate change? Specify ……

40. Do you think that coffee based agroforestry is better than other coping mechanisms?

Yes: No:

41. If the answer for question 40 is yes, what makes it better compared to the other ones? Specify ……

42. Do you think that coffee production is affected due to climate change? Yes: No:

Part VI. Livestock Ownership and related information

45. How do you make your living?

A. Cattle rearing D. Off-farm activities

B. Crop production E. Other specify _____

C. Mixed farming

46. What type of agriculture do you practice?

A. Rain-fed C. Mixed rain-fed and irrigated

B. Irrigated D. Others_____

47. In which category do you classify your soil?

A. Highly Infertile D. Fertile

B. Poorly Fertile E. Highly fertile

C. Moderately fertile

48. Do you apply fertilizer in your farm?

A. Yes

B. No

49. If yes, what kind of fertilizer

A. Compost

B. Artificial fertilizer

C. Others specify_____

50. What is your main source of income?

A. Agriculture B. Off- farm C. Both

51. Do you have kinships or people that you rely on for adaptation to get information and support from?

A. Yes B. No

52. Type and number of livestock do you own? (TLU)

Cattle Heifer Calf Donkey Sheep Goat

Part VII. Assessment of adaptation options and barriers

53. When negatively affected by adverse climatic condition, which of the following adaptation strategies do you pursue in order to reduce the impact?

53.1. Improved crop varieties A. Yes B. No

53.2. Soil and water conservation A. Yes B. No

53.3. Planting tree A. Yes B. No

53.4. Shifting planting date A. Yes B. No

53.5. Crop diversification A. Yes B. No

53.6. Planting drought resistant crops A. Yes B. No

53.7. Use of small scale irrigation A. Yes B. No

53.8. Use of fertilizer A. Yes B. No

53.9. Off-farm activities A. Yes B. No

53.10. Adjust livestock management A. Yes B. No

54. What are the constraints of adaptation strategy you face?

A. Market problem

B. Lack of knowledge

C. Lack of metrological information

D. Lack of agricultural technologies and input

E. Lack of knowledge

F. Feed and Forage scarcity

G. Other, specify_____

55. What do you suggest for the future on climate change adaptation strategy (which you wish personally and better for community)?

Annex 3.3 Assessing smallholder coffee farmers' perceptions on trends of climate change and the coping strategies that the farmers use to adapt to climate change.

Focus Group Discussion

March 2020

Executive summary

This report summarizes the key findings of the focus group discussion conducted in six kebeles of Gimbi district, western Ethiopia. The discussion involved six focus group, one from each respective kebele. The objective of this study is to assess smallholder coffee farmers' perceptions of trends in climate change and identify the coping strategies that the farmers use to adapt to the change. The discussions revealed that smallholder farmers have perceived the presence of climate change in their

area. The way they were perceived slightly varied among the participants. They also stated the impact of climate change on agricultural production, forests, soil fertility, rivers, and humans. In order to survive, they use different specific and local adaptation strategies. Among the adopted strategies, crop management, intensive farm management, and soil and water management are the most common. As a result, the discussions provided valuable insight into the underlying fears of climate change, as well as how to better adapt to the changing climate using more reliable and sustainable strategies.

1. Introduction

The Addis Ababa University, College of Development Studies, has proposed a study area for assessing climate change perception and adaptation strategies of coffee smallholder farmers to the changing climate. Accordingly, the study was conducted in the Gimbi district of western Ethiopia. For the purpose of the study, focus group discussion was used for the qualitative study. Members of the focus group were chosen with the assistance of local leaders based on a variety of criteria. Some of the criteria used were length of farming experience, level of knowledge about the village, and ability to retrieve and express long-term stories about the study area.

2. Objective

Focus group discussions (FGD) were conducted to (1) assess smallholder coffee farmers' understanding and coping strategies in response to climate change and (2) investigate the determinants of smallholder coffee farmers' strategy adoption in Western Ethiopia.

3. Methodology

The researcher obtained a support letter from Addis Ababa University. The letter was submitted to the West Wollega Zone Administration Office, and consent was obtained. The zonal administration office then wrote an official letter to the Gimbi District Environmental Protection Office. The researcher presented the objectives of the study to the district's Environmental Protection Office, and consent was obtained. Based on the consent, different experts, like those from Environmental Protection, the Agricultural Office, and Oromia Forest and Wildlife Enterprise, were assigned to support the study in the process. The experts have played their role in providing primary and secondary data to the researcher.

