IMPACTS OF RAINFALL VARIABILITY AND DROUGHT ON FOOD SECURITYAND SMALLHOLDER FARMERS' ADAPTATION STRATEGIES IN GUJI ZONE, OROMIA REGIONAL STATE, ETHIOPIA

PHD DISSERTATION

MENBERE SAHILU GEBREHANA

JANUARY 2025

HARAMAYA UNIVERSITY, HARAMAYA, ETHIOPIA

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A Dissertation Submitted to School of Geography and Environmental Studies, Postgraduate Program Directorate

HARAMAYA UNIVERSITY

In Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Geography and Environmental Studies (with Specialization in Climate Change and Disaster Risk Management)

Menbere Sahilu Gebrehana

January 2025

Haramaya University, Haramaya, Ethiopia

APPROVAL SHEET

HARAMAYA UNIVERSITY

POSTGRADUATE PROGRAM DIRECTORATE

As dissertation research Advisory Committee Member, we hereby certify that we have read and evaluated this dissertation entitled **"Impacts of Rainfall Variability and Drought on Food Security and Smallholders Farmers' Adaptation Strategies in Guji Zone, Oromia Regional State, Ethiopia"** which has been prepared under our guidance by Menbere Sahilu Gebrehana. We recommend that it be submitted as fulfilling the dissertation requirement.

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Yimer Mohammed (PhD)	_______________	_______________
Solomon Asfaw (PhD)	_______________	_______________
Haji Kedir (PhD)	_______________	_______________
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As members of the Board of Examiners of the PhD Dissertation Open Defense Examination of Menbere Sahilu Gebrehana, we certify that we have read and evaluated the PHD dissertation prepared by Menbere Sahilu and examined the candidate. We recommend that the dissertation be accepted as it fulfills the Dissertation requirement for the award of the Degree of Doctor of Philosophy (PhD) in Climate Change and Disaster Risk Management.

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_________________________	_______________	________________
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Final approval and acceptance of the dissertation is contingent upon submission of its final copy to the Council of Graduate Studies (CGS) through the candidate's School Graduate Committee (SGC) of the candidate's department or school/Department.

DEDICATION

The research work is dedicated to my beloved mother Askale Berriso for her maternity care, love and commitment from my early childhood years until the present. God bless you.

STATEMENT OF THE AUTHOR

By my signature below, I declare that this dissertation is my original work. In the planning, data gathering, data analysis, and dissertation completion phases, I adhered to all scholarly ethics guidelines. Every piece of academic content that is mentioned in the dissertation has been cited. I certify that I properly cited and referenced every source used in this dissertation. A serious effort has been made during the writing of this dissertation to prevent any instances of plagiarism.

This dissertation has been submitted to the Directorate of the Postgraduate Program at Haramaya University in partial fulfillment of the requirements for the degree of Doctor of Philosophy (PhD). The dissertation is made available to borrowers following the library's policies after being deposited in the Haramaya University Library. I hereby endorse soberly that this dissertation has not been submitted to any other organization, anywhere, to receive a diploma, certificate, or academic degree.

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Name: Menbere Sahilu Gebrehana

Signature:

Date of Submission: January 2025

School of Geography and Environmental Studies

Place: Haramaya University, Haramaya

BIOGRAPHICAL SKETCH

The author Menbere Sahilu Gebrehana was born in October 1984 in Guji Zone, Oromia Regional state, Ethiopia. She has attended Adola Primary and Secondary School for her primary and secondary studies. She received her first degree in Geography and Environmental studies in 2005 from Bahir Dar University. She started to work as a teacher at Gimbichu Preparatory School, for around seven months. Then, she worked as a Graduate Assistant at Hossana College of Education from 2006 to 2009. She joined Addis Ababa University to pursue an MA degree in 2010. In 2011, she graduated with her master's degree in Environment and Development. Then she rejoined Hosanna College of Education and served as a lecturer from 2011 to 2018. In addition to teaching activities, she initiated, conducted and participated in research in the college.

Finally, she has been enrolled in the School of Social Sciences and Humanities Post Graduate Program at Haramaya University in 2018 to pursue a PhD in climate change and disaster risk management.

ACKNOWLEDGMENTS

First and foremost, I want to give special gratitude to the almighty God who gave me the strength to complete the study. I am grateful to chairman of the board of advisors, Solomon Tekalign (PhD), for his professional guidance, encouragement and critical reading of the paper. He encouraged self-learning and provided continuous feedback, which helped me to finish the study. I am grateful to Yimer Mohammed (PhD) for his professional review on the manuscript, persistent follow up, continuous feedback, and encouragement. I express my gratitude to Tegegn Sishaw (PhD), Solomon Asfaw (PhD) and Haji Kedir (PhD), for their guidance and criticism.

I gratefully acknowledge Hosanna College of Education for providing me with the opportunity to pursue a PhD while off duty. I want to extend my gratitude to Befikadu W/Hana (PhD) Dean of HCTE, Teka Muche the Vice Dean, and Desta Bekele (PhD) for their encouragement and appreciation. I want to thank Dr. Kassaye Hussien for his support with GIS. I would like to thank Dr. Gusha Beleko, Samual Abera, Ejigu Alem, Kedja Abduraman, Hana Samuel and Aseged Desta for their encouragement and technical support.

I am grateful to Haramaya University for providing the opportunity to enroll in the PhD program, for partially guaranteeing the research afterward, and for housing my family during my studies. I express my gratitude to the postgraduate program directorate of Haramaya University, namely Professor Mengistu Urge, Feyera Dinsa (PhD), and Ashenafi Yimam (PhD), for their graciousness. I would like to express my gratitude to the Haramaya University Model School for accommodating my children, which made the journey of my PhD manageable and enjoyable.

My greatest appreciation goes to the Ethiopian Meteorological Institute for their complimentary, well-organized data supply for the study. I would like to express my gratitude to the government officials of three Woredas of Guji Zone, (Adola, Bore, and Liben) for their facilitation of access and to provision for the required valuable data during focus group discussion and key informant interview. I would like to sincerely thank everyone who participated in the household survey, including the enumerators and the respondents.

In addition, my father Debebe Sahilu and mother Askale Beriso deserve my heartfelt recognition for their nurturing care from my early childhood years until the present. I want to express my gratitude to my elder sister Birtukan Alemu for her inspiration and assistance. My sincere gratitude goes out to brothers and sisters Tadele, Seble, Abyot, Mamush, Addis, and Yared for their unwavering support and encouragement. I express my gratitude to Amelework Biresaw (PhD) and Nigist Bekele (PhD) for their excellent friendship. I am grateful to my husband Nebiyu Shiferaw and his mother Anchinalu Aklom and sister Kidist Shiferaw, for their care and support. Again, I want to thank the heavenly God for his blessing of my children: Abenezer, Abigia, Natan, and Lidia Nebiyu. They are the source of my inspiration. Finally, I am really blessed to have such wonderful gifts from the heavenly God. God be with you all and bless you all abundantly for everything.

ABBREVIATIONS AND ACRONYMS

AEZ	Agro Ecological Zone
BLRM	Binary Logistic Regression Model
CV	Coefficient of Variation
CC	Climate Change
CSA	Central Statistical Authority
CSI	Coping Strategies Index
DOY	Days of the Year
EMI	Ethiopian Meteorological Institute
ENSO	El Niño Southern Oscillation
FANTA	Food and Nutrition Technical Assistance Project
FGD	Focus Group Discussion
FAO	Food Agriculture Organization
HFIAS	Household Food Insecurity Access Scale
HHS	Household Hunger Score
FRQ	Frequency
GIS	Geographic Information System
HHH	Household Head
HHS	Household Survey
IDWI	Inverse Distance Weighted Index
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
IOD	Indian Ocean Dipole
KII	Key Informant Interview
LGP	Length of Growing Period
MAM	March April May
MASL	Meter Above Sea Level

MK	Mann Kendall
MMR	Mean Monthly Rainfall
NMA	National Meteorological Agency
PCI	Precipitation Concentration Index
PET	Potential Evapotranspiration
PFA	Priority Forest Areas
RDI	Reconnaissance Drought Index
SFHH	Smallholder Farmers Household
SPI	Standard Precipitation Index
SPEI	Standard Precipitation Evaporation Index
SRA	Standardized Rainfall Anomaly
SSA	Sub Saharan Africa
SST	Sea Surface Temperature
TLU	Tropical Livelihood Unit
TEJ	Tropical Easterly Jet
UNCCD	United Nation Convention to Combat Desertification
UNEP	United Nation Environmental Program
UNFCCC	United Nation Framework Convention on Climate Change
UNISDR	United Nation International Strategy for Disaster Reduction
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
WMO	World Meteorological Organization
USAID	United State Agency for International Development
WFP	World Food Program

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LIST OF ARTICLE /MANUSCRIPTS/

This PhD dissertation is based on the following four papers (articles/manuscripts). The first article was published under the Plos one journal, and the third article is under review in springer nature journal. The remaining are in due process of publication. .

The titles of the articles that constitute the dissertation are:
Spatiotemporal trends and variability of rainfall across agro-ecologies in East Guji Zone, Southeast Ethiopia

Citation: Sahilu M, Tekalign S, Mohammed Y, Sishaw T, Kedir H, Asfaw S (2024) Spatiotemporal trends and variability of rainfall across agro ecologies in East Guji Zone, Southeast Ethiopia. PLOS Clim 3(3): e0000361. https://doi.org/ 10.1371/journal.pclm.0000361

Drought Characterization in East Guji Zone, Oromia Regional State, Ethiopia: Sahilu, M., Tekalign, S., Mohammed, Y., Sishaw, T., Kedir, H., and Asfaw, S. (It is in due process of publication).

The Impact of Rainfall Variability and Drought on Food Security of Smallholder Farmers in East Guji Zone: Sahilu, M., Tekalign, S., Mohammed, Y., Sishaw, T., Kedir, H., and Asfaw, S. (It is in due process of publication).

Farmers Perception of the Impact of Rainfall Variability and Drought and determinants of their Adaptation Strategies in East Guji Zone, Oromia Regional State, Ethiopia: Sahilu, M., Tekalign, S., Mohammed, Y., Sishaw, T., Kedir, H., and Asfaw, S. (It is in due process of publication).

Impacts of Rainfall Variability and Drought on Food Security and Smallholder Farmers' Adaptation Strategies in Guji Zone, Oromia, Ethiopia

ABSTRACT

Rainfall distribution and trends reveal spatial and temporal variability which has a significant impact on smallholder farmers' livelihood. This research sought to examine spatio-temporal variability and trends of spring and autumn rainfall, characterize drought, and assess perceptions of smallholder farmers towards the impacts of rainfall variability and drought on food security and adaptation strategies across three Agro ecological Zones (AEZs). Primary data were collected via sample survey, key informant interviews, and focus group discussions. Gridded rainfall time series data were obtained from the Ethiopian Meteorological Institute from 1990-2020, besides different published and unpublished data sources were used. The onset and cessation date of rainfall was determined using Walter's formulation. The Mann Kendall trend test was employed to detect the trend of rainfall and drought, while Sen's slope was used to test their magnitude of change. The seasonal and annual variability of rainfall was assessed using Precipitation Concentration Index (PCI) and Coefficient of Variation (CV). The Inverse Distance Weighted Index (IDWI) was used to interpolate the spatial distributions of annual and seasonal rainfall. The Reconnaissance Drought Index (RDI) was applied to analyze the severity, duration, and spatial coverage of drought. The Household Food Security Access Scale (HFIAS) was used to analyze the level of food insecurity across the three AEZ of East Guji Zone. The binary logistic econometric model was used to identify determinants of food security and adaptation techniques of smallholder farmers in the study area. Descriptive statistics were used at every level of data analysis. Geographic Information System, Excel stat, SPSS and DrinC 1.7 software programs were utilized to examine quantitative data. The findings demonstrated that altitude and rainfall decrease as one descends from the western (highland AEZ) to the eastern (lowland AEZ) in the study area. Rainfall in the study area varies from the lowland Negele (624mm) which recorded the smallest to the highland Solemo (1262mm) the highest mean annual rainfall. Similarly, the mean length of the growing season declines from the western to eastern part of the study area. The PCI of the lowlands, midlands, and highlands AEZs were 19 %, 17%, and 12 % respectively implying that both lowlands and midlands had an irregular distribution of rainfall while highlands had *moderately concentrated rainfall distribution. In contrast, the low and midlands had shown high variability of rainfall (CV >30%) in all seasons. Conversely, the highland's CV suggests moderate variability of rainfall (CV <30 %), with values of 28%, 29 %, and 29% in the spring, summer, and autumn seasons respectively. Moreover, a significant (p< 0.05) increasing trend of annual rainfall was observed in the highlands AEZs (Bore 15.3 mm/year and Solemo14.6 mm/year), in the lowland AEZs (Chembe 10.9 mm/year, Dawa 8 mm/year and Bitata 7.8 mm/year) as well as in the midland AEZs (Kercha 14.5 mm/year). In the meantime, drought has shown statistically significant (p <0.05) declining trend in the autumn and annual (12 months) drought in the highland AEZs (Bore and Solemo), in the midland (Kercha) and in the lowlands (Chembe and Dawa). Food insecurity increases from high to mid and lowlands in the same manner with the increase in seasonal rainfall variability from high to mid and lowlands (CV >30). The finding indicates that food insecurity decreases from lowlands through midlands to highlands. Based on the HFIAS of the lowland AEZ (Negele) was severely food insecure (17.5), midland (Adola) was moderately food insecure (11.3) and highland (Bore) was mildly food insecure with (8.7) value. The results of the binary logistic model revealed that age and sex of the household head, household size, cultivated land size, farming experience, AEZ, size of the tropical livestock unit, level of education, distance from the market and receipt of food aid all positively contribute to household food security significantly at (p <0.05).On the other hand, factors that are less likely to predict households' food security include marital status, access to credit, and access to drought resistant crops. The most popular adaptation strategies pursued by the smallholder farmers of the study area were planting eucalyptus trees (planting trees) in place of food crops, utilizing drought-resistant crop varieties, and mixed cropping. The significant (p <0.05) factors which determine choices of adaptation strategies were AEZ, sex of the HH, household size, size of the tropical livestock unit, level of educational HH, having enough food, obtaining food aid, and time to reach to the local market. Since shortage and variability of rainwater has been identified as a serious problem, strategies should be designed to use additional water resources for irrigation, supplying irrigation pumps, providing short-cycle growth, and drought-resistant crops in the midlands and lowlands AEZ.*

Keywords: Adaptation methods; Agro ecological zone; East Guji; Food security; Rainfall variability and Drought; Perception

CHAPTER ONE

INTRODUCTION

1.1. Background of Study

Global climate change and variability result in increasing rainfall variability so, international activities to reduce carbon emissions and limit global warming levels are urgently needed (Merabtene *et al.*, 2016; Zhang *et al.*, 2021). Precipitation changes will vary globally, with high latitudes and the equatorial Pacific likely to experience increased annual mean precipitation while mid-latitude and subtropical dry regions may experience decreases or increases (IPCC, 2014)**.** Consequently, two-thirds of land on Earth will face a “wetter and more variable” hydro climate; wet regions will become wetter, while dry areas will become drier (Oceanic and Science, 2006; Sciences *et al.*, 2008; Climate, 2015). Especially, the warmer and drier regions are negatively affected by climate change (Stern, 2008). Increased precipitation variability increases the risk of floods and droughts, potentially leading to rapid transitions between them (Swain *et al*., 2018). Recent studies have suggested an increase in rainfall variability under future warming globally over a range of time scales (Swain *et al.*, 2018; Dong *et al.*, 2018; He and Li, 2019; Alves *et al.*, 2021).

Global temperatures, atmospheric moisture demand, and circulation patterns have aggravated the frequency of droughts and dry areas since the 1950s particularly in developing continents like Africa (Hulme *et al.*, 2000; Dai, 2011). Africa is facing significant challenges due to global climate change causing an increased rainfall variability and temperature rises (Barana, 2017; Schwarz-Heroin, 2018). Rainy days in Sub Saharan Africa have declined by 20% (Parry *et al.*, 2004; Rani and Sreekesh, 2019), while its variability is increasing (Van Lanen HAJ, 2014). Although some parts of Africa will get wetter and some will go drier, most of the continent will suffer economically (Collier *et al.*, 2008). Eastern Africa has experienced a decrease in rainfall in the past three decades between March and May/June (Rosell and Holmer, 2007).

Future climate change projections suggest a decrease in rainfall in subtropics and tropics and increases in land precipitation at higher latitudes. Drought has become more common in the tropics and subtropics and widespread throughout much of Africa (Trenberth, 2011). The availability of water, which is affected by climate change determines the future socio-economic development of the African community (Washington, 2006; Matondo *et al.,*2021). Notwithstanding, the majority of African smallholder farmers practice rain fed agriculture. Rainfall variability limits water availability which restricts crop growth, leading to food insecurity for smallholder farmers. Africa's vulnerability is due to geographical location (already a warm region), high dependence on agriculture, limited adaptive capacity due to poverty, and low level of technological development (Stern, 2008; Collier *et al.,* 2008).

Ethiopia's rainfall and drought distributions are influenced by local and global factors with diverse topography being a major factor, which determines the spatial variation of rainfall and drought across the different AEZs in Ethiopia. There is high variability of rainfall in Ethiopia across space and time within a short distance due to geographical location and topographic complexity (Daniel *et al.,* 2014; Kourouma *et al.,* 2022). The altitudinal variability ranges from 4620m above sea level at Ras Dashen Mountain to the lowest at Afar Depression (Kobar Sink) 120m below sea level (Belay *et al.,* 2016; FAS, 2019)

Global factors like El Nino–Southern Oscillation (ENSO), warming and cooling of the Pacific and Western Indian Oceans, Indian Ocean Dipole (IOD) and the Inter Tropical Convergence Zone (ITCZ) influence the seasonal rainfall variability over Ethiopia (Black, 2005; Diro *et al.,* 2011; Nicholson, 2017). Sea Surface Temperature anomalies over Indian, Pacific, and Atlantic Oceans significantly influence the March, April, and May (MAM) seasonal variability in rainfall in Ethiopia (Makula *et al.,* 2020). Besides, large-scale atmospheric circulation systems and moisture tracks control the local rainfall conditions in Ethiopia (Kourouma *et al.,* 2022). La Niña-associated warm SST anomalies in the western Pacific cause Walker circulation and drought in the Horn of Africa (Liebmann *et al.,* 2014; Anderson *et al.,* 2023). Thus, Ethiopian intense and extended drought periods coincide or follow El Nino (Yimer *et al.,* 2018; Getachew *et al.,* 2021). However, complete models on El Nino's impact on Ethiopian climate variability and drought are lacking because of the existence of different AEZs which resulted in many microclimates and a lack of meteorological data (Tsegaye and Members, 2000).

Drought negatively affected the small-scale farmers who rely on rain-fed agriculture for their livelihood in Ethiopia (Kourouma *et al.,* 2022).The annual probability of drought occurrence is over 40% for many parts of Ethiopia (Bartel, 2007). In the same vein, the Guji zone was prone to drought and famine (Fedhassa and Megarsa, 2019). Rainfall variability and recurrent droughts have a considerable impact in the life of SFHH in Guji Zone.

1.2. Statement of the Problem

Smallholder farmers in developing countries contribute up to 80 % of food production but face unpredictable rainfall patterns, affecting agricultural yield and household welfare (Linderman *et al*., 2011; Shiferaw *et al.,* 2014; Esilaba, 2015). Rainfall variability affects smallholder farmers' livelihoods by increasing food insecurity and hunger risk (IPCC, 2007; WFP, 2016; FAO, 2018). Despite these challenges, Ethiopia's economy remains agricultural (World Bank, 2011; Conway and Schipper, 2011; EPCC, 2015). Agriculture is crucial for the Ethiopian economy, contributing 40% of the GDP, 80% employment, and 90% exports. Besides, 79% of the income of the population depends on rain-fed agriculture (Tafesse and Tewodroso, 2019; Young and Klingaman, 2020).

The variability in Ethiopia's rainfall distribution has significantly impacted the livelihoods of smallholder farmers. Studies show complex trends in rainfall distribution across the country (Conway *et al.*, 2004; Yilma and Zanke, 2004; Rosell and Holmer, 2007) with significant declines in the annual and summer (*kiremt*) rainfall totals in the eastern, southern, and southwestern, northern, north-central, north-western, and western parts of the country. However, some areas Rosell and Holmer, (2007) showed an increasing trend in annual rainfall in eastern Ethiopia as well as an increase in annual and summer (*kiremt*); decrease in spring (*belg)* rainfall in central Ethiopia. Getachew *et al*. (2021) reported the annual rainfall showed a non-significant decreasing trend over Western Harerge. Similarly, Matios *et al*. (2022) reported a declining trend of annual and March-May rainfall (long rain) or spring in the Guji Zone.

A study by Negash *et al.* (2013) has also shown varied rainfall patterns in Ethiopia. Likewise, Yimer *et al.* (2018) reported some of the stations experiencing significant increase in summer and others experiencing decline in spring rain in South Wollo. Wagaye and Antensay, (2020) also reported central Ethiopia was experiencing increasing annual and summer rainfall significantly decreasing trend in spring (*belg),* winter (*bega*), and (*kiremt*) rainfall. Likewise, Arragaw *et al.* (2020) showed significantly increasing trends in total rain in western part of Ethiopia. Similarly, Abrham *et al*. (2021) reported southern Ethiopia experiences a significant decrease in the spring (*belg*) rainfall. Mitiku *et al.* (2022) found a significant increase in rainfall during August, October, and November in Borena. Markos *et al.* (2023) reported an increased trend in rainfall in most parts of the Sidama region.

Ethiopia's drought has been examined in a number of earlier studies (Desalegn *et al.,* 2010; Viste *et al.,* 2013; Mekonnen and Weldeamlak, 2015; Yimer *et al.,* 2018; Martha, 2020; Yimer and Asnake, 2021; Kourouma *et al.*, 2022; Indale *et al.,* 2023). Complex patterns in frequency, severity, and magnitude of drought events, with empirical evidence indicating highly localized negative effects and varying intensity classes were reported. However, there are few studies that focus on characterizing drought using AEZs. Therefore, by examining the localized drought pattern in the Guji Zone, the AEZs based characterization of drought adds to the existing knowledge.

Studies on the impacts of rainfall variability and drought on food security in Ethiopian farm households are extensive (Regassa and Stocker 2012; Malla *et al.,* 2017; Alem meta and Singh, 2018; Shishay and Dawit, 2018; Bereket *et al.,* 2019; Abebe *et al.*, 2021; Mesfin *et al.*, 2021; Amogne *et al.,* 2021). However, there is minimal empirical evidence on the distinct effect of AEZ on the food security of farm households. Climate change has a negative impact on crop production in countries located in low-latitude and can have positive or negative effects in higher latitudes (Gitz *et al.,* 2016). Rainfall variability and drought in Ethiopia have divergent impacts, making climate a misappropriation of the causal factor for food insecurity necessitating a local level study of climate dynamism (Lewis, 2017). Thus, an examination of the effects of rainfall variability and drought on food security based on AEZs is necessary.

Although topography is prominent in determining the distribution of rainfall and drought, AEZs based research was limited in Ethiopia. Few among who conducted AEZs based study of rainfall variability includes Befikadu *et al.* (2018) in Wolayita; Mintesinot *et al.* (2019) in Northwestern Ethiopia; Ashenafi *et al*. (2022) in Northern Shewa; Toni *et al.* (2022) in Wabi Shebele basin. Large-scale studies overlook local conditions, necessitating local-level investigation into variability and trends of rainfall. The ongoing issue of rainfall variability and drought, perception of impacts and adaptation strategies requires further investigation across the AEZs and at diverse microclimates in the country (Woldeamlak and Conway, 2007; Mekonnen and Woldeamlak, 2015;

Daniel, 2016; Mitiku *et al.*, 2022). The present study focuses on the impact of rainfall variability and drought on food security and smallholder farmers' adaptation strategies across the three AEZs of Guji Zone, yet the locality remains unexplored.

Given high dependence on the rain fed agriculture, identifying the spatial variability and temporal trends of rainfall characterizing drought, perception of farmers to impacts on food security and corresponding adaptation strategies on each AEZ are pertinent issues to study. This study examines rainfall variability and drought across the three AEZs of East Guji, focusing on impacts on food security, perception and adaptation strategies of smallholder farmers. The research aimed to provide context-specific local level decisions on adaptations to rainfall variability and drought in the three AEZs. The study uses rainfall and temperature data to analyze spring and autumn spatial variability and temporal trends of rainfall, characterize drought, perceptions of impacts on food security, and adaptation strategies across the three AEZs of Guji Zone.

1.3. Scope of the Study

The study examined spatiotemporal trends and variability of rainfall, characterizing drought, perceptions of smallholder farmers to the impacts of rainfall variability and drought, and adaptation strategies at the three AEZs of Guji Zone. Rainfall variability and drought had an interrelated impact on Small Holders Household (SFHH). As a result, an interconnected adaptation method was used to reduce or avoid the impact of both rainfall variability and drought.

The altitude in the study area ranges from 632-2960m, which limits the study to be done on the three AEZ of Guji Zone. In addition, in Guji zone there are pastoralist, agro pastoral and farm households. The study focused on smallholder farm households found at different AEZs of Guji Zone. Smallholders are characterized by family-focused motives and low input /low output rain fed mixed farming. These smallholder farmers manage areas ranging from 1 to 10 hectares using family labor for production and using part of their production for family consumption (BoFED, 2008 and CEEPA, 2006).

In most parts of Ethiopia summer or June, July, August (JJA) are the major wet season. However, in the study area this season is wet only in the highland AEZs. The study analyzed rainfall variability and drought in spring or March, April and May (MAM) and autumn or September October and November (SON) which are the main wet seasons in the mid and lowland part of the study area. Therefore, the result of the study is applicable to other areas which had similar geographical settings with the study area.

Furthermore, there are four types of droughts: meteorological, hydrological, agricultural and socio economic. Despite the complexity of studying all types of droughts, the study focuses on meteorological drought, which is closely linked to rainfall variability.

To assess rainfall variability and drought in the Guji Zone, eleven grid locations were selected and analyzed from the three AEZ based on data from EMI. However, the three representative districts from each AEZ in Guji zone were used for investigation of the impact of rainfall variability and drought on food security, perceptions and adaptation methods of smallholder farmers based on the data from the HHS, FGD and KII. Empirical analysis of meteorological variables was associated with SFHH perception and impacts on food security also done for the chosen districts from the three AEZ.

1.4. Limitation of the Study

The current study focuses on rainfall variability and meteorological drought considering variables like precipitation, temperature, and potential evapotranspiration. Further assessment of the spatial variability and temporal trends of rainfall seasons with rate of evaporation together with the required level soil moisture in cropping season is recommended since most parts of the study area experience high evaporation. To understand the effect of rainfall variability and drought on water resources at various spatial and temporal scales a more integrated and systemic approach to understanding the water- evaporation and soil system is also necessary. In short, detailed study on agricultural drought and the impact of meteorological drought on water soil system and the level of PET in Guji zone is required.

There has been a big security issue in the Guji Zone which limited freedom to move and collect data across the study area. In the process of gathering data on some of the variables which determine the adaptation strategies towards the impact of rainfall variability and drought was missed.

1.5. Significance of Study

The study will benefit government officials, development experts, and smallholder farmers. This evidence can be used by authorities to create better policies. Professionals can plan a local AEZ based economy that is climate resilient by using the findings of the study. Thus, this study provides insights to understand the onset and cessation of spring and autumn season rainfall, its spatial variability and temporal trend, effects on food security of smallholder's farmers in the study area. The study can be used by SFHH to use the most effective adaptation techniques. By using the findings of the study local government officials can provide support for SFHH through supplying the climate related information about the onset and cessation of rainy seasons.

The information gained from drought analysis helps to monitor, mitigate, and manage spring and autumn drought in the Guji Zone. Since shortage and variability of rainwater has been identified as a serious problem in the midland and lowland AEZ. Strategies should be designed to use additional water resources for irrigation; and provide small-scale irrigation pumps, short-cycle grown and drought-resistant crops in the rest of the midlands and lowlands AEZ.

Empirical analysis of time series data together with smallholder farmers' perceptions of rainfall variability and drought was done in the study. Corresponding, the quantitative and qualitative result was made in the research. Such findings provide empirical evidence for governmental and nongovernmental organizations to develop appropriate adaptation strategies towards the impact of rainfall variability and drought. The finding enables the government and SFHH to adjust their farming accordingly.

The study analyzed socio-economic and demographic factors influencing food security and adaptation strategies of smallholder farmers to rainfall variability and drought hazards. Most socio-economic factors determine food security and adaptation choice of the SFHH. It emphasized the importance of improving the level of awareness and assets of SFHH to enhance food security and adaptation methods.

The study highlights the negative impacts of rainfall variability and drought on smallholder farmers' crop productions especially in the lowlands and midland AEZ. It provides policy input for government and other organizations to identify and implement adaptive strategies to address food insecurity in the lowlands and midland AEZ of Guji zone. Besides, to rely on agriculture as a major source of income and food for SFHH the governments must work on income diversification of SFHH in Guji zone .

Research Questions

- Is there significant variability and trends of rainfall across the three agro ecologies of Guji zone?
- Do the spatial and temporal distribution, severity, and duration of drought significantly vary across three AEZ?
- Does the impact of rainfall variability and drought on food security of smallholder farmers significantly vary across the different AEZs? Does the socio-economic and demographic profile of smallholder farmers significantly determine food security?
- Do smallholder farmers' perceptions and utilizing different adaptation tactics towards the impact of rainfall variability and drought significantly differ across the three AEZs of Guji Zone? Does the socio-economic and demographic profile of smallholder farmers significantly determine their adaptation practices to rainfall variability and drought?

1.6. Objective

1.6.1. General objective

The general objective of the study was to analyze spatial variability and temporal trend of spring and autumn rainfall and characterize drought, impacts of rainfall variability and drought on food security, household perception and adaptive strategies of the smallholder's farmers in the three AEZs of Guji zone, Oromia Regional State, Ethiopia.

1.6.2. Specific objectives

The specific objectives of this study were to:

- Analyze spatio-temporal distribution, trends, onset and cessation, and variability of spring and autumn rainfall across three AEZs.

- Characterize the spatio-temporal distribution, severity, and duration of drought.
- Assess the impact of rainfall variability and drought on food security and determinants of food security on smallholder farmers.
- Examine the perception and adaptation practices of smallholder farmers to the impact of rainfall variability and drought and the determinants of adaptation of smallholder farm households.

CHAPTER TWO

LITERATURE REVIEW

This chapter provides a comprehensive review of previous research work on rainfall variability and drought, impacts on food security, perceptions and adaptation strategies of smallholders' farmers. The review of related literature was presented with the aim of providing theoretical and analytical background as well as to specify the conceptual framework of the study.

2.1. Concepts of Rainfall Variability, Drought, and Adaptation

2.1.1.Rainfall variability

Rainfall variability is a crucial aspect of meteorology or climatology, affecting the environment and society. It involves variation in precipitation amount, intensity, frequency, and type over time (Trenberth, 2011; Thornton *et al.*, 2014).There are two types (components) of rainfall variability; spatial variability refers to the variation of rainfall amount at specific locations, while temporal variability refers to, the variation of rainfall at a given location across a time interval (Thornton, 2014). Rainfall can be temporally varied from days to decades in terms of the direction and magnitude of rainfall trends over regions and seasons (Jury and Funk, 2013). Temporally, it varies from, with the magnitude and direction of historic rainfall trends varying from region to region and season to season (Yilma and Zanke, 2004; Viste *et al.*, 2013).

Precipitation in Africa is irregular, with short-period variations mixed with long periods (Glantz and Katz, 1977). Precipitation in Africa exhibits high spatial and temporal variability, ranging from 10mm in Sahara to 2000mm in tropical rainforests and equatorial regions (Hermes *et al.*, 2018). Ethiopia's rainfall varies significantly across time and space due to its complex topography and varying latitude (Daniel, 2016). Its seasonal cycle, onset, and cessation times and growing period vary significantly ranging from days to decades (Segele *et al.*, 2009).

2.1.2. Drought

There is no universally accepted definition of drought. Drought, a common global hazard, poses significant threats to agriculture, economy, and society. They are complex, and the least understandable, affecting more people than any natural hazard (Mishra and Desai, 2005). Drought is a prolonged period of abnormally dry weather conditions leading to a severe shortage of water (AMS,1997). Drought is a result from a deficiency of precipitation and excessive evapotranspiration. It is a natural hazard due to a substantial reduction in water availability over a prolonged period (Sousa *et al*., 2011). Drought is a prolonged period of less than normal rainfall, causing water supply issues and endangering food and water security. It is a complex natural event, resulting from lack of precipitation, effecting slowly over time (Hayes *et al.*, 2012)

Drought can be categorized into four types: meteorological, hydrological, agricultural and socio-economic drought. Meteorological drought is a deficiency of precipitation that is measured in terms of seasons, years or decades impact on soil moisture and stream flow. Hydrological drought affects surface or subsurface water supply, lag meteorological and agricultural droughts. Agricultural drought's impact depends on magnitude, duration, timing, soils, plant, and animal responses, and socio-economic drought arises when drought adversely affects economic goods supply and demand.

2.1.3. Food security

The concept of food security emerged in the 1970s focusing on the volume and stability of food supplies. The 1974 World Food Summit defined it as adequate world food supplies to sustain consumption and offset production and price fluctuation (Singh and Siahpush, 2006). FAO expanded its concept to include vulnerable people's access to basic food (FAO, 1975).

Food security is achieved at the individual, household, national, regional and global levels when all people have access to sufficient, safe, and nutritious food to meet their dietary needs and preferences for being active and healthy (FAO, 1996). According to The State of Food Insecurity 2001:Food security is a situation that exists when all people always have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 2002).

FAO stressed that food security is primarily influenced by socio-economic conditions and access to food rather than the production or availability of food. It stated that, to evaluate the potential impacts of climate change on food security, it is not enough to assess the impacts on domestic production in food-insecure countries (FAO, 2003).

Food availability exists when households have access to enough adequate and necessary foods obtained through local production, commercial imports, or agency donations. Access refers to having necessary resources for the purchase or interchange of goods with the aim of obtaining a variety of foods to comprise a nutritionally adequate diet. Utilization addresses the safe distribution, storage, and preparation of foodstuffs (Castell *et al.*, 2015). Food insecurity (FI) refers to the limited availability of nutritious food, with low and very low levels resulting in reduced in food intake due to insufficient resources, disrupted eating patterns (Castell *et al.*, 2015).

Household food security is dependent on the physical availability of food, the ability of households to access the available food and the ability of individuals to secure entitlement to it (Bouis and Hunt, 1999). Food security can be classified into three main components-availability, access, and utilization (FAO, 1996). Food availability exists when households have access to enough adequate and necessary foods obtained through local production, commercial imports or agency donations. Access refers to having necessary resources for the purchase or interchange of goods with the aim of obtaining a variety of foods to comprise a nutritionally adequate diet. Utilization addresses the safe distribution, storage, and preparation of foodstuffs (Castell *et al.*, 2015). A household is considered food secure if it can acquire the food needed by its members (Pinstrup-Andersen, 2009).

2.1.4. Adaptation to Climate Change

Adaptation is the process of adjusting to climate change and its effects aiming to minimize harm or exploit beneficial opportunities (IPCC, 2014). Adaptive capacity refers to a system's ability to respond successfully to climate variability, reduce adverse impacts, and take advantage of new opportunities (IPCC, 2007). Adaptation can mitigate climate change impacts but cannot solve the problem. Residual costs may arise such as lower productivity for smallholder farmers (Adger *et al.*, 2003). While adaptation can reduce adverse impacts of climate change, it does not prevent all damages (Davidson *et al.*, 2001). Those societies that can respond to change quickly and successfully have a high adaptive capacity (Smit and Wandel, 2006).

The dominant approach to climate change adaptation emphasizes technology, institutions, and managerial systems as key to successful adaptation (Eriksen *et al.* 2011). However, these strategies may not be sustainable due to resource misuse or constraints. Understanding the underlying social, economic, institutional, and cultural conditions is crucial (Eriksen *et al.*, 2011).

2.2. Rainfall Variability, Drought, and their Impacts on Food Security and Smallholders Farmers' Adaptation Strategies

2.2.1. Major features of rainfall variability

Climate change has significantly impacted natural and human systems globally, with increased frequency of high temperature events, while decreased low temperature events (IPCC, 2014). Precipitation changes will vary globally, with high latitudes and the equatorial Pacific is likely to experience increased annual mean precipitation while mid-latitude and subtropical dry regions may experience decreases or increases (IPCC, 2014)**.** Rainy days in SSA have declined by 20% , (Parry *et al.*, 2004; Rani and Sreekesh, 2019), while its variability is increasing (Van Lanen HAJ, 2014). Eastern Africa has experienced a decrease in rainfall in the past three decades between March and May/June (Rosell and Holmer, 2007).

Rainfall variability can be explained temporally, spatially or both, and is the most significant meteorological parameter (Song and Zhou, 2014). Rainfall variability is crucial for agriculture, as it affects crop production levels which employes 85% of the Ethiopian labor force in rain-fed agriculture (Woldeamlak, 2009; Diro *et al*., 2011). Ethiopia faces significant crop production challenges due to high inter-seasonal and annual rainfall variability, frequency of drought and intra-seasonal variations. This variability costs the country over a-third of its growth potential, potentially reducing it by 38%, and increasing poverty by 25% over a 12-year period (World Bank, 2011). Rainfall variability was associated with risks such as late onset, early cessation, short and lengthy dry spells, and moderate-to- severe drought that occur frequently (Habte *et al.*, 2023)

2.2.2. Major features of drought

Climate change is causing longer dry spells; duration, intensity, and frequency of drought have increased in the past drought events (Stocker, 2014). Global temperatures, atmospheric moisture demand, and circulation patterns have increased the frequency of droughts and dry areas since the 1950s particularly in developing continents like Africa (Hulme *et al.*,1999; Dai, 2011). Africa is facing significant challenges due to global climate change causing an increased rainfall variability and temperature rises (Berena, 2017; Schwarz-Herion, 2018).Future climate change projections suggest a decrease in rainfall in subtropics and tropics and increases in land precipitation at higher latitudes. Drought has become widespread throughout much of Africa and more common in the tropics and subtropics (Trenberth, 2011). Even though drought is a recurring phenomenon and affects all geographical areas, its impacts are more severe in arid and semi-arid regions where there already exists high natural variability in the rainfall pattern. The main characteristics include severity, intensity, areal extent, progression and withdrawal of droughts (Gebrechorkos *et al.*, 2019; Thomas *et al.,* 2016).

Global warming is increasing the frequency and the severity of the impact of droughts in Ethiopia, (Wilhite and Smith, 2005). Droughts in Ethiopia are increasing due to increased evaporation demand and spatial-temporal variability of droughts (Ault *et al.,* 2016). Drought severity is complex and dependent on the duration, intensity, and geographical extent, human activities and vegetation demands (Wilhite and Glantz, 2019). Early detection and estimation of agricultural production losses can predict food insecurity and provide timely assistance, and improve food security (Kogan *et al.*, 2019) .

2.2.2.1. Type of drought

Drought, categorized into meteorological, agricultural, hydrological, and socio-economic drought types, can be devastating and costly, impacting society, agriculture, infrastructure, economy, and ecosystems.

1. Meteorological Drought

Meteorological parameters are crucial indicators of drought occurrence (Wu *et al.,* 2004) . Meteorological drought, defined as lack of precipitation causing hydrological and agricultural hazards. Increased drought episodes, famines and climate-sensitive diseases in the northern highland and southern lowland regions (United Nations, 2009; Ansarifard and Shamsnia, 2018).

2. Hydrological Drought

Drought is a hydrological condition where surface water and groundwater level are below the long-term average, with indicators including streams, lakes, and groundwater delayed precipitation (Zargar *et al.*, 2011).

3. Agricultural Drought

Agricultural drought occurs when soil moisture is less than a plant's water demand causing tension, and decreased yield. It is caused by precipitation shortfall, temperature increase and wind, usually occurring after meteorological drought and hydrologic drought (Webster, 1980).

4. Socio economic Drought

Drought negatively impacts people's lives and society due to water crises and crop deficits. Socioeconomic drought occurs when demand for economic goods exceeds supply due to weather-related water shortages. It involves meteorological, hydrological, and agricultural drought affecting water, grains, fish and hydro-electric energy supply (Eslamian *et al*., 2017).

2.2.2.2. Dimension of drought

Droughts are characterized by severity, duration, and spatial distribution with additional factors like frequency, magnitude (accumulated deficit) predictability, rate of onset, and timing (Tozier de la Poterie and Baudoin, 2015). Magnitude: the accumulated deficit of water (e.g., precipitation, soil moisture, or runoff) is below some threshold during a drought period (Zargar *et al*., 2011). Intensity: the ratio of drought magnitude to its duration. Severity: drought severity two aspects: the degree of the precipitation deficit (i.e., magnitude), or the degree of impact resulting from the deficit (Wu *et al.,* 2004). Geographic extent: the aerial coverage of the drought which is variable during the event. This area can cover one or several pixels (cells), watersheds or regions (Zargar *et al.*, 2011). Frequency (return period): the frequency or return period of a drought is defined as the average time between drought events that have a severity that is equal to or greater than a threshold (Zargar *et al.,* 2011). Based on various characteristics such as severity, duration, spatial extent, loss of life, economic loss, social effects, and long-term impacts, several studies have found that drought is the most far-reaching among all-natural disasters.

2.2.3. Major impacts of rainfall variability and drought on smallholder farmers'

2.2.3.1. The worldwide impact of rainfall variability and drought

Global warming is expected to decrease precipitation in parts of the world which are located at lower latitude affecting irrigation water availability and crop cultivation suitability (Bradshaw *et* *al.*, 2004; IPCC, 2014). The combination of declining water availability due to warmer temperature will impact harvest time and crop cultivation (Webb *et al.*, 2008). Climate change is expected to impact food security particularly in sensitive regions, with global marine species redistribution and marine biodiversity reduction posing challenges to sustain fisheries productivity and ecosystem services, despite potential benefits (IPCC, 2014). Climate change without adaptation negatively impacts wheat, rice and maize production in tropical and temperate regions due to local temperature increases exceeding late 20th century levels (IPCC, 2014).

Climate change is reducing renewable water resources in subtropical regions, intensifying water competition and increasing drought (IPCC, 2014). This leads to water stress, land degradation, and food shortages. Changes in precipitation patterns may also affect groundwater recharge rates causing more damage to crop and soil (Bates *et al.*, 2008; Webb *et al*., 2008). The future social-economic development of the African community is influenced by the water availability from highly variable rainfall, which is affected by climate change (Washington, 2006; Matondo *et al.*, 2021).Notwithstanding, the majority of African smallholder farmers practice rain fed agriculture. Water availability limits crops' growth. Rainfall variability restricts crop growth, leading to food insecurity for smallholder farmers. Africa's vulnerability is due to geographical location (already a warm region), high dependence on agriculture, limited adaptive capacity due to poverty, and low level of technological development (Stern 2008; Collier *et al*., 2008).

Extreme events have exposed large populations in developing countries to various risks making them highly vulnerable to disasters (Singh and Siahpush, 2006; UNISDR, 2010). Developing countries and low-income countries and their poor are disproportionately affected due to lower level of preparedness, high degree of exposure, and vulnerability (UNISDR, 2010; Tozier de la Poterie and Baudoin, 2015). Climate change will exacerbate existing health problems leading to increased ill-health in many regions particularly in low income developing countries, in the 21st century (IPCC, 2014)

2.2.3.2. Impacts of rainfall variability and drought in Africa

Africa is highly vulnerable to the impacts of climate stress due to highly variable climates. Floods and droughts can cause famine and disrupt socio-economic well-being. One third of Africans live-in drought- prone areas and 220 million are exposed to drought annually (UNDP, 2006). Climate change in Africa has reduced freshwater availability in low latitudes, impacting farmers yields and longer growing seasons (FAO, 2015; Matondo *et al.*, 2021). The consequences are expected to be adverse, especially for the poor and the marginalized, who lack the means to withstand shocks (FAO, 2011). Finally, greater exposure to flooding will have severe effects on infrastructure, most notably the road system which is currently predominantly unpaved and therefore particularly vulnerable to erosion from flooding. Although it is not possible to quantify the cost of the increased proneness to climatic shocks, the typical shock in a developing country reduces GDP in the year of the shock by around 0.4% (Collier *et al.*, 2008).

Global warming is causing Africa's climate to become more variable, with frequent and severe extreme weather events increasing health risks (Few *et al.*, 2004). This is also affecting the distribution of disease vectors, such as malaria which migrate to new areas and higher altitude (IPCC, 2007). The temperature in the highlands of East Africa has risen by 0.5ºC since 1980 much faster than the global average temperature and this is correlated with a sharp increase in mosquito populations. Climate change threatens Africa's threatened ecosystems, species, and habitats, potentially triggering species migration and habitat reduction putting up to 50% of its total biodiversity is at risk (IPCC, 2007).

2.2.3.3. Impacts of rainfall variability and drought on food security of SFHH

Smallholder farmers in developing countries contribute to up to 80 % of food production but face unpredictable rainfall patterns, affecting agricultural yield and household welfare *(Linderman et al.*, 2011; Van Lanen HAJ, 2014; Esilaba, 2015). Rainfall variability affects smallholder farmers' livelihoods, increasing food insecurity and hunger risk (IPCC, 2007; WFP, 2016; FAO, 2018). The variability in Ethiopia's rainfall distribution significantly impacts the livelihoods of smallholder farmers. Despite these challenges, Ethiopia's economy remains agricultural (World Bank 2010; Conway and Schipper, 2011; EPCC 2015). Agriculture is crucial for the Ethiopian economy, contributing 40% of the GDP, 80% employment, and 90% exports. Besides, 79% of the income of the population depends on rain-fed agriculture (Tafesse and Tewodroso, 2019; Young and Klingaman, 2020).

Extreme weather events, rising sea levels and irregular rainfall patterns impacting food production, distribution infrastructure, food emergencies, livelihood assets and human health in rural areas

(FAO, 2008). Global food production may increase with local average temperatures (IPCC, 2007). Crop productivity may slightly increase at mid-to high latitude with moderate temperature increases, while at lower latitudes productivity decreases (IPCC, 2007). By 2050, crop yields in tropics and subtropics may fall by 10 to 20% (Thornton *et al.*, 2009).

Climate variability in Ethiopia, which is characterized by frequent droughts, has increased risk due to its impact on food security components such as availability, accessibility, utilization and food stability over the years (Shishay and Dawit, 2018). Rainfall shortage and excess hampers food production, leading to food insecurity and famine. Bad weather indirectly affects people by depleting assets (Shishay and Dawit, 2018). Hunger is worse in countries with sensitive agricultural systems and high population dependency on agriculture (FAO, 2018).

Ethiopia's erratic rainfall characterized by high intensively, extreme spatial and temporal variability has led to food insecurity exacerbated by population growth (Aklilu *et al.,* 2014) Climate variability is affecting food security, water and energy supply, poverty reduction and sustainable development efforts, causing natural resource degradation and natural disasters (Van Lanen HAJ, 2014). Climate-induced extremes like drought and intermittent rainfall impact food availability, agricultural productivity, and crop production (IPCC, 2007; Schmidhuber and Tubiello, 2007). Variability in rainfall and drought affect food insecurity in Guji Zone, with different effects across the three AEZs.

2.2.4. Perception towards adaptation to rainfall variability and drought

Perceptions and knowledge of climate variability are crucial for adaptive responses and decision-making at farm level (Vedwan and Rhoades, 2001). According to (Paulos and Belay, 2017; Temesegen *et al.*, 2011), farm-level adaptation involves two stages: perceiving a change in climate and deciding on adaptation strategies. However, perception alone is not sufficient; a complex interplay of social, economic, environmental, and institutional factors influences adaptation responses (Maddison, 2006).

Understanding local perceptions and adaptive behavior is crucial for sustainable agricultural development in uncertain environments (Belay *et al.*, 2016). Climate variability perceptions and factors shaping them are important (Temesgen *et al.*, 2011; Poulos and Belay, 2017; Befikadu *et al.*, 2019). Farmers' adaptation to climate change influenced by climatic stimuli, personal, economic and policy motivations (Smith, 1996). The perception of rainfall variability and drought plays a crucial role in practical adaptation practices. Misleading perceptions can lead to inappropriate adjustment, limiting farmers' expectations (Taylor *et al.*,1988).

Numerous studies have looked at the substantial relationship between how people perceive and adapt to climate variability and drought given that perception is required for effective responses to adaptation measures for SFHH drought and rainfall variability. In a similar vein, the study evaluated how farm households at different AEZs perceive the impact of drought and rainfall variability. Subsequently, a comparison was made between the real meteorological data analysis with SFHH perceptions.

2.2.5. Adaptation strategies to rainfall variability and drought

Coordination across governance scales can increase the effectiveness of adaptation, even while its primary focus is on local to national scale results. At national, sub-national, and local levels, the development of adaptation plans, strategies, and activities has been aided by international cooperation. To address mitigation and to encourage adaptation at national and sub-national levels, a range of climate policy instruments have been used at international and regional levels; research indicates that fair outcomes may encourage more productive cooperation (IPCC, 2014).

The IPCC highlights the importance of coordinating adaptation efforts at all levels, including individuals and governments, to protect vulnerable groups, support economic diversification and by providing information policy and legal frameworks and financial support (IPCC, 2014). Local governments and the private sector are crucial for accelerating adaptation efforts, managing risk information and financing, and assisting communities, households and civil society (IPCC, 2014).

The agricultural sector in developing countries faces significant challenges due to geography, sensitivity, and lack of adaptive capacity. Temperature increases impact water availability, and sectors like agriculture are particularly sensitive. Lack of resources, including financial, governance, infrastructure, and information, hinders adaptive capacity (Mendelsohn and Williams, 2006; Millner and Dietz, 2015) Ethiopia's low adaptive capacity, high population growth, inadequate infrastructure, lack of institutional capacity and high dependence on climate sensitive natural resource-based activities make the country vulnerable to climatic variability (NMA, 2005).

Farmer adaptation decisions are location-specific and influenced by socio-economic, environmental, and institutional factors, resulting in varying responses due to the complex interplay among social, economic, environmental, and institutional factors (Maddison, 2006). Farmers adapt to climate changes by changing crop mix, planting, and harvesting dates, and agronomic practices (Nhemachena and Mano, 2007; Temesgen *et al*., 2011). Crop choice is crucial, influenced by warmer climate effects. Farm level adaptation depends on technology; soil types, and farmers' capacity to detect climate change (Kurukulasuriya and Mendelsohn, 2008; Hassan *et al.*, 2008).

Climate change adaptation strategies in eastern Ethiopia include crop diversification, soil and water conservation, and water harvesting practices (Belayneh *et al.*, 2013). Smallholder farmers in different AEZs adopt varying adaptation mechanisms, adjusting their agriculture, irrigation systems, plant and animal species in accordance with its agro ecological zone (Seo *et al.*, 2008). Farmers in the highland and lowlands regions adapt their agricultural systems to weather variability and drought using various strategies.

The study explores the constraints that hinder adaptation planning and implementation, including limited resources, government integration, uncertainties, risks perceptions, competing values, absence of key leaders, and insufficient research, monitoring, and monitoring tools (IPCC, 2014)**.** Constraints or factors that hinder SFHH to adapt to rainfall variability and drought conditions were also investigated in the study.

2.3. Empirical Studies on Rainfall Variability and Drought, Impacts on Food Security and Adaptation Strategies

2.3.1. Empirical studies on rainfall variability

Woldeamelak and Conway (2007) found significant rainfall variability in the drought-prone Amhara region of Ethiopia, with higher amounts of rainfall and lower variability in the western part of the region. Similarly, Gebrehiwot and Van der Veen, (2013) who studied in northern Ethiopia revealed high climate variability, with mean annual rainfall below the mean in seven years. Drought is a significant disaster associated with climate variability, causing food production instability and increase in incidence, frequency, and spatial distribution of drought between 1970-2008.

Likewise, Negash *et al.* (2013) found significant decreasing trends in summer rainfall in northern, northwestern, and western Ethiopia, while some grid points in eastern areas show increasing annual rainfall trends. Alike, Asaminew (2015) found significant variability in rainfall, temperature, and rainy days in northern Oromia zone over the past 32 years, with both positive and negative anomalies(1982-2014). Aragaw *et al.* (2020) studied rainfall and temperature trends in Alwero watershed, Ethiopia. finding low inter annual variability, significant increasing and decreasing trend in annual, October -February, May, November, and March.

Wagaye and Antensay (2020) study on central Ethiopia's variability and trends revealed a significant increasing trend in length of the growing period, with Kiremt contributing 75%, the annual rainfall, making Northern Shewa Vulnerable to drought. Likewise, Getachew *et al*. (2021) found high rainfall variability in West Hararge zone, Eastern Ethiopia, with seasonal rainfall having higher inter-annual variability in the dry season (*Bega*), with monthly trends decreasing and increasing in the *Bega* season. Also, Ashenafi *et. al.* (2022) found significant variability in annual rainfall patterns across three agro-ecological zones in North Shewa, Central Ethiopia, with *Kolla* AEZ showing the highest percentage (97.1%) of irregular distributions followed by *Weina Dega* (82.9%).

Similarly, Mitiku *et al. (*2022) studied rainfall variability in the Borana zone of Oromia Regional state revealed highly variable monthly and seasonal trends, with a significant increase in autumn and annual rainfall, and decreasing spatially from the northeast and northwest parts of Borana towards the southwest. Likewise, Matios *et al.* (2022) examined climate variability's impact on livestock productivity in Guji Zone, Oromia, revealing declining annual rainfall trends (-4.7 mm/year), autumn (-4.5 mm) and winter (-0.54 mm), 13 drought years over the past 32 years, with 53.85% occurring between 2007- 2017. Similarly, Markos *et al.* (2023) found increasing annual rainfall, summer (*Hawado*), and spring (*Badhessa)* trends in Sidama Regional State, except northwest parts, with low annual variability.

2.3.2. Empirical studies on drought

According to Viste *et al.* (2013), Ethiopia experiences annual drought in all zones, with decline in precipitation in southern Ethiopia. Spring droughts have been more frequent in the last 10 -15 than in previous decades. Mekonnen and Weldeamlak (2015) studied drought trends in the Omo Gibe

Basin, finding complex spatial patterns and localized spatial patterns and recurrent risks in the Southern part of the basin.

According to Yimer *et al.* (2018), meteorological drought in Ethiopia's northeastern highlands, extreme droughts were more pronounced in stations above 3,000 masl during spring and less than 3,000 masl during summer, with the 1984 year being the most severe drought in Ethiopia history. Likewise, Abebe *et al.*(2020) conducted a study on drought incidence in Ethiopia’s northeastern highlands. They found severe droughts in the *belg* rainy months in 2008 and 1984, with 1999 being the driest year. The study also found that drought risk events in *belg* season were three times greater than those in the kiremt season, and complex spatial variation were observed.

Alike Yimer and Asnake (2021) found an increasing frequency of drought in the Lake’s Region of Ethiopian Rift Valley, with significant drought observed at six out of 10 stations, but with localized distribution and variability. Likewise, Ashenafi *et al.* (2022) studied rainfall variability in North Shewa, Central Ethiopia, revealing a higher drought rate in *Kolla* AEZ and negative annual anomalies for 18 years in Kolla and Dega AEZs.

Indale *et al.* (2023) found that drought severity in the Borana area, southern Ethiopia, varies across stations. Moderate to extreme drought conditions occur from March to June and September to November with driest years being 1984, 1985, 1992, 1999, 2000, 2001 and 2011.Gezahegn, (2024) analyzed El Niño induced meteorological drought in Oromia region of Ethiopia, revealing a slight decrease in short-term to long-term drought durations from 1991–2020, despite higher frequency of extreme droughts.

2.3.3. Empirical studies on the impacts of rainfall variability and drought on food security

Mendelsohn and Williams (2006) found that poor countries will disproportionately suffer from climate change damage due to their location with high temperatures in low latitudes and further warming pushing them further away from optimal temperatures for climate-sensitive economic sectors. Likewise, Torban (2010) studied Ethiopia's economic distributional impacts and found that climate change will hinder economic development by reducing agricultural production and income inequality, potentially reducing Ethiopia's GDP by 10% and fueling poverty. Fekadu and Mequanent (2010) studied determinants of food security among rural households of Central Ethiopia. Variables related to experiences in farming activities, off-farm and non-farm incomes, land, and livestock holdings, as well as soil and water conservation practices significantly affect household food security.

According to Nigatu and Stoecke (2012) 17.7 % of households were food secure with 6.8 % being mildly, moderately 27.7 % and severely food insecure. Factors predicting food insecurity and hunger include migration of a household member, agro-climatic zone, and younger age, less education and lower radio access for the woman, safety-net credit program eligibility, and limited animal ownership.

Similarly Murendo *et al.* (2011) found that drought in Ethiopia's Awash River Basin have led to a significant crop yield decline, death of livestock and increased food insecurity and prolonged insecurity, despite efforts to manage droughts. Likewise, the study by Kabubo-mariara and Kabara (2023) indicated that climate change in Kenya increases food insecurity, influenced by favorable agro-ecological zones, soil drainage, and population density.

Alem meta and Singh (2018) also studied determinants of food insecurity in the rural farm households in South Wollo Zone of Ethiopia. Households headed by men often had better food security than households headed by women. The finding showed that variables contributing to this type of food insecurity include lack of farmland, poverty, recurring drought and climate change, lack of rainfall, and land degradation. However, there is no significant relationship between the gender of household heads, policy support, farmland topography, soil fertility, erosion, and land redistribution. Likewise, Shishay and Dawit (2018) conducted a study on effects of climate variability on household food availability in Tigray and found 84.3% of the households fell below the daily recommended calorie intake 2100 kcal per adult equivalent/day and 15.7% of the households met the recommended daily calorie intake.

Getachew *et al.* (2018) evaluated rural households' food insecurity in Boset district of Ethiopia. By using the Months of Adequate Household Food Provisioning, Household Food Insecurity Access Scale, and Household Dietary Diversity Score the results showed that 26.5%, 21.7%, and 41.3% of respondents were extremely food insecure. Additionally, the study's finding demonstrated that although access to irrigable land, frequent droughts, distance to input/output markets, and distance to road transport were negatively associated with household food security situation, educational status, farmland size, total annual income, distance from health facilities, and the availability of supporting organizations were positively associated.

Temam *et al.* (2019) also studied long-term drought trends in Ethiopia with implications for dry land agriculture. Increased dryness during *Meher* has severe consequences on the production of corn and sorghum. The drying trends noted resulting from rainfall declines and temperature increases in the central parts of the country (37.5^0 E-42.5^0 E) place greater risk on agricultural production of the nation, as a substantial proportion of agricultural lands and rangelands lie in this portion of the country. High-valued crops such as corn are grown during this season and increasing drying trends in major agricultural production regions significantly increase the risk to food and economic security of the nation.

Fasil (2020) studied the determinants of rural households' food insecurity in Southern Ethiopia. He found out that 79.83 percent of households in the study areas were food insecure, with moisture stress lowlands being more affected compared to households in the middle lands and highlands. Factors such as family size and land size significantly affect food insecurity in the study areas. Moreover, food entitlement theory related factors like market access, education, livestock ownership, off-farm participation and productive safety net participation also significantly influenced food insecurity in Southern Ethiopia. Thus, both the demand and supply side factors are the main causes of food insecurity in Southern Ethiopia.

Abebe *et al.* (2021) found that age and family size, cultivated land and rainfall, were the significant (p <0.05) factors influencing household food security status. Abebaw and Mesele (2022) study reveal family size, age of the household head, educational level of the head, off-farm activities, monthly income of the household, and distance from the market are the major determinants of rural household food security in the North Shewa Zone. Wondimu *et al*. (2022) the study examined the factors influencing food security status of households in Central and North Gondar Zone, Ethiopia. The study found significant differences in training, oxen number, farmland size, and age, sex, family size, off-farm income, the tropical livestock unit, livelihood diversification and household on-farm in influencing food security.

2.3.4. Empirical studies on perception towards adaptation to rainfall variability and drought

Based on their practical experiences with the effect of rainfall variability and drought, SFHH accommodated at different agro-ecological environments in Ethiopia have varying experiences and perceptions regarding adaptation to the impacts of rainfall variability and drought. Poulos and Belay, (2017) and Temesgen *et al.* (2011) who studied farmers' perception revealed that: farmers living in the dry lowland area perceived more change in climate than farmers in the wet lowland. This could be linked to various environmental changes that cause reduced water availability and agricultural yield in the dry lowland areas. Regarding adaptation, farmers in wet lowland areas demonstrated better awareness and use of adaptation measures compared to the dry lowland.

According to Temesegen *et al.* (2007) who investigated the factors influencing farmers' views of climate change and their choice of adaptation strategies in the Nile Basin of Ethiopia. The majority of the farmers in the study area were aware that temperature is rising, and precipitation is declining. The finding also shows farmers' views of changes in climatic features are positively influenced by social capital, age of the household head, and knowledge on climate change. Moreover, farmers living in *Dega* (highlands) areas perceived climate variations.

Likewise, Nega *et al.* (2015) studied how smallholders in pastoral/agro pastoral systems of Borana, South Ethiopia perceived climate change and its impact. Based on their findings, it appeared that most participants saw climatic change to their economic development and means of subsistence, with varying levels of perception regarding its effect on traditional rain-fed agriculture. Enhancing access to agricultural support services will also increase rural communities' awareness of climate change by improving the availability and quality of pertinent climate information.

Limantol *et al.* (2016) evaluated farmers' perception of and practices for adapting to climate variability and change in Vea catchment in Ghana. According to the results, almost 94 % of the surveyed farmers believe that the amount of rainfall, duration, intensity, and number of rainy days had dropped during the last 30 years, while nearly 90 % of them think that the temperature has increased. Approximately 96 % of the farmers think that droughts, less rainfall, and shifted rainfall events pose a serious threat to their farms. The catchment climatic data shows a trend towards increasing temperature but no long-term changes in annual and monthly rainfall, which may lead to an increase in evapotranspiration.

Likewise, Wondimagegn and Lemma (2016) evaluated how people perceived climate change and what adaptation measures they chose based on actual data from smallholder farmers in east Ethiopia. Most farmers in the study area were aware of the negative effect of climate change on food security, diversity, income, food prices, forest resources, and diseases of crops and livestock. Similarly, Recha *et al.* (2017) studied climate variability and causes in Tharaka people of eastern Kenya, revealing misconceptions and gaps in understanding climate change causes and mismatch between community and individual perception of onset and cessation of rainfall.

Alike, Ubisi *et al.* (2017) found that subsistence farmers in Limpopo province, South Africa, primarily experience prolonged droughts (56.4%) as major shock to crop production, leading to low crop yield and high crop failure. Similarly, Habtamu *et al.* (2018) studied farmers' perception of droughts and found significant economic impacts, including decreased income and livestock loss during drought years in Tigray and Afar regions of Ethiopia.

Likewise, Hailay *et al.* (2019) studied farmers' perceptions of climate change trends in eastern Tigray and found that 98% and 92 % of farmers perceived a decrease in annual rainfall increase in temperature. Israel and Belay, (2019) also conducted a study on smallholder farmers' perception and adaptation to climate variability and change in Fincha sub-basin of Ethiopia and found 96.8 % and 56 % of the community responded that there is an increasing trend of temperature and trend of precipitation.

2.3.5. Empirical studies on adaptation strategies to rainfall variability and drought

Nhemachena and Hassan (2007) analyzed Southern Africa farmers' adaptation to climate change, highlighting crop diversification, changing planting date, increased irrigation, water and soil conservation techniques, and diversification from farm to non-farm activities as important adaptation options. According to Temesgen *et al.* (2007) and Torban (2010) smallholder farmers utilize improved crop varieties, agroforestry practices, soil conservation practices, irrigation, and adjusting planting dates as crucial adaptation strategies.

Similarly, Murendo *et al.* (2011) studied drought impacts and risk management by smallholder farmers in Awash River basin, in Ethiopia. They found that farmers were responsive to drought risk, using ex-ante adaptation strategies like, the storage of crop residues, drought-tolerant livestock rearing, mixed cropping, the use of soil and water conservation practices. Ex-post coping strategies utilized to manage the consequences of drought include the sale of assets and the reliance on consumption loans and support offered by informal networks.

Likewise, Akinnagbe and Irohibe (2015) evaluated African agricultural adaptation strategies to climate change impacts, identifying drought-resistant crop varieties, crop diversification, changes in cropping pattern and calendar of planting, soil moisture conservation, irrigation efficiency, and afforestation. Teshome (2016) explored indigenous knowledge's role to climate change and adaptation response in southern Ethiopia, revealing communities' adaptation response, including crop production, grazing, herd management, alternative income and traditional mutual supporting systems.

Similarly, Abreham *et al.* (2017) studied determinants of adaptation decisions to climate change in the Central Rift Valley of Ethiopia, and found that education, family size, gender, age, livestock ownership, farming experience, market access, climate information, farm size, income are key factors determining smallholders farmers' adaptation decisions.

Melese (2019) found that Ethiopian farmer's response to climate change in less rainfall and higher temperature are more likely to adopt different adaptation measures, indicating that rural households living in the mid highland (*Waina Dega*) are more likely to adapt to the changing situations than those in highland (Dega).

Zelalem *et al.* (2022) found that factors such as agro-ecological location of farmers, age, education, farm size, income from farming, access to information, extension service, and livestock ownership influence smallholders farmers adaptation strategies to climate variability in Suha watershed, Upper Blue Nile basin, Ethiopia.

Esubalew *et al.* (2023) found that factors like agro-ecology, education level, age, and active labor, number of livestock (TLU), off-farm income, and frequency of extension contacts, credit access, and market access significantly influence farmers' adaptation strategies change impacts in northwestern Ethiopia. Farmers employ various adaptation strategies to mitigate climate change impacts, such as altering crop variety, changing planting date, livestock production, animals' migration, feeds change, soil and water management, tree planting, off-farm employment planting short season and irrigation/water harvesting.

2.4. Major Indices of Rainfall Variability, Drought and Food Security

2.4.1. Major indices of rainfall variability

To examine rainfall variability data, several techniques have been implemented. Methods such as mean, coefficient of variation (CV), standard rainfall Anomaly (SRA) and Precipitation concentration index (PCI) are used to examine rainfall variability data. It is possible to characterize the temporal and spatial variability of rainfall using all these methods.

Arithmetic mean is given by: $\bar{x} = \frac{\sum \boldsymbol{X}}{\boldsymbol{n}}$ Equation (1)

Where, $\bar{x}$ =Mean X = variant n = total number of observations

Coefficient of Variation: Variability of rainfall has been computed using coefficient of variation (CV) Hare (2003), Coefficient of variation (CV) provides a measure of year-to-year variation the data series. Where,

$$\text{cv} = \frac{\sigma}{\bar{x}} * 100 \qquad \text{Equation (2)}$$

CV= coefficient of variation σ = standard deviation $\bar{x}$ = Mean rainfall (mm)

According to Hare (2003), CV is used to classify the degree of variability of rainfall events as less (CV < 20), moderate (20 < CV < 30), high (CV >30), very high CV >40% and CV >70% indicate extremely high inter-annual variability of rainfall. Based on this, the observed data considered that all the months had above 30 % coefficient of variation (CV) highlighting the high variability of precipitation over the zone.

Precipitation Concentration Index (PCI) defined by Oliver (1980) is also a powerful indicator for temporal precipitation distribution. Precipitation Concentration Index is used for evaluating seasonal precipitation changes to investigate the heterogeneity of monthly rainfall data. The calculation is described as follows:

$$\mathrm{PCI} = \frac{\sum_{i=1}^{12} pi^{2}}{\left(\sum_{i=1}^{12} pi\right)^{2}} \times 100 \qquad \text{Equation (3)}$$

Standardized Rainfall Anomaly (SRA). For each of the station seasonal mean precipitation, temperature and long-term mean seasonal rainfall and temperature series were analyzed for fluctuation using the SRA which is commonly used for regional climate change studies (Woldeamlak and Conway, 2007).

$$SRA = \frac{(s_t - s_m)}{\sigma} \qquad \text{Equation (4)}$$

Where SRA is the standardized seasonal rainfall anomaly in season t, S_t is the seasonal rainfall in season t, S_m is the long- term mean seasonal rainfall over the period of observation, and σ is the standardized deviation of seasonal rainfall over the period of observation. Therefore, positive (+) results of SRA indicate wet period and negative (-) indicate dry season.

2.4.2. Major indices of drought

Drought indexes are quantitative indicators that quantify and compare drought severity, duration, and extent across regions with varied climatic and hydrologic regimes. They simplify complex interrelationships between climate and climate-related parameters making them essential for drought monitoring and assessment (Stagge *et al.,* 2014). It makes it easier to communicate information about climate anomalies to diverse user audiences and allows scientists to assess quantitatively climate anomalies in terms of their intensity, duration, frequency, and spatial extent (Wilhite and Svoboda, 2000). An index presented as a numerical value is more usable and comprehensible than raw data providing decision making power for planners and policy makers (Zargar *et al.*, 2011).

Meteorological drought indicators, like the Palmer Drought Severity Index (PDSI) (Palmer, 1965), deciles (Gibbs and Maher, 1967), and the Standardized Precipitation Index (SPI) (McKee,1993). Numerous drought representation indices exist, some with superior performance in specific conditions, such as the (SPI) outlined in McKee, (1993) measures normalized anomalies in precipitation and have been recommended as a key drought indicator by the World Meteorological Organization (WMO, 2006).

The Standardized Precipitation-Evapotranspiration Index (SPEI) was developed to account for atmospheric conditions beyond precipitation such as temperature, wind speed, and humidity which may impact drought severity (Vicente-Serrano *et al.*, 2010). The SPEI normalizes climatic water balance anomalies, providing a more comprehensive measure of water availability, incorporating potential evapotranspiration PET, while maintaining simplicity, multi-temporal nature, and statistical interpretability (McMahon *et al.,* 2013).

The reconnaissance drought index, developed to characterize drought using precipitation and temperature data, was chosen for this study due to its ability to accommodate water deficiency (Tsakiris and Vangelis, 2005; Tigkas *et al.*, 2015). The reconnaissance drought index is best used for studies at a small spatial scale, whilst the SPI is used for varying time scales (Ikegwuoha and Dinka, 2020). Most studies primarily focus on regional and national scales, but local scale predictions are crucial. RDI for calculating the spatial and temporal distribution of drought as it balances precipitation and potential evaporation, and incorporates evapotranspiration, resulting in better association with agricultural and hydrological droughts impacts (Tsakiris *et al.*, 2005).

The Reconnaissance Drought Index (RDI) is an improved version of the Standardized Precipitation Evapotranspiration Index (SPEI), incorporating precipitation and potential evapotranspiration as key variables. The RDI is used for drought monitoring and climate change impact assessment, estimating drought as a ratio of accumulated precipitation and potential evapotranspiration PET (Tsakiris *et al*., 2007; Tigkas *et al.*, 2015).

Some of the advantages of the RDI are as follows:

The RDI is a reliable tool for assessing drought severity, calculates the aggregated deficit between precipitation and atmospheric evaporative demand. It can be used for various periods and directly linked to regional climatic conditions, making it an ideal tool for assessing drought severity across large geographical areas (Tsakiris *et al.*, 2007).

2.4.3. Major Dimensions of food security

The multidimensional nature of food security has been recognized that there is a need for a variety of means of measurement. Different measures or indices of food security have been developed; all these measures are capturing something about the multidimensional nature of food security. Some of the measures of food security are explained here:

Dietary diversity and food frequency: This form of statistic counts many types of food that people eat and how often they eat them. It may also include weighing the different food groups. The outcome is a score that indicates the variety of consumption rather than the quantity; yet studies have demonstrated a strong correlation between these scores and measures of caloric sufficiency (Coates *et al.,* 2007). The UN Food and Agriculture Organization and USAID have extensively marketed the Household Dietary Diversity Score (HDDS), which is like Food Consumption Score, but includes a 24-hour recall period without frequency information or weighted category cut-offs (FANTA 2006, FAO 2010).

Spending on food: Calculates the amount of money spent on food. Since those who are closer to the poverty line tend to spend a larger and larger percentage of their income on food, calculating the percentage spent on food has become a crucial metric (Smith *et al.,* 2006).

Consumption behaviors: Through the measurement of food-related behaviors, these metrics indirectly assess food security. The Coping Strategies Index or CSI (Maxwell and Caldwell, 2008) is the most well-known example. It measures the frequency and intensity of people's behaviors when they don’t have enough food or enough money to buy food. A more “universal” sub-set of coping strategies has been found to be significant in 14 distinct context-specific CSI instruments, according to the CSI (Maxwell, Caldwell, and Langworthy, 2008).

Self-assessment measures: self-assessment measures are not new, but they are very subjective and too easy to manipulate in a programmatic environment. These comprise the shift in livelihood status over a longer period and self-assessments of present food security status over a recent recall period. The Gallup survey was used to gather self-assessed food security data in order to analyze how the global food price crisis has affected food security (Headey, 2013).

Experiential measures: Certain indicators incorporate both psychological and behavioral measurements. The most well-known and frequently utilized of these measures in global settings are the Household Food Insecurity Access Scale and the Latin America and Caribbean Food Security Scale (ELCSA) (Coates, Swindale, and Bilinsky, 2006). The HFIAS was created to identify behaviors in households that indicate inadequate quantity and quality, as well as concern related to unsecured access. Three questions, none of which are psychological in character, make up the Household Hunger Score (HHS), which was developed from the HFIAS as a culturally invariant subset (Deitchler *et al*., 2010). FAO, USAID, and other organizations have embraced and supported HFIAS and HHS.

While the HFIAS encompasses a wider range of food security spectrum, the HHS measures the most severe effects of food insecurity (Maxwell *et al*., 2013). Throughout all four rounds of the study, the HFIAS measure reveals the highest prevalence of food insecurity in the survey areas. The distribution of HFIAS scores may suggest that, during stressful but manageable situations, the attitudes and actions measured by the HFIAS would be more regularly distributed than the coping mechanism found in the CSI. Another argument is that a high estimate of food insecurity is produced by the algorithmic process used to calculate the HFIAS (Maxwell *et al*., 2013).

2.5. Conceptual Framework

Climate change and variability pose significant global development challenges, particularly to developing and poor countries of the world (Dore, 2005; Mendelsohn and Williams, 2006; IPCC, 2007; Trenberth, 2011; IPCC, 2014). Climate change induced decreased precipitation, and increased temperature leads to drought in tropical areas, affecting agricultural performance, rural livelihoods, and food security due to (Amogne *et al*., 2017). Climate change could exacerbate food insecurity by increasing the frequency of rainfall variability and drought which causes significant damage to agricultural production, thereby escalating the existing food insecurity (WFP, 2016). Climate-sensitive sectors or resources may pose a significant risk to livelihoods that rely on them (IPCC, 2014). Societies who rely on rainfed agriculture are at a higher risk of food insecurity due to their vulnerability to climate change impacts (WFP, 2016). The impact of drought on agricultural communities varies, based on their socio-economic status, duration, and intensity of the drought (Ayanlade *et al.*, 2018). Frequent failure in crop production leads to food insecurity at a household's level.

Adaptation and mitigation options can help address climate change, but no single option is sufficient by itself (IPCC, 2014). Adaptation is location specific and temporarily reduces the negative impact of rainfall variability and drought on food security of SFHH. It involves perception and practice, with perception determining community practical experiences of adaptation. Smallholder farmers with the right perception use various adaptation strategies. Household perception, economic status and agro ecological setting influence SFHH's adaptation practices to rainfall variability and drought.

Perceptions and knowledge of rainfall variability and drought were the foundation of decision-making on adaptive responses. The community's experience should be taken into consideration when assessing climate data. Because the meteorological analysis of the climate variables demonstrates partial information required for decision. Therefore, understanding smallholders' view of the changing climate variable provides better insight to develop appropriate policy in the face of changing climate. Because decisions of adaptation practices of the SFHH were mainly based on perceptions of SFHH and empirical analysis of climate variables. However, misleading perceptions can induce inappropriate adjustment measures (Taylor *et al.,* 1988).

Local government and non-governmental organizations are crucial in implementing adaptation strategies for SFHH, promoting sustainable technologies, investments, and livelihoods to reduce greenhouse gas emissions, improving local microclimate (IPCC, 2014). Detected and accurately estimating drought duration and intensity can significantly alleviate its impact on food security in an area (Kogan *et al*., 2018). Governments must enhance early warning systems and communication channels to mitigate the negative impact of rainfall variability and drought on food insecurity. Mal-adaptation strategies, lack of early warning information, can lead to increased rainfall variability and drought, causing harm to the local environment and reducing agricultural productivity.