In the district, the area is classified as lowlands, midlands, and highlands based on the altitudinal gradients set by the district’s agroecological experts to help coffee producers get specific crop types for cultivation. Developmental agents were assigned to each kebele in the district to support the farmers. The farmers could get all necessary information about their ecology beyond what they already knew through their experiences. The agro-ecologies of each kebele were identified and

classified in the district. Consequently, among the 32 kebeles of the district, six kebeles were selected as representatives of the three agro-ecological zones. The six kebeles were Aba Sena and Enango Dembel from the lowlands; Choli Mikael and Melka Gasi from the midlands; and Bikiltu Tokuma and Lelisa Yesus from the highlands.

The assessment of the socioeconomic and environmental situation of the respective kebele was completed with the help of focus group discussions with the smallholder coffee farmers. During the group discussions, farmers were encouraged to share information regarding their farming experiences, like types of cultivated crops, production shifts, soil fertility, rainfall conditions, prevalence of diseases, other economic activities, income, community perceptions of climate change, and how they adapt to the changing climate. Information was also collected on the types of climate adaptation strategies.

The FGDs were conducted in each kebele according to their agro-ecological zones. Each FGD was composed of 12 members, with 33 percent female participation. The questionnaire for the FGD included questions on demography, farming experiences (like types of cultivated crops, production shift, soil fertility, rainfall condition, and prevalence of diseases), other economic activities, income (farm and non-farm), community perceptions of climate change, and how they adapt to the changing climate. The questionnaire was written in English but was translated into the local language (Afan Oromo) during the conversations.

Smallholder farmers were selected based on the following criteria.

1. Accessibility of farmers' villages in the kebeles
2. Geographical location to represent the three agroecological zones
3. Farm experiences, including types of animals and crops produced and farming systems
4. Interactions between district administration, environmental protection, agricultural, and Oromia forest and wildlife enterprise.
5. Interaction with coffee unions in the district.

4. Discussion Themes

Each focus group discussion was carried out within 2:30-3:00 hours. The first 30 minutes are allocated for briefing the agenda and setting discussion rules. The remaining time was allotted for the group discussions.

Theme

To structure the discussion, we have classified the agenda into three basic discussion themes. The facilitator guides the discussion and keeps time but respects the right of participants to speak freely about what they feel.

S/N Themes

Time allotted

1. Introduce the agenda, facilitators, participants and purpose of the focus group discussion= 30

2. Theme 1: Farm characterization and its trend analysis =40 minutes

2.1. Identify farm characteristics like types of cultivated crops and their productivity in the last two decades, in relation to seasonal changes.

3. Theme 2: Perceptions on climate change and adaptation strategies to adapt to the change 40 minutes

3.1. Understanding of presence of climate change and experience based knowledge of farmers.

3.2. Sources of information for climate change perceptions

3.3. Strategies communities use to manage risks of climate change related calamities

4. Theme 4: Limiting factors to climate change adaptation strategies 40 minutes

4.1. List of factors affecting adaptation strategies to the change

4.2. Prioritize those limiting factors

5. Closing session

Theme 1: Farm characterization and its trend analysis

We use list of farming systems used by the community in the area.

1. List of farming system
   I. Coffee crop production
   II. Livestock rearing
   III. Mixed farming

2. List the crops and compare their types and productivity with those that were produced two decades ago (decrease, increase)

i. Major crops planted in long rain season
ii. Major crops planted in short rain season
iii. Unseasonal crops(it can be planted at any time)
iv. Major perennial crops
v. Major vegetable crops
vi. Major fruits crops
vii. Major cash crops

3. Mode of crop production

i. Rain-fed
ii. Irrigation

4. Impact of agricultural expansion on environment

i. Forest cover (decrease, increase)
ii. Biodiversity (decrease, increase)
iii. Soil fertility (decrease, increase)
iv. Fertilizer application (decrease, increase)

Theme 2: Perceptions on climate change and adaptation strategies to adapt to the change

We use lists of elements related to perceptions and adaptation strategies as well as word descriptions of the elements to indicate the prevailing situation surrounding them.