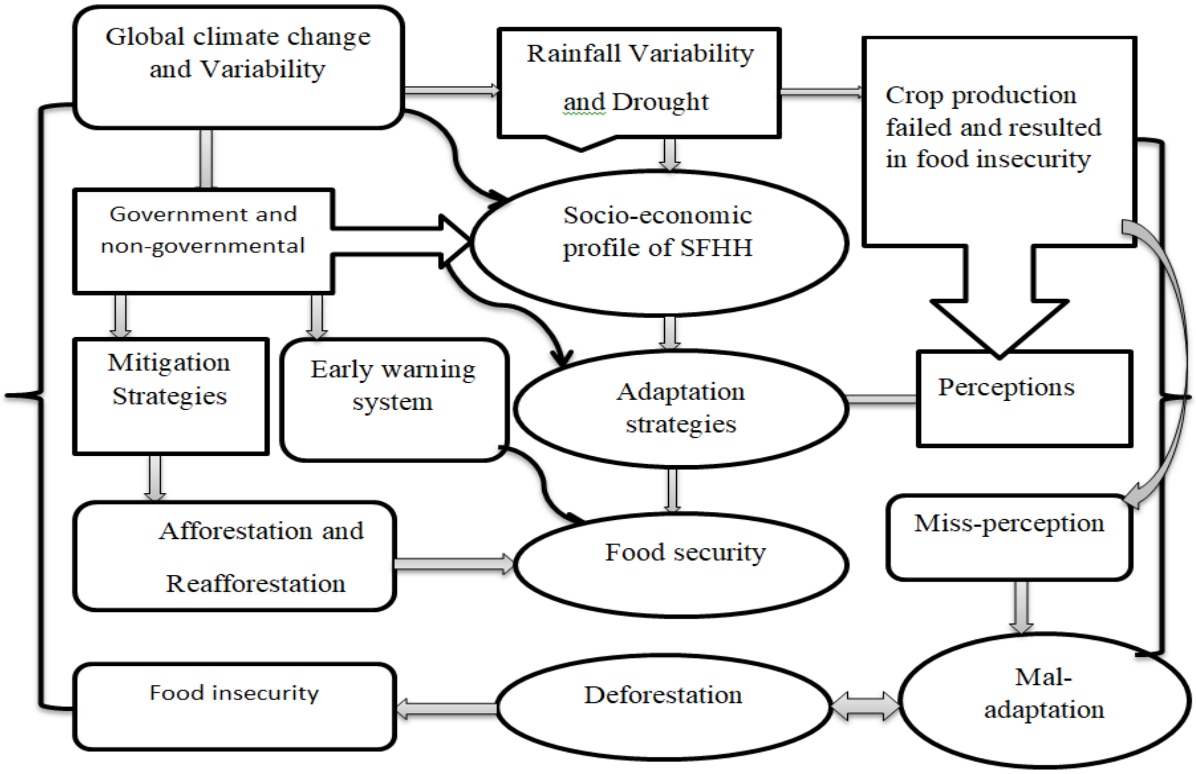


Figure 2. 1. Conceptual Framework of the Study

2.6. Research Design

In this study, a mixed concurrent research design was used. Both quantitative and qualitative research methods were applied concurrently. The design is intended to provide a better understanding of research problems by combining quantitative and qualitative approaches. Concurrent mixed research strategies seek to elaborate on or expand the findings of one methodology with another. In the same manner, in the study undertaken the quantitative finding was elaborated with a qualitative method. Because assessing drought and studying rainfall requires observed (recorded) statistical data, quantitative research is used. Thus, the study combined non-experimental quantitative research with narrative qualitative research methods. Therefore, the research is observational, descriptive, and non-experimental. Drought and rainfall variability were analyzed using standardized statistical procedures. Accordingly, a non-experimental quantitative research design does not involve manipulation of variables. The quantitative method was used to assess the spatial variability and temporal trends of rainfall and drought throughout the three AEZs in East Guji.

Gridded daily rainfall and minimum and maximum temperature data (0.04^0 by 0.04^0) of the sample stations were used to identify, measure, generalize variability and trends of rainfall and drought across the three AEZ of the study area under the study period (1990-2020). Since meteorological station data have fewer time series and more missing values, gridded rainfall data was preferred over it. Eleven stations' gridded time series rainfall data were quantitatively evaluated to characterize drought and analyze spatial variability and temporal trends of rainfall throughout the three AEZs. Using RDI, the trend, duration and severity and spatial coverage of drought were evaluated. As such, results of the study can be repeated and extrapolated to a comparable geographical area.

Methodological framework of the study

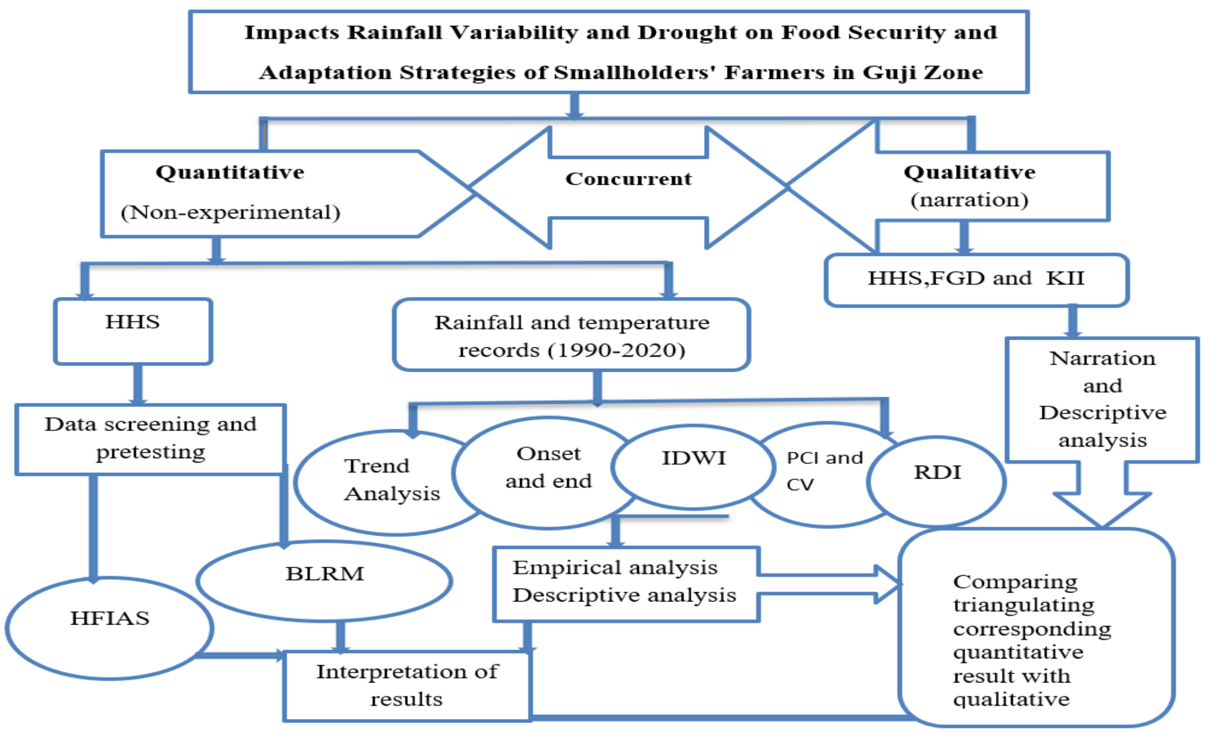


Figure 2. 2.Methodological Flow of the study

The combination of quantitative and qualitative research methodologies was used in study to examine smallholder farmers' perceptions of the effect of rainfall variability and drought on their food security and use of adaptation strategies. Based on the selected interpretivism, epistemology reality is multiple and subjective, formed and interpreted by individuals depending on their experiences, and there is neither control nor prediction. Corresponding households' perceptions with quantitative results of the empirical investigation of rainfall variability and drought was made. The study examined the effects of rainfall variability and drought on food security and adaptation strategies based on the household data, KII and FGD.

The empirical results need to be further explained with qualitative investigations. Thus, quantitative findings of rainfall variability and drought were combined with their implications on food security. The data from HHS, along with FGD and KII, were utilized to comprehend how a smallholder's household perceives the effects of rainfall variability and drought on their food security, their perceptions and adaptation plan. Based on the data gathered by HHS, FGD, and KII, the type of adaptation techniques employed in the three AEZ of the study area was assessed. Based on the socio-economic and demographic data collected from the HHS, the BLRM was applied to identify the determinants of adaptation strategies and food security SFHH. Ultimately, transcription, interpretation, and description (narration) of the qualitative data were done.

CHAPTER THREE

SPATIOTEMPORAL TREND AND VARIABILITY OF RAINFALL ACROSS AGRO-ECOLOGIES IN EAST GUJI ZONE, ETHIOPIA

ABSTRACT

Distribution and trends of rainfall reveal spatial and temporal variability that have paramount effects on the life and livelihood of smallholder farmers. This study aimed to analyze spatial variability and temporal trends of rainfall distribution across the three Agro-Ecological Zones (AEZs) of East Guji. Time series gridded daily rainfall data (1990-2020) were collected from the Ethiopian Meteorological Institute. Different descriptive statistics, Man Kendal trend tests and Sen's slope estimator, Inverse Distance Weighted Index (IDWI), Precipitation Concentration Index (PCI) and Coefficient of Variations (CV) were used in the study. The finding demonstrated that altitude and rainfall decrease as one advances from the western (highland) to the eastern (lowland) direction in the study area where the highest rainfall was recorded in Solemo (highland) and the least in Negele (lowland). The study revealed the positive relationship between altitude and rainfall as altitude increases rainfall also showed rise. Similarly, the mean length of the growing season declines as one descends from the highlands to the lowlands. The PCI of the lowlands, midlands, and highlands AEZs was 19%, 17%, and 12% respectively. The PCI showed that those highlands had moderately concentrated rainfall but both lowlands, and midlands, had an irregular distribution of rainfall. The CV indicated that highland areas had moderate variability in rainfall in all seasons except winter. In contrast, the low and midlands had shown high variability of rainfall (>30%) in all seasons. From a seasonal perspective, both CV and PCI revealed that the winter (December to February) season showed more variability than others. Moreover, a significant increasing trend of annual rainfall was observed in the highlands AEZs (Bore 15.3mm/year and Solemo14.6mm/year), lowland AEZs (Chembe 10.9mm/year, Dawa 8mm/year and Bitata 7.8mm/year) as well as midland AEZs (Kercha 14.5mm/year) at a significant level of 5%. Therefore, strategies should be designed to use additional water resources for irrigation; and provide short-cycle grown and drought-resistant crops in the rest of the midlands and lowlands AEZs.

Keywords: Autumn; Onset and Cessation; Temporal trends; Smallholder farmers and Spatial variability of rainfall and Spring

3.1. Introduction

Global climate change and climate variability increased erratic rainfall in many parts of the world (Merabtene *et al.,* 2016). Africa is a continent highly affected by the problem. Climate change caused increased rainfall variability in much of Sub-Saharan Africa (SSA) (Barana, 2017). Rainfall variability has a significant effect on the welfare of the household and national production of agriculturally based economies (Aschalew *et al.,* 2014). The future social-economic development of the African community is determined by water acquired from highly variable rainfall (Washington, 2006). In most parts of SSA, the amount of precipitation will decline by about 20% (Parry *et al.,* 2004) while its variability will increase (IPCC, 2014).

The remarkable spatial variability of rainfall will continue in the future (EPCC, 2015 ; Belay and Getaneh, 2016; Belay *et al.,* 2016). Several factors from local to global level influence the distributions of rainfall in Ethiopia. In Ethiopia, a spatial variation of rainfall is observed across the different AEZs. The local variability of rainfall in Ethiopia is articulated by multifaceted topography which ranges from 4620m above sea level at Ras Dashen Mountain to the lowest at Afar Depression (Kobar Sink)120m below sea level (FAS, 2019). There is also temporal variability of rainfall from days to season and decades. Particularly, rainfall variability has great influences on the life and livelihood of smallholder farmers in Ethiopia. Ethiopia is the most vulnerable to the effects of rainfall variability. Since agriculture is the backbone of the Ethiopian economy it contributes about 40% of the GDP, 80% of total employment, and 90% of exports. Besides, 79% of the population depends on rain-fed agriculture for their income (Young and Klingaman, 2020, Tafesse and Tewodros, 2019).

Besides global factors: such as the El Nino–Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) and the Inter Tropical Convergence Zone (ITCZ) influenced the seasonal rainfall variability over Ethiopia (Diro *et al.,* 2011; Nicholson, 2017). El Nino weakens the high-pressure air mass in the South Indian and South Pacific Oceans that causes rainfall in Ethiopia (Kassahun, 1999). Complete models on the impact of El Nino on Ethiopian climate variability are lacking because of the existence of different AEZs which resulted in many microclimates and a lack of meteorological data (Tsegaye *and* members, 2000).

So far, several studies have found that complex trend of rainfall distribution in various parts of the country. Conway *et al.,* (2004); Yilma and Zanke, (2004); Rosell and Holmer, (2007) reported significant declines in the annual and summer (*kiremt)* rainfall totals in the eastern, southern, and southwestern, northern, north-central, north-western, and western parts of the country. However, the study by Rosell and Holmer, (2007) also indicated an increasing trend of annual rainfall at some locations in eastern Ethiopia as well as an increase in annual and summer *(kiremt);* a decrease in spring (*belg*) rainfall in central Ethiopia. Getachew *et al.* (2021) reported the annual rainfall showed a non-significant decreasing trend over West Harerge. Matios *et al.* (2022) reported a declining trend of annual and March-May rainfall (long rain) or spring in the Guji Zone.

Further, the national-level study by Negash *et al.* (2013) showed varied rainfall patterns in different parts of the country. Likewise, Yimer *et al*. (2018) reported a significantly increasing trend of summer rainfall in some of the stations and a declining tendency in spring rain in all studied stations in Southern Wollo. Wagaye and Antensay, (2020) also reported a significant decreasing trend in spring *(belg)* and winter (*bega)* rainfall and increasing annual and summer (*Kiremt)* rainfall in central Ethiopia. Likewise, Aragaw *et al.* (2020) showed significantly increasing trends of annual and seasonal rainfall totals in the western part of Ethiopia. Similarly, Abrham *et al.* (2021) reported an increasing trend of annual, summer (*kiremt*) and winter (*bega*) rainfall whereas the spring (*belg*) season rainfall showed a significant decreasing trend in southern Ethiopia. A recent study conducted by Mitiku *et al.* (2022) demonstrates rainfall showed a significant increasing trend during August, October, and November and was extremely variable during December, January, and February in Borena, Southern Ethiopia.

Although topography is prominent in determining the distribution of rainfall in Ethiopia most of the existing studies were not AEZs centered except the study by Befikadu *et al.* (2018) in Wolaita; Mintesinot *et al.* (2019) in North Western Ethiopia; Ashenafi *et al.* (2022) in Northern Shewa; Toni *et al.* (2022) in Wabi Shebele basin. Since large-scale studies highly mask the spatial and temporal variability of rainfall, further AEZ based local-level investigation of variability and trends of rainfall events were suggested by many authors (Woldeamlak and Conway, 2007; Mekonnen and Weldeamlak, 2015; Daniel, 2016; Mitiku *et al*., 2022) due to the existence of diverse microclimates in the country. This study gives prior emphasis on the influences of AEZs in the spatial variability and temporal trends of rainfall distributions in Guji Zone.

Given the high dependence on rain-fed agriculture, it is important to precisely characterize the spatial variability, temporal trends, onset and secession, and distribution of rainfall in each AEZ. Hence, there is no previous investigation that has examined the spatial variability and temporal trends of spring and autumn rainfall in the three AEZs of the study area. The study fills gaps in knowledge of the spring (*belg*) and autumn (*meher*) seasons, spatial variability and temporal trends of rainfall in the different AEZs of the Guji zone. Thus, identifying rainfall variability at this micro-scale level provides relevant information which enables stakeholders to design context-specific adaptation strategies in different AEZs. Therefore, the objective of this study is to analyze spatial variability, temporal trends, onset and cessation, and distribution of spring and autumn rainfall across the three AEZs using long-time series rainfall data.

3.2. Materials and Methods

3.2.1. Descriptions of the study area

This study was conducted in the East Guji Zone, in the Southern part of Oromia Regional State, Ethiopia. Geographically, the East Guji Zone is located between 4^0 30' N - 6^0 30' N latitude and 38^0 15' - 40^0 5' E longitudes (Figure 3.1) and covers a total area of about 18,577 Km^2. It shares a border with Gedeo and Sidama in the North, Somali Regional State in the South, Bale Mountain in the East and Borena Zone in the West. The northern and eastern neighbors of the East Guji zone mainly have highland AEZs that experience a wetter microclimate (Matios *et al*., 2022). The southern and the western adjacent land of the study area holds the lowland AEZs that experience relatively drier climate conditions (Mitiku *et al.*, 2022). Borena which border the east Guji zone in the west is mainly lowland which embraces a semiarid and arid climate and recently has been highly affected by drought (Indale *et al.* 2023).The total population of the area as projected by (CSA, 2022) was 2,030,667 in 2022. The Guji Oromo are the dominant ethnic group which represented 95.57%, the Amhara people 2.43%, and the Somali 2% (CSA, 2007). They are predominantly pastoralists, agro-pastoralists and farmers (Teshome, 2016). Coffee is an important cash crop in the Guji zone (Lazzari *et al.*, 2021).

The biophysical characteristics of East Guji

The study area is situated in the southern part of Ethiopia, which experienced bimodal rainfall

cycles in spring (March–May) with a peak in April/May and autumn (October–November) (Diro *et al.*, 2011). The area is characterized by a bimodal rainfall pattern where the long rainy season (*Arfansa*) occurs from March to May and accounts for 48% of the annual rainfall whereas the short rainy season (*Hagaya*) extends from September to November which shares about 36% of the annual rainfall. Thus, spring (*belg or arfansa*) and autumn (*meher or Hagaya*) cover around 84% of rainfall in lowlands and midlands AEZs of East Guji (Figure 3.2). Besides, the mean rainfall in the midlands and lowlands for winter and summer was 6% and 10% respectively.

Thus, four distinct seasons have been identified within the study area namely; the major dry season winter, also known as *bega* (December to February), spring also known as *belg* is long rainy period (March-May); summer or *kiremt* (June-August) are relatively dry seasons except for the highland area which receives better rainfall in the summer season; and autumn also known as *mehe*r (September-November), which is the short rainy period. The highland area receives better rainfall in the summer, but for low and midland AEZ the winter (*bega*) and summer (*kiremt)* are comparatively dry seasons. As such, the highlands part of East Guji receives a corresponding amount of rainfall in the three seasons of spring (34%), summer (30%), and autumn (29%).

The elevation of the study area ranges from 632m to 2960m above sea level, and is categorized under the three AEZs. They are lowlands (*kola*) 500m-1500m, midland (*woina Dega*) 1500m-2300m, and highland (*Dega*) 2300m-3200m based on (Hurni, 1998) which; covers about 27.3%, 51.5%, and 21.2% of the total area, correspondingly. The mean annual rainfall in the Guji Zone for lowlands, midlands, and highlands is 747mm, 932mm, and 1232mm respectively (Table 3.6 and Table 9.1 in the appendices). The mean temperature records were 22.1˚C, 19.4˚C, and 15.8˚C in the lowlands, midlands and highlands AEZs correspondingly (Table 9.2.1. in the appendices).
As a result of a multiplicity of AEZs and soil set up in the area, there are a variety of vegetation covers: dense natural forests, planted trees, acacia, and scrubs are major land covers in Guji. The dense forest resource of the Eastern Guji Zone comprises the Bore-Anferara National Priority Forest Area and the Anferara-Wadera National Forest Priority area. These areas are among the 58

Priority Forest Areas (PFAs), which have been so designated to protect biodiversity and conserve forest resources in Ethiopia.

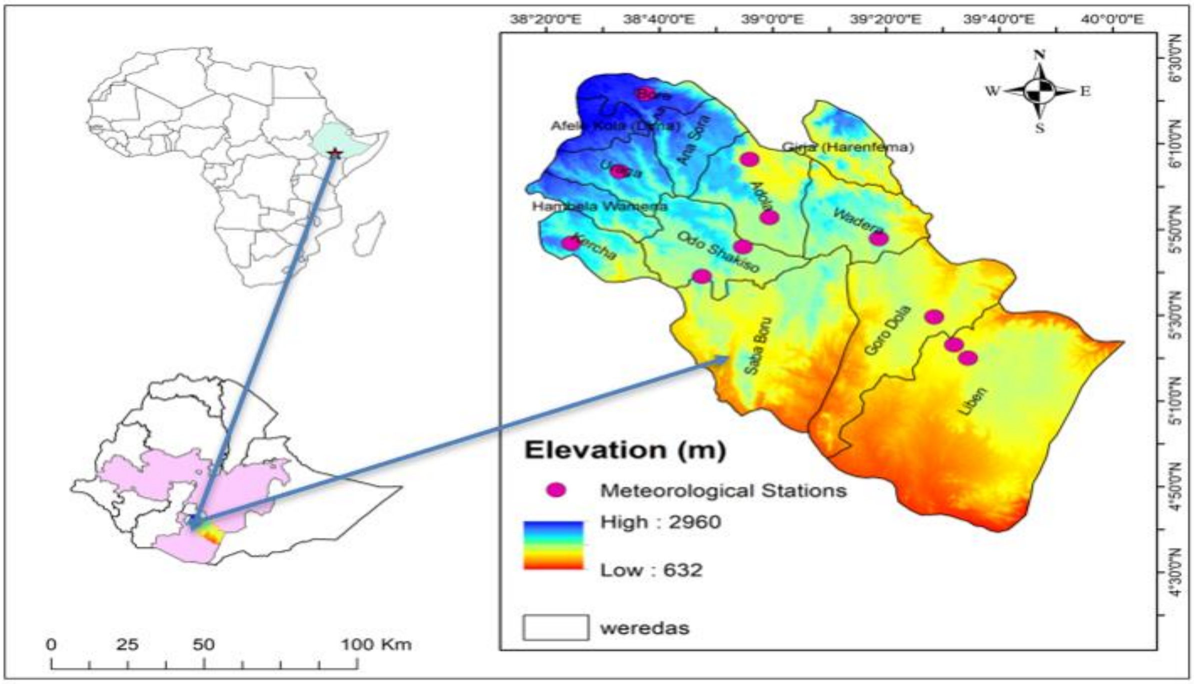


Figure 3. 1.Location Map of the Study Area

Source: Projection WGS_1984_ UTM _Zone_37^{0}

3.2.2. Sources of data

The study followed quantitative research design. Quantitative research is selected because the study is grounded on observed (recorded) statistical data. A standardized procedure was followed to analyze the data. Thus, the output of the study can be replicated and generalized to a similar study. It is non-experimental, descriptive and observational research. Non-experimental quantitative research design refers to there is no manipulation of variables in the study. The research described the spatial variability and temporal trends of rainfall across the three AEZs in Eastern Guji. Gridded rainfall data (0.04˚ by 0.04˚) of the sample stations were taken from Ethiopian Meteorological Institute (EMI) to detect, quantify and generalize variability and trends of rainfall over the studied period (199-2020). The gridded rainfall data was chosen over meteorological station data since the latter has more missing values and short time series data. Gridded time series rainfall data of eleven stations were assessed quantitatively to analyze spatial variability, temporal trends, onset and cessation and distribution of rainfall. Some descriptive statistics such as percentage, mean, and standard deviation were used in the study. Finally, results were systematized on tables and figures followed by proper discussions.

3.2.3. Sampling procedure

Probability and non-probability sampling procedure was used to select an appropriate sample for the study. Guji Zone was selected through purposive sampling as it represents three AEZs such as lowlands, midlands and highlands which can be used to show the spatial dimensions of rainfall variability in the area. Moreover, the area has been experiencing more rainfall variability in recent years. A stratified random sample procedure was applied to select the required groups or strata for the study. AEZs are considered as strata for the study. A random sample is selected from each stratum based on the percentage of each AEZs embraced. Lowland, midland and highland AEZs cover about 27.3%, 51.5% and 21.2% of the total area, respectively (Figure 3.2). By considering the distributions of AEZ in the study area, five, four, and two stations from midland, lowland, and highland AEZs respectively were randomly assigned. Accordingly, the randomly chosen stations (grid cells) include: Chembe, Dawa, Negele, Bitata, Oddo Shakiso, Adola (Kibre Mengist), Harekello (Goro Dola), Wadera, Kercha, Solemo (Uraga), and Bore (Table 3.1).

Table 3. 1.Location of the study Stations and Length of Rainfall Series (1990-2020)

AEZs	Stations	Elevation in Meter(m)	Latitude In degree (^{0})	Longitude In degree (^{0})
Lowlands *(Kola) 632m-1500m*	Chembe	1025m	6^0	$38^055'$
	Dawa	1177m	$5^033'$	$38^048'$
	Negele (Liben)	1439m	$5^041'$	$39^036'$
	Bitata	1473m	$5^030'$	$39^025'$
Midlands *(Woinadega)* 1500m -2300m	Odo Shakiso	1620m	$5^045'$	$38^056'$
	Adola (Kibre Mengist)	1680m	$5^054'$	$38^058'$
	Harekello (Goro Dola)	1708m	$5^025'$	$39^028'$
	Wadera	1750m	$5^046'$	$39^018'$
	Kercha	2036m	$5^046'$	$38^025'$
Highlands (*Dega*) 2300m-2960m	Solemo (Uraga)	2362m	$6^005'$	$38^034'$
	Bore	2712m	$6^025'$	$38^036'$

Data Source: Ethiopian Meteorological Institute

3.2.4. Method of data collection

To evaluate the temporal trend and spatial distribution of rainfall in the Guji Zone, secondary data is crucial to understanding the overall situation. Secondary data, including rainfall, temperature, altitude, latitude, and longitude, were gathered from the sources of registered meteorological data (Table 3.1) from the EMI. Gridded daily rainfall data with a grid cell size of 0.04 degrees, or 4 km ×4 km for the years 1990-2020 were acquired from the EMI for the chosen locations. A wide range of sources, including academic journals, books that have been published, unpublished working papers, research and thesis papers, government policy papers and reports, and regional agricultural and climatic documents, were also consulted for valuable information. This data was collected to examine the temporal trend and spatial distribution of rainfall in the Guji Zone.

3.2.5. Methods of data analysis

Descriptive Analysis

At every level of data analysis descriptive statistics such as frequencies, means, percentages and standard deviation were utilized. Using those descriptive statistics, the distribution, trend, and variability of rainfall in the Guji zone were examined. Besides, descriptive statistics were employed to examine the mean, standard deviation and coefficient of variation of rainfall of each station under the study period. The mean onset and cessation period of rainfall was explained using descriptive statistics. The contribution of seasonal rainfall to annual and the frequencies of positive and negative trends in MMR distribution were described in percentage. The results were then arranged in tables and figures and appropriate debates ensued.

Empirical analysis

Excel-STAT and GIS software programs were utilized to examine quantitative data. Excel-STAT was used to perform statistical analysis of rainfall. Geographic Information System (GIS) software was used to interpolate rainfall using IDWI. The spatial distributions of annual and seasonal rainfall were mapped using IDWI interpolation in arc GIS. The study employed several data analysis techniques. Rainfall data were analyzed using a variety of statistical methods. Olaniran modification of Walter's formulation was used to determine the variability of the onset and cessation date of rainfall in each of the three AEZs within the study area. The non-parametric Mann Kendall and Sen's slope estimator tests were used to analyze trends and magnitude of change in rainfall respectively. Furthermore, monthly, seasonal and annual rainfall variability was identified through the application of PCI and CV.

3.2.5.1. Onset and cessation of rainfall

The knowledge and variation of rainfall onset, cessation and length of the growing season has a paramount importance to agricultural activities and planning for sustainable food yield depending on rainfall. Several methods exist to estimate the variability of the date of rain onset and cessation of the growing season. For the study onset and cessation date was determined using Walter's formulation as modified by Olaniran (1989). The approach was chosen because it determined the onset using a threshold value of 51mm cumulative rainfall. Given that lowland and midland make up around 80 % of the research area. The area is distinguished by comparatively high temperatures and evapotranspiration. As a result, the locality needs a lot of precipitation before planting can take place. The approach reduces the amount of time that false onset days are considered, which causes the rainy season to end earlier than expected. According to this method, the first day of rain is not the onset date of the rain; rather, it is the moment a location receives an accumulation of rainfall exceeding 51mm is considered as the day of rainfall commencement. The date after which 51mm of rain is not predicted is known as the cessation date (Patrick *et al.*, 2019). The procedure is stated as follows:

$$\text{Onset/End} = \frac{DM}{TM} \times (51 - AP) \qquad \text{Equation (1)}$$

Where, DM= number of days in the month that contain the onset; TM = is the total monthly rainfall that falls below 51mm; AP = is the monthly total rainfall from months prior to the month under consideration; and 51mm is the threshold of rainfall for both Onset/End months. The next rainy date that is up to 51 mm or more will be selected in cases where rainfall levels less than 51 mm occurred after such an onset date (Mosunmola *et al.*, 2020). The time between the start of the rainy season and its end is known as the length of the growing season's duration in rain-fed environments.

3.2.5.2. Trend analysis of rainfall

To determine long-term trends in rainfall variability as well as the rate of change in seasonal and annual time steps in three AEZs of the study area, the study used nonparametric Mann-Kendal's trend test and Sen's slope estimators. The World Meteorological Organization (WMO) strongly advises using the Man Kendall test (Abebe and Arega, 2020). It is selected for trends test in a time series data because it doesn't require linearity or normality, is less sensitive to outliers or is resistant against the influence of extremes (Wang *et al.,* 2020; Poudel and Shaw, 2016)

When Z indicates a significant trend at a given significance level at ($P < 0.05$) it surpasses both confidence limit lines. Therefore, H_o is rejected and H_1 is accepted instead. Where, n denotes the number of data points; and x_j and x_i are the time series observations in years' j and i, j>1.The Mann-Kendall statistic S of the series x is obtained using the following Equation:

$$S = \sum_{i=1}^{n-1} \sum_{i=K+1}^{n} sign\left(X_j - X_i\right) \qquad \text{Equation (2)}$$

$$\text{Sign of } (X_j - X_i) = \begin{cases} +1 \text{ if } (x_j - x_i) > 0 \\ 0 \text{ if } (x_j - x_i) = 0 \\ -1 \text{ if } (x_j - x_i) < 0 \end{cases} \qquad \text{Equation (3)}$$

The individual sign capacity that can take on the values [1,0, or -1] is denoted by the symbol Sign (X_j–X_i). An increasing trend is shown by a positive S value, whereas a decreasing trend is indicated by a negative value. Compute the variance of S using the formula below:

$$Var = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p\left(t_p - 1\right)\left(2t_p + 5\right)\right] \qquad \text{Equation (4)}$$

Where t_p is the total number of data points in the p^{th} group, n is the number of data points, and g is the zero difference between compared values. The following formula is used to get standardized measures of test statistics (Z_{mk}):

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} if S > 0 \\ 0 \text{ if } \quad S=0 \\ \frac{S+1}{\sqrt{VAR(S)}} if S < 0 \end{cases} \qquad \text{Equation (5)}$$

The magnitude of time series change was identified using a straightforward non-parametric method developed by (Sen, 1968). According to Sen (1968), this test calculates the interception and the linear rate of change (slope). Sen's slope estimator is used in the following calculation to determine the trend’s magnitude. The Sen's slope is calculated by using equation 6:

$$\beta = Median\left(\frac{x_j - x_i}{j - i}\right), j > i \qquad \text{Equation (6)}$$

Where β is Sen's slope estimate $\beta > 0$ indicates an upward trend in a time series. Otherwise, the data series presents a downward trend during the period.

3.2.5.3. Precipitation concentration index (PCI)

Oliver (1980) established the precipitation concentration index (PCI), which is a prominent measure of the temporal distribution of precipitation. PCI was utilized to assess seasonal variations in precipitation and investigate the heterogeneity of monthly rainfall data. The annual, seasonal and monthly variability of precipitation was examined in the study using PCI. The calculation is explained in equation 7 as:

$$\mathrm{PCI} = \frac{\sum_{\mathrm{i}=1}^{12} \mathrm{pi}^2}{\left(\sum_{\mathrm{i}=1}^{12} \mathrm{pi}\right)^2} \times 100 \qquad \text{Equation (7)}$$

Where: Pi=the total rainfall of i^{th} month

According to Oliver (1980), PCI values fall into one of four categories: uniform (<10) presents a uniform distribution of rainfall, (11-15) indicates moderate, (16-20) shows irregular, and (> 21) shows a strong irregular monthly rainfall distribution.

3.2.5.4. Coefficient of variation (CV)

The coefficient of variation (CV) is used to calculate the variability of rainfall. Coefficient variation (CV) provided a measurement of year-to-year fluctuation in the data series. The degree of rainfall variability is categorized as high (CV> 30), moderate (20 < CV > 30) and low (CV < 20) (Hare 2003),

$$\mathrm{cv} = \frac{\sigma}{\bar{x}} \times 100 \qquad \text{Equation (8)}$$

Where: CV= coefficient of variation σ = standard deviation $\bar{x}$ = Mean rainfall (mm)

3.2.5.5. Inverse distance weighted index (IDWI)

A method for spatial analysis called Inverse Distance Weighted Index (IDWI) is used to show the spatial trends of rainfall. For time series, the IDWI is a metric between neighboring stations. Inverse distance interpolation is among the most straightforward, simplest, and most popular interpolation techniques. It blends the idea of proximity with the trend surface's steady change. A geographically weighted average of the sample values inside the search neighborhood is known as inverse distance (ID) weighted interpolation is defined (Diodato and Ceccarelli, 2005). The spatial distributions of annual and seasonal rainfall were mapped using IDWI interpolation in arc GIS (spring and autumn).

3.3. Results and Discussions

3.3.1.Agro ecology-based spatial variability of rainfall

The section describes the spatial distribution of rainfall over the three AEZs of the East Guji. The spatial distribution of rainfall in the studied area was influenced by altitude where 27%, 51.5% and 21.2% of the study areas, are highlands (*dega*), midlands (*weina Dega*), and lowlands *(Kola)* AEZs respectively (Figure 3.2). The highland (dega AEZ) in the western portion of the study area where Solemo (Uraga) is found, received the maximum annual rainfall (1273mm). The midland (*weina Dega*) AEZ makes up the majority of the research area's central and eastern regions. The southeast part of the study area is lowland (*Kola*) with Negele (Liben) recording the least amount of rainfall (624 mm) is found. In the study area, altitude and rainfall decrease as one moves from the west (highlands) to east (lowlands) (Figure 3.3). The spatial distribution of rainfall map shows that the study area obtained the highest amount of rainfall in spring (*belg*) and autumn (*meher*) seasons. The midlands Adola and Shakiso received their highest rainfall during spring, while the lowlands Chembe received its highest rainfall in autumn. The highland AEZ's Bore and Solemo received the highest rainfall in summer and annual.

Finally, the spatial variability of rainfall in the study area was expressed through contrasting reality observed across the highlands, midlands, and lowlands AEZs. Primarily, the variability in the onset and cessation resulted in LGP diminishing from the highlands to the lowlands and midlands AEZs.

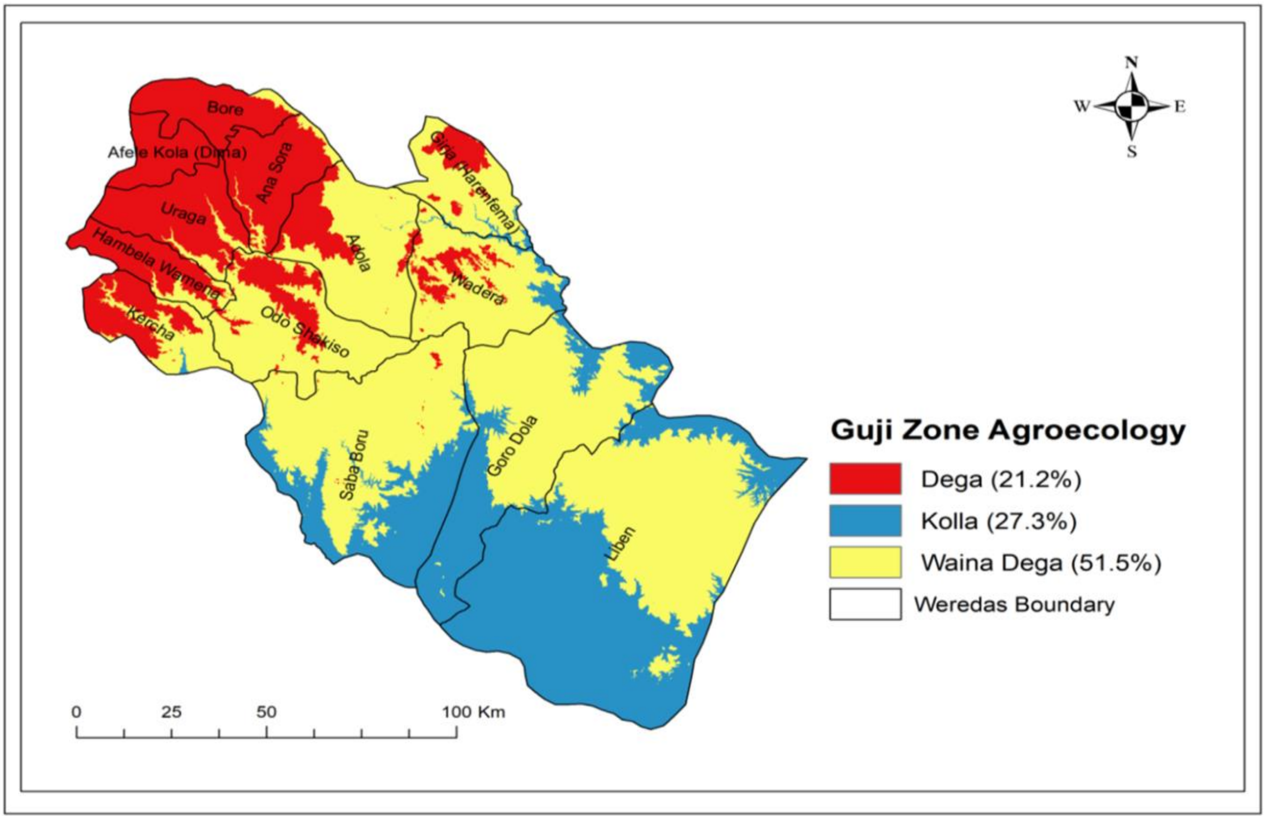


Figure 3. 2. Distributions of AEZs in the Study Area

Data Source: Extracted from Ethiopian Meteorological Institute

Single and long LGP was witnessed in the highland AEZ whereas a dual growing period with short LGP was observed in the lowlands and midland AEZs of the study area. Besides, the seasonal distribution of rainfall in the three AEZs of the study area revealed that the highlands received almost the same amount of rainfall in three seasons except winter (Figure 3.3). In contrast, the lowlands and midlands gain maximum rainfall in the spring and autumn seasons whereas summer and winter are relatively dry seasons (Figure 3.3). In addition, a significant increasing trend of the annual and autumn rainfall was observed mainly in the highlands, most of the lowlands and in some of the midlands AEZ. On the other hand, the rest of the stations in the mid and lowlands AEZs have an insignificant increasing trend of the annual rainfall. To conclude, 78.8% of the study area is enclosed with the midlands and lowlands which received scarce rainfall. The implication is that midlands and lowlands faced severe problems of variability in the onset and end, short LGP and lack of significant trend on monthly and seasonal rainfall. Consequently, variability and scarcity of rainwater for agriculture prevailed in the midland (*Weinadega*) and lowlands (*Kola*) AEZ of the study area.