5. Mention crop production season and compare them with those that were used to produce crops two decades ago.

i. Rainy season (onset, offset time)
ii. Amount of rainfall (decrease, increase)

6. Compare the current temperature with those times 20 years ago.

i. Temperature decrease
ii. Temperature increase

7. List farm related problems of climate events

i. Droughts
ii. Disasters and cyclones
iii. Floods
iv. Pests and diseases

8. Sources of information for climate change

i. Own experience
ii. From development agent
iii. From other farmers
iv. From radio and TV
v. Meeting

9. List of adaptation strategies to the changing climate

i. Planting trees
ii. Practicing agroforestry management
iii. Shifting planting dates
iv. Soil and water conservation
v. Using drought-resistant crops
vi. Using improved crop varieties
vii. Crop diversification
viii. Small-scale irrigation
ix. Fertilizer application
x. Livestock adjustment

Theme 3: Limiting factors on the perceptions and adaptation strategies

We use a list of factors chosen by farmers as aspects determining choices for adopting climate-change coping strategies. The listing included socioeconomic and environmental factors listed below.

i. Age
ii. Sex
iii. Education
iv. Marital status
v. Family size
vi. Land size
vii. Income
viii. TLU (Tropical Livestock Unit)

ix. Market distance
x. Agricultural training
xi. Soil fertility status
xii. Credit access

The discussion was guided around the agricultural characterization, perceptions, and adaptation strategies of farmers and the limiting factors for adopting coping measures for climate change. The discussion guide served as a template for the focus group session, allowing the conversation time to be managed according to the plan.

Thematic analysis

This section presents the findings from the focus group interviews in the form of a summary of what the respondents said in response to specific questions. The information in this section represents the researches' interpretation based on notes made during the focus group discussions and a content analysis of the typed transcripts.

Theme 1: Farm characterization

Theme 2: Perceptions on climate change and adaptation strategies

Theme 3: Limiting factors on the perceptions and adaptation strategies

Outcomes of focus group discussions (FGDs)

Generally, six FGDs covering the six kebeles were conducted to understand the perceptions of smallholder farmers on climate change and the strategies that they apply to adapt to the changing climate. As a result, 72 people participated in the discussion. During the focus group discussions, the interaction of the farmers with the district administration, the environmental protection authority, the agriculture office, and the forest and wildlife enterprise was taken into consideration. Key stakeholders who participated in the focus group have included kebele administration, agricultural development agents (DA), and knowledgeable coffee farmers.

The result of focus group discussions indicated that the majority of the farmers perceived the existence of climate change and were managing to adapt to the changing climate. However, a few participants did not detect any changes in climatic characteristics. The outcomes of the discussion are presented in the table below.

Focus Group Discussion 1 Name of kebele Aba Sena

Participants Male = 8 Female = 4

Aba Sena kebele is located in the eastern direction of the district, toward the main city of Eastern Wollega, Nekemte. It is approximately 20 kilometers from the Gimbi district. Farmers use a mixed farming system. They produce different types of crops, which mainly include coffee production.

Animal production is also among the main livelihoods in the area. They use both rain-fed and small-irrigation crop production.

- All farmers are dependent on agricultural activities for their livelihoods. During the off-farm season, farmers participate in non-farm activities to support their families and pass on hard conditions when intermittent weather conditions (drought, late onset and early offsetting of rainfall, disease damage, etc.) occur.
- The majority of the farmers perceive that there is climate change, and they think that the change is affecting their livelihoods through its impact on the environment.
- Irrigation systems are used in about 20% of agricultural production. This includes fruit and vegetable production, nursery seedling raising, and corn stack production.
- Due to free grazing, agricultural expansion, and forest cover reduction, biodiversity is declining and erosion is intensifying. Such combined factors are reducing the productivity of the land resources in the area.
- Previously, farmers used forest resources for construction, fuelwood, charcoal-making, medicinal purposes, etc. However, currently, the farmers are under threat due to the reduction of forest cover.
- As adaptation strategies, the farmers are planting trees, practicing agroforestry management, shifting planting dates, practicing soil and water conservation, and using drought-resistant varieties and improved crop types to adapt to the changing climate.

Focus Group Discussion 2 Name of kebele Enango Dembel

Participants Male = 7 Female = 5

Enango Dembel kebele is located in the eastern direction of the district, toward the main city of Eastern Wollega, Nekemte. It is located at a distance of about 15 km from Gimbi district. Farmers use a mixed farming system. They produce different types of crops, which mainly include coffee production. Animal production is also among the main livelihoods in the area. They use both, mainly rain-fed and less-irrigated types of crop production.

- All farmers are dependent on agricultural activities for their livelihoods. During the off-farm period, they participate in non-farm activities to support their families and pass on hard conditions when intermittent weather conditions (drought, late onset and early offsetting of rainfall, disease damage, etc.) occur.
- The majority of the farmers perceive that there is climate change, and they think that the change is affecting their livelihoods through its impact on the environment.

- About 20% of agricultural production is conducted under irrigation systems. This includes fruit and vegetable production, nursery seedling raising, and corn stack production.
- Irrigation systems are used in about 20% of agricultural production. This includes fruit and vegetable production, nursery seedling raising, and corn stack production.
- Due to free grazing, agricultural expansion, and forest cover reduction, biodiversity is declining and erosion is intensifying. Such combined factors are reducing the productivity of the land resources in the area.
- Previously, farmers used forest resources for construction, fuelwood, charcoal-making, medicinal purposes, etc. However, currently, the farmers are under threat due to the reduction of forest cover.
- As adaptation strategies, the farmers are planting trees, practicing agroforestry management, shifting planting dates, practicing soil and water conservation, and using drought-resistant varieties and improved crop types to adapt to the changing climate.

Focus Group Discussion 3

Name of kebele Choli Mikael

Participants Male = 9 Female = 3

Choli Mikael kebele is located in the eastern direction of the district, toward the main city of Eastern Wollega, Nekemte. It is located at a distance of about 5 km from Gimbi district. Farmers use a mixed farming system. They produce different types of crops, which mainly include coffee production. Animal production is also among the main livelihoods in the area. They use both, mainly rain-fed and less-irrigated types of crop production.

- All farmers are dependent on agricultural activities for their livelihoods. During the off-farm period, they participate in non-farm activities to support their families and pass on hard conditions when intermittent weather conditions (drought, late onset and early offsetting of rainfall, disease damage, etc.) occur.
- The majority of the farmers perceive that there is climate change, and they think that the change is affecting their livelihoods through its impact on the environment.
- About 25% of agricultural production is conducted under irrigation systems. This includes fruit and vegetable production, nursery seedling raising, and corn stack production.
- Due to free grazing, agricultural expansion, and forest cover reduction, biodiversity is declining and erosion is intensifying. Such combined factors are reducing the productivity of the land resources in the area.

- Previously, farmers used forest resources for construction, fuelwood, charcoal-making, medicinal purposes, etc. However, currently, the farmers are under threat due to the reduction of forest cover.
- As adaptation strategies, the farmers are planting trees, practicing agroforestry management, shifting planting dates, practicing soil and water conservation, and using drought-resistant varieties and improved crop types to adapt to the changing climate.

Focus Group Discussion 4 Name of kebele Melka Gasi

Participants Male = 7 Female = 5

Melka Gasi kebele is located in the eastern direction of the district, toward the main city of Eastern Wollega, Nekemte. It located at a distance of about 4 km from Gimbi district. Farmers use a mixed farming system. They produce different types of crops, which mainly include coffee production. Animal production is also among the main livelihoods in the area. They use both, mainly rain-fed and less-irrigated types of crop production.

- All farmers are dependent on agricultural activities for their livelihoods. During the off-farm period, they participate in non-farm activities to support their families and pass on hard conditions when intermittent weather conditions (drought, late onset and early offsetting of rainfall, disease damage, etc.) occur.
- The majority of the farmers perceive that there is climate change, and they think that the change is affecting their livelihoods through its impact on the environment.
- About 20% of agricultural production is conducted under irrigation systems. This includes fruit and vegetable production, nursery seedling raising, and corn stack production.
- Due to free grazing, agricultural expansion, and forest cover reduction, biodiversity is declining and erosion is intensifying. Such combined factors are reducing the productivity of the land resources in the area.
- Previously, farmers used forest resources for construction, fuelwood, charcoal-making, medicinal purposes, etc. However, currently, the farmers are under threat due to the reduction of forest cover.
- As adaptation strategies, the farmers are planting trees, practicing agroforestry management, shifting planting dates, practicing soil and water conservation, and using drought-resistant varieties and improved crop types to adapt to the changing climate.

Focus Group Discussion 5 Name of kebele Bikiltu Tokuma

Participants Male = 8 Female = 4

Bikiltu Tokuma kebele is located in the eastern direction of the district, toward the main city of Eastern Wollega, Nekemte. It is located at a distance of about 11 km from Gimbi district. Farmers

use a mixed farming system. They produce different types of crops, which mainly include coffee production. Animal production is also among the main livelihoods in the area. They use both, mainly rain-fed and less-irrigated types of crop production.