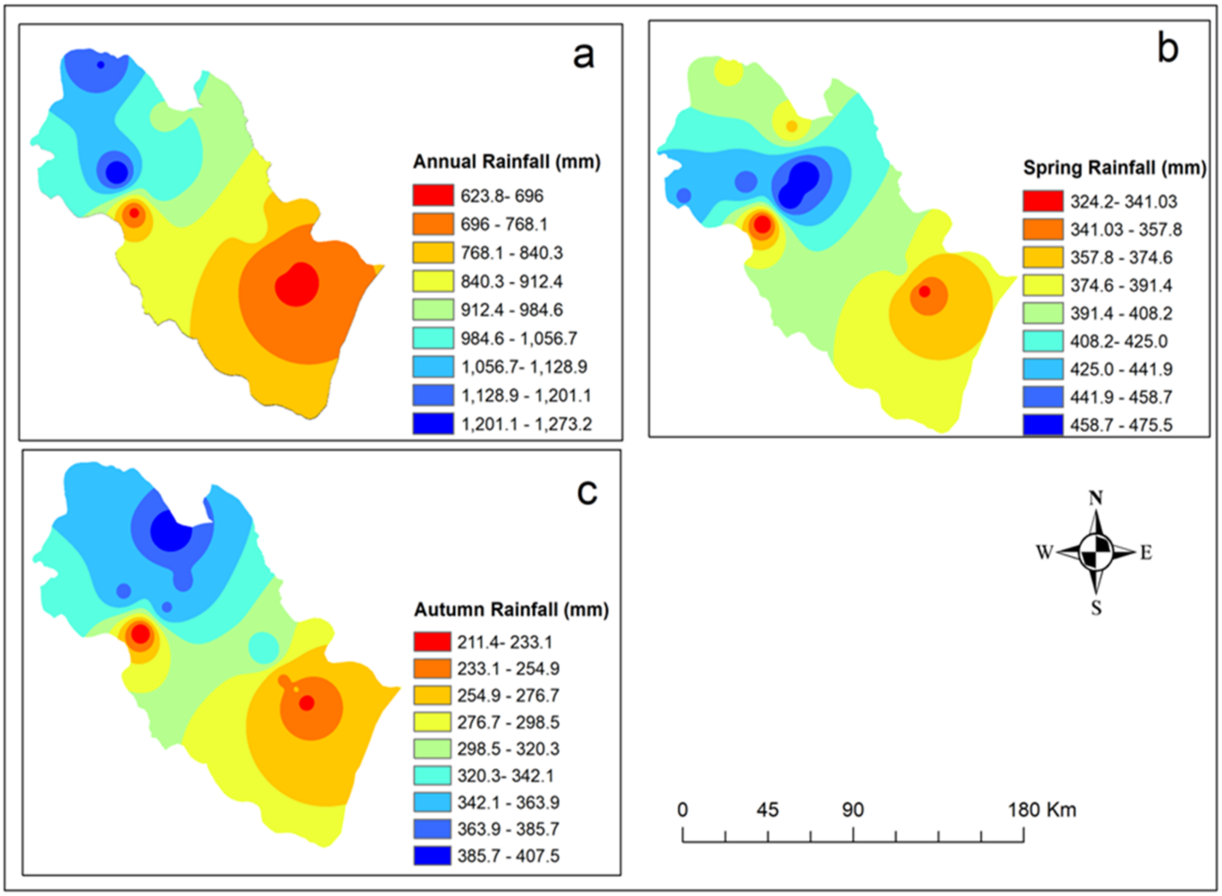


Figure 3. 3. Spatial Distributions of Rainfall in the Study Area Using IDWI

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

3.3.2. Agro ecology-based variability of onset and cessation of rainfall

The section explains the nature of rainfall onset and cessation in East Guji from 1990-2020. There are two different onset and cessation phases in the autumn and spring seasons for the lowlands and midlands (Table 3.2). They are accustomed to having two growing seasons. In the midland AEZ, the spring rainfall season starts on April 20 and terminates on 24 May; the autumn rainfall starts on October 13 and ceases on November 10. Consequently, the mean length of growth period (LGP) in the midlands was 35 days for the spring and 27 days for the autumn seasons. In the lowlands AEZ, spring rainfall starts on April 25 and ends on May 18; autumn rainfall begins on October 15 and ends on November 7. The LGP for spring and autumn seasons in the lowlands were 23 and 16 days, respectively. On the other hand, the highland AEZs, where single growing prevails, spring rainfall typically begins on April 18 and ends on November 2. Therefore, the LGP decreases as one descends from highlands AEZs to midlands and lowlands AEZs in the study area.

Table 3. 2.Onset and Cessation of Rainfall in the Study Area

Stations	Spring Onset			Spring Cessation				Autumn Onset			Autumn Cessation			
	$\bar{x}$	CV	DOY	$\bar{x}$	CV	DOY	LGP	$\bar{x}$	CV	DOY	$\bar{x}$	CV	DOY	LGP
Chembe[1]	115	13	April, 25	142	40	May, 22	27	271	9	Sep, 28	295	12	Oct, 22	24
Dawa[1]	115	43	April, 25	146	37	May, 26	31	297	34	Oct, 24	311	50	Nov, 7	14
Negele [1] (Liben)	117	15	April, 27	132	36	May, 12	15	307	30	Nov, 3	313	32	Nov, 9	6
Bitata[1]	112	11.5	April, 22	132	20.5	May, 12	20	299	25	Oct, 26	318	48.5	Nov, 13	19
Shakiso[2]	109	20	April, 19	147	21	May, 27	38	289	7	Oct, 16	315	38	Nov, 10	26
Adola[2] (KM)	107	20	April, 17	146	26.5	May, 26	39	285	26	Oct, 12	317	35	Nov, 13	32
Hare Kello[2]	115	13	April, 25	139	32	May, 19	24	296	19	Oct, 23	317	44	Nov, 13	21
Wadera[2]	112	17	April, 22	137	39	May, 17	25	289	6	Oct, 16	314	40	Nov, 10	25
Kercha[2]	107	24	April, 17	151	45	May, 31	44	259	43	Oct ,9	309	26	Nov, 5	50
Solemo[3]	107	16	April, 17	NA	NA	NA	NA	NA	NA	NA	306	5	Nov, 2	199
Bore[3]	108	16	April, 18	NA	NA	NA	NA	NA	NA	NA	306	7.5	Nov, 2	198

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)
Note: [1]Located at lowlands AEZ (*Kolla*); [2]Located at midlands AEZ (*Woina Dega*); and [3]Located at highland AEZ (*Dega*); $\bar{x}$ =mean day of onset; NA=Not Applicable; DOY=Days of the year; LGP=Length of Growing Period, and AEZ=Agro Ecological Zone

Small variations in LGP, especially in short LGP, have significant ramifications. CV is a helpful indicator of variability in the length of the growing season. Short growing seasons are associated with high CV values, and long growing seasons are associated with low CV values. The highland AEZs have low CVs of 16 % and 6% for the onset and cessation periods, respectively. Besides they had a long LGP of 198 days. The result suggests that the highlands enjoy an extended period of rainfall from April to November. The distribution of rainfall in the highlands was regular. In the midland and lowland AEZs, however, practicing rain-fed agriculture with such a short LGP has been puzzling.

In the lowland and midland, the CV for the beginning of spring rains was 21% and 19%; autumn season was 24% and 20% respectively. The CV for the end of spring and autumn rainfall was 33% and 36%, respectively. Very high CV (>30) in the cessation of the spring and autumn rainfall together with short LGP was detected in the lowland and midland AEZs. Lowlands and midlands experienced greater variability of rainfall during the cessation period than start period (Table 3.3).

Table 3. 3. Trends of Onset and Cessation of Rainfall in the Study Area

Stations	Spring Onset			Spring End			Autumn Onset			Autumn End		
	MKT	S	P	MKT	S	P	MKT	S	P	MKT	S	P
Chembe[1]	0.03	13	0.83	-0.21	-95	0.11	-0.24	-94	**0.07***	-0.02	-11	0.86
Dawa[1]	-0.14	-63	0.29	0.15	70	0.24	-0.04	-14	0.77	0.02	9	0.88
Negele[1]	-0.05	-21	0.73	0.04	18	0.78	0.09	40	0.51	0.007	3	0.97
Bitata[1]	-0.14	-65	0.27	0.06	30	0.62	0.09	46	0.44	0.11	48	0.39
Shakiso[2]	0.08	37	0.54	-0.13	-47	0.33	-0.19	-85	0.13	0.13	43	0.35
Adola[2]	0.05	25	0.68	-0.15	-73	0.22	-0.32	-152	**0.01***	0.15	73	0.22
Harekello[2]	-0.10	-49	0.41	-0.03	-12	0.85	-0.23	-101	**0.07***	0.30	139	**0.01***
Wadera[2]	0.07	28	0.61	0.27	125	**0.03***	-0.04	-19	0.75	0.13	60	0.31
Kercha[2]	0.14	65	0.27	0.096	44	0.46	-0.04	-18	0.77	0.26	107	**0.05***
Solemo[3]	-0.02	-7	0.92	NA	NA	NA	NA	NA	NA	0.17	77	0.196
Bore[3]	-0.006	-3	0.97	NA	NA	NA	NA	NA	NA	0.114	53	0.38

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)
Note: * Level of significance = P <10 %

Note: [1]Located at lowlands AEZ (*Kolla*)**;** [2]Located at midlands AEZ (*Woina Dega*); and [3]Located at highland AEZ (*Dega*); NA=Not Applicable

Therefore, the ending date for both spring and autumn rainfall is unexpected which has an immense impact on crop production. The opposite conclusion was reached by Mesay (2006), who discovered that the beginning of the spring *(belg)* rains had more variability than the ending period.

In addition, the National Meteorological Agency (NMA, 2015) reported that *belg* season is characterized by a delayed start, extended dry spells, and an early end to the rainy season.

The trends of the onset and cessation of seasonal rainfall in Guji Zone are illustrated in (Table 3.3). In all AEZs, there was no statistically significant trend in the onset of spring season rains; a rather insignificant declining trend was noted during this season. Furthermore, an insignificant trend was detected in the cessation date of spring rainfall in all AEZs except the midland (Wadera), where the date of cessation of spring rainfall increased significantly.

Furthermore, the midlands (Adola and Harekello) and lowland (Chembe) had a statistically significant decrease in the arrival of autumn rainfall at ($p < 0.01$). The midland (Harekello and Kercha) showed a significant rising trend in the cessation of autumn rainfall. Except for the above mentioned few localities there were no statistically significant trends in the onset as well as the cessation of spring and autumn seasonal rainfall in all AEZs. Similarly, Wagaye and Antensay, (2020) discovered that there were non-significant decreasing and increasing trends, at the onset and cessation dates respectively. The significant inter annual fluctuation in the beginning and end of the rainfall seasons are causes for the occurrence of frequent drought and famine (McSweeney *et al.* 2010).

In summary, as one moves from highlands to lowlands in the research area, the LGP decreases, rainfall reliability decreases, and rainfall variability increases (Table 3.3). As a result, in the lowlands and midlands of the research areas, SFHH faced significant hurdles from too short LGP and unpredictable rainfalls. Consequently, the crops will experience lack of moisture resulting in inadequate crop yield. Planting after a 'false' onset of the growing season may result in failure and leads to costly replanting, as planting delayed due to late onset and early departure of rain may result in reduced yield (Dunning *et al.*, 2016; Aragaw and Woldeamlak, 2016).

The empirical findings of the study were supported by the KII and FGD. The members of KII and FGD confirmed the late onset and early secession of rainfall in the mid and lowland AEZs. They also clarified the shortening growing season which brought about changes in agro-ecology in the study area. As a result, the kind of crops grown in the area have changed. Participants in the KII and FGD discussed how farmers in the midland AEZ had ceased cultivating crops which were productive in the past (wheat and Ye Guji Bokolo). Changes in agro-ecological circumstances have a direct impact on food production and on the demand for agricultural products (Schmidhuber and Tubiello, 2007).

3.3.3. Agro ecology-based distribution of rainfall in the study Area

The section describes the temporal and spatial distribution of monthly, seasonal, and annual rainfall in the three AEZs of the East Guji Zone. Figure 3.4 summarizes the mean monthly rainfall (MMR) distribution in the East Guji zone. Accordingly, the three AEZs exhibited notable temporal and spatial differences in the distribution of rainfall. In the southern and southeastern region of Ethiopia, March, April, May, as well as September, October, and November are predicted to be the wettest months of the year. However, the finding shows that September and March remained dry months due to apparent fluctuation of rainfall in the study area.

In the lowland and midland AEZs, April, May, and October were the three wettest months of the year (Figure 3.4). The months from April to November were moist and December to March were dry in the highlands AEZs. The PCI result (Figure 3.9 and 3.10) confirmed that the monthly rainfall distribution was moderately concentrated in the highland, but the lowland and midland regions showed an irregular distribution of rainfall.

Rain falls in two seasons during the spring *(belg)* and autumn *(meher)*, with spring maxima in the lowlands and midlands AEZs. Furthermore, with the exception in the highlands, very little rain falls during the summer and winter seasons in the study areas. Due to the ITCZ's two sweeps across southern and southeastern Ethiopia, there is a bi-modal rainfall pattern in the study area. When the convergence zone moves north, from March-May, there is a rainy season; when it migrates to south, from September-November, there is another wet season. However, summer is the dry season (Diro *et al.*, 2011; Nicholson, 2017)**.**

The highlands received extra rainfall in the summer season in addition to the spring and autumn rainfall seen in most other sections of the study area. In the highlands, summer, spring and autumn are hence the wet seasons. Much of the year was marked by prolonged wet spells for the highland AEZ. According to the EPCC, 2015 topographic height is crucial in releasing the moist entering air's conditional thermodynamic instabilities, which in turn strengthens convective processes. As a result, the highland, midlands, and lowland AEZs had different seasonal rainfall contributions to the overall annual rainfall. The midlands and lowlands receive 84% of their precipitation in the spring and autumn seasons (Figure 3.6). Additionally, all places located in mid and lowland AEZs except Chembe received their rainfall peak in the spring (*belg)* season (Figure 3.4 and 3.6).

The three main AEZs show a significant variation in the distribution of annual rainfall (Figure 3.7). As a result, throughout the study period, the lowland Negele (624mm) had the smallest mean annual rainfall while the highland Solemo (1262mm) had the highest mean annual rainfall (Figure 3.8). Therefore, the lowlands obtain the least amount of rainfall while the highland AEZ receives the highest. To sum up, there is both temporal and spatial variability in the distribution of monthly, seasonal, and annual rainfall in the study area.

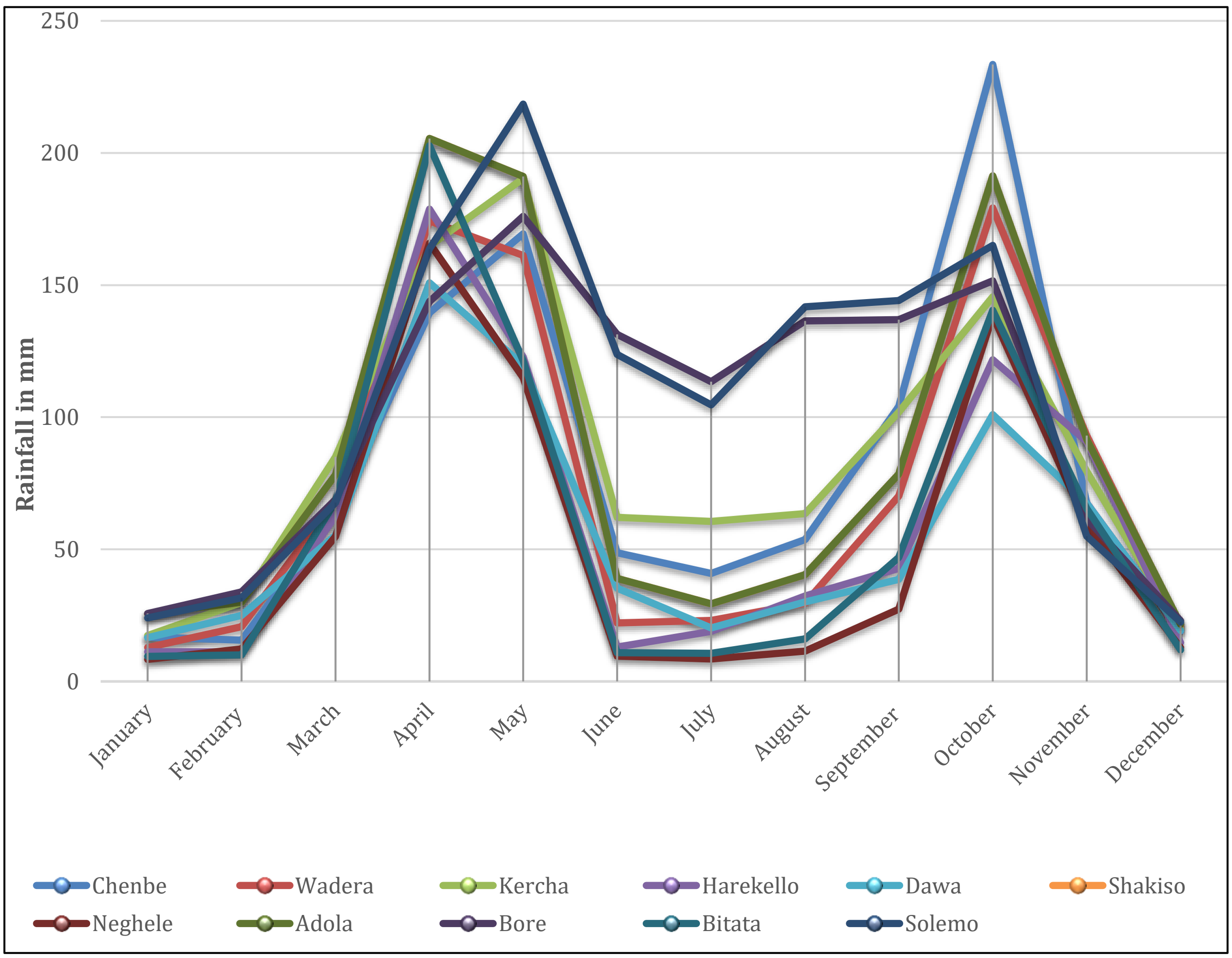


Figure 3. 4. Distributions of Mean Monthly Rainfall in Guji Zone

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

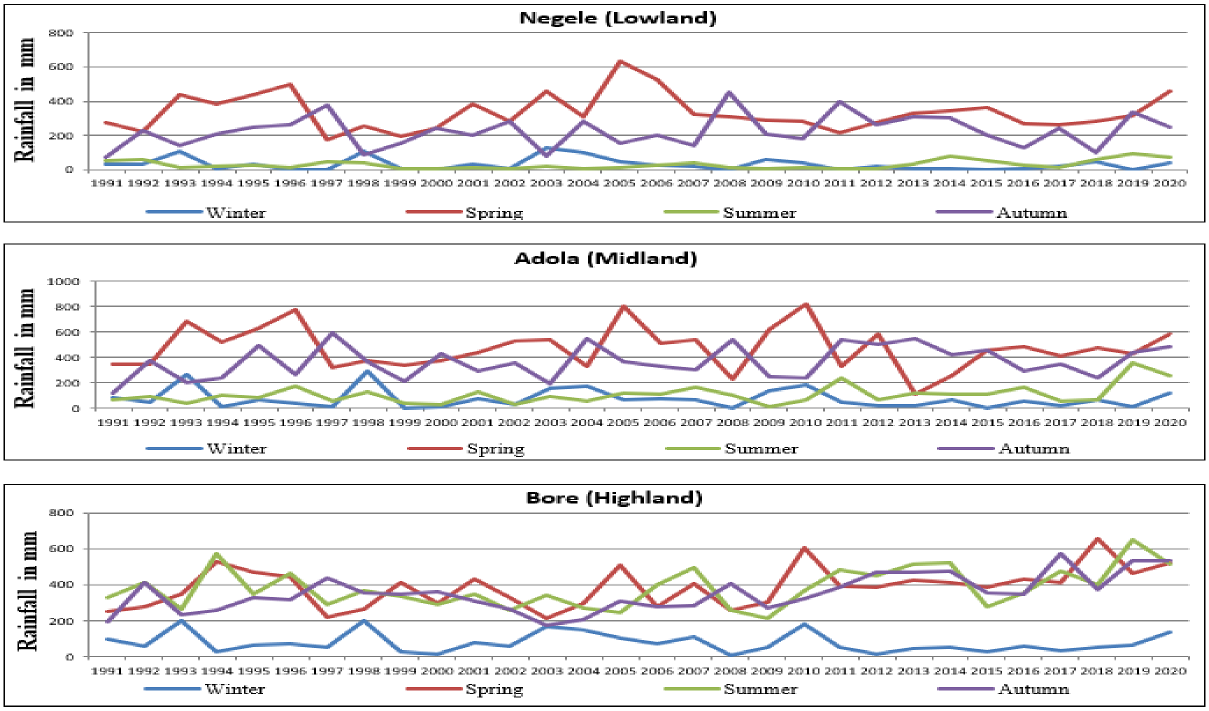


Figure 3. 5. Distributions of Mean Seasonal Rainfall of the three AEZ in Guji Zone

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

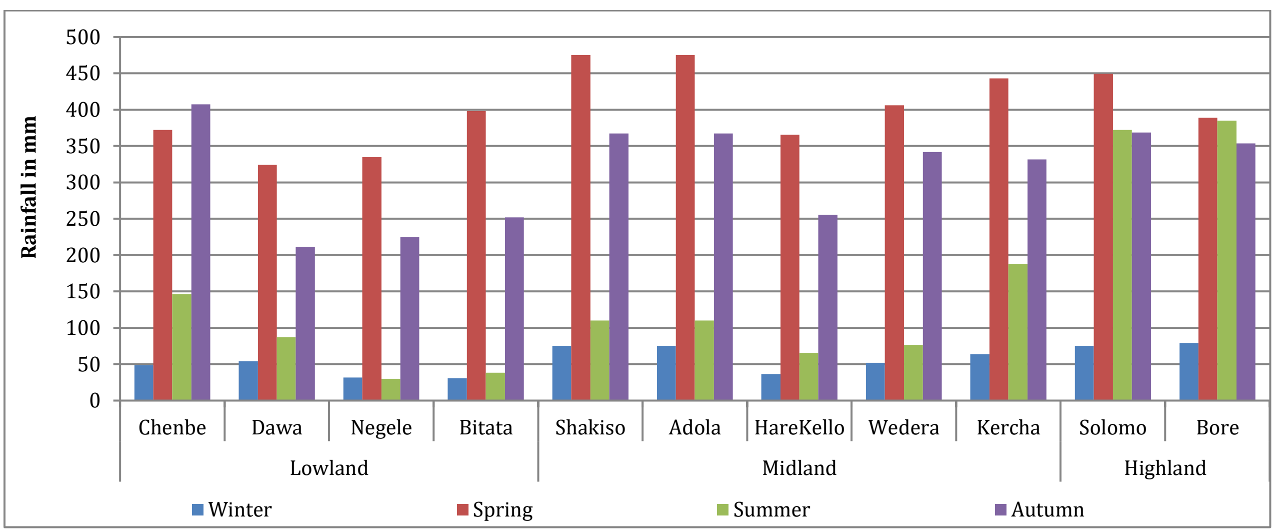
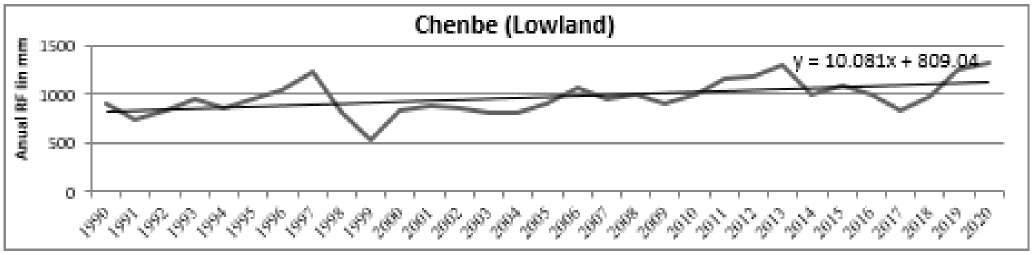
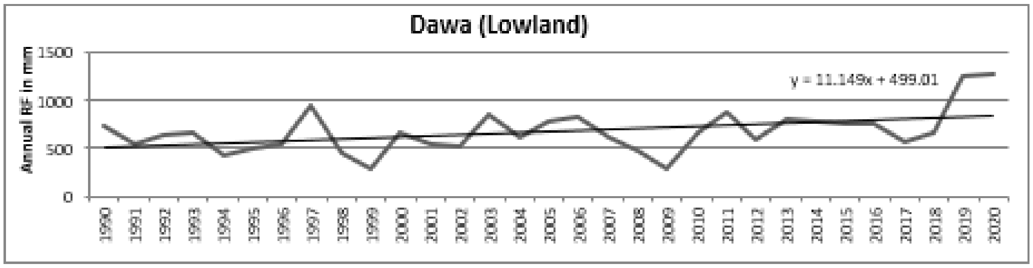
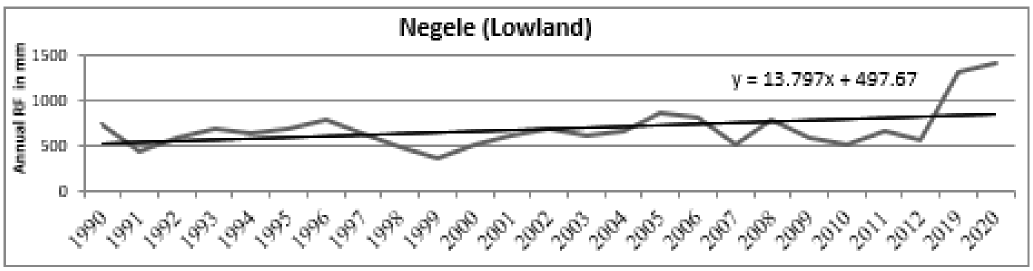


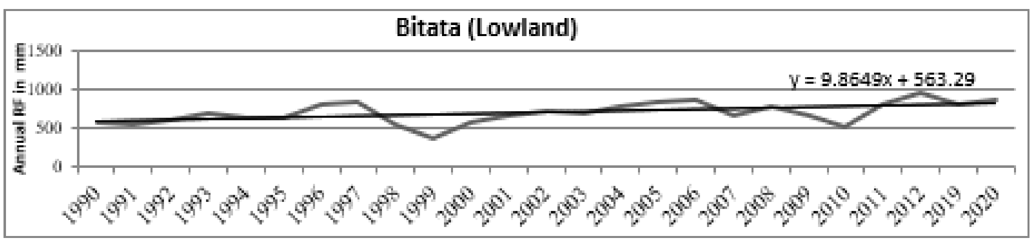
Figure 3. 6. Distributions of Seasonal Rainfall in East Guji

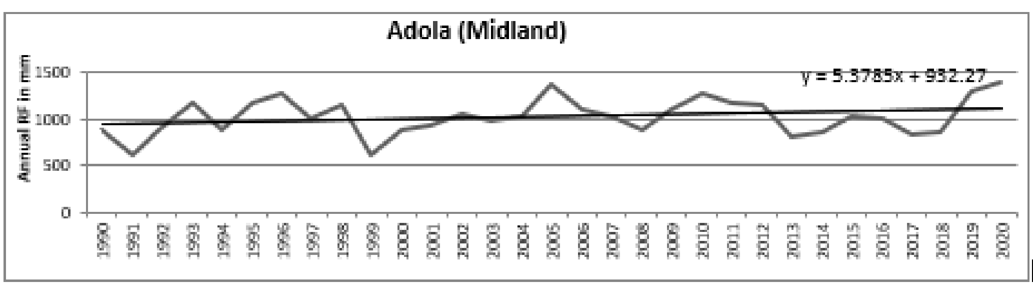
Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)


Chenbe (Lowland)
Anual RF iin mm
y = 10.081x + 809.04


Dawa (Lowland)
Annual RF in mm
y = 11.149x + 499.01


Negele (Lowland)
Annual RF in mm
y = 13.797x + 497.67


Bitata (Lowland)
Annual RF in mm
y = 9.8649x + 563.29


Adola (Midland)
Annual RF in mm
y = 5.3785x + 932.27

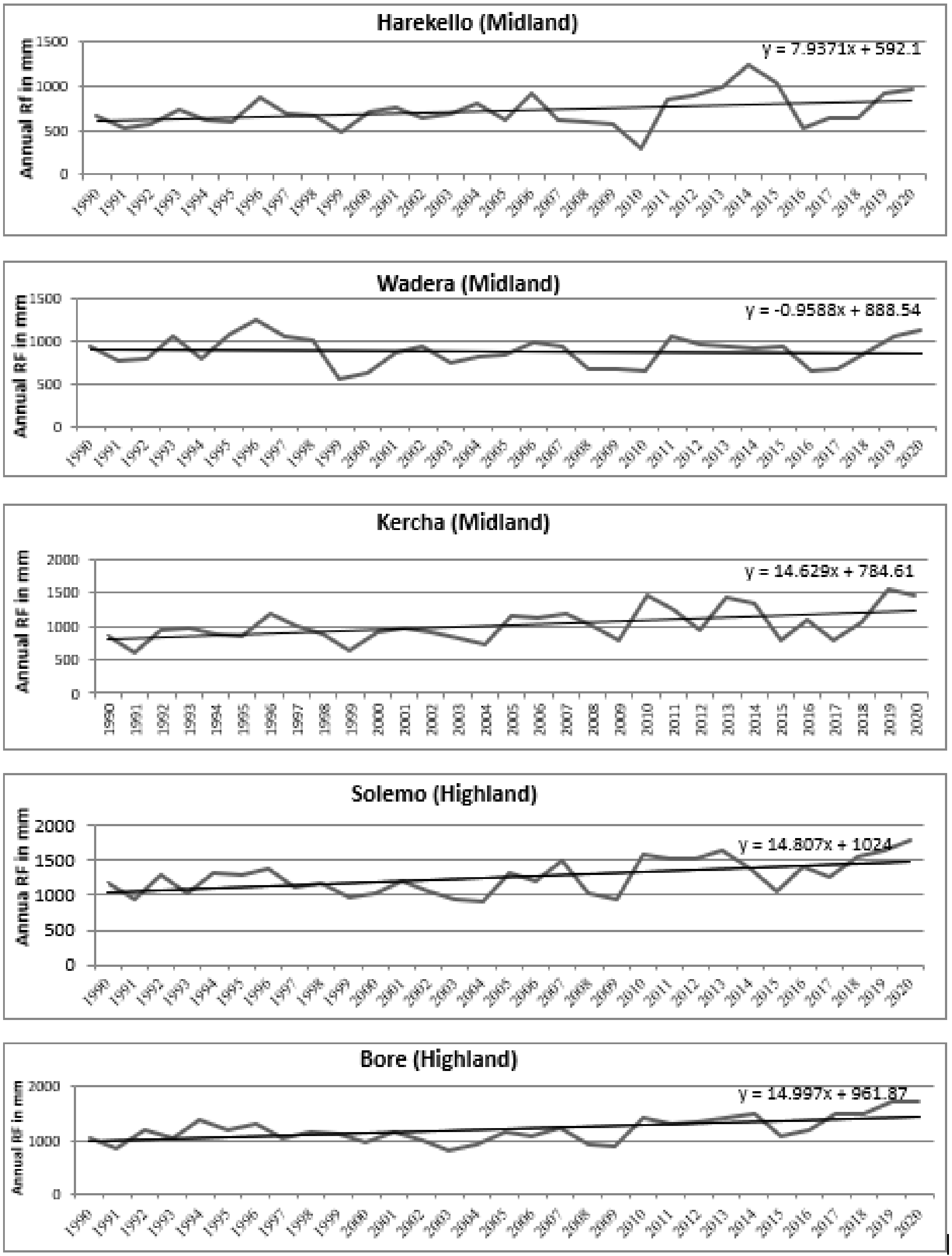


Figure 3. 7. Distributions of Annual Rainfall in the three AEZs of East Guji Zone

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

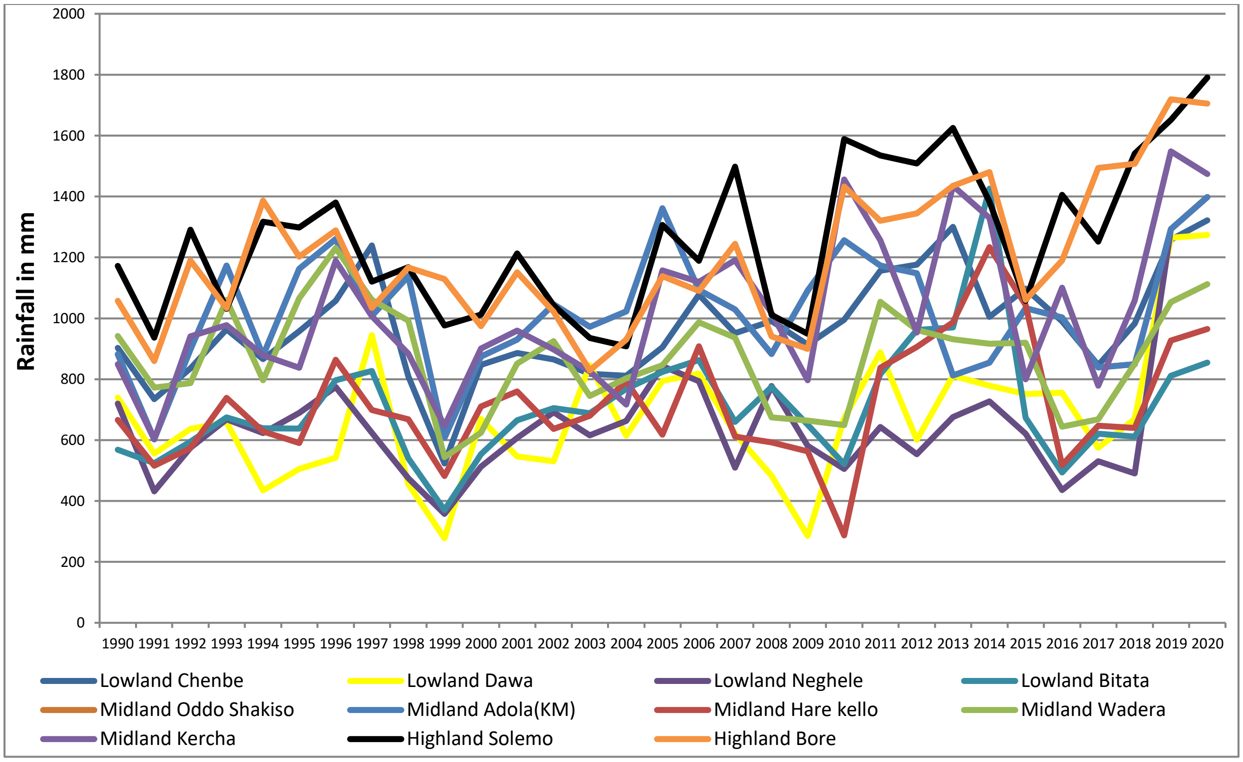


Figure 3. 8. Distributions of Annual Rainfall in the Study Area

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

3.3.4. Agro ecology-based rainfall variability in the study area

The variability of rainfall has been analyzed with PCI and CV. Precipitation Concentration Index is a prominent measure of rainfall variability. It clearly demonstrates the degree of consistency or concentration in rainfall distribution throughout the year. The PCI score of the East Guji zone revealed the existence of an irregular monthly rainfall distribution. As a result, no location in the research area had an evenly distributed rainfall throughout the year (PCI <10%). Thus, the lowlands, midlands, and highlands AEZs had mean PCI values of 19 %, 17%, and 12 % respectively. As a result, the lowlands and midlands acquired irregular rainfall distribution, but highlands have moderately concentrated precipitation.

Similarly, the lowlands, midlands, and highlands had annual rainfall variation of 27 %, 21%, and 19 % CV respectively. Comparatively, highlands have low rainfall variability, whereas the lowland and midlands have moderate year-to-year rainfall variability (Figure 3.9). Similarly, the midlands *(weinadega) and* lowlands (*kola*) had comparatively greater PCI and CV values than highlands

(*Dega*) AEZ. Thus, there was a significant difference in the degree of rainfall variability amongst the three AEZs based on PCI and CV. In the research area, as one moves from highlands to lowlands, altitude and rainfall decrease, and inter-seasonal and annual variability of rainfall increases. The findings of the study correspond with the studies of (Woldeamlak and Conway, 2007; Misrak *et al.*, 2021) which stated that as annual and seasonal rainfall increases, PCI values decrease.

Based on the CV in the lowland and midland AEZs there was high (CV>30) during the spring and autumn season (Figure 3.10). In the mid and lowland AEZs, considerable variability in the seasonal rainfall distribution has been confirmed by both PCI and CV. Ashenafi *et al.* (2022) obtained a similar result which showed an irregular rainfall distribution in the Northern Shewa's mid-and lowland AEZs. For farmers who depend on rain-fed agriculture, rainfall variability greater than 30% CV is dangerous (NMA, 2007). As a result, the seasonal rainfall was less reliable for agricultural activities in the lowland and midland AEZs due to the identified increase in CV.

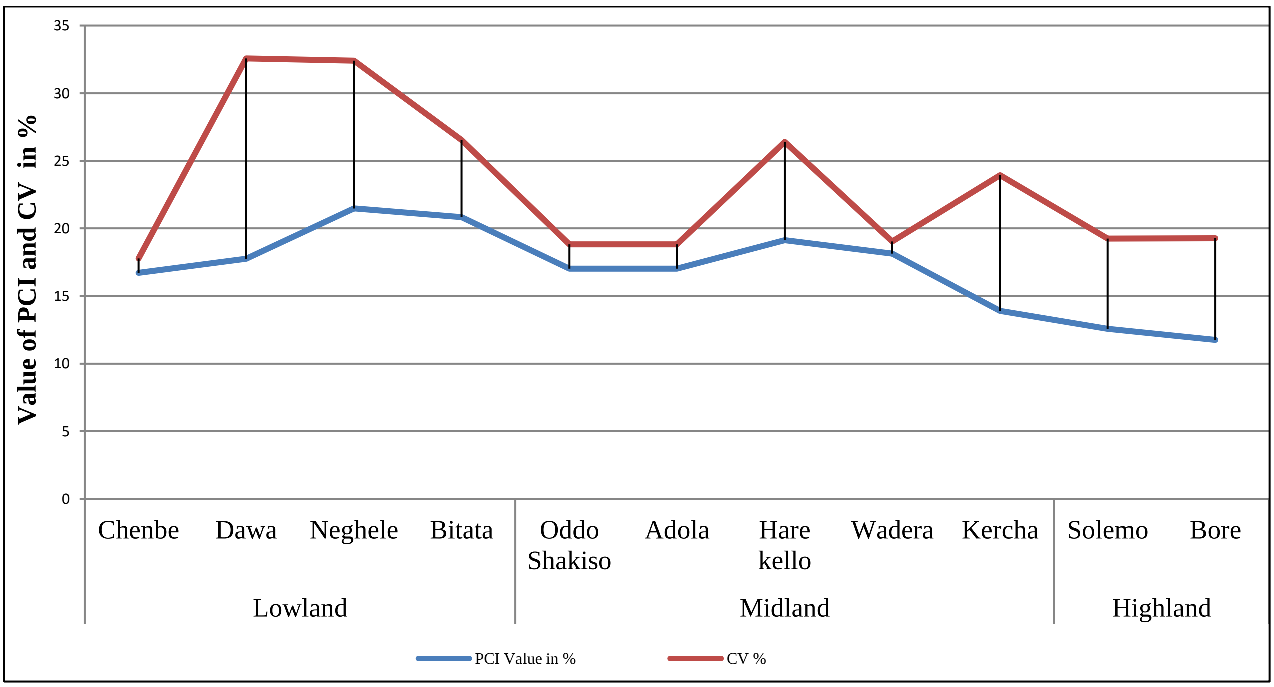


Figure 3. 9. Annual Rainfall Variability Using PCI and CV

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

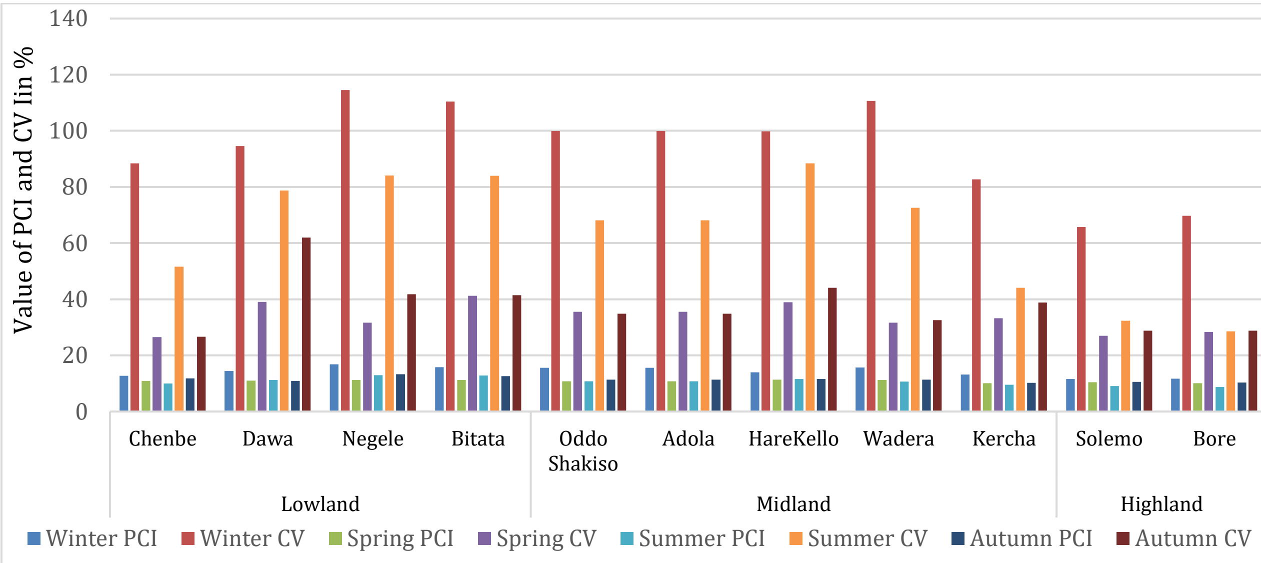


Figure 3. 10. Seasonal Variability of Rainfall Using PCI and CV

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

Conversely, the highland's CV suggests moderate variability of rainfall (CV <30 %), with values of 28%, 30 %, and 29% in the spring, summer, and autumn seasons respectively. In all AEZs, the trend and magnitude of winter rainfall indicated a non-significant declining trend. Additionally, very high CV was noted during the winter season 102%, 99%, and 68% respectively in lowlands, midlands, and highlands AEZs. The high CV that was found reflected the presence of high rainfall throughout the winter season in the study areas. Similarly, wintertime PCI value is highest, indicating increased rainfall variability in the study area. Similar findings were reported by Matios *et al.* (2022); Mitiku *et al.* (2022), who noted that the winter season rainfall in the Guji and Borana Zones had very high variability (CV >90%). In fact, the least quantity of rain falls in winter. Wilhite (2000) states that a significant dry period in winter may have an effect if the shortfall persists into the growing season. This could lead to poor and insufficient soil moisture recharge for spring planting.

The participants of FGD and KII in the mid-and lowland AEZs confirmed the presence of high rainfall variability and recurrent drought in the area. They claim that rainfall is declining in the midland and lowland. They confirmed that autumn and spring rainfall was showing high variability in the lowland. They also noticed a reduction of growing season in the lowland and midland AEZs throughout the spring and autumn rainfall seasons because of let onset and early secession of rainfall.

3.3.5. Agro ecology-based trends of rainfall in Guji Zone

Table 3.4 provides an overview of the trends and magnitudes of variation in mean monthly rainfall (MMR) across the three AEZs. It is demonstrated that in nearly all months of the year, there were no statistically significant trends in monthly rainfall. Remarkably, a statistically significant ($p < 0.05$) increase trend of rainfall was noted in September in Solemo (highland AEZ) and Bitata (lowland AEZ).Likewise, October rainfall in Kercha (midland AEZ) showed statistically significant ($p < 0.05$) upward trends. There was a variation in the magnitude of rainfall in different months. The finding revealed that 38% of the months or periods under study had a negative slope of MMR distribution. On the other hand, positive magnitude in the MMR distribution was observed for 62% of the months studied. The implication is an increase in the amount of rainfall in the study area.

Seasonally, the rainfall distribution showed no statistically significant trends, except for the autumn season. During the study period, a non-significant declining trend of spring season rainfall was noted in the midlands (Adola, Shakiso, Wadera) and lowland (Negele). The decreasing trend of spring or *belg* (March-May) season rainfall in different sections of the country were reported by Viste *et al.* (2013); Yimer *et al*. (2019); Wagaye and Antensay,(2020); Abreham *et al*. (2021) ; Matios *et al.* (2022) which are consistent with the findings of decreasing trend of spring rainfall in East Guji. Similarly, declining trend in the ‘‘long rains’’ season of March–May, were reported in Eastern Africa (Lyon and Dewitt, 2012; Funk *et al.*, 2014; Rowell *et al.*, 2015; Palmer *et al.,* 2023). Southern Ethiopia experiences deficient rainfall due to La Niña impact on MAM rainfall (McSweeney *et al.*, 2010).

On the other hand, spring rainfall showed a non-significant increase in some areas in the three AEZs (Chembe, Dawa and Bitata) in the lowlands and (Harekello) in the midlands (Table 3.5). In addition, Sen's slope value of Kercha (midland) AEZ indicated a non-significant drop in the magnitude of spring rainfall. Similarly, summer rainfall declined insignificantly in the midlands (Harekello) and lowlands (Bitata, Negele) stations.

Table 3. 4. Magnitude and Trend of Monthly Rainfall Distribution

Centers	Sen's Slope (Magnitude)		MKT (Trends)	
	Months with Positive (S)	Months with Negative (S)	Trend	No trend
Chembe[1]	January, April, June, August, September, November, December	February, March, May, July, October		All Months
Dawa[1]	January, March, April, May, August, September, October, December	February, June ,July, November		All Months
Negele[1]	January, April, May, August, September, November	February, March, June, July, October, December		All Months
Bitata[1]	April, September, October, November, December	January, February, March, May, June, July, August	September	11 Months
Shakiso[2]	March, May, June, July, August, September, November, December	January, February, April, October		All Months
Adola[2]	March, May, June, July, August, September, November, December	January, February, April, October		All Months
Hare Kello[2]	January, April, August, September, November, December	February, March, May, June, July, October		All Months
Wadera[2]	January, February, June, July, August, September, November, December	March, April, May, October		All Months
Kercha[2]	January, March, April, May, June, July, September, October, November, December	February and August	October	11 Months
Solemo[3]	January, March, April, May, August, September, November, December	February, June, July, October	September	11 Months
Bore[3]	January, April, May, July, August, September, November, December	February, March, June, October		All Months

Data Source: Extracted from Ethiopian Meteorological Institute

[1]Located at lowlands AEZ (*Kolla*)**;** [2]Located at midlands AEZ (*Woina Dega*); and [3]Located at highland AEZ (*Dega*)

There were no statistically significant increasing trends in summer and spring rainfall in the highland AEZs, while the autumn and annual rainfall increased in a statistically significant way ($p< 0.05$). Surprisingly, autumn rainfall exhibited a significant increasing trend in the stations located in the highlands of Bore and Solemo, the lowland Chembe and the midland of Kercha at a significant level of ($p < 0.05$). This is consistent with research conducted by (Matios *et al.,* 2022; Mitiku *et al.,* 2022; Markos *et al.,* 2023) which found that rainfall in Borana, Guji, and Sidama Regional States increased significantly during the autumn season (short rainy period). Research has also demonstrated that there has been excess rainfall during the small rainfall season (ON) and deficiency of rainfall during the main rainfall season in Southern Ethiopia (MAM) and (Mekkonnen *et al.,* 2017; Nicholson, 2017; Amogne *et al.,* 2017).

As with the long rains, there are noticeable anomalous rainfall intervals within these regional-mean long-term linear trends. The years 1997–1998 and 2019–2020, in which the total number of short rains exceeded climatological values by two or three times, are examples of these periods. Indeed, variations in precipitation within the range 100–250 mm $year^{-1}$ have been recorded in 1997, 2006, 2012, 2015 and 2019, and they have been linked to variability associated with ENSO-related and its interactions with the IOD (Saji *et al.,* 1999; Webster *et al.,* 1999; Black, 2005).The short-term fluctuation brought on by changes in the IOD and ENSO, and the unequal warming across the Indian Ocean (Liebmann *et al.,* 2014). In similar vein, remarkable wet years were noted in the research areas in 1993, 1996, 2001, 2005, 2006, 2012, 2013, 2014, 2015, 2018, and 2020.

The trend in annual rainfall in the three AEZ showed increasing tendencies except for Wadera. The increasing trend was significant ($p < 0.05$) at 6 out of 11 stations (Table 3.6). The statistically significant increase in autumn rainfall might be attributed to the increasing trends of annual rainfall. The highlands (Bore 15.3 mm/year and Solemo14.6 mm/year), lowlands (Chembe 10.9 mm/year, Dawa 8mm/year and Bitata 7.8 mm/year), as well as midlands (Kercha 14.5mm/year) station all showed a significant positive change in annual rainfall at ($p < 0.05$) (Table 3.6). Consequently, in the study area, an insignificant increase in annual rainfall was noted. In addition, the remaining midlands (Adola, Shakiso and Harekello) and lowlands (Negele) showed a non-significant increasing trend in annual rainfall, except for the midland stations, Wadera, which showed an insignificant dropping trend.

Table 3. 5. Trends of Seasonal Rainfall in the Study Area

Seasons	Centers	Mean	STD	CV	MKT	Slope	P- Value

Winter	Chembe[1]	49	43.4	88.5	-0.071	-1.439	0.707
	Dawa[1]	54.2	51.2	94.5	-0.095	0.194	0.599
	Negele[1]	32	36.5	114.5	-0.190	-3.306	0.259
	Bitata[1]	31	34	110.4	-0.190	-2.145	0.260
	Shakiso[2]	75.2	75.2	100	-0.167	-8.163	0.329
	Adola[2]	75.2	75.2	100	-0.167	-8.163	0.329
	Hare Kello[2]	37	36.5	100	-0.167	-1.614	0.329
	Wadera[2]	52	57.5	111	-0.167	-5.866	0.329
	Kercha[2]	64	53	83	-0.143	-3.036	0.409
	Solemo[3]	75.5	50	66	-0.262	-6.464	0.115
	Bore[3]	79.3	55.3	70	-0.286	-6.095	0.084
Spring (long rain)	Chembe[1]	372.1	98.5	26.5	0.143	14.047	0.408
	Dawa[1]	324.2	127	39.1	0.261	10.104	0.115
	Negele[1]	335	106	31.6	-0.071	1.0346	0.707
	Bitata[1]	398.4	164.3	41.2	0.214	11.96	0.202
	Shakiso[2]	475.5	169.1	35.6	-0.166	6.559	0.328
	Adola[2]	475.5	169.1	35.6	-0.166	6.558	0.328
	Hare Kello[2]	366	143	39	0.000	1.982	1.000
	Wadera[2]	406	129	32	-0.095	1.678	0.599
	Kercha[2]	443	147.4	33.3	0.119	-0.832	0.499
	Solemo[3]	449.3	121	27	0.143	13.43	0.408
	Bore[3]	389	110.5	28.4	0.119	13.33	0.499
Summer	Chembe[1]	146.3	75.5	51.6	0.214	8.650	0.201
	Dawa[1]	87.4	69	78.7	0.261	6.214	0.115
	Negele[1]	30	25.2	84.1	0.000	-0.513	1
	Bitata[1]	38.2	32.1	84	-0.071	-1.07	0.707
	Shakiso[2]	110.1	75	68.1	0.166	2.147	0.328
	Adola[2]	110.1	75	68.1	0.166	2.147	0.328
	Hare Kello[2]	65.5	58	88.4	-0.071	-0.324	0.707
	Wadera[2]	77	54	72.6	0.095	6.982	0.201
	Kercha[2]	188	83	44.1	0.095	0.656	0.599
	Solemo[3]	372	120.3	32.3	0.071	6.40	0.707
	Bore[3]	385	110	28.5	0.071	2.69	0.707
Autumn (short rain)	Chembe[1]	407.5	109	26.7	0.357	31.677	**0.029*** **
	Dawa[1]	211.4	131	62	0.166	14.132	0.329
	Negele[1]	225	94	42	0.166	10.189	0.328
	Bitata[1]	252.1	104.5	41.4	0.214	23.17	0.202
	Shakiso[2]	367.2	128.1	35	0.166	18.508	0.329
	Adola[2]	367.2	128.1	35	0.166	18.507	0.328
	Hare Kello[2]	255.5	113	44.1	0.214	17.831	0.202
	Wadera[2]	342	111.3	33	0.095	8.915	0.599
	Kercha[2]	332	129	39	0.357	33.029	**0.029*** **
	Solemo[3]	369	106.1	29	0.404	27.674	**0.013*** **
	Bore[3]	354	102	29	0.404	21.468	**0.013*** **

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

Note: ***Level of Significant = 1% ; [1]Located at lowlands AEZ (*Kolla*)**;** [2]Located at midlands AEZ (*Woina Dega*); and [3]Located at highland AEZ (*Dega*)

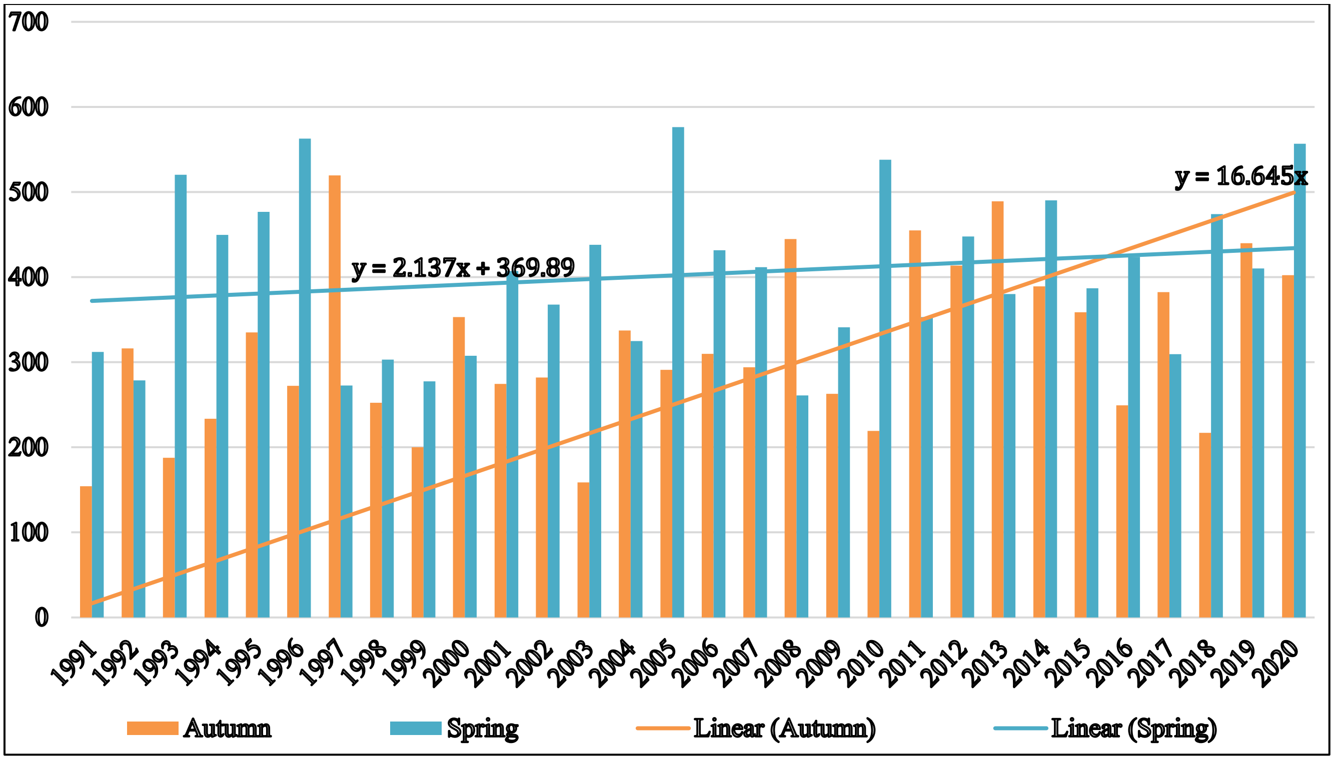


Figure 3. 11. Distribution of mean autumn and Spring Rainfall in Guji Zone

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

The result is consistent with research by Rosell and Holmer, (2007); Wagaye and Antensay, (2020); Aragaw *et al.* (2020); Getachew *et al.* (2021); Abrham *et al.* (2021); Markos *et al.* (2023) who reported an increasing trend in annual rainfall in several region of Ethiopia. The finding is also in line with Shongwe *et al*. (2011); Otieno and Anyah, (2013); Amogne *et al*. (2017); Mekonnen *et al*. (2017) who reported a considerable rise in rainfall in East Africa. The increase in annual rainfall is highly associated with the significant rising trend autumn rainfall in the study area (Table 3.5). The findings of Amogne *et al.* (2017) also indicated the contribution of the autumn rainfall to the annual rainfall increment in their study area. Thus, in the specified locality, the observed significant increase in trend in autumn *(meher)* rainfall is closely associated with most of the statistically significant increases in annual rainfall (Table 3.6).

In contrast, several finding by Rosell and Holmer, (2007); Adisu *et al.* (2021); Matios *et al.*(2022) revealed a decreasing trend of annual rainfall in a different part of the country, however, are inconsistent with the finding of increasing trend in annual rainfall in present study. Findings confirmed that the distribution of rainfall in Ethiopia showed variation both spatially and temporally. Furthermore, it has been demonstrated by Diro *et al.*(2011) that a cold Gulf of Guinea strengthens the TEJ and suppresses the ITCZ, which increases rainfall in southern Ethiopia while decreasing in the north and central regions. As a result, differences in the amount of rainfall were noted in various regions of Ethiopia. This disparity has sometimes been called the East African climate paradox (Rowell *et al.*, 2015).

Table 3. 6. Trends of Annual Rainfall in the Study Area

Centers	Minimum	Maximum	Mean	CV	MKT	Slope	P-value
Chembe[1]	523.15	1321.7	971.8	18.1	0.393	10.86	**0.002*****
Dawa[1]	277.51	1273.6	679.4	32.8	0.264	8.13	**0.038****
Negele[1]	357.65	843.1	623.8	19.5	0.045	0.75	0.73
Bitata[1]	370.31	1425.6	714.1	26.8	0.247	7.82	**0.05****
Shakiso[2]	603.14	1398.02	1022.2	19.5	0.101	4.86	0.43
Adola[2]	603.14	1398.02	1022.2	19.5	0.101	4.86	0.43
Hare Kello[2]	287.02	1233.6	720.7	26.6	0.226	8.36	0.07
Wadera[2]	544	1230.6	875.9	19.7	-0.045	-0.70	0.73
Kercha[2]	602.19	1548.1	1020.4	24.2	0.333	14.46	**0.008*****
Solemo[3]	908	1790.7	1262.3	19.6	0.354	14.63	**0.005*****
Bore[3]	829	1719.1	1202.5	19.6	0.376	15.33	**0.003*****

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

Note:***Level of Significant= P < 1% and P < 5% **; [1]Located at lowlands AEZ (*Kolla*); [2]Located at midlands AEZ (*Woina Dega*); and [3]Located at highland AEZ (*Dega*)

The choice of research period has a significant impact on trend analysis of rainfall outcomes due to temporal variability of rainfall (Woldeamlak and Conway, 2007).The finding of (Matios *et al.*, 2022) indicates a decreasing trend of annual rainfall in Guji from 1986-2017. Palmer *et al.* (2023) also observed a similar conclusion in Eastern Africa, where long rains showed persistently unfavorable trends between 1985 and 2017. There were notable drops in Eastern Africa rainfall in 1999 and 2010-2011.

On the other hand, as can be seen in Figs 3.8 and 9.2, 2019 and 2020 were wet years. The recovery of extremely wet lengthy rains in Eastern Africa in 2018 and 2020 was explained by the study of Palmer *et al.* (2023), which verified the findings of the current study. As a result, East Africa saw a similar downward trend in lengthy rainfall 1985-2017, but from 2018 to 2020, the wetness of the region was restored. Consequently, the current study's divergent findings could be the result of the selected study periods, which already influence the temporal trend analysis. As a result, the time frame for the study helps to describe the temporal variability of rainfall in the study area. On the other hand, the Guji zone's observed spatial variability of rainfall was mostly caused by the area's varied AEZ that ranged from 632 meters-2960 meters' elevation (Figure 3.2).

3.4. Conclusions

Identifying the variability of rainfall in space and time, onset and cessation, and distributions across AEZs is essential since rain-fed agriculture is the mainstay of smallholder farmers in the study area. The finding denotes the presence of spatial and temporal variation in the distribution of rainfall in the three AEZs of the study areas. Midlands and lowlands experience bimodal rainfall, two distinct onset and cessations and dual LGP in the autumn and spring seasons. Whereas highlands obtain a considerable amount of rainfall in spring, autumn and summer. Furthermore, variability in the days of onset and departure of rainfall was observed in the three major AEZs of the study area. Complex trends in the distribution of rainfall have been found in the area. Insignificant, increasing trends of spring rainfall have been discovered in most parts of the study area. Partially, there was a significant increase in autumn rainfall in the study area. Likewise, the annual rainfall had shown an insignificant increasing trend in some parts of the study area, a significant increasing trend of annual rainfall was observed in the highlands (Bore and Solemo); lowlands (Chembe, Dawa and Bitata) as well as in the midland (Kercha) stations.

Thus, the PCI value decreases with increasing altitude and rainfall. As one moves from the highlands to the lowlands in the study area, rainfall decreases, and the inter-annual variability of precipitation will increase. Therefore, moderate year-to-year variability was detected in the low and midlands whereas the highlands exhibited lesser year-to-year variability of rainfall. High monthly and seasonal variability together with the late onset and early termination of the spring and autumn rainfall in the midlands and lowlands parts of the study was a challenge for the small-holder farmers. Although rainfall variability was discovered as a problem its magnitude varies across the different AEZs in the study area. The high variability of rainfall resulted in shortage of water for rain fed agriculture in the mid and lowlands AEZ. Thus, more consideration should be given to the lowlands and midland AEZs of the study areas.

Therefore, selecting and providing appropriate short-cycle grown and drought-resistant crops to the midlands and lowlands AEZs of the study area is critical. Furthermore, additional support to strengthen the use of water resources for (irrigation/water harvesting) agricultural activities should be provided for smallholder farmers in the midlands and lowlands AEZs. Accurate, reliable, and timely information about the onset and end of rainfall should also be provided for the community to avoid planting crops on the false onset date. The current study was done at the scope of 'Spatiotemporal Trends and Variability of Rainfall'. Further investigation of the spatial distribution and temporal trends of temperature together with an assessment of the rate of evaporation across the three AEZ in the study area is vital to understanding the microclimate of the area. So that the result will alleviate the issues related to the livelihood of smallholders.

CHAPTER FOUR

DROUGHT CHARACTERIZATION IN EAST GUJI ZONE, OROMIA REGIONAL STATE, ETHIOPIA

ABSTRACT

This study examines the severity, duration, spatial coverage and trends of drought in the three agro ecologies of the East Guji Zone using Reconnaissance Drought Index (RDI). Gridded rainfall, minimum and maximum temperature data from Ethiopian Meteorological Institute in the period of 1990-2020 was utilized. Using the Reconnaissance Drought Index (RDI), the severity, duration and spatial coverage of drought were described. The Mann Kendall trend test was employed to detect the trend of drought, while Sen's slope was used to test the magnitude of change. To interpolate the spatial patterns of drought the inverse distance-weighted index was used. The frequency of mild, moderate, severe and extreme droughts in the locality was 43%, 38%, 14%, and 5% respectively. Extreme reconnaissance drought index value of -2.8 was recorded in Shakiso and Adola in spring of 2013, and -2.77 in Wadera in spring 2000. The finding of the study revealed that the duration of spring, annual and autumn drought was 34%, 33% and 30 % respectively. Droughts in autumn and annual (12 months) showed opposite patterns with the trend of rainfall in the area. Drought under the studied period showed statistically significant (< 0.05) declining trends in Chembe and Dawa (lowlands), Kercha (midland), and Bore and Solemo (highland) AEZs. In other words, there has been a drop in drought trend along with an increase in rainfall and vice versa. Appropriate drought management is required in the localities where drought trend have shown a rise.

Keywords: Autumn and spring drought; Duration; RDI; Severity of drought; Spatial coverage

4.1. Introduction

Drought is the consequence of a natural reduction of precipitation which is extended over a season or longer period of time (Wilhite and Svoboda, 2000; Wilhite, 1993).When there is not enough rainfall to fulfill human activities, either anticipated or abnormal, it results in drought which has an influence on environment, economy and social life (Tannehill, 1945). Rainfall variability is the major cause for the occurrence of drought (Viste *et al*., 2013). Drought is a universal problem. Both high as well as low rainfall regimes experienced it. Drought is the most detrimental environmental event, which affects global agriculture and causes considerable losses of production that result in food insecurity (Kogan *et al.*, 2019).

Changes in persistent atmospheric circulation patterns, which are typically linked to slowly varying atmospheric boundary conditions (changes in sea-surface temperature), create droughts. (Global Assessment Report on Disaster Risk Reduction Special Report on Drought, 2021).The variations in air pressure associated with the changes in SST are known as El Niño Southern Oscillation (ENSO). El Niño is a warming of the central Pacific that produces weather systems with high pressure. A colder SST called La Niña causes weather systems with low pressure. Along with other low-frequency sources the ENSO is one of the main causes of episodic droughts globally (Trenberth *et al.,* 2014). A La Niña-related warm SST anomaly in the western Pacific causes increased Walker circulation, more subsidence and drought over the Horn of Africa (Funk *et al.,* 2014; Anderson *et al.,* 2023). The Ethiopian intense and extended drought periods either coincide or follow El Nino. El Nino reduces the strength of the South Indian and South Pacific high pressure air mass that provides rainfall in Ethiopia (Kassahun 1999; Yimer *et al.,* 2016). However, because of the country's diverse microclimates the weather in some areas might not be correlated with El Niño events.

The majority of people in the world are affected by drought, which is a very costly disaster, particularly in developing countries of Africa and Asia. Ethiopian small-scale farmers who rely on rain-fed agriculture for their livelihood are negatively affected by drought (Kourouma *et al.,* 2022). The annual probability of drought occurrence is over 40% for many parts of Ethiopia (Bartel, 2007). Despite this, agriculture remained crucial for the Ethiopian economy, contributing 40% of the GDP, 80% employment, and 90% exports. Besides, 79% of the income of the population depends on rain-fed agriculture (Taffese and Tewodroso, 2019; Young and Klingaman, 2020). Meanwhile, the Guji Zone was prone to drought and famine. Droughts have a complicated history and considerable impact on the area. Therefore, characterizing the intensity, duration, areal extent, and trends at this micro scale provides important insight for managing the smallholder farmers' means of subsistence in the study area.

Ethiopia's drought has been examined in a number of earlier studies (Desalegn *et al.,* 2010; Viste *et al.,* 2013; Mekonnen and Woldeamlak, 2015; Teshome, 2016; Martha *et al.,* 2020; Yimer and Asnake 2021; Kourouma *et al.,* 2022; Fikru *et al.,* 2022). Complex patterns in frequency severity, and magnitude of drought events, with empirical evidence indicating highly localized negative effects and varying intensity classes were reported. However, there are only a few studies that focus on characterizing drought using AEZs. Therefore, by examining the localized pattern of drought in the Guji Zone, the AEZs based characterization of drought adds to the existing knowledge.

Studies which characterize drought based on agroecology are very scarce. Moreover, very few studies were done about drought emanating from the letdown in spring *(belg)* and autumn *(meher)* seasons rainfall. Thus, to fill these gaps, the current study analyzed severity, duration and spatial coverage spring (*belg*) and autumn (*meher*) seasons as well as assessment of annual occurrences of drought across the three AEZs of East Guji. Therefore, the general objective was to analyze severity, duration and spatial coverage of spring *(belg)* and autumn *(meher)* seasons drought throughout the three AEZs using RDI drought indices. The findings will help improve the decisions on drought management and monitoring in the area.

4.2. Material and Methods

4.2.1. Descriptions of the study area

This study was conducted in the East Guji Zone, southern part of Oromia National Regional State, Ethiopia. Geographically, the East Guji Zone is located between 4^0 30′ N - 6^0 30′ N and 38^0 15′ E-40^0 5′ E (Figure 3.1) and covers a total area of about 18,577 Km^2. It shares a border with the Gedeo Zone and Sidama Regional State in the North, Somali Regional State in the South, Bale Mountain on the East, and Borena Zone in the West. The northern and eastern neighbors of the East Guji zone mainly have highland AEZs that experience wetter microclimates (Matios *et al.*, 2022). The southern and the western adjacent land of the study area holds the lowland that experiences relatively drier climate conditions (Mitiku *et al.,* 2022). The western neighboring Borena Zone is mainly lowland which embraces a semi-arid and arid climate and recently has been highly struck with drought (Indale *et al.,* 2023).

The total population of the area as projected by CSA (2022) was 2,030,667 in 2022. The Guji Oromo are the dominant ethnic group which represented 95.57%, the Amhara 2.43%, and the Somali 2% CSA (2007). They are predominantly pastoralists, agro-pastoralists, and farmers (Teshome, 2016). Coffee is an important cash crop in the Guji zone (Lazzari *et al.*, 2021).

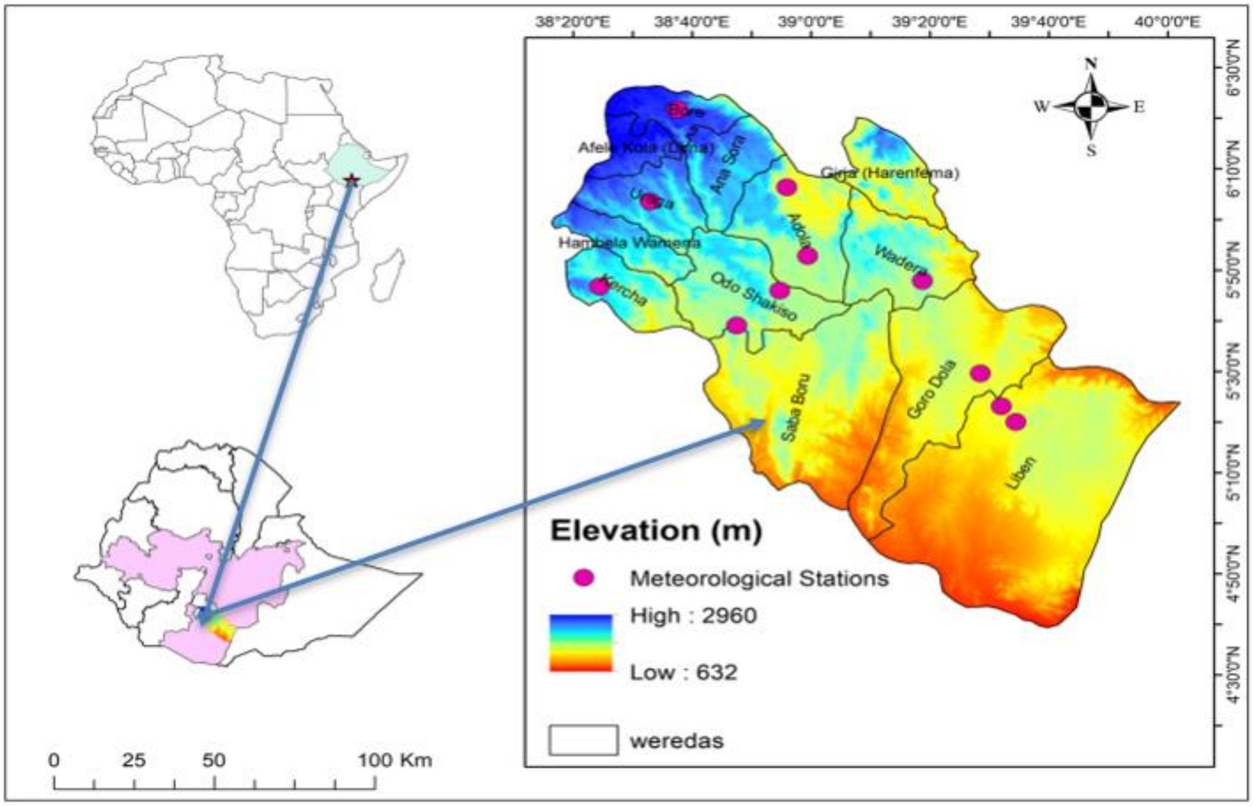


Figure 4. 1. Location Map of the Study Area

Source: Projection WGS_1984_ UTM _Zone_37^{0}

The study area is situated in the southern part of Ethiopia, which experienced bimodal rainfall cycles in spring (March–May) with a peak in April/May and autumn (September–November) (Diro *et al.*, 2011). The area is characterized by a bimodal rainfall pattern where the long rainy season (*arfansa*) occurs from March to May and covers about 48% of the annual rainfall whereas the short rainy season (*hagaya*) extends from September to November which shares about 36% of the annual rainfall. Thus, spring (*belg or arfansa*) and autumn (*meher or hagaya*) cover around 84% of rainfall in lowlands and midlands AEZs of East Guji (Figure 3.3). Besides, the mean rainfall in the midlands and lowlands for winter and summer was 6% and 10% respectively.

Thus, four distinct seasons have been identified within the research area: winter, also known as *bega* (December to February) which is predominantly dry season; spring also known as *belg* is long rainy period (Mar-May); summer also known as *kiremt* (June-August); and autumn also known as *mehe*r (September-November), which is the short rainy period. The highland area receives better rainfall in the summer, but for low and midland AEZ the winter (*Bega*) and summer (*kiremt)* are comparatively dry seasons. As such, the highland parts of Eastern Guji receive a corresponding amount of rainfall in the three seasons of spring (34%), summer (30%), and autumn (29%) (Figure 9.3).

4.2.2. Sources of data

The study followed quantitative research design. Quantitative research was selected because the study is grounded on observed (recorded) statistical data. A standardized procedure was followed to analyze the data. Thus, the output of the study can be replicated and generalized to a similar study. It is non-experimental, descriptive and observational research. Non-experimental quantitative research design refers to the fact that there is no manipulation of variables in the study. The research described the severity, duration and spatial coverage of drought across the three AEZs in the East Guji. Gridded rainfall data (0.04˚ by 0.04˚) of the sample stations were taken from Ethiopian Meteorological Institutions (EMI) to characterize drought over the studied period (1990–2020). The gridded rainfall and temperature data was chosen over meteorological station data since the latter has more missing values and short time series data. Gridded time series rainfall and minimum and maximum temperature data of eleven stations were assessed quantitatively to analyze the severity, duration and spatial coverage of drought across the three AEZs in East Guji.

4.2.3. Sampling procedure

Probability and non-probability sampling procedure was used to select an appropriate sample for the study. Guji Zone was selected through purposive sampling as it represents three AEZs such as lowlands, midlands and highlands which can be used to show the spatial dimensions of drought in the area. A stratified random sample procedure was applied to select the required groups or strata for the study. AEZs are considered as strata for the study. A random sample is selected from each stratum based on the percentage of each AEZs embraced. Lowland, midland and highland AEZs cover about 27.3%, 51.5% and 21.2% of the total area, respectively. By considering the

Table 4. 1.Location of the study Stations and Length of Rainfall Series (1990-2020)

AEZs	Stations	Elevation in Meter(m)	Latitude In degree (^{0})	Longitude In degree (^{0})
Lowlands *(Kola) 632m-1500m*	Chembe	1025m	6^{0}	$38^{0}55'$
	Dawa	1177m	$5^{0}33'$	$38^{0}48'$
	Negele (Liben)	1439m	$5^{0}41'$	$39^{0}36'$
	Bitata	1473m	$5^{0}30'$	$39^{0}25'$
Midlands *(Weinadega)* 1500m -2300m	Odo Shakiso	1620m	$5^{0}45'$	$38^{0}56'$
	Adola (Kibre Mengist)	1680m	$5^{0}54'$	$38^{0}58'$
	Harekello (Goro Dola)	1708m	$5^{0}25'$	$39^{0}28'$
	Wadera	1750m	$5^{0}46'$	$39^{0}18'$
	Kercha	2036m	$5^{0}46'$	$38^{0}25'$
Highlands (*Dega*) 2300m-2960m	Solemo (Uraga)	2362m	$6^{0}05'$	$38^{0}34'$
	Bore	2712m	$6^{0}25'$	$38^{0}36'$

Data Source: Extracted from Ethiopian Meteorological Institute

Table 4. 2. AEZ Vs Aridity Index based Classifications of the Climate of the Study Area

R.NO	Centers	Agro Ecology	Local AEZ	FAO Aridity Index	Aridity Index
1	Chembe	Lowland	*Kola*	0.57	Arid Sub humid
2	Dawa	Lowland	*Kola*	0.36	Semi-Arid
3	Negele	Lowland	*Kola*	0.39	Semi-Arid
4	Bitata	Lowland	*Kola*	0.43	Semi-Arid
5	Shakiso	Midland	*Weinadega*	0.58	arid Sub humid
6	Adola	Midland	*Weinadega*	0.55	dry Sub Humid
7	Harekelo	Midland	*Weinadega*	0.45	Semi-arid
8	Wadera	Midland	*Weinadega*	0.53	dry Sub humid
9	Kercha	Midland	*Weinadega*	0.71	Humid
10	Solemo	Highland	*Dega*	0.84	Humid
11	Bore	Highland	*Dega*	0.89	Humid

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

distributions of AEZ in the study area, five, four, and two stations from midland, lowland, and highland AEZs respectively were randomly assigned. Accordingly, the randomly chosen stations (grid cells) include: Chembe, Dawa, Negele, Bitata, Oddo Shakiso, Adola (Kibre Mengist), Harekello (Goro Dola), Wadera, Kercha, Solemo (Uraga), and Bore (Table 4.1).