- All farmers are dependent on agricultural activities for their livelihoods. During the off-farm period, they participate in non-farm activities to support their families and pass on hard conditions when intermittent weather conditions (drought, late onset and early offsetting of rainfall, disease damage, etc.) occur.
- The majority of the farmers perceive that there is climate change, and they think that the change is affecting their livelihoods through its impact on the environment.
- About 10% of agricultural production is conducted under irrigation systems. This includes fruit and vegetable production, nursery seedling raising, and corn stack production.
- Due to free grazing, agricultural expansion, and forest cover reduction, biodiversity is declining and erosion is intensifying. Such combined factors are reducing the productivity of the land resources in the area.
- Previously, farmers used forest resources for construction, fuelwood, charcoal-making, medicinal purposes, etc. However, currently, the farmers are under threat due to the reduction of forest cover.
- As adaptation strategies, the farmers are planting trees, practicing agroforestry management, shifting planting dates, practicing soil and water conservation, and using drought-resistant varieties and improved crop types to adapt to the changing climate.

Focus Group Discussion 6 Name of kebele Lelisa Yesus

Participants Male = 9 Female = 3

- Lelisa Yesus kebele is located in the eastern direction of the district, toward the main city of Eastern Wollega, Nekemte. It is located at a distance of about 9 km from Gimbi district. Farmers use a mixed farming system. They produce different types of crops, which mainly include coffee production. Animal production is also among the main livelihoods in the area. They use both, mainly rain-fed and less-irrigated types of crop production.
- All farmers are dependent on agricultural activities for their livelihoods. During the off-farm period, they participate in non-farm activities to support their families and pass on hard conditions when intermittent weather conditions (drought, late onset and early offsetting of rainfall, disease damage, etc.) occur.
- The majority of the farmers perceive that there is climate change, and they think that the change is affecting their livelihoods through its impact on the environment.

- About 5% of agricultural production is conducted under irrigation systems. This includes fruit and vegetable production, nursery seedling raising, and corn stack production.
- Due to free grazing, agricultural expansion, and forest cover reduction, biodiversity is declining and erosion is intensifying. Such combined factors are reducing the productivity of the land resources in the area.
- Previously, farmers used forest resources for construction, fuelwood, charcoal-making, medicinal purposes, etc. However, currently, the farmers are under threat due to the reduction of forest cover.
- As adaptation strategies, the farmers are planting trees, practicing agroforestry management, shifting planting dates, practicing soil and water conservation, and using drought-resistant varieties and improved crop types to adapt to the changing climate.

5. Main outcomes of the focus group discussions

All of the focus groups held in the six selected kebeles provided information on agricultural practices, farmers' perspectives on climate change, and adaptation plans. Furthermore, it has studied factors that influence farmers' adaptation decisions in response to climate change. The participants universally shared several facts during the discussion, and the most essential facts are stated below.

- Temperatures have risen in all kebeles over the last two decades.
- Rainfall is decreasing in most cases and becoming more unpredictable due to its late onset and early offset characteristics over the last two decades.
- Climate change is attributed to agricultural expansion, which resulted in deforestation, free grazing, which resulted in forest degradation, and the inefficient use of natural resources. As a result, biodiversity and soil fertility have decreased, as has agricultural production, as some crops were unable to withstand the environment's drought and high temperatures.
- The incidence of uncommon diseases, pests, and weeds is increasing, endangering a wide range of crops and animals, including humans.
- Crops grown in the lowlands are migrating to the midlands and highlands. For example, coffee was historically farmed primarily in the lowlands, but production is now moving to the highlands and displacing existing crop varieties.
- Food products are imported at high prices from other sections of the country because of shifting crop types.
- Farmers use different adaptation strategies to adapt to the changing climate. The adaptation strategies include tree planting, shifting planting/sowing dates, using improved crops, using

drought-resistant species, soil and water conservation, small-scale irrigation management, agroforestry practices, and fertilizer application.

- Farmers' adaptation options are limited by determinants such as market distance, access, and soil fertility.
- The discussions give valuable insight into the underlying dreads of climate change impacts and the need to adjust more to the changing climate by using more reliable and sustainable strategies accordingly.