Side by side aridity index of the randomly selected stations were assessed. The aridity index is an output of RDI analysis using the DrinC software. Tables 4.1.and 4.2.demonstrate the classification of the stations in the study area based on the AEZ and the FAO aridity index. Given that both classifications show the presence of diverse climate zones in the study area. They placed in nearly the same class; Table 4.1 illustrates how much more similar the old AEZ-based categorization is to the FAO aridity index of the research area. There was evidence of varied microclimate in the research area according to both the FAO aridity index classification and the AEZs.

4.2.4. Methods of data collection

Secondary data, including rainfall, temperature, altitude, latitude, and longitude, were gathered from the sources of registered meteorological data (Table 4.1) from the EMI. For the years 1990-2020, gridded daily rainfall data with a grid cell size of 0.04 degrees, or 4 km ×4 km were acquired from the EMI for the chosen locations. Besides, a wide range of sources, including academic journals, published, unpublished books, working papers, research and thesis papers, government policy papers and reports, and regional agricultural and climatic documents, were also consulted for valuable information. This data was collected to examine the temporal trend and spatial distribution, severity, duration and spatial coverage of drought in Guji Zone.

4.2.5. Methods of data analysis

4.2.5.1. Descriptive statistics

At every level of data analysis descriptive statistics such as frequencies, means, percentages and standard deviation were utilized. Using those descriptive statistics, the condition of drought in Guji the zone was examined. Percentage and frequencies were used to express severity, duration and spatial coverage of drought in Guji Zone. The results were then arranged in tables and figures and appropriate debates ensued.

4.2.5.2. Inferential analysis

Excel-STAT, Drin C 1.7 and GIS software programs were utilized to examine quantitative data. Excel-Stat was used to perform the trend analysis of climate variables. The Reconnaissance Drought Index (RDI) was applied to characterize drought using Drin C 1.7 software. GIS software was used to interpolate the spatial distribution of drought in the Guji Zone using IDWI.

The study employed several data analysis techniques. Climate data for the study were analyzed using a variety of statistical methods. The non-parametric Man Kendal and Sen's slope estimator test were used to analyze trends and magnitude of change in drought respectively. The severity, duration and spatial coverage drought were all described using RDI.

1. Trend analysis

To determine long-term trends in drought as well as the magnitude of change in seasonal and annual time steps in the study area, the nonparametric Mann-Kendall trend test and Sen's slope estimators were used. The World Meteorological Organization (WMO) strongly advises using the Mann Kendall test (Abebe and Arega, 2020). It is selected for trends test in a time series data because it doesn't require linearity or normality, is less sensitive to outliers or is resistant against the influence of extremes (Poudel and Shaw, 2016; Wang *et al.,* 2020).

When Z value indicates a significant trend at a given significance level (< 0.05) it surpasses both confidence limit lines. Therefore, H_o is rejected and H_1 is accepted instead. Where n denotes the number of data points; and x_j and x_i are the time series observations in years' j and i, j>1.The Mann-Kendall statistic *S* of the series x is obtained using the following Equations:

$$S = \sum_{i=1}^{n-1} \quad \sum_{i=K+1}^{n} \quad sign\left(X_j - X_i\right) \qquad \text{Equation (1)}$$

$$\text{Sign of } (X_j - X_i) = \begin{cases} +1 \text{ if } (x_j - x_i) > 0 \\ 0 \text{ if } (x_j - x_i) = 0 \\ -1 \text{ if } (x_j - x_i) < 0 \end{cases} \qquad \text{Equation (2)}$$

The individual sign capacity that can take on the values [1,0, or -1] is denoted by the symbol Sign (X_j–X_i). An increasing trend is shown by a positive S value, whereas a decreasing trend is indicated by a negative value. Compute the variance of S using the formula below:

$$Var = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p\left(t_p - 1\right)\left(2t_p + 5\right)\right] \qquad \text{Equation (3)}$$

Where t_p is the total number of data points in the p^{th} group, n is the number of data points, and g is the zero difference between compared values. The following formula is used to get standardized measures of test statistics (Z_{mk}):

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} if S > 0 \\ 0 \text{ if } \quad S=0 \\ \frac{S+1}{\sqrt{VAR(S)}} if S < 0 \end{cases} \qquad \text{Equation (4)}$$

The magnitude of time series change was identified using a straightforward non-parametric method developed by (Sen, 1968). According to (Sen, 1968), this test calculates the interception and the linear rate of change (slope). Sen's slope estimator is used in the following calculation to determine the trend's magnitude. The Sen's slope is calculated by using equation 5:

$$\beta = Median\left(\frac{x_j - x_i}{j-i}\right), j > i \qquad \text{Equation (5)}$$

Where β is Sen's slope estimate $\beta > 0$ indicates an upward trend in a time series. Otherwise, the data series presents a downward trend during the period.

2. Drought characterization using Reconnaissance Drought Index (RDI)

SPI has been employed as an index in most prior studies investigating drought. However, SPI only considers rainfall as a climate variable when analyzing drought. The study opted for the Reconnaissance Drought Index (RDI) because of its capacity to account temperature variability alongside precipitation variability and integrate potential evapotranspiration (PET) to characterize drought (Zarch *et al.*, 2011). Since RDI incorporates precipitation and potential evapotranspiration which are directly affected by climate change, it is a more suitable index for studying drought severity under climate change (Thomas *et al.*, 2016).

The advantages of RDI over SPI include its more comprehensiveness, physical bases, ability to compute the aggregated deficit between precipitation and atmosphere's evaporative requirements, flexibility across time, improved correlation with agricultural and hydrological droughts. Additionally calculating RDI with monthly precipitation and PET is straightforward and easy (Tsakiris and Vangelis, 2005). RDI is more adapted to arid and semi-arid regions since it takes PET into consideration (Thomas *et al.*, 2016).

Using Hargreaves's method, the monthly minimum and maximum temperature were utilized to calculate potential evapotranspiration. The RDI model was applied to analyze the drought using Drin C 1.7 software. The process for computing the final expression, the Standardized RDI (RDI_{st}), is comparable to that which was employed in computation of the SPI. The Standardized RDI equation is as follows:

$$RDI_{st}(K) = \frac{Y_k - \bar{Y}_k}{\sigma_k} \qquad \text{Equation (6)}$$

where y_k is the ($In_k^{(i)}$) $\bar{y}_k$ is the arithmetic mean, and σ_k is the standard deviation. When the gamma distribution is used, the RDI_{st} can be computed using composite cumulative distribution function by fitting the gamma probability density function (PDF) to the brief reference periods (e.g. monthly or 3-months) which may contain zero values for period's cumulative precipitation (Ikegwuoha and Dinka, 2020).

Both the standardized RDI and the results interpretation exhibit SPI-like behavior. As such, the RDI_{st} and SPI can be compared to the same thresholds. The a_o values in the RDI analyzing process have a lognormal distribution; the lognormal distribution fits the data, as demonstrated by the goodness-of-fit test. The supplied frequency distribution of α_k will be for fitting using the gamma probability density function (pdf) (Tsakiris and Vangelis, 2014).

According to the interpretation of RDI value, episodes classified as drought and non-drought occur when the values of RDI are negative and positive, respectively. A drought period is declared when the RDI reading is less than zero to (<-0.5). When compared to the area's typical conditions, positive values up to -0.5 RDI_{st} value suggest wet periods while negative values indicate dry periods. Drought severity can be categorized based on the thresholds of RDIst as mild (-0.5), moderate (-1.0), severe (-1.5) and extreme (-2.0) (Thomas *et al.*, 2016).

Table 4. 3. Classifications of RDI Value

RDI Values	**Classification**
-0.5 to -0.99	Mild (near to normal)
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
< -2.0	Extremely dry

Source: Tsakiris and Vangelis (2005)

Drought is a three-dimensional event, characterized by its severity or intensity, its duration, and its affected area (Tsakiris and Vangelis, 2005; Tigkas *et al.*, 2013). Drought severity being the absolute value of the sum of negative index values during drought events (Adhyani *et al.*, 2017). Drought severity is dependent not only on the duration, intensity, and geographical extent of a specific drought episode but also on the demands made by human activities and vegetation on a region's water supplies (Wilhite, 1993).Droughts also differ in terms of their spatial characteristics. The areas affected by severe drought evolve gradually, and regions of maximum intensity shift from season to season indicate the spatial characteristics of drought (Wilhite and Svoboda, 2000). Lastly, drought frequency represents the number of drought events divided by the total number of years of the study period (McKee *et al.*,1993; Naumann *et al.*, 2015). Frequency describes the number of events per time interval, severity describes the accumulated deficit over the entire duration of an event (Global Assessment Report on Disaster Risk Reduction Special Report on Drought, 2021).

4.3. Results and Discussion

4.3.1. Characterization of severity of drought

The distribution of drought severity in the three AEZs of East Guji Zone from 1990-2020 is shown in Figure 4.3-4.4. Due to the failure of spring, autumn and annual (12 months) rainfall, serious drought occurred across the three AEZs of Guji zone. The lowlands and midlands, which make up about (80%) of the study area, and receive their maximum rainfall during the spring and autumn, are often affected by drought. However, these rainfall periods are not major rainfall seasons in most parts of Ethiopia. This is in line with the findings of NMSA (1996) who reported the presence of double wet seasons that occur between March-May and September-November with two dry seasons in between in the south and southeast of Ethiopia. It is unlikely to get much rain throughout the summer in most of the study region due to its dry conditions (Korecha and Barnston, 2007; Diro *et al.*, 2011).

Drought affected around 91% of the study area in 1992,1999, 2000, 2008, and 2017. The first known extreme drought event during the study period occurred in 1992, and it affected the whole study area. For example, 91% and 100% of Guji Zone was affected by the drought in 1991 and 1992 respectively. Throughout the first decades of the study period (1991-2000), there were more instances of drought. Similarly, Gezahegn (2024) documented a comparable drought period in Oromia Regional state, with extreme drought in 1999, 2000, 2011, 2014, and 2015, and severe drought conditions in 1991, 1994, 1995, 2002, 2004, 2008, 2009, and 2017. Likewise, Abebe *et al.* (2020) documented an exceptionally severe drought in the *belg* in March 2008, and the year 1999 was the driest year on record in Ethiopia's northeastern highlands. In the same vein, over 73% of the study area was struck by drought 1991,1992,1994,1997,1999, 2000, 2002, 2004, 2008, 2011, 2017.

A severe drought struck much of lowland and midland Guji areas in 1991-92. Once more, midland AEZ had severe drought in 1998-99. In 2000, the midland experienced severe drought. In 2008, moderate drought affected almost all AEZ in Guji zones. In 2016, a severe drought hit the lowlands, and moderate drought affected the midland AEZ in the study area (Figure 4. 3).

The temporal distribution of drought for each of the three AEZs is presented in Figure 4.2. 55%, 27%, 18% drought years were recorded during the first (1991-2000), second (2001-2010) and third (2011-2020) decades of the study period respectively. Figure 4.2 illustrates a slight drop in the frequency of drought years from the beginning of the studied period to recent years. The lowering tendency of drought in recent years in the study area was associated with the significant increasing trend of rainfall in recent years that has been seen in most parts of the study area (Menbere *et al*., 2024). Drought trends showed a drop as rainfall indicated statistically significant positive change. Furthermore, it was shown that compared to the first and the second decades of the examined period, the final decade (2011-2020) of the studied period was comparably wetter. The tendency of drought has shown a declining trend as rainfall has increased from the first (1991-2000), to the last (2011-2020) decades. Palmer *et al.* (2023) observed a similar trend of rainfall in east African countries .

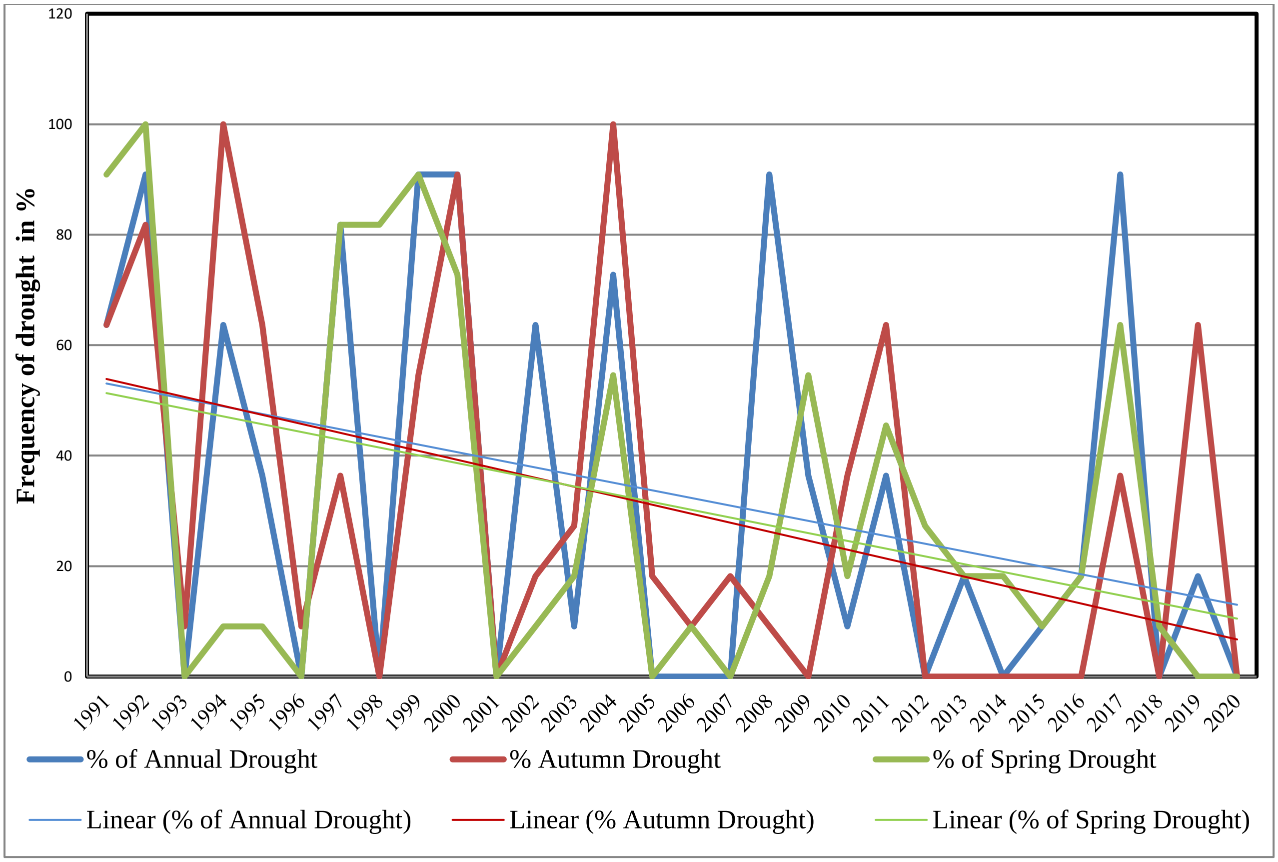


Figure 4. 2. Temporal Distributions of Annual, Spring and Autumn Drought in Guji Zone

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

The area occasionally experienced unique and comparable drought events to those that occurred in other parts of Ethiopia. Several studies have shown the various mechanisms relating to sea surface temperature that regulate rainfall in various regions of Ethiopia. According to a study of Diro *et al.* (2011), a cold Gulf of Guinea causes the TEJ to strengthen and the ITCZ to become repressed, which increases rainfall in southern Ethiopia while decreasing in the north and central regions. The effects of ENSO vary spatially in this region. El Niño occurrences cause lower than normal rainfall in the northern part of Ethiopia but higher than usual rainfall over the southern parts of the country (Korecha and Barnston, 2007). Degefu *et al.* (2017) further explained the positive and significant correlation between Nino 3.4 and the IOD and the Small Rainfall season (ON) in the Southern Region of Ethiopia. There is an excess of rainfall during the Small Rainfall season (ON), and a shortage of rainfall during the main rainfall season (MAM) over Southern Ethiopia. They reported an excess of rainfall during the small rainfall season (ON), and a shortage

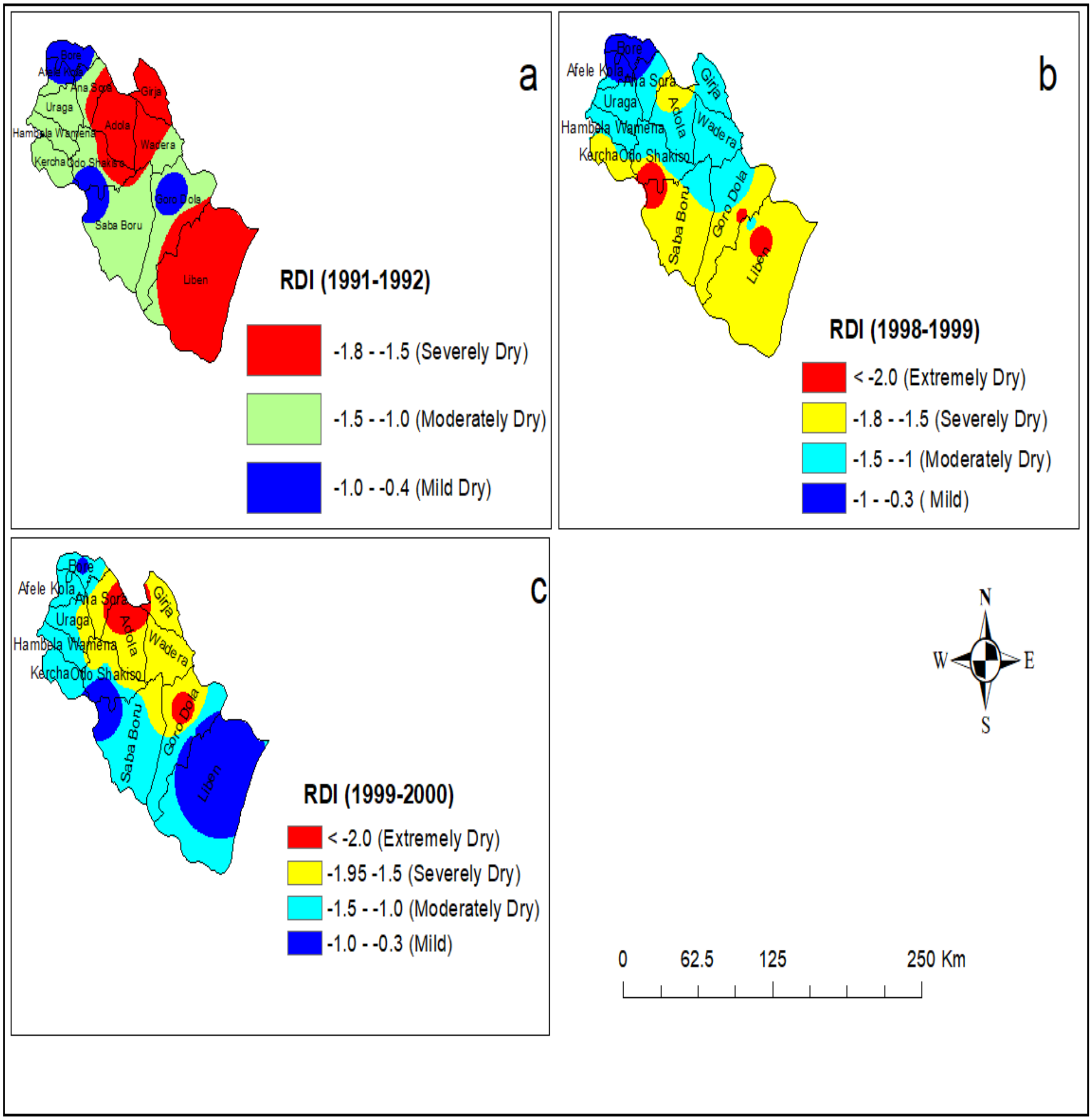


Figure 4. 3. Above 90 % of Guji Zone was affected by drought

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

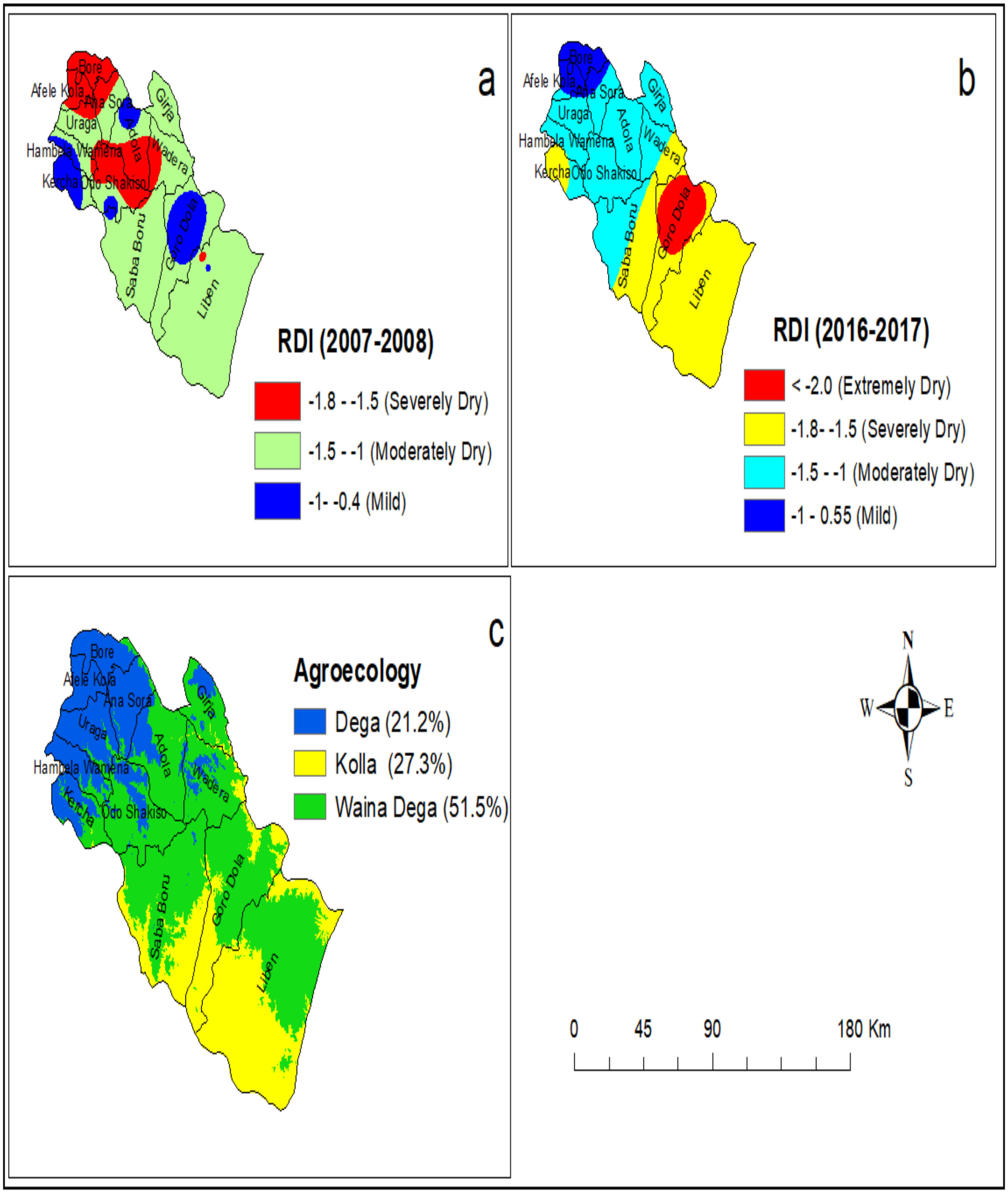


Figure 4. 4. Above 90 % of Guji Zone was affected by drought

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

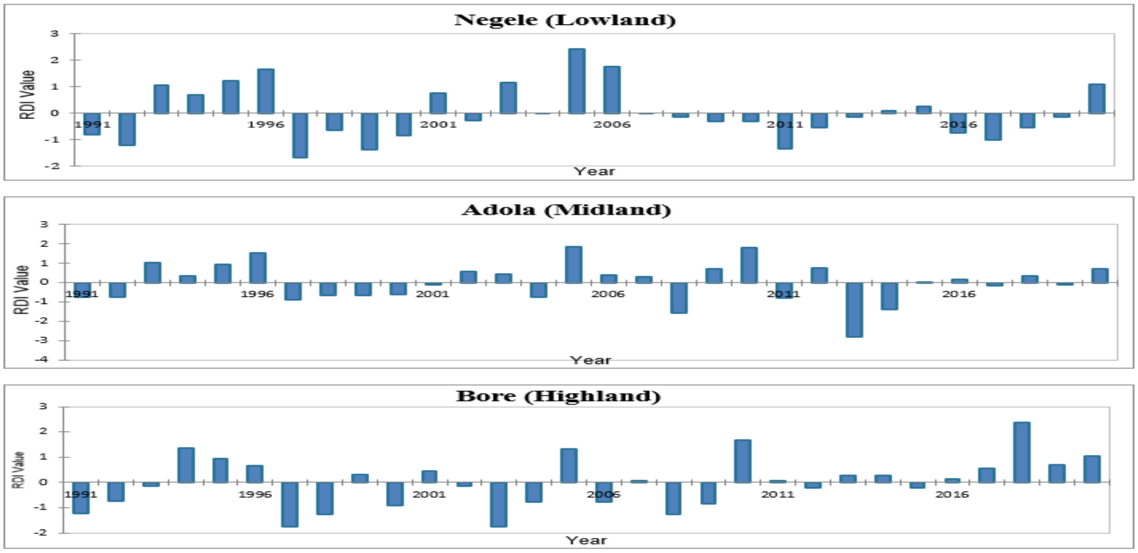


Figure 4. 5. Spring Drought in the three AEZ of East Guji

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

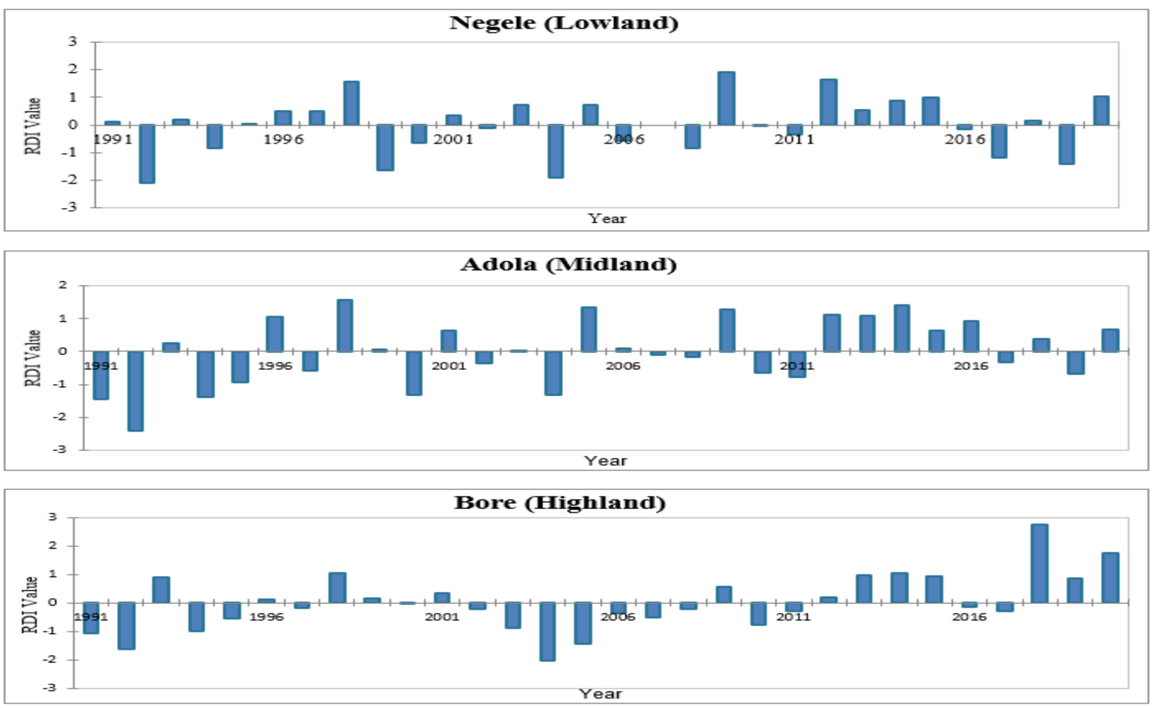


Figure 4. 6. Autumn Drought in the three AEZs of East Guji

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

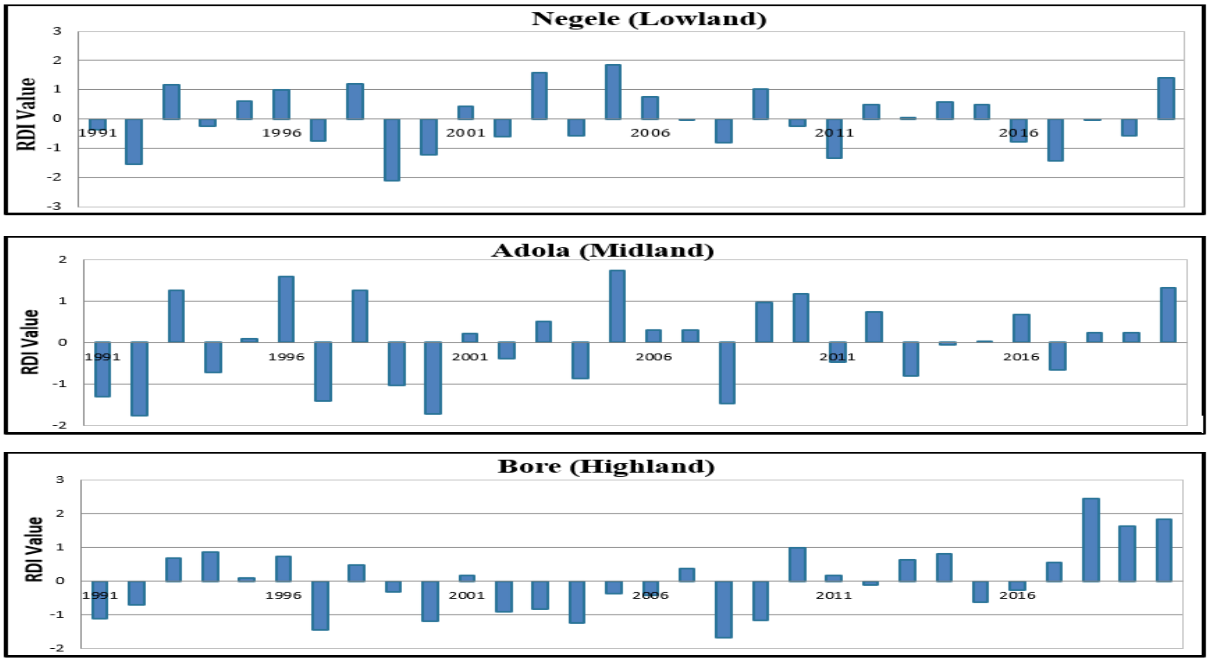


Figure 4. 7. Annual Drought in the three AEZs of East Guji

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

of rainfall during the main rainfall season (MAM) over Southern Ethiopia. Similar dry periods were noted in several southern part of Ethiopia. Additionally, there is a correlation between the local drought periods in Guji and the drought in the southern parts of Ethiopia. As a result, the studies on the Oromia regional state (Gezahegn, 2024), Sidama regional state's (Markos *et al.*, 2023) and Borena Zone (Gelgelo *et al.*, 2021) reported comparable drought years with the Guji zone. Additionally, drought in Awash River basin partially corresponds to drought periods in Guji (Desalegn *et al.*, 2010)

An extreme RDI value of -2.8 was noted at Shakiso and Adola in the spring 2013 and -2.77 at Wadera in spring 2000. Chembe experienced a similar extreme drought with an RDI value of -2.64 at 12 months (annual) timescale in 2000 (See Table 9.4 in the appendixes). There is a correlation between El Niño and the drought event in Guji. According to earlier research, there was a correlation between El Niño and the drought in the study area (1991/92, 1994/1995 1997/1998, 2002/2003, 2004/2005, 2006/2007, 2009/2010) (United Nations OCHA, 2017; Yimer *et al.*, 2018) which led to dry spells in various part of the world, including the horn of Africa. In conclusion, there is a correlation between El Nino and the drought occurrences in the Guji Zone.

4.3.2. Agro ecology-based duration and spatial distribution of drought in the study area

The distribution of duration and spatial coverage of drought months across the three AEZs of Guji zone is shown in Table 4.4. As can be seen, each AEZ experienced different levels and spatial coverage of drought. Despite rainfall variability having disparately affected the low and midlands AEZs (CV >30), drought was intensified across all AEZs. Table 4.3 shows that the total number of months of drought during the autumn season was higher in Shakiso, Adola, Kercha and Bore. The total number of spring droughts was higher in Kercha, Negele, Shakiso and Adola and the drought months at annual (12 months) timescale were highest in Negele and Bitata.

Table 4. 4. Duration of Drought in the Study Area

Seasons	Drought Magnitude	Total Number of Drought Months (1991-2020)										
		Lowland *(Kola)*				Midland *(Weinadega)*					Highland *(Dega)*	
		Chembe	Dawa	Negele	Bitata	Shakiso	Adola	Harekello	Wadera	Kercha	Solemo	Bore
Autumn	Mild	9	15	12	0	15	15	6	12	12	12	15
	Moderate	12	9	6	21	12	12	12	3	15	6	9
	Severe	3	3	6	0	0	0	3	3	3	6	3
	Extreme	3	0	3	3	3	3	3	6	0	3	3
	Total	**27**	**27**	**27**	**24**	**30**	**30**	**24**	**24**	**30**	**27**	**30**
Spring	Mild	18	21	18	21	24	24	15	6	24	6	15
	Moderate	6	3	12	6	3	3	12	3	9	18	9
	Severe	3	3	3	3	3	3	3	6	3	3	6
	Extreme	3	3	0	0	3	3	0	3	3	0	0
	Total	**30**	**30**	**33**	**30**	**33**	**33**	**30**	**18**	**39**	**27**	**30**
Annual	Mild	72	72	72	72	48	48	36	36	36	24	48
	Moderate	12	24	36	24	48	48	60	36	72	84	60
	Severe	24	12	12	36	24	24	12	0	12	12	12
	Extreme	12	12	12	0	0	0	0	24	0	0	0
	Total	**120**	**120**	**132**	**132**	**120**	**120**	**108**	**96**	**120**	**120**	**120**

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

Note: [1]Located at lowlands AEZ (*Kolla*)**;** [2]Located at midlands AEZ (*Woina Dega*); and [3]Located at highland AEZ (*Dega*)

Table 4.4 demonstrated the complex spatial variation in the duration of drought episodes at the three AEZs and seasons. This demonstrated that throughout the period of 1990-2020 all AEZs in the area had a deficit in rainfall or duration of drought lasting 96–132 (27%-37%) months. In other words, the area experiences drought every 2.7-3.7-year interval. Similar findings were reported by (Tagel *et al.*, 2011; Getachew *et al.*, 2024). In Northern Ethiopia, drought of varying intensities has occurred at least every two or three years. There has been an increase in the frequency of drought in Ethiopia. For instance, the drought that characterized the 1970s and 1980s typically happened once every ten years (Crompton *et al.*, 2012; Almeida *et al.*, 2016). Between 1980 and 2004 it occurred roughly every 3 years as well (World Bank 2006) and once a year between the 1990s and 2011 (Viste *et al.*, 2013).

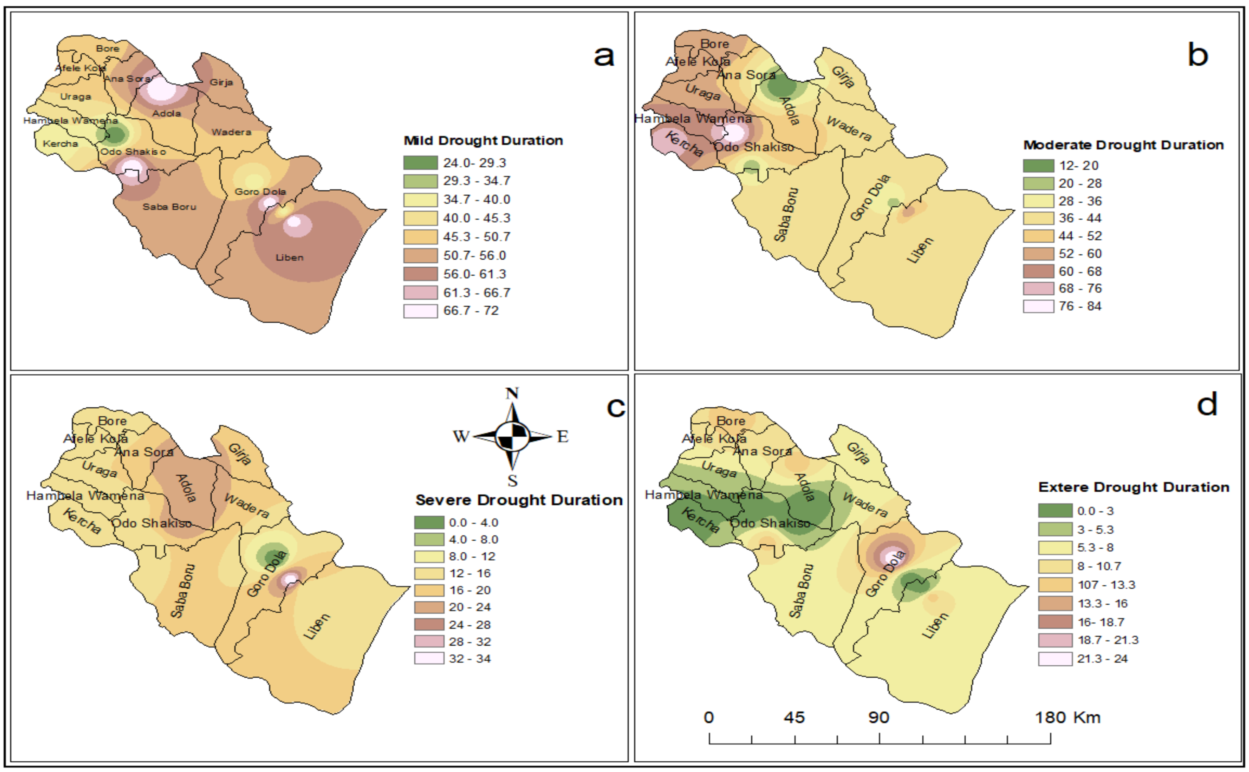


Figure 4. 8. Duration of Mild, Moderate, Severe and Extreme Drought months in Guji Zone

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

The frequency of mild, moderate, severe, and extreme drought events was 43%, 38%, 14% and 5%, respectively (Figure 4.8). The predominant type of drought experienced in the research area was mild drought (RDI value of -0.5 to -0.9) or near normal dry conditions. There was also a significant quantity of moderate drought (38%) detected in the area. Additionally, the frequency of moderate drought at annual timescale in Solemo, Kercha and Harekello stations was 17%, 14%, and 12% of the study period, respectively. Severe annual drought occurrences were observed in Bitata, Chembe, Adola and Shakiso. Extreme drought affected most of the lowland AEZs.

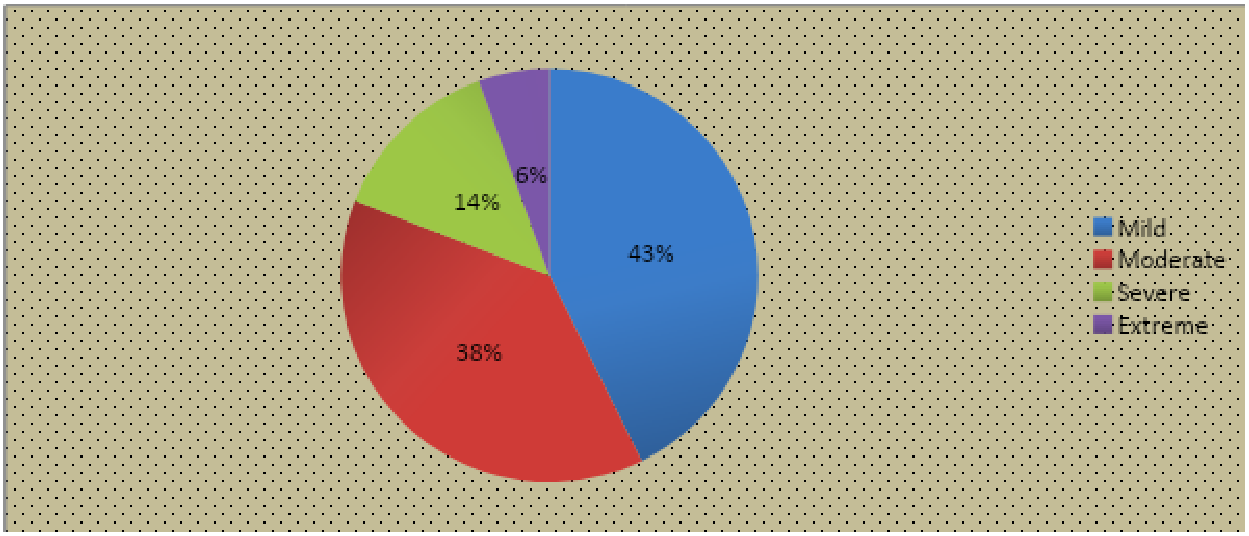


Figure 4. 9. Frequency of Drought in Percentage in Guji Zone

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

Apart from Wadera, the remaining Midland and highland AEZs did not experience any extreme drought. The percentage drought in spring, annual and autumn season was 34%, 33% and 30 % respectively. Slightly greater frequency of drought occurred in spring than autumn and annual (12 months) timescale (Table 4.4). Similar research findings revealed the two centuries drying trend as well as an increase in the frequency of spring drought over the Horn of Africa from March–May (Viste *et al.,* 2013; Lyon, 2014; Tierney *et al.,* 2015).

4.3.3. Agro ecology-based trends of drought in the study area

In the study area, it was found that the trend of drought and rainfall followed an opposite pattern. In other words, there has been a drop in drought along with an increase in rainfall and vice versa. Droughts at autumn and annual time scale (12 months) showed statistically significant at ($p < 0.05$) declining trends in Chembe and Dawa (lowlands), Kercha (midland), and Bore and Solemo (highland) AEZs (Table 4.5). Negative RDI value in the MK test indicates the increasing tendency of drought and vice versa. Whereas positive RDI reveal a declining trend of drought. This declining trend of drought was due to statistically significant increase in autumn and annual rainfall in some parts of the study area (Menbere *et al.*, 2024).

Table 4. 5. Trends of Drought for Spring, Autumn and Annual (12 Months) Time Scale

Stations	RDI 3 Spring MK test			RDI 3 Autumn MK test			RDI 12 Months MK test		
	MKT	S	P	MKT	S	P	MKT	S	P
Chembe[1]	0.170	74	0.193	0.356	155	**0.006*** **	0.295	128	**0.023*** **
Dawa[1]	0.251	109	**0.054** **	0.268	116	**0.040*** **	0.327	142	**0.012*** **
Negele[1]	-0.014	-6	0.929	0.117	51	0.372	0.009	4	0.957
Bitata[1]	0.122	53	0.354	0.145	63	0.269	0.124	54	0.344
Shakiso[2]	-0.002	-1	1	0.239	104	**0.066* **	0.173	75	0.187
Adola[2]	-0.002	-1	1	0.239	104	**0.066* **	0.173	75	0.187
Harekello[2]	0.122	53	0.353	0.244	106	**0.061* **	0.166	72	0.205
Wadera[2]	-0.014	-6	0.929	0.058	25	0.668	0	0.000	1.000
Kercha[2]	0.251	109	**0.054** **	0.520	226	**<0.0001*** **	0.439	191	**0.001*** **
Solemo[3]	0.292	127	**0.025*** **	0.467	203	**0.000*** **	0.396	172	**0.002*** **
Bore[3]	0.260	113	**0.046** **	0.327	142	**0.012*** **	0.249	108	**0.056** **

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

Note: ***Level of Significance = P < 1%, P <5%**,and P < 10%*

Note: [1]Located at lowlands AEZ (*Kolla*)**;** [2]Located at midlands AEZ (*Woina Dega*); and [3]Located at highland AEZ (*Dega*)

4.4. Conclusion

Each AEZ in the research area experienced varying degrees of drought, in terms of duration, severity, and spatial coverage. Drought's trend follows a reciprocals pattern with the trend of rainfall in each AEZs. As a result, the trend of drought has declined in place of significant rainfall and vice versa. Due to the study area's location in the Southern part of the country, there is partial divergence in the drought trend compared to the national average. This is because Ethiopia's southern, the northern and central regions receive rainfall from different sources of moisture. In addition to its association with ENSO, climate variability has been linked to occurrences of drought and famines in many parts of Ethiopia. It was discovered that there is correlation between the El Niño in the Pacific and Atlantic oceans and the drought in the studied area. Therefore, the impact on SFHH will be lessened if the incident is accurately predicted using a timely, effective and relevant early warning system. In comparison to highlands, lowlands and midlands AEZs should receive more attention to provisions of adaptation techniques.

CHAPTER FIVE

THE IMPACT OF RAINFALL VARIABILITY AND DROUGHT ON FOOD SECURITY OF SMALLHOLDER FARMERS IN GUJI ZONE

ABSTRACT

The research examined the impact of rainfall variability and drought on food security of smallholder households at the three agro ecological Zones of Guji Zone, Southern Oromia, and Ethiopia. To undertake the study three decades (1990-2020) rainfall and temperature data were taken from EMI. The household survey was undertaken on 400 selected households from the three agro ecological zones using stratified simple random sampling. Precipitation Concentration Index (PCI), Coefficient of Variation (CV) and Reconnaissance Drought Index (RDI) were used to analyze rainfall variability and drought in the area. The Mann Kendall trend analysis and Sen's slope were used to determine the rate of change and magnitude of change in climate variables. The HFIAS were used to analyze the level of household security .The PCI and CV showed that highlands had moderately concentrated but both lowlands, and midlands, had an irregular distribution of rainfall. In contrast, the low and midlands had shown high variability of rainfall (CV >30%) in all seasons. Based on HFIAS the three AEZ of Guji zone had varying levels of food insecurity score 8.7 the highland (Bore) is mildly food insecure. Midland (Adola) is moderately food insecure (11.3) and there was severe food insecurity (17.5) in the lowland AEZ in Negele. The finding of logistic regression analysis showed that socio-economic and demographic factors including the head of the household age, sex, household size, number of cattle, agro ecological zone, level of education, cultivated land size, farming experience, distance from the market and receipt of food aid positively and significantly contribute to food security status of the smallholder's farmers. Results suggest that agro ecologic based investigations are useful in developing context-specific adaptation towards the impacts of rainfall variability and drought on food security of smallholder farmers.

Keywords: Agro ecological zones; Binary logistic Regression Model; Food insecurity; Household food insecurity access scale; Rainfall variability and drought

5.1. Introduction

Climate change has affected food security by disrupting availability, access, and making utilization of food more difficult from local to global level (Metadel and Yihunie, 2020). Drought reduces agricultural production of grain which is the principal staple food especially in the developing countries (Kogan, 2019). Climate change undermines food security in tropical regions through having a negative impact on wheat, rice and maize production for local temperature increases of 2°C or more above late 20th-century levels, although individual locations may benefit (IPCC, 2014). The worldwide grain deficit caused by drought, which reduced global food supply, is the reason behind malnutrition, hunger, and under nutrition (Kogan *et al.*, 2019; Verschuur *et al.*, 2021). Climate change and variability have an influence on agriculture-related activities which in turn have an impact on food production, farmers' income, accessibility, and supply, all of which have an impact on food availability (Alelign, 2017;`Affoh *et al.*, 2022).

In east Africa, production loss from food and cash crops due to climate change and variability is predicted to reach 50 % by 2020 (IPCC, 2007; Adhikari *et al.*, 2015). In comparison to the baseline period (1960-1990), the growing season in some parts of Ethiopia could be 20% shorter by the 2050s which will have a negative effect on food production (van de Steeg *et al.*, 2009). Higher rainfall variability and associated droughts lead to crop failures, which have contributed to food insecurity in Ethiopia (Yilma and Zanke, 2004; World Bank, 2006). Decreasing rainfall is diminishing food availability (Schmidhuber and Tubiello, 2007).

Smallholder farmers in developing countries contribute to up to 80 % of food production but face unpredictable rainfall patterns, affecting agricultural yield and household food security (Linderman *et al.*, 2011; Bekele *et al.*, 2014; Esilaba, 2015).Rainfall variability affects smallholder farmers' livelihoods, increasing food insecurity and hunger risk (IPCC, 2007; WFP, 2016; FAO, 2018). Despite these challenges, Ethiopia's economy remains agricultural (Diao and Pratt 2007; World Bank 2010; Conway and Schipper 2011; EPCC 2015). Agriculture is crucial for the Ethiopian economy, contributing 40% of the GDP, 80% employment, and 90% exports. Besides, 79% of the income of the population depends on rain-fed agriculture (Tafesse and Tewodroso, 2019; Young and Klingaman, 2020).

Household food security is dependent on the physical availability of food, the ability of households to access the available food and the ability of individuals to secure entitlement to it (Bouis and Hunt, 1999). Food security can be classified into three main components-availability, access, and utilization (FAO, 1996). Food availability exists when households have access to enough, adequate and necessary foods obtained through local production, commercial imports or agency donations. Access refers to having necessary resources for the purchase or interchange of goods with the aim of obtaining a variety of foods to comprise a nutritionally adequate diet. Utilization addresses the safe distribution, storage, and preparation of foodstuffs (Castell *et al.*, 2015). A household is considered food secure if it can acquire the food needed by its members (Pinstrup-Andersen, 2009).

Access to food is affected by climate which is a feature of the food system (Lewis, 2017). The Household Food Insecurity Access Scale self-reported household food insecurity status was used to assess the level household's food insecurity. Availability alone does not guarantee access and if food security is to be a measure of household welfare, it must address the issue of access (Pinstrup-Andersen, 2009). Besides, econometric models were used in the study because the socio- economic and demographic characteristics of farm households are also a basic factor determining SFHH food security. Thus, the binary logistic regression was used to assess the determinant socio-economic and demographic variables that affect food security of smallholder farmers.

Studies on the impacts of rainfall variability and drought on food security in the Ethiopian farm households are extensive (Nigatu and Stoecke, 2012; Malla *et al.*, 2017; Alem meta and Singh, 2018; Shishay and Dawit, 2018; Bereket *et al.*, 2019; Argaw and Aragaw, 2021; Abebe *et al.*, 2021; Mesfin *et al.*, 2021; Amogne *et al.*, 2021). Most of the above-mentioned studies were undertaken at district, subnational and national levels. However, there is minimal empirical evidence on the distinct effect of diverse AEZ on the food security of farm households. Climate change has a negative impact on crop production in countries located in low-latitude and can have positive or negative effects in northern latitudes (Gitz *et al.*, 2016). Rainfall variability and drought in Ethiopia have divergent impacts, making it a misappropriation of climate as the causal factor for food insecurity necessitating a local study of climate dynamism (Lewis, 2017). In other words, the average rainfall of a relatively larger area could not explain the food insecurity disasters in each AEZ. Since localized deficit in rainfall directly corresponds to localized food insecurity. Thus, an examination of the effects of rainfall on food security based on AEZs is necessary.

Therefore, the study of the effect of rainfall variability and drought on food security must consider dynamism in the local climate. Guji Zone is one of the areas with high rainfall variability and drought. As a result, smallholder farmers in the area were highly affected by food insecurity. Therefore, understanding the influence of rainfall variability and drought on food security at different AEZ enables us to identify appropriate adaptation to alleviate rainfall variability and drought-induced food insecurities. The objective of the study was to assess the impact of rainfall variability and drought on food insecurity of smallholder households across the three AEZs of Guji Zone.

5.2. Materials and Methods

5.2.1. Descriptions of the study area

This study was conducted in East Guji Zone. The area is situated in the Southern part of Oromia Administrative Regional State, Ethiopia. Geographically, the East Guji Zone is located between $4^0\,30'$ N - $6^0\,30'$ N and $38^0\,15'$ E-$40^0\,5'$ E (Figure 3.1) and covers a total area of about 18,577 Km^2. It shares a border with Gedeo and Sidama in the North, Somali Regional State in the South, Bale Mountain in the East, and Borena Zone in the West.

The total population of the area as projected by CSA (2022) was 2,030,667 in 2022. The inhabitants are predominantly pastoralists, agro-pastoralists, and farmers (Teshome, 2016). Coffee is an important cash crop; vegetables are also produced in large quantities in the Guji zone (Lazzari *et al.*, 2021). Guji zone has an average household size of 5.1, consisting of 3.9 in urban areas and 5.3 in rural areas. These are 4.8, 3.8 and 4.9 for Oromia region, and 4.8, 3.8 and 4.9 for Ethiopia (CSA, 2007).

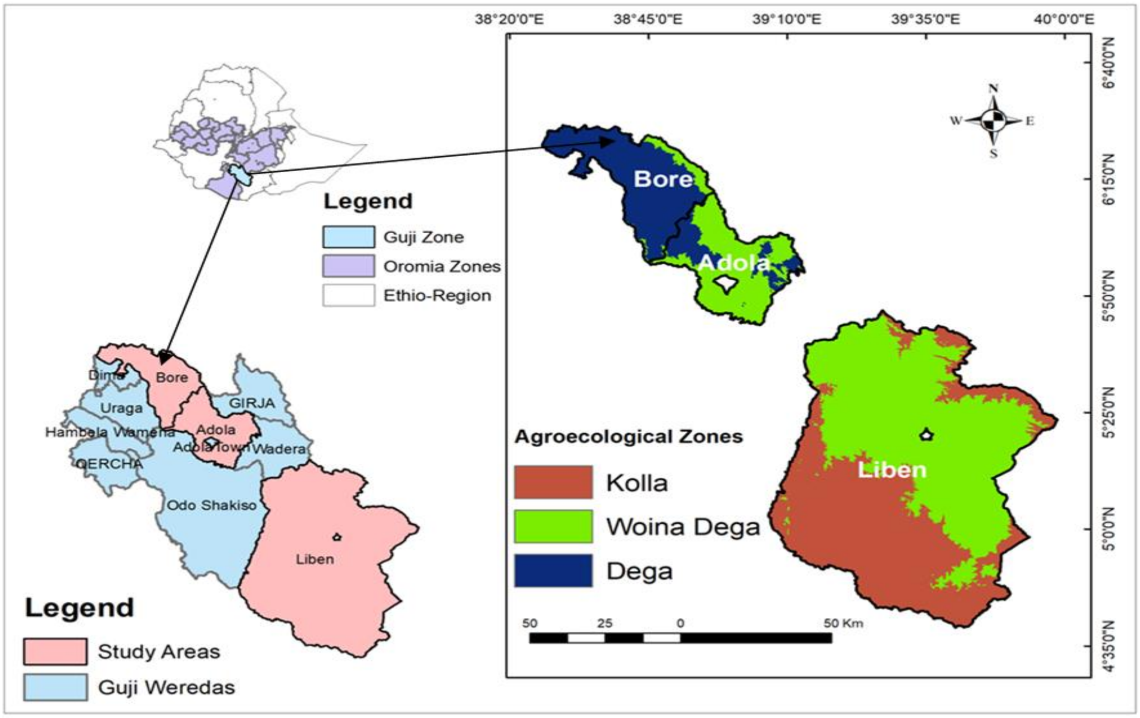


Figure 5. 1. Map of the three selected districts

5.2.2. Sampling techniques and sampling size

5.2.2.1. Sampling techniques

The East Guji Zone is the study's targeted population (Figure 5.1). There are thirteen political administrations in the Guji Zone. The study area's altitude varies greatly, from 632 meters to 2960 meters (Figure 3.1). As a result, the zone has three AEZs, which are significant for illustrating the spatial dimension of rainfall variability and drought, as well as effects on food security of smallholder farmers in the area (Figure 3.2). The three AEZ in the study area were represented by the selected three districts for AEZ-based examination (Figure 5.1). The household survey was undertaken under the three districts at the lower administrative unit, or *kebeles*.

The study employed a multi-stage sampling approach. In the first stage, Guji Zone was chosen using non-probability purposive sampling, because it has lowlands, midlands and highlands that illustrate the geographical aspects of rainfall variability and drought. Then, a stratified simple random sampling was undertaken to select representative grid points (Table 3.1) for empirical analysis of rainfall variability and drought. Next, the study area was stratified under the three AEZs

Table 5. 1. Collection Methods by the Respective AEZs

Basic features	Agro Ecological Zone (AEZs)		
	Highlands (*Dega*) 2300m-3300m	Midlands (*Weinadega*) 1500m-2300m	Lowland (*Kola*) 500m-1500m
Fieldwork carried out	2021 August-October	2021 August-October	2021 August-October
Spatial coverage of each AEZ	21%	51.5%	28.3%
Main meteorological stations	Bore and Solemo (Uraga)	Odo Shakiso, Adola Harekello (Goro Dola), Wadera and Kercha	Chembe, Dawa, Negele and Bitata
Selected district	Bore	Adola (Kiber Menigist)	Negele (Liben)
Climate Database Period	1990-2020	1990-2020	1990-2020
Field data collected.	90 HHS, one FGD and three KII	200 HHS, one FGD and three KII	110 HHS, one FGD and three KII
Average Annual rainfall of 30 year	1232.4mm	932mm	747mm
Average Temperature	15.8^0c	19.4^0c	22.1^0c
Climate System	Temperate rainy climate: the warm humid temperate, the warm temperate per humid and the cool highland climates	The tropical humid and tropical sub-humid climates	dry climate: the hot arid, semi-arid, dry sub-humid climates
Main growing seasons	Single growing period: uni modal growing period but undergone change currently	Bi modal growing period: Spring (April-may) and Autumn (September-November)	Bi modal growing period: Spring (April-may) and Autumn (September-November)
Farming system	Barley, Pea, Beans, wheat, highland oilseeds, highland pulses	Wheat, Teff, barely, maize, Sorghum, chickpeas, and haricot beans	Sorghum, finger Millet, caw peas, Sesame, ground nuts

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

(Figure 3.2). AEZs are regarded as strata in the study. Subsequently, the necessary groups or strata for the investigation were chosen using a stratified simple random selection process.

Districts for field data collection were chosen at random for the study from the stations mentioned under each AEZ (Table 3.1). Thus, from the lowlands, midland and highland AEZs, respectively, Negele, Adola and Bore were chosen at random. 90, 200, and 110 heads of the household were chosen from the highland (Bore), midlands (Adola), and lowland (Negele) respectively. At the lower-level administration unit *kebele* where the household survey was conducted. Then, based on their proportion, *kebeles* were assigned at random from each AEZ.

5.2.2.2. Sample size determination

It is not feasible to study the entire population. To get representative samples from the population, sampling is necessary for the purpose of gathering primary and secondary data for the research. Determining the appropriate number of observations or individuals to include in a sample from a bigger group is the process of determining sample size. The statistical analysis strategy must carefully take the level of significance, effect size, and sample size into account when determining the appropriate sample size.

The three AEZ in Guji Zone are where the study was undertaken. Given that the study is an AEZ-based inquiry, three representative *woredas* from Guji Zone were chosen at random to serve as typical AEZs. Thus, the household survey was conducted in representative rural *kebeles* of the three AEZs. There were 55632 SFHH in the three districts of each AEZ. There are various methods for figuring out sample sizes. Equation 1 illustrates the sample size determination utilized for the investigation, which was based on Yamane (1967). As a result, the confidence level (Z) is 95 % and the degree of precision (e) is 5%,

$$n = \frac{N}{1+N(e)^{2}} \qquad \text{Equation (1)}$$

n = Sample size to be studied

N= the Population of the study

e = margin of error in the calculation

$n \ \frac{N}{1+N(e)^{2}}$ $\qquad$ $n= \frac{55632}{1+55632(0.05)^{2}}$

n = 397 farm households were selected sampled for the study

A total of 400 heads of households were enumerated and survey questionnaires were proportionally distributed in the midlands, lowlands, and highlands AEZ as 200, 110 and 90 respectively. Besides, three FGD were held at the selected districts, each comprising six to eight members. Furthermore, three KII were undertaken at each AEZ (3*3=9).

5.2.3. Methods of data collection Instruments

To undertake the study mixed data sources were employed. A combination of primary and secondary data was used. Primary data were gathered through the household survey, (HHS) Key informant interviews (KII), and Focus group discussion (FGD). A structured open and close-ended questionnaire was used for the household survey, and both qualitative and quantitative methods of data collection techniques were used. The survey evaluated the sampled households' socio-economic and demographic attributes, as well as the impacts of rainfall variability and drought on households' food security. Besides, secondary data from the Ethiopian Meteorological Institution (EMI) was gathered for the period of 1990-2020 for time series analysis of rainfall, temperature and drought.

5.2.3.1. Primary data collection

To conduct research, the primary data gathering instruments used include household surveys, FGD, and KII. The household survey contains assessment tools about the household's socio-economic and demographic characteristics and effects of rainfall variability and drought on food security of SFHH. Several data gathering tools were employed to collect information from several sources and conduct triangulations to validate and elucidate the research questions. This section provides an overview of the fundamental ideas behind the key data collection tools that were employed in this study, along with an explanation of how each tool was used.

Household survey

A field survey was conducted in-person interviews, and a questionnaire was carried out at the household level. The survey questionnaire was used to gather the socio-economic and demographic details of the sampled SFHH. The purpose of the questionnaire was to gather information about the impacts of rainfall variability and drought on food security. The survey instruments were combined with the HFIAS, to evaluate households' food security.

Focus Group Discussion (FGD)

Focus group discussion brings together individuals from similar experiences or backgrounds to talk about a particular topic of interest. It is a type of qualitative research methodology in which participants were questioned regarding their attitudes, beliefs, opinion, and ideas. Participants in FGD are free to converse with one another. The FGD fosters conversations among participants on a range of interesting themes. A moderator interviewer led a group interview in this process. In the process of gathering information during the FGD, every participant has an equal opportunity to provide information. A moderator, often known as an interviewer, facilitates free-flowing discussions on a range of interesting topics. Because it guarantees that every participant in the FGD gets an equal opportunity to provide information and assess it accurately and consistently.
Moreover, FGD was utilized as an additional compressive primary data source to complement the other data sources. Information gathered from the HHS as well as from the EMI is confirmed by FGD. More precisely, each AEZ hosted one focus group discussion with six to eight participants in each and three in total. A carefully chosen group of people participated in FGD, including two local government official leaders, one model farmer, one agriculture and rural development expert, one food security expert, one expert in climate change and forestry as well as one local elderly. In FGD the elderly were incorporated to offer their experiences with rainfall variability and drought in the study location. Their experience with rainfall variability and drought, and the effect on food security on SFHH are among the qualitative data gathered through FGD.

Key Informant Interview

The goal of Key informant interviews is to gather information from a wide range of people, including community leaders, professionals, or residents who have firsthand knowledge about the issue of rainfall variability and drought. Key informant interviews are qualitative in-depth interviews with people who know what is going on in the community concerning rainfall variability and drought.

The individuals chosen for knowledge and information exchange in KII are those who can supply the necessary knowledge, concepts and insights on a given subject. The main subject covered in the KII includes the history of rainfall, temperature, drought, and impact on food security. In addition, in the KII questions were raised about the effects of rainfall variability and drought on crop productivity, and livestock husbandry. Interview data on their experience of unpredicted rainfall and drought, as well as the effects on household food security were gathered.

Experts in food security, forestry, climate change, and agriculture and rural development participated in the key informant interview. Therefore, in the study a total of nine individuals included in three key informant interviews with participants from each AEZ **(** 3*3=9).

5.2.3.2.Secondary data collection instruments

To evaluate the impact of rainfall variability and drought on farmers' food security, secondary data is crucial to understanding the overall situation. Secondary data, including rainfall, temperature, altitude, latitude, and longitude, were gathered from the sources of registered meteorological data from the EMI (Table 3.1). Gridded daily rainfall data for the chosen locations with a grid cell size of 0.04 degrees, or 4 km ×4 km for the years 1990-2020 were used (Table 3.1). A wide range of sources, including academic journals, books that have been published, unpublished working papers, research and thesis papers, government policy papers and reports, and regional agricultural and climatic documents, were also consulted for valuable information. These data were incorporated to examine the temporal trend and spatial distribution of rainfall as well as its effect on SFHH food security in Guji Zone.

5.2.4. Methods of data analysis

5.2.4.1. Descriptive statistics

At every level of data analysis descriptive statistics such as frequencies, means, percentages and standard deviation were utilized. Using those descriptive statistics, the socio-economic and demographic characteristics of smallholder farmers in the three AEZ of Guji zone were examined. Besides, descriptive statistics were employed to examine the effects of rainfall variability and drought on smallholder farmers' food insecurity. The data about the level of food insecurity of SFHH was also analyzed using various descriptive statistics. The results were then arranged in tables and figures and appropriate debates ensued.

5.2.4.2. Household food insecurity access scale (HFIAS)

A measure of the access component of household food insecurity was released in 2006 by the Academy for Educational Development on behalf of the USAID Food and Nutrition Technical

Assistance Project. With relatively modest adjustments to accommodate various sociocultural situations, the tool was designed to be straightforward, user-friendly and applicable (Coates *et al.* 2013). The assessment tool tracks a development that starts with worry over food availability, progresses to a decline in food quality and quantity, and ends with going without food all day and night and going to bed hungry (Coates *et al.*, 2007). The head of the household was questioned during interviews to find out if any of the nine items had happened to their household in the previous year (Coates *et al*., 2007).

The HFIAS shows if there was a food shortfall during the previous twelve months of the year. The HFIAS was created to identify behaviors in households that indicate inadequate quantity and quality, as well as concern related unrestricted access (Maxwell *et al.*, 2013). Rarely (once or twice in the previous year's months), sometimes (three to ten times in the previous year's months) or frequently (more than ten times in the previous month of the year) was how their experience was assessed. The answers were said, with 'never' receiving a score of 0, 'rarely' receiving a score of 1, 'sometimes' receiving a score of 2 and 'often' receiving a score 3. The lowest score that could be obtained was 0 and the highest 27. A higher score indicated that there was more food insecurity in the household. According to the HFIAS, the continuous scores are divided into four categories: (0-1) for food-secure households, mildly (2-8), moderately (9-16), and severely food-insecure households (17-27) (Assessing Food Security Household Effectively).

The tool has nine questions which requests the respondent's recall of food insufficiency and related psychological responses in the past 12 months (Windale , Bilinsky, 2006; Coates *et al.*, 2007).
The shortened versions of the questions are as follows:
Q1: 'Did you worry that your household would not have enough food?' ('Worry for food')
Q2: 'Were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources?' ('Unable to eat preferred foods')
Q3: 'Did you or any household member eat just a few kinds of food day after day because of a lack of resources?' ('Eat a limited variety of foods')
Q4: 'Did you or any household member eat food that you did not want to eat because of a lack of resources to obtain other types of food?' ('Eat food that you did not want')
Q5: 'Did you or any household member eat a smaller meal than you felt you needed because there was not enough food?' ('Eat a smaller meal')

Q6: 'Did you or any household member eat fewer meals in a day because there was not enough food?' ('Eat fewer meals in a day')
Q7: 'Was there ever no food at all in your household because there were no resources to get more?' ('No food to eat of any kind')
Q8: 'Did you or any household member go to sleep at night hungry because there was not enough food?' ('Go to sleep at night hungry')
Q9: 'Did you or any household member go a whole day without eating anything because there was not enough food?' ('Go day and night without eating'); the capital letter 'Q' denotes a question and subscripts 1–9 are item numbers in increasing severity.
The HFIAS shows if there was a food shortage during the previous twelve months of the year. The HFIAS was created to identify household behaviors in the home that indicate inadequate quality and quantity, as well as fear of unsecured access (Maxwell *et al.*, 2013).

5.2.4.3. Binary logistic regression model

In addition to the HFIAS, the binary logistic regression model (BLRM) was applied to identify the socio-economic and demographic profile of the household that determines household food security in the study area. The BLRM was used to analyze the factors that influence SFHH food security. Logistic regression allows you to test models to predict categorical outcomes with two or more categories. Your predictor (independent) variables can be either categorical or continuous, or a mix of both in the one model. BLRM allows you to assess how well your set of predictor variables predicts or explains your categorical dependent variable. The binary logistic regression model deals with two replies. The use of linear regression is limited when the dependent variables are not continuous in nature. The underlying assumption of binary choice is that individuals express their preference between two alternatives; that is, there is a chance of choosing one over the other, whether the SFHH food is secured or not. Moreover, BLRM is a common statistical procedure that has been widely used in studies to relate the probability of a dichotomous outcome (food secured or insecure) to a set of explanatory variables. Thus, the food security of SFHH was used as a dummy dependent variable with dichotomous outcome; we assign a value of 0 to food insecurity and a value of 1 to food secure households. Functionally, the logit regression model can be specified as:

$$P_i = Prob(y_i = \frac{1}{x_i}) = \frac{1}{1+e^{-zi}} \qquad \text{Equation (2)}$$

Equation 2 can be simplified as: $P_i = Prob(y_i = \frac{1}{x_i}) = \frac{1}{1+e^{-(B_O+B_iX_i)}}$

Where P = chance of a household being food secured (i.e., probability of the event occurring)

1-P = chance of a household food in secured (i.e., probability of an event not occurring)

P_i = is the probability or risk of the event occurring which is the odds 1- P_i

$$P=\beta o +\beta_1X_1 +\beta_2X_2 +\beta_3X_3 \ldots\ldots \beta zXz, + e \qquad \text{Equation (3)}$$

$Xi = X_1, X_2, X_3, X_4 \ldots\ldots\ldots X_Z$ are the independent variables used in the model

B_o =is the intercept $\beta_1 +\beta_2 +\beta_3 \ldots\ldots \beta z$ are the slope parameter

Dependent Variable: The food security status is a bivariate dependent variable that takes a value of 1=for households that are food secure and 0 (zero) for those that are food insecure households.

The factors influencing smallholder households' food security were examined using the binary logistic regression model. The household characteristics such as AEZ, heads of the household age, head of the household sex, marital status, education level, farm size, household size, number of cattle, farming experiences in a year, credit availability, receipt to food aid, use of contemporary drought-resistant crops and proximity to the closest market were used as a set of predictor variables in the model. The socio-economic characteristics of the households which determine food security were identified using the binary logistic regression model. The model examined the degree to which a set of socio-economic demographic characteristics of the household influence food security status of SFHH.

Before the analysis was carried out, both independent or explanatory and dependent or response variables were identified using different literature. The dependent or response variable is also known as outcome variable, its value is predicted, or its variation is explained by the explanatory variable; it is the outcome that is measured following manipulation of the explanatory variable. The dependent variable is food security of SFHH. The household's characteristics are considered as independent variables in the model.

Table 5. 2.Independent or explanatory variables used in BLRM

Variables	Acronym	Measurements	Anticipated result
Age	age	Years	+/-
Sex	sex	Dummy variable (1 and 0)	+/-
Marital Status	maritalstatus	1=married 2 =Single 3=Divorced	+/-
Education	levelofeduca		+/-
Agroecology	agroecology	1=Dega 2=Weinadega and Kola	+/-
Farming Experience	farmingexpe	Years in formal learning	+/-
Household size	households	Members of the household	+/-
Cultivated land size	cultivatedland	Hectares	+/-
Number of livestock	numberofcattle	TLU	+/-
Distance from market	timetoreach	Minutes	+/-
Drought resistant crop	gettingdrought	Dummy variable (1 and 0)	+/-
Extension services	extensionwor	Dummy variable (1 and 0)	+/-
Adaptation strategy	adaptused	Dummy variable (1 and 0)	+/-
Access to credit	accesstocredit	Dummy variable (1and 0)	+/-
obtaining food aid	obtainingfoodaid	Dummy variable (1 and 0)	+/-

Data Source: Household Survey, 2021

Independent Variables (Explanatory Variable)

Also known as the independent or predictor variable, it explains variations in the response variable. Numerous socio-economic and demographic factors, including age, sex, education level, agro ecological zone, farming experience, household size, land size, number of cattle, distance from the market, access to credit, availability of drought resistant crop, and receipt of food aid, influenced the level of SFHH food security. The above-mentioned socio-economic and demographic attributes of SFHH serve as the independent variables for food security. The characteristics of the household determine the level of food security of SFHH.

Age: is a continuous variable in the model that is measured in years. The degree of food security of SFHH might be positively or negatively impacted by age. Research reported (Cohen, 2002; Daniel and Elias, 2013; Jemal and Kim 2012; Abebaw and Mesele, 2022) found the positive relationship between the age of the head of the household and food security.

Sex: incorporated as a dummy variable in the model, with a value of 0 for women and 1 for men. It is anticipated that the head of household sex will have an impact on the degree of food security of SFHH.

Level of education is a continuous variable that is expressed as the head of the household's years of education. Education is thought to improve a household's food security. Higher education level is frequently thought to improve the likelihood of food security of SFHH. Likewise, studies by Worku *et al*. 2014; Jemal and Kim, 2012; Sisay *et al*. 2018; Abebaw and Mesele, 2022 have shown a positive correlation between increasing educational attainment and household food security. In contrast, Garrett and Ruel, (1999) and Fekadu and Mequanent, (2010) found a negative relationship between a household's food security and education.

Agro ecological Zone (AEZ) : is a continuous variable that the model considers, with 1 denoting highland *(Dega*) AEZs and 2 denoting a combination of midland or *Weinadega* and lowland or *Kola* AEZs. The effects of rainfall variability and drought are anticipated to be impacted by local climate and AEZ setting. It is anticipated that SFHH located in various AEZ will exhibit varying degrees of exposure and susceptibility to effects of fluctuation in rainfall and drought which impact SFHH food security.

Household size (Family size): is a continuous variable that is determined by how many family members live in a home. It is believed to be a representation of the labor required for farm operations. According to Mano and Nhemachena, (2006) large households are more likely to shift a portion of their labor force into non farming activities. However, Hassan and Nhemachena (2008) disputed this claim, arguing that since off-farm opportunities are typically hard to come by the opportunity cost in most smallholder farming systems may be too low. Several studies of Fekadu and Mequanent, (2010); Worku *et al.* (2014); Mesfin, (2014); Sisay *et al*.(2018); Wondimu *et al.* (2022) have documented the negative and significant effect that an increased family size had on food security status households. Therefore, it is expected in this study that the variable will either positively or negatively affect the food security of smallholders' farmers.

Farm Size: Farm size is a continuous variable expressed in hectares. Farm size can affect a household's food security in a favorable or negative way. For the SFHH, having a large plot of land is regarded as a sign of wealth. Farm size and the habit of producing alternative crops to meet family requirements are also related. Research results reported by Teklay and Tesfaye, (2013), Mesifin, (2014); Fekadu and Mequanent, (2010); Jemal and Kim, (2012) found that total farmland size has a positive association with the food security status of the household. It is anticipated in this study that farm holding size will have positive or negative connections with SFHH level of food security.

Livestock holding in TLU: The total number of cattle, camels, horses, donkeys, mules, sheep and goats in SFHH is represented by the continuous variable known as TLU. To enter TLU, multiply each of the entities by their respective values. Farmers mostly drive their wealth from their cattle, which they accumulate over time. It is anticipated that households with significant livestock numbers will be less susceptible to food insecurity. A positive significant association between livestock ownership and food security was reported by (Fekadu and Mequanent, 2010; Jemal and Kim, 2012; Worku *et al*., 2014; Mefin, 2014; Sisay *et al.*, 2018; Adanech *et al*., 2023).

Distance from the Market: The trip time that SFHH takes to get to the closest market is a continuous variable which is expressed in minutes. The likelihood of gaining access to contemporary technologies and innovations declines with increasing distance from the local market. This is because of the fact that households closer to the local market will have better access to information, expertise and experience regarding contemporary technologies and innovations. As a result, the likelihood of gaining access to contemporary technologies and innovations declines with increasing distance from the local market.

Access to extension services: This is a reference to the quantity of interactions the farmers who responded made with extension agents. Most writers have found a favorable relationship between farmers' extension contacts and SFHH level of food security. Smallholder farmers in Ethiopia can benefit greatly from the information, expertise, and guidance provided by agricultural extension services.

Access to credit: access to credit service is crucial for farmers to close financial gaps and buy the necessary farm inputs and technologies to increase agricultural production. Sisay *et al.* (2018) documented a negative correlation between household food security and credit availability. Therefore, it is expected that this variable either positively or negatively affects farmers' food security due to rainfall variability and drought in Guji Zone.

Access to drought Resistant crops: is a dummy variable that is measured as zero (0) for not having access to crop varieties resistant to drought and as one (1) for getting access to drought resistant crops.

Access to food Aid is a dummy variable that is assessed as 1 for receiving food assistance and zero (0) for otherwise.

Data reliability and validity

The survey instrument was first translated into the *Oromiffa* language spoken in the area. Then the accuracy of the translations of various concepts was examined. Next, each woreda's data collectors were enumerated. They were first-degree holders who were conversant in the community language and custom. The data collectors received one day's instruction on how to fill out the questionnaire with each question and speak with the respondents SFHH.

Data Pretesting

Before the real data collection phase began, the questionnaire underwent a pretest. In pilot research, the validity and reliability of the data gathering tools were examined. Certain questions in the pilot research were rewritten to make them clear once they had been pretested. The questionnaire was checked for logical errors and completeness based on participant opinions. The questionnaire's consistency was verified and adjusted through cross-checked. Pretesting the data collecting instrument's clarity and dependability was conducted prior to data collection.