Guide to focus group discussions

Assessing smallholder coffee farmers' perceptions on trends of climate change and the coping strategies that the farmers use to adapt to climate change, in western Ethiopia. The case of Gimbi District.

March 2020

Introduction

The focus group was planned and facilitated discussion among smallholder coffee farmers to obtain perceptions and adaptation strategies to climate change of the area. The discussions were helpful for initial concept exploration, generating creative ideas, testing ideas and determining differences in opinion between various stakeholder groups. Focus groups were often used as a means of triangulation with other data collection methods. Focus groups were relatively inexpensive and the format was flexible, because it allows participants to question each other and to elaborate upon their answers. Guided discussion in focus groups more closely captured the spontaneous give and take of social interaction that goes into opinion formation, which could be missing in a structured interview. The method was relatively simple, allowing participants to readily grasp the process and purpose. When the power differential between the participants and the decision-makers was great enough to discourage frank participation, the focus group provides the security of a peer group.

The researcher gave thorough attention to managing the problems that could arise because of the multiple voices of the participants and the flexibility of the process structure. From experience, it has been observed that sometimes group expression can interfere with individual expression, and the results may reflect group perception. Furthermore, to avoid the reflection of only the views of the most dominant participants, the selection of the group participants and the facilitation were properly conducted.

OVERVIEW

Focus groups consistently comprised 12 participants selected from six kebeles in the Gimbi district. The discussion was relatively included a homogenous participants to reduce inhibitions and facilitate interaction. The moderators were made to pose some open-ended questions to guide the discussion and take notes so that the information could be analyzed after the discussion session. During the discussion, audio and video recordings were not allowed to be made as the area was under command due to security issues in the region at that moment. It was only allowed to take pictures of the participants that were captured by the security body and checked by the district police office. As a result, detailed note-making was properly conducted and used for the qualitative data analysis process.

TASKS

Administrative tasks

• Selecting participants and sending consent letter to them

• Arranging safe public place for discussion and allocating security body/police

• Preparing questions

Guide to Focus Group Discussions

• Notice taking • Analyzing data • Preparing report

FACILITATION

In all discussions, two moderators were assigned to facilitate the focus group. They were assigned based on their experiences in the district and respective kebele. In addition to their experiences, the moderators' mental alertness, free from distraction, skill at listening to others in a group, and ability to listen and think at the same time were considered. Furthermore, to make the discussions effective, their time management skill related to the topic under discussion and information saturation point identification ability was checked. Accordingly, as the topic was nearly narrow, the focus group usually lasted averagely 150 minutes.

PREPARING FOR THE DISCUSSION

QUESTIONING ROUTE

Five sets of questions were created focusing on the topic selected for discussion. These were:

1. How do the participants characterize their farm conditions?
2. How do they compare the productivity of their farm with the previous 20 years?
3. How do they perceive whether climate is changing or not
4. What are the adaptation strategies they use in order to adapt to the changing climate, if they perceive the presence of climate change and;

5. What are the limiting factors that affect the choices of farmers to adapt to the changing climate?

The questions were formulated based on their order, from the more general to the more specific, and topics of greater importance were raised early in the discussion. The questioning route was flexible and adapted to the group's natural conversation process. The questions were clear, relatively short, and used simple wording. The questions were accompanied by sufficient background to minimize assumptions and placed in the appropriate context. The questions were open-ended rather than dichotomous. In addition, the participants were asked for definitions, impressions, examples, their ideas of others' perceptions, and the like. The redundancy of questions was avoided, and instead they were broken down into specific sub-issues to address the required objective without revolving around the bush.

ANALYZING THE DISCUSSION

Once the discussion commenced, the analysis were conducted as follows:

• Listening for inconsistent comments and probing for understanding.

• Listening for vague comments and seeking clarification.

• Considering asking each participant a final preference question.

• Offering a summary of key questions and seeking confirmation.

Themes, hunches, interpretations, and ideas were noted immediately after the focus group discussion. Comparing and contrasting the focus group to other groups as well as transcribing the entire discussion to provide complete notes of the discussion and facilitate analysis of the data were made. They declared that the data from the focus group interviews were group data. They are not the same as individual interview data. They reflected the collective ideas shared and negotiated by the group. Additionally, they were careful about how focus group data could be indicators of larger trends.

Annex 2.45COREQ Statement

Determinants on perception of climate change and adaptation strategies of coffee-based agroforestry farmers in western Ethiopia

Domain 1: Research team and reflexivity

Personal Characteristics

1. Interviewer/facilitator. Which author/s conducted the interview or focus group?

Beshea Abdissa

2. Credentials. What were the researcher's credentials? E.g. PhD, MD.

Beshea Abdissa - PhD student in Evironment and Development

Feyera Senbeta - Professor

Emiru Birhane - Professor

3. Occupation. What was their occupation at the time of the study?

Researcher, and PhD student in Evironment and Development

Researcher and lecturer

Researcher and lecturer

4. Gender. Was the researcher male or female?

All autors are male

5. Experience and training. What experience or training did the researcher have?

Extensive research and training, both qualitative and quantitative methods, for a range of 12-26 years experience..

Relationship with participants

6. Relationship established. Was a relationship established prior to study commencement?

No

7. Participant knowledge of the interviewer. What did the participants know about the researcher? e.g. personal goals, reasons for doing the research?

The personal goals of the researcher were to complete the aims and objectives of the study only. The researcher had no personal goals or reasons for doing the research. As part of recruitment and gaining informed consent participants were fully informed about the aims and objectives of the study.

8. Interviewer characteristics. What characteristics were reported about the interviewer/facilitator? e.g. Bias, assumptions, reasons and interests in the research topic.

The background of the researchers was explained to the participants during the introductory phase of the focus group session, but there was no specific biases discussed.

Domain 2: study design

Theoretical framework

9. Methodological orientation and Theory. What methodological orientation was stated to underpin the study? e.g. grounded theory, discourse analysis, ethnography, phenomenology, content analysis

In the data analysis section, we explained how we used semi-structured interviews and thematic analysis. This was informed by grounded theory and the constant comparison method.

Participant selection

10. Sampling. How were participants selected? e.g. purposive, convenience, consecutive, snowball.

We used purposive sampling to select participants.

11. Method of approach. How were participants approached? e.g. face-to-face, telephone, mail, email

Households that were informed and gave consent were contacted face-to-face in public places.

12. Sample size. How many participants were in the study? A total of 72 households participated in the discussions.

13. Non-participation. How many people refused to participate or dropped out? Reasons

All the invited participants were willing and punctual to undertake the discussion. No one refused to not to participate in the discussion, except some people hurrying to complete soon the discussion started due to market day or other ceremonies 'coincidence with the discussion date.

Setting

14. Setting of data collection. Where was the data collected? e.g. home, clinic, workplace

During the study period, there have been security concerns in the area. Due to this, it was impossible to move from village to village to get participants at their homes. As a result, once the sampling was determined, it was decided to approach the participants in person in public places such as kebele offices, farmer training centers (FTC), health centers (HC), traditional local institutional (TLI) (e.g., Idir and Afosha), and ritual places.

15. Presence of non-participants. Was anyone else present besides the participants and researchers?

No

16. Description of sample. What are the important characteristics of the sample? e.g. demographic data, date.

The focus group discussions were conducted in each kebele according to their agro-ecological zones. Since the total number of kebeles selected for the study was 6, the total number of focus group discussions also totaled 6. Each FGD was composed of 12 members, with 33 percent female participation.

Data collection

17. Interview guide. Were questions, prompts, guides provided by the authors? Was it pilot tested?

A semi-structured, topic guide used for all interviews. The focus of the topic guide was participants' views and experiences of the climate perception and adaptation strategies. The topic guide was used flexibly so that interviewees could raise other issues they felt were important and also allowed for in-depth exploration of the themes.

18. Repeat interviews. Were repeat inter views carried out? If yes, how many?

We did not conduct repeat interviews

19. Audio/visual recording. Did the research use audio or visual recording to collect the data?

N/A.

20. Field notes. Were field notes made during and/or after the interview or focus group?

All data collection was conducted by taking notes during the discussions in order to avoid data missing.

21. Duration. What was the duration of the interviews or focus group?

Averagely it was 150 minutes

22. Data saturation. Was data saturation discussed?

Yes.

23. Transcripts returned. Were transcripts returned to participants for comment and/or correction?

No. It was not possible to offer it in the time available in the study.

Domain 3: analysis and findings

Data analysis

24. Number of data coders. How many data coders coded the data?

Beshea Abdissa coded and analyzed the data.

25. Description of the coding tree. Did authors provide a description of the coding tree?

No.

26. Derivation of themes. Were themes identified in advance or derived from the data?

Themes were derived inductively from the data.

27. Software. What software, if applicable, was used to manage the data?

No. We used pen and pencils.

28. Participant checking. Did participants provide feedback on the findings?

No.

29. Quotations presented. Were participant quotations presented to illustrate the themes /findings? Was each quotation identified? e.g. participant number

Yes. The paper contains anonymized quotations to illustrate key themes. Each quotation is incorporated in the text as per its relevant consolidated idea under the topics.

30. Data and findings consistent. Was there consistency between the data presented and the findings?

Yes, we think so.

31. Clarity of major themes. Were major themes clearly presented in the findings?

Yes, we think so.

32. Clarity of minor themes. Is there a description of diverse cases or discussion of minor themes?

Yes, we think so.

Annex 4.1 Crop diversification for improving food security of coffee-based rural households in Gimbi district, western Ethiopia. Questions for constructing Households Food Insecurity Access Scale (HFIAS)

Questions and Response Options.

Assign code according to the following answers:

CODE: 1= Yes, 0= No, it did not happen in the past [4 weeks], if, yes, how often

(0) Rarely= once or twice in the past [4 weeks]

(1) Sometimes = three to ten times in the past [4 weeks]

(2) Often = more than 10 times in the past [4 weeks]

(3) Or locally-defined terms of frequency corresponding to these ranges

1. In the past [4 weeks], did you worry that your household would not have enough food? 1= Yes, 0= No, it did not happen in the past [4 weeks] If yes: ask respondent "how often did this happen?"1 = Rarely (1-2 times), 2 = Sometimes (3-10 times), 3 = Often (more than 10 times)

2. In the past [4 weeks], did it happen that you or any household member were not able to eat the kinds of foods you would have preferred to eat because of lack of resources? 1= Yes, 0= No= it did not happen in the past [4 weeks] If yes: ask respondent "how often did this happen?" 1 = Rarely (1-2 times), 2 = Sometimes (3-10 times), 3 = Often (more than 10 times)

3. In the past [4 weeks], did it happen that you or any household member had to eat a limited variety of foods because of lack of resources? 1= Yes, 0= No = it did not happen in the past [4 weeks]. If yes: ask respondent "how often did this happen?" 1 = Rarely (1-2 times), 2 = Sometimes (3-10 times), 3 = Often (more than 10 times)

4. In the past [4 weeks] did it happen that you or any household member had to eat some foods that you really did not want to eat because of lack of resources? 1= Yes, 0= No= it did not happen in the past [4 weeks].If yes: ask respondent "how often did this happen?" 1 = Rarely (1-2 times), 2 = Sometimes (3-10 times), 3 = Often (more than 10 times)

5. In the past [4 weeks] did it happen that you or any household member had to eat a smaller meal than you felt you needed because there was not enough food? 1= Yes, 0= No= it did not happen in the past [4 weeks]. If yes: ask respondent "how often did this happen?" 1 = Rarely (1-2 times), 2 = Sometimes (3-10 times), 3 = Often (more than 10 times)

6. In the past [4 weeks] did it happen that you or any household member had to eat fewer meals in a day because there was not enough food? 1= Yes, 0= No= it did not happen in the past [4 weeks]

If yes: ask respondent “how often did this happen?” 1 = Rarely (1-2 times), 2 = Sometimes (3-10 times), 3 = Often (more than 10 times)

7. In the past [4 weeks] did it happen that there was no food to eat of any kind in your house, because of lack of resources to get food? 1= Yes, 0= No= it did not happen in the past [4 weeks].

If yes: ask respondent “how often did this happen?” 1 = Rarely (1-2 times), 2 = Sometimes (3-10 times), 3 = Often (more than 10 times)

8. In the past [4 weeks] did it happen that you or any household member went to sleep at night hungry because there was not enough food? 1= Yes, 0= No= it did not happen in the past [4 weeks]

If yes: ask respondent “how often did this happen?” 1 = Rarely (1-2 times), 2 = Sometimes (3-10 times), 3 = Often (more than 10 times)

i “***In the past [4 weeks] did it happen that you or any household member went a whole day and night without eating anything at all because there was not enough food?” 1= Yes, 0= No = it did not happen in the past [4 weeks].*** If yes: ask respondent “how often did this happen?” 1 = Rarely (1-2 times), 2 = Sometimes (3-10 times), 3 = Often (more than 10 times)