Validation

The internal consistency of the questionnaire was checked. The internal validity items that measured how SFHH perceive rainfall variability and drought. Cronbach's alpha was used to assess the internal consistency of the nine HFIAS tools for assessing households' food insecurity used in the data collection process. Cronbach's alpha values greater than eight (8) were found to indicate a high degree of internal consistency in the items (Table 9.8). Martha *et al.* (2015) evaluated the validity of the HFIAS questions and found that the tool's validity in the central Ethiopia area of Butajira was satisfactory.

Pretesting the data collected in the HHS

The binary logistic regression econometric assumption was checked before the model applied. Pretesting data for logistic regression entails determining the data's multicollinearity, linearity, and normality. The normality of the data was examined. Multicollinearity is the presence of high inter-correlations among your predictor (independent) variables. Variance Inflation Factor (VIF) was used to diagnose multicollinearity using the SPSS software (Table 9.1.9). A multicollinearity issue is indicated by a result with a VIF greater than 10. However, the study's is below five (<5) is less than five which indicates that there is no issue of multicollinearity among the independent variables. Additionally, an outlier is detected. The outcome shows that the data does not contain any outlier.

The goodness of fit in BLRM

The goodness of fit test indicated that the model fits the data well. The Omnibus Tests of Model Coefficients and the Hosmer-Lemeshow test of goodness of fit showed the model fits the data well. The Omnibus Tests of Model Coefficients gives us an overall indication of the goodness of fit test for this set of results of significant value if the significant < .05. In this case the value is .000 which means p<.0005.The chi-square value is 160.619 with degree of freedom 16. Besides, the Hosmer-Lemeshow goodness of fit test poor fit is indicated by a significance value < .05, so to indicate the model fits well, value greater than .05 is required. Besides the chi-square value for the Hosmer-Lemeshow test 7.202 with a significance level of .515. This value is larger than .05, therefore indicating the model fit data. Therefore, both the Omnibus Tests of Model Coefficients and the Hosmer–Lemeshow test of goodness of fit showed the model fits the data well.

The Cox and Snell R Square and the Nagelkerke R Square values provide an indication of the amount of variation in the dependent variable explained by the model from a minimum value of 0 to a maximum of approximately 1. These are described as pseudo-R square statistics, rather than the true R square values. In the analysis the two values are .331 and .441, suggesting that between 33.1 % and 44.1 % of the variability is explained by this set of independent variables. The Classification table output provides an indication of how well the model predicted the correct category for each case. The model correctly classified 74.5 % of cases overall, or the percentage accuracy in classification which showed an improvement over 51.5 % in Block 0 without the inclusion of independent variables.

5.3. Results and Discussion

5.3.1. Characteristics of sample households

5.3.1.1. Socio economic and household characteristics of respondents

The household survey was used to gather data about the socio-economic and demographic traits of the sampled households. Eighty percent of the respondents to the SFHH survey were men and twenty percent were women. Comparably, just 21 % of Ethiopian small family farms are run by women; most are managed by men (FAO, 2018). The sampled household age distributions show that most respondents, or 60 % of them, are under the 29-48 age range. Eighty-seven percent of the respondents were married. The sampled SFHH respondents' age distribution suggests that they are mature enough to understand the effects of rainfall variability and drought and to adjust their agricultural practices accordingly.

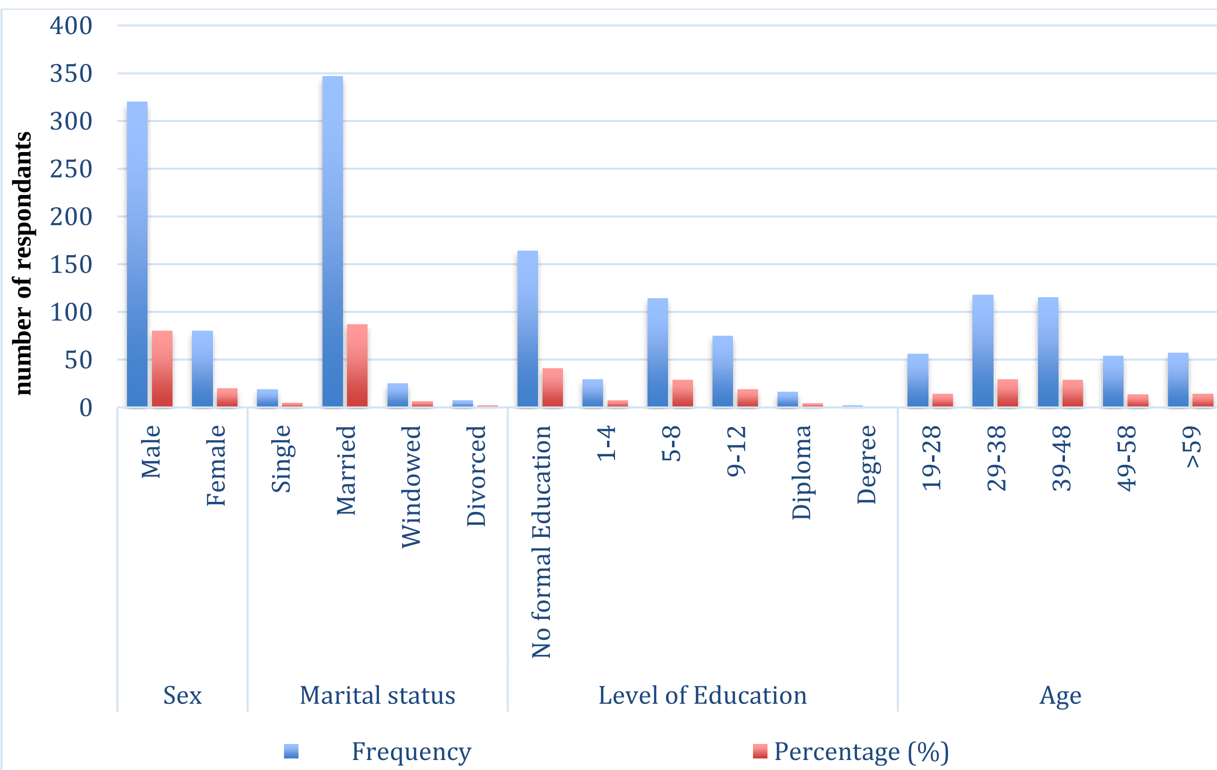


Figure 5. 2.Socio-economic Characteristics of Sampled Household

Data Source: Household Survey, 2021

Thirty-two percent of the sampled SFHH respondents did not have formal education, according to the distribution of their education attainment. Over half of the respondents (55%) had an education level between grade 5 and 12 (Figure 5.2). In Ethiopia, the average household head has less than two years of primary schooling according to FAO (2018). Ethiopia's average years of schooling grew at an average annual rate of 3.87%, from 1.56 years in 2001 to 3.2 years in 2021.The statistics update for Human Development Report for 2021-2022 can be found at (HDREPT, 2020)

The distribution of smallholder households' educational attainment based on agro-ecology shows that the lowland had the lowest mean level of schooling (3^{rd} grade), while the midland and highland had similar mean levels of schooling (6^{th} grade). Based on the data on the sampled household, the average educational attainment of the household head in Guji Zone was five 5.

Table 5. 3.Agro-Ecology-Based Mean Level of Education

AEZs	Centers	Mean year of schooling	STD. Dev	STD. Error
Highland	Bore	6	4.24	.447
Midland	Adola	6	4.05	.286
Lowland	Negele	3	3.16	.302
Total		5	4.09	.204

Data Source: Household Survey, 2021

In the research area, the average family size in highland and midland was seven, whereas in lowland AEZ there were five. According to FAO (2018), the average family size in Ethiopia is five members. As a result, the highland and midland have larger households than the norm. Based on CSA (2007) report, Guji zone has an average household size of 5.1, consisting of 3.9 in urban areas.

Table 5. 4. Average Number of Households in Each AEZ

AEZs	Centers	Mean family size	Std. Deviation	Std. Error
Highland	Bore	7	2.117	.223
Midland	Adola	7	2.254	.159
Lowland	Negele	5	2.655	.253
Total		6	2.534	.126

Data Source: Household Survey, 2021

and 5.3 in rural areas. These are 4.8, 3.8 and 4.9 for Oromia region, and 4.8, 3.8 and 4.9 for Ethiopia. The figure indicates that the population of Guji has been increasing at an alarming rate for the past twenty years.

In order to get to the local market SFHH in the lowland AEZ area travels roughly twice as far as SFHH does in the highland and midland AEZ. It is implying that SFHH in the lowland AEZ are in remote places and must travel a great distance to get to the closest local market.

Table 5. 5. Agro Ecology Based Mean Distance from the Market

AEZs	Centers	Mean (in Minutes)	STD Dev.	STD. Error
Highland	Bore	85.5	34.80	3.66
Midland	Adola	94	47.69	3.37
Lowland	Negele	179	87.08	8.30
Average		115	70.96	3.54

Data Source: Household Survey, 2021

Since most SFHH in Ethiopia practiced mixed agriculture, which included both crop cultivation and animal husbandry, livestock provides means of subsistence for all households. According to the current study, in the lowland smallholders maintain rather large herds of cattle-roughly nine TLU per household. In the highland and midland, the average TLU is 8 and 5, respectively. For SFHH cattle provide food and revenue.

Table 5. 6.Agro Ecology-Based Average TLU of Households

AEZ	Centers	Mean TLU	Standard Dev.	STD. Error
Highland *(Dega)*	Bore	8	7.6	.798
Midland (*Weinadega)*	Adola	5	4.7	.332
Lowland *(Kola)*	Negele	9	4.5	.426
Total		7	5.7	.284

Data Source: Household Survey, 2021

The Guji village is renowned for raising large herds of cattle. As a source of money and social pride, they raise huge herds of cattle. Possession of large herds of cattle really helped SFHH in the area to manage with the regular unpredictability in rainfall and recurring drought.

5.3.1.2. Land holding characteristics of the Smallholder households

The quantity of land that each SFHH holds is directly correlated with the population density of the surrounding area. Smallholders' farm households are anticipated to have a comparatively lesser amount of land per household in the highly populated areas. East Guji Zone has a population density of 109/km^2, which is relatively among the sparsely populated parts of the country, according to the CSA (2022) country report. It follows that the area's smallholder farmers have comparatively better landholdings. The HHS states that the SFHH in Guji has average land size of 1.51 hectares in the highlands, 2.27 hectares in the midlands and 2.83- hectares in the lowlands. Ethiopian SFHH mean farm sizes are about 0.8 hectares (FAO, 2018).

Table 5. 7. Agro Ecology-Based Land Size of the Farm Household

AEZs	Centers	Population density /kilometer square	Mean	Std. Deviation	Std. Error
Highland	Bore	234.3	1.51	1.23	.129
Midland	Adola	126.3	2.27	1.17	.082
Lowland	Negele	26.3	2.83	1.12	.107
Average		109.3	2.25	1.26	.063

Data Source: Household Survey, 2021 and Central Statistical Agency, 2022

As a result, smallholders in the research area acquire bigger land holdings than the national average. However, agricultural production and food security of SFHH in the area were severely challenged due to the area's regular rainfall unpredictability and drought. Rainfall variability and recurring drought prevented the SFHH from supporting their way of life despite owning larger tracts of land.

Table 5. 8.The Cultivated Land of SFHH in Guji Zone

AEZs	Centers	Cultivated land size in (hectare)	Cultivated Land in (%)	Std. Deviation	Std. Error
Highland	Bore	.944	62.5	.634	.066
Midland	Adola	1.51	66.5	.580	.041
Lowland	Negele	1.88	66.4	.526	.050
Average		1.48	65.7	.667	.033

Data Source: Household Survey, 2021

The SFHH did not use all their land for crop production; instead, 62.5%, 66.5% and 66.4% of their land holdings were planted with crops in the highland, midland and lowlands AEZ respectively. It implies that they utilize a considerable area of land for related reasons such as feeding their cattle.

5.3.1.3. Sources of climate information for households

Smallholder farmers have access to a variety of climatic information. Extension agents, friends and neighbors and the mass media account for 35.6%, 23% and 13.6% of the information sources, respectively. The least useful source of information is the local leadership.

Table 5. 9. Sources of Climate Information

Sources of Climate Information	Frequency	Percentage
Extension workers	144	35.6
Neighbors/friends	93	23.0
Mass media	55	13.6
School/teachers/	45	11.1
Scientists	31	7.7
Experiences	20	5.0
Local leaders	12	3.0
Total	400	100

Data Source: Household Survey, 2021

5.3.1.4. Status of households' food security

Table 5.10. Provides a summary of the descriptive statistics that demonstrate how rainfall variability and drought affect the household's food security. As a result, 72.5%, 17%, and 9.5% of respondents noticed a decrease, an increase or no change in food production respectively. Rainfall variability and drought were cited by the majority of SFHH (89%) as a reason for the decline in crop yield. Furthermore, SFHH claimed that they experienced food insecurity due to a decrease in crop yield. Crop production, which is the primary source of food for SFHH, is negatively impacted by rainfall variability and drought.

As Table 5.11. illustrates the relation between food security with rainfall and drought. Therefore, SFHH observed how rainfall variability and drought affected crop productivity and food security. The majority of SFHH (97%) also noted that over the past thirty years food security has become worse. This suggests that there has been a decline in their access to food in recent years, which is caused by the reduction of crop yield. They identified rainfall variability and drought as main causes of the decline in crop yield. They altered their farming practices by planting trees to address the issue. Therefore, in response to high rainfall variability and drought, SFHH substituted exculpates trees instead of food crops, as verified by 75.5% respondents. Because trees can withstand unpredictable rainfall and drought better than crops can do.

Table 5. 10. Characteristics of Household Food Security

Features of Food insecurity	Responses	Frequency	Percentage (%)
Production over the past 30 years	Increased	68	17.0
	Decreased	289	72.5
	The same	38	9.5
Rainfall variability and drought are causes for decreases in crop production	Yes	311	77.8
	No	60	15.0
Rainfall variability and drought resulted in Food insecurity	Yes	354	88.5
	No	41	10.3
Meal per day	Once	8	2.0
	Twice	101	25.5
	Three wise	274	68.5
	Four	16	4.0
Enough food to sustain your household	Yes	184	46.0
	No	216	54.0

Data Source: Household Survey, 2021 **Note**: N=400

The erratic nature of rainfall is the reason for replacing food crops with eucalyptus trees as was confirmed by the FGD and KII in midland AEZ. However, in the highlands the increase in the acidic nature of the soil due to torrential rainfall is a reason for replacing crops with eucalyptus. The discussion results of FGD and KII are verified with a household survey 75% of respondents replaced food crops with eucalyptus tree due to rainfall variability and drought. This is because trees can withstand more variation in rainfall than food crops which are more vulnerable to the variability of onset and end of rainy period. This created the problem of food insecurity in the midland AEZs of the study area because more lands are covered in trees and households have less access to enough food. In the meantime, prices in the local market were elevated because there was more demand than supply of food crops in the area.

In addition, the respondents requested ways to address the issues of irregular rainfall and drought. 96 % of the respondents mentioned that properly communicated early warning measures lessen the impact of unpredictable rainfall and drought on food insecurity. The respondents believed that to reduce the effects of unpredictable rainfall and drought on crop production, timely and reliable information obtained from early warning systems was crucial. The government must endeavor to improve the early warning system. Because research also indicates that reducing the harm caused by rainfall unpredictability and drought to crops may be achieved by early identification of climate information. Relief from drought on food security can be obtained if the drought's duration and intensity is precisely identified and known beforehand (Kogan *et al.*, 2019). Timely, accurate, and effective early warning systems lessen the detrimental effect of rainfall variability and drought on food insecurity within the household. The effectiveness of the early warning system and the methods used by governments to distribute information via various communication channels need to be improved.

Table 5. 11. Basic Features of Household Food Security

	Features of household food Insecurity	Responses in percentage (%)					
		None	Little	Less	Much	Great Deal	Total
1	Association of rainfall variability and drought with food shortage	5	4	16.5	31.8	42.8	100
2	Effect of rainfall variability and drought on crop production	1.8	3	9	21	65.3	100
3	Influence of rainfall variability and drought on food security	3.3	4.3	7.5	28.3	56.8	100
4	Rainfall variability and drought aggravated the incidence of food insecurity from better to worse	2.8	3.8	8.8	20.3	64.5	100
5	Replacing food crop with eucalyptus tree due to rainfall variability and drought	24.5	6	19.3	18.8	31.5	100
6	Properly communicated early warning measures reduced food insecurity	3.3	14.8	30.8	19	32.3	100

Data Source: Household Survey, 2021 Note: None=0 ; Little=1; Less=2 Much=3 Great deal=4

5.3.2. The impact of rainfall variability and drought on food security

The effect of rainfall and temperature on food security of the SFHH is discussed in this section. Rainfall and temperature data from the three AEZ of Guji zone over the course of three decades (1990-2020) were evaluated to determine how rainfall variability and drought affected the food security of the SFHH. While mid-and lowland AEZ showed a non-significant increasing trend in annual rainfall there was a statistically significant increase ($p < 0.05$) in the highland AEZ. Three AEZ had different crop production experiences because of the different rainfall trends that have been observed. These led to differences in the status of households' food insecurity.

In the highland AEZs of the research areas, rainfall showed a significant increasing trend. The year-to-year variability of rainfall (Table 5. 12) in the study area was lower (CV <20) than that of seasonal rainfall variability (Table 5.13). During the spring and autumn season, considerable seasonal variability in the distribution of rainfall has been confirmed by PCI and CV in the lowlands and midlands AEZs. The NMA states that (NMA, 2007), farmers who rely on rain-fed agriculture face the danger if variability of rainfall is greater than (CV >30%). As a result, the seasonal rainfall in the lowland and midland AEZs was less reliable due to the increased rainfall variability that was observed.

Table 5. 12.Trends of Annual Rainfall in Selected stations of the Study Area

AEZs	Centers	Minimum	Maximum	Mean	CV	MKT	Slope	P-value
Lowland *(Kola)*	Negele	357.6	843.1	623.8	19.5	0.045	0.75	0.73
Midland *(Weinadega)*	Adola	603.1	1398.02	1022.2	19.5	0.101	4.86	0.43
Highland *(Dega)*	Bore	829	1719.1	1202.5	19.6	0.376	15.33	**0.003*** **

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

Note: ***Level of Significant at 1%

Conversely, the highland's (Bore) CV suggests moderate variability of rainfall (CV <30 %), with values of about 28%, 28.5%, and 29% in the spring, summer, and autumn seasons respectively (Table 5.13). In all AEZs, the trend and magnitude of winter rainfall indicated a non-significant declining trend. Additionally, very high CV was noted in lowlands, midlands, and highlands AEZs during the winter season (115%, 100%, and 70%) respectively. The study area's exceptionally high variability in rainfall throughout the winter season is reflected in the exceptionally high CV that was found. Likewise, winter season PCI and CV are highest, indicating increased rainfall variability in the study area. Similar results were reported by (Matios *et al.*, 2022; Mitiku *et al.*, 2022) whereby very high variability (CV >90%) rainfall during winter season was seen in the Guji and Borana Zones respectively.

Table 5. 13.Trends of Seasonal Rainfall in the Study Area

Seasons	AEZs	Centers	Mean	STD	CV	MKT	Slope	P- Value
Winter	Negele	Lowland	32	36.5	**114.5**	-0.190	-3.306	0.259
	Adola	Midland	75.2	75.2	**100**	-0.167	-8.163	0.329
	Bore	Highland	79.3	55.3	**70**	-0.286	-6.095	0.084
Spring (long rain)	Negele	Lowland	335	106	31.6	-0.071	1.035	0.707
	Adola	Midland	475.5	169.1	35.6	-0.166	6.558	0.328
	Bore	Highland	389	110.5	**28.4**	0.119	13.33	0.499
Summer	Negele	Lowland	30	25. 2	84.1	0.000	-0.513	1
	Adola	Midland	110.1	75	68.1	0.166	2.147	0.328
	Bore	Highland	385	110	**28.5**	0.071	2.69	0.707
Autumn (short rain)	Negele	Lowland	225	94	42	0.166	10.189	0.328
	Adola	Midland	367.2	128.1	35	0.166	18.507	0.328
	Bore	Highland	354	102	**29**	0.404	21.468	**0.013*****

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

Note: ***Level of significant at 1%

Agriculture and food production are impacted by climate change in various ways. In the study area, highly erratic rainfall had an adverse impact in crop production. Besides, the significant variability of rainfall at the beginning and end of harvesting seasons in the mid and lowland AEZs primary cause for the reduction of agricultural production. There was high seasonal variability especially in cessation of cropping seasons in the mid and lowland AEZ. The lack of a statistically significant trend in monthly and seasonal rainfall implies that there is seasonal and monthly variability in mid and lowland AEZ of the study area. Consequently, the HFIAS indicates that there was moderate food insecurity in the midlands and severe food insecurity in the lowlands.

There was no statistically significant trend on the monthly and seasonal rainfall except the positive significant trend (P <0.05) observed in the highland AEZ during autumn season. Conversely, a longer growing season, lower rainfall variability (CV <30%) and significantly increasing trend of rainfall lead to improved crop productivity in the highland and lower level of food insecurity (mild). Similarly, to this Salinger *et al.* (2005) found that higher precipitation level during the growing period of crops if not excessive precipitation-tends to boost yields.

Table 5.14 summarized the trend of maximum, minimum and average temperature during the previous thirty years in East Guji. The distribution of temperature across the three AEZs of the Guji zone reveals a complex trend.

Table 5. 14.Trends of Temperature Distribution in Guji Zone

AEZs	Maximum Temperature			Minimum Temperature			Average Temperature		
	MKT	S	P	MKT	S	P	MKT	S	P
Lowland (Negele)	0.39	169	**0.002****	-0.39	-173	**0.002****	0.25	107	**0.06***
Midland (Adola)	-0.28	-123	**0.029****	0.34	149	**0.008****	0.15	63	0.27
Highland (Bore)	0.20	91	0.10	-0.28	-121	**0.032****	-0.11	-47	0.41

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

Note: *******Level of significant at p < 10% and represented P <5% by **

The maximum temperature in the midlands Adola showed a declining trend while it grew in lowland Negele at ($p <0.05$) significance level. Additionally, there was a statistically significant decline in the minimum temperature observed in the lowland (Negele) and highland (Bore) while an increasing trend in midland Adola at a significant level ($p <0.05$). Overall, there were no clear trends in temperature distribution trends across the different AEZs. For example, the highland (Bore) average temperature showed a non-significant drop. Temperature is the primary element that limits plant growth at high altitude regions. While an increase in temperature may boost agricultural yields in lowland areas, it will also increase the risk of water stress (Thornton *et al.*, 2009).The combination of lesser rainfall and significant average temperature increases at ($p < 0.001$) in the lowland Negele exacerbated the water scarcity, decreased crop yield and increased food insecurity was found in the locality.

All the study locations were affected by drought with different magnitude, while each AEZs ability to withstand droughts varied. Consequently, lowlands *(kola)* are more vulnerable than highland *(dega)* AEZs under the same level of drought severity. Similarly, the study found food insecurities brought by drought and irregular rainfall are a major problem in the lowland Negele. The reason is that there has been a significant increase in temperature together with a drop in rainfall trend. This has led, according to HFIAS, to the locality experiencing a severe level of food insecurity induced by high levels of rainfall variability and drought. All the AEZ in study areas experienced an increased impact of drought although the lowland AEZ experienced a more severe impact because of the area's lower vegetation cover. This explains why the drought in the lowland *(kola)* causes a serious food scarcity, which is followed by the death of animals and people. However, the effect's severity was lessened in the highland *(dega)* locations. Consequently, it's crucial to manage the negative effects of rainfall variability and drought by using various coping techniques that take the local AEZ into account.

The autumn and annual rainfall trends in the highland AEZ have demonstrated a statistically significant increase. In summary, varied rainfall trends were found in the three AEZs in the research area (Figure 9.1 and 9.2). The highland (*dega*) AEZ of Ethiopia's, resembles the high latitude climate of the world temperate zone. Global evaluation of precipitation has also shown that variation in precipitation will occur across the world. The equatorial Pacific and high latitudes are expected to experience an increase in mean annual precipitation. Mean precipitation is expected to rise in mid-latitudes wet regions and decrease in many mid-latitude and subtropical dry regions (IPCC, 2014). Generally speaking, land precipitation has increased at higher latitudes, particularly across North America, Eurasia, and Argentina while subtropics and tropics regions have seen decreases in precipitation (Trenberth, 2011). There is a decline in rainfall throughout Africa. A large portion of Africa is now experiencing severe drought, with the tropics and subtropics experiencing higher rates of it (Trenberth, 2011). On the other hand, over the past 50 years, the rainy season has extended by up to three weeks in certain boreal high latitude regions (Trenberth *et al.*, 2007) .

Thus, climate change assisted the mid and higher latitude regions of the world with increases in temperature and precipitation (Dore, 2005; Mendelsohn and Williams, 2006; IPCC, 2007, Trenberth, 2011; IPCC, 2014). However, rain-fed agriculture was greatly influenced by rainfall variability and its subsequent decline, in the impoverished nations located in tropical and subtropical regions of the world. Furthermore, areas with relatively low temperatures such as temperate zones benefit from climate change and variability. Increased temperature and rainfall in the world's temperate regions improve their agricultural productivity.

In summary, there is a chance that food insecurity may rise because of climate change due to several variables, including frequency and intensity of climate hazards that result in diminishing agricultural yields and lower production, climate change will exacerbate already existing vulnerability to food security and livelihoods (WFP, 2016). Without adaptation, climate change is expected to have a detrimental impact on wheat, rice and maize output in tropical and temperate regions for local temperature increases of 2°C or more over late 20th century levels, however specific locations may benefit (IPCC, 2014). Consequently, frequent failure in crop production leads to food insecurity at a household's level.

5.3.3. Agro ecology-based food security status of the SFHH based on HFIAS

The food security situation of the households located in the three AEZ of Guji zone was examined using HFIAS. Food security is indicated by a lower value or (0-1) on the HFIAS output, which runs from 0 to 27. The degree of food insecurity rises in tandem with the HFIAS rating. The continuous HFIAS scores range from 0 to 1 denoting food-secure households, mild food-insecure households (2-8), moderately food-insecure households (9-16), and severely food-insecure households (17-27). Based on HFIAS score 8.7 the highland (Bore) is mildly food insecure. Midland (Adola) is moderately food insecure (11.3) and there was severe food insecurity (17.5) in the lowland AEZ in Negele. It follows that food insecurity increased in the midland and lowland AEZs where the seasonal rainfall variability was higher (CV >30). It may be deduced that there were varying degrees of food insecurity in each of the three AEZ in Guji Zone.

The affirmative answers to question number one (Q_1) indicate that nearly 50% of the small-holder farmers in the mid-and highlands are worried about food. For the following questions Q2-Q6, higher percentages of affirmative response (> 80%) were recorded for both the mid and lowlands. However, in the midland AEZs the HFIAS score changes to lower when it comes to question Q_7-Q_9, which claims that there is no food to eat and that they go through the day and night hungry. In the lowlands, however, the answers to the identical questions were significantly higher. In the highland, midlands and lowlands, the average affirmative response to the nine questions were 51.6%, 68%, and 92% respectively. Based on the findings, HFIAS 70.5 % of the sampled SFHH in Guji Zone were food insecure. Similar result was reported by Eshetu (2020) 79.83 % of households in Southern Ethiopia were food insecure. Corresponding finding of HFIAS scale measurement revealed that 54.1%, 58%, 70.7% in Sidama, Addis Ababa and Farta District in Northwestern Ethiopia respectively were food insecure (Niguse and Stoecker, 2012; Girma, 2012 ; Worku *et al.*, 2014).

Table 5. 15. SFHH Response on Food Shortage based on the nine indicators of HFIAS

	Indicator	Highland		Midland		Lowland	
		FRQ	%	FRQ	%	FRQ	%
1	Worried about food.	43	48	106	53	118	98.2
2	Unable to eat healthy and nutritious food.	48	53	166	83	92	83.6
3	Eat a limited variety of foods.	56	62	174	87	109	99
4	Eat food that you did not want to eat	55	60	164	82	108	98.2
5	Eat a smaller meal than needed	49	54	162	81	71	64.5
6	Eat fewer meals in a day?	52	58	169	84.5	108	98.2
7	No food to eat of any kind	46	51	116	58	110	100
8	Go to sleep at night hungry?	40	43	87	43.5	104	94.5
9	Go day and night without eating?	32	35.5	83	41.5	101	91.8
Average		51.6%		68%		92%	

Data Source: Household Survey, 2021
Note: FRQ=Frequency %=Percentage

Smallholder households' affirmative answers to the nine HFIAS questions revealed differences throughout the three AEZs. In general, the lowlands and midlands AEZ had a higher proportion of food insecure smallholder households than the highland AEZ. In a related study, Eshetu (2020) found that compared to rural households in midlands and highlands AEZs, households at moisture -stressed lowlands are more food insecure. As the discussion of KII and FGD explained, rainfall variability induced food insecurity and drought are not as big problems in the highland AEZ. Since the area's crop productivity has benefited from an observed increasing trend of rainfall.

In the highland AEZ, SFHH were experiencing heavy rainfall as reported by the FGD and KII participants. Consequently, SFHH in the highland AEZ faced challenges from flooding, soil leaching, and soil acidification. The benefits of the increasing rainfall pattern in the highland were also discussed by smallholders. The SFHH in the highlands have adequate water to support crop cultivation. They perceived that the highland AEZ was getting hotter. As a result, they believe that the increasing trend of rainfall created an environment that was relatively favorable for crop production in the highland AEZ. In some parts of the highland smallholders began to produce twice a year. They produce crops including barley, beans, peas, wheat, and maize using the summer rains that fall between (June-December). During the long rainy period in spring (April-May) they grow vegetables like potatoes, onions, cabbages, and tomatoes.

Conversely, based on the findings of HFIAS and as verified by the model result of the study, increases AEZ explained food insecurity positively and significantly. Besides, as the FGD and KII confirmed, rainfall variability and drought had a significant negative impact on food insecurity of the smallholder households in the lowlands AEZ. Finally, researchers would like to recommend that the government or other concerned bodies should improve the food insecurity conditions in the midland and lowlands AEZ of East Guji.

5.3.4. Determinants of smallholder farmer's food security

Food insecurity is one of the most crucial problems which is also highly affected by the socio-economic and demographic characteristics of the SFHH. The determinant factor affecting SFHH food security in Guji Zone was identified using the binary logistic regression model. The assumption of the binary logistic regression model was checked before the analysis was performed. The model investigated variables which have an impact on household food security in various circumstances, and ten of the fourteen variables were determined to be significant. The results of the model analysis, at a statistically significant level at ($p < 0.05$) showed that the age, sex, educational level of household head, agro ecological zone, size of the household, cultivated land size, farming experience, livestock ownership, distance from the market and receipt of food aid all positively contribute to household food security. But access to credit, marital status, extension services and access to drought resistant crops is less likely to predict household food security.

According to Table 5.16, the model indicates that there is positive and significant ($p < 0.05$) correlation between the age of the household head and family food security. Remaining all factors unchanged, food security of the household increases by a factor of 1.875 for every year increase in the age of household head. This indicates that there is an odd ratio of 1.875 times the increase in food security with a one-year increase in the age of the head of the household. An explanation for this positive correlation could be that, in comparison to young farmers, elderly household heads have more experience and dedicate more time to farming activities. A similar finding was reported by Cohen, (2002); Daniel and Elias, (2013); Jemal and Kim (2012); Abebaw and Mesele, (2022); Wondimu *et al.* (2022) who found the positive relationship between age of the head of the household with food security.

The household headed by male had shown positive and significant ($p < 0.05$) correlation with food security of the household. Being in male headed household increases food security by a factor of 2.354 times than a female headed household. Similar results was reported by (Worku *et al.*, 2014; Sisay *et al.*, 2018; Wondimu *et al.*, 2022).

Table 5. 16. Determinants of Household Food Security

Variable Explanation	B	S.E	Wald	Sig	Exp.(B).	95% C.I EXP(B)	
						lower	Upper
1.Age	.629	.404	2.415	**.004****	1.875	.849	4.143
2.Sex	.856	.263	10.584	**.001*****	2.354	1.405	3.942
3.Marital Status	.058	.126	.212	.646	1.060	.828	1.357
4.Level of Education	.133	.026	25.959	**.000*****	1.142	1.085	1.202
5. AEZ	.791	.249	10.086	**.001*****	2.207	1.354	3.596
6.Farming Experience	.240	.088	7.422	**.006****	1.271	1.070	1.510
7. household Size	.141	.41	11.706	**.001*****	1.151	1.062	1.248
8.Cultivated Land Size	.659	.217	9.252	**.002****	1.933	1.264	2.955
9. TLU	.061	.016	14.901	**.000*****	1.063	1.030	1.096
10.Distance from market	-.012	.002	41.479	**.000*****	.988	.984	.991
11.Access to drought resistant crop	-.306	.223	1.889	.169	.736	.476	1.139
12.Access to credit	.424	.253	2.800	.094	1.528	.930	2.510
13.Extention service	.158	.225	.496	.481	1.171	.754	1.820
14.Access to food aid	1.973	.270	53.373	**.000*****	7.190	4.235	12.205

Data Source: Household Survey, 2021

Note: **Level of significance = p <5% and, P <1% by***

Increased AEZ has a positive impact on household food security at statistically significant ($p < 0.01$). Considering other factors constantly, a unit increase in altitude enhances food security for the household with an odd ratio of 2.207 times. The finding is consistent with HFIAS score results of the highlands being at a better level of food insecurity (mild) than low and midlands AEZ. The result supports the importance of AEZ based investigation to precisely solve food insecurity at local level.

The food security of farmers was positively impacted by family size, which was unexpected. Keeping other factors constant, with each additional household member increasing food security in the household rises with an odd ratio of 1.062 that is significant at ($p < 1\%$). Large families have a greater number of workers to produce more crops with the same amount of land. This result is consistent with findings of Fekadu and Mequanent, (2010); Mesfin, (2014) who reported the positive correlation of household's food security and family size. However, Jemal and Kim, (2012); Worku *et al.* (2014); Mequanent *et al.*(2014); Sisay *et al.*(2018); Abebaw and Mesele, (2022); Wondimu *et al.* (2022) have documented the negative and significant effect that an increased family size had on food security status of the households.

Being other variables controlled; a unit increased farming expertise boosts the household’s food security by an odd ratio of 1.070 at a statistically significant level ($p< 0.05$). The chance of food security rises in tandem with farmers' increasing experience. Because more experience in farming adds better skills, experience and expertise to manage farming in the face of rainfall variability and drought.

Besides, the parameter estimate for number of cattle was positive and statistically significant in the model, suggesting that having more livestock increased household food security. While holding other factors constant, an increase in TLU per unit increases household food security with an odd ratio of 1.030 times. Similar results showing a positive and significant association between livestock ownership and food security were found by (Fekadu and Mequanent, 2010; Jemal and Kim, 2012; Worku *et al*., 2014; Mesfin, 2014; Sisay *et al*., 2018; Adanech *et al.*, 2023).

Smallholders farm households in Guji are renowned for their enormous herds of cattle. The Guji community's accumulate wealth in terms of ownership of numerous cattle. In other words, having a greater number of cattle are signs of wealthiness. Furthermore, dairy products from cattle can be marketed or used as supplemental revenue streams for smallholder's farmers in addition to being a direct source of food. Having livestock helps households deal with the effects of rainfall variability and drought on food security. Thus, having relatively greater number of TLU decreased the chance of food insecurity in households. Besides, oxen are primary sources of traction power for farming in rural Ethiopia, having livestock is thus closely associated with production (Kim, 2014). Wondimu *et al.* (2022) revealed the opposite conclusion, indicating a negative correlation between livestock ownership and food security.

Decreased distance from the market significantly contributed to the SFHH food security at statistically significant ($P < 0.01$). Considering other factors constantly, a unit decrease in distance from the market increases food security of the household with an odd ratio of .988 times. Which indicates SFHH who inhabited relatively closer to the local market were under a better level of food security compared with their counterpart in distantly found. Similar findings by Khalid and Schilizzi, (2013); Abebaw and Mesele, (2022) reported that the longer it takes to reach the market, the less frequently the farmer visits the market and hence the less likely he/she is to get market information. Lack of adequate information negatively affects food security of SFHH.

There was severe food scarcity in the lowland and midland parts of the study areas. As a result, the local communities received food assistance from governments and non-governmental organizations. Thus, the model's outcome showed that receiving food assistance improved households' food security. Keeping other variables controlled, a unit increase in food assistance raised the household degree of food security with 7.190 odd ratios at a statistically significant level of $p < .001$. As a result, compared to other households, SFHH who received food help were under a better level of food security. A possible explanation for the surprising result could be that SFHH in the study area are under serious shortage of food and in need of food aid to achieve household food security.

Moreover, other factors being controlled, a unit increase in schooling raises the household's food security with an odd ratio of 1.142 which is statistically significant at $p <.001$. Additionally, studies by Jemal and Kim, (2012); Worku *et al*. (2014); Mequanent *et al.* (2014); Sisay *et al*. (2018); Abebaw and Mesele, (2022) have showed a positive correlation between increasing educational attainment and household food security. In contrast Garrett and Ruel, (1999) and Fekadu and Mequanent, (2010) found a negative relationship between household's food security and education.

In the research area, the amount of the farmed land size is found to be positive and significantly $p < 0.01$ correlated with the SFHH food security. Thus, it was discovered that a unit increase in land size boosts household food security with an odd ratio of 1.933 times. Therefore, the land holding of smallholders is directly associated with their crop output and food security. Similar research results, Fekadu and Mequanent, (2010); Teklay and Tesfaye, (2013); Mesfin (2014) found that total farmland size has a positive association with the food security status of the household. In contrast, Wondimu *et al*. (2022) discovered that the amount of land owned by households which is measured in the hector has a negative relationship with the status of food security in the household at a significant level of ($p < 5\%$).

Furthermore, in the research area, food security is less likely to be predicted by marital status, credit availability, access to extension service and access to drought resistant crops. The result of the model showed that a household's food security is not much impacted by their marital status, credit availability, access to extension service and availability of drought resistant crops. Likewise, Jemal and Kim (2012), Sisay *et al.* (2018) documented a negative correlation between household food security and credit availability.

5.4. Conclusions

Building the future with increased and sustainable food secure households requires a clear understanding of the level of food security at the different AEZ. Thus, as perceived and observed divergent spatial distribution, temporal trend and variability of rainfall were found in the three AEZ of the research area. The three decades' rainfall of the districts also confirmed that there was a high seasonal variability in rainfall in the lowland and midlands AEZ during the main cropping season. As a result, each of the three AEZ experienced rainfall variability and drought, which have different effects on SFHH food security. According to HFIAS the lowland, midland and highland AEZ of the research area had mild, moderate, and severe levels of food insecurity respectively. Based on HFIAS score 8.7 the highland (Bore) is mildly food insecure. Midland (Adola) is moderately food insecure (11.3) and there was severe food insecurity (17.5) in the lowland AEZ in Negele. It follows that food insecurity increased in the highlands to midlands and lowlands AEZs as seasonal rainfall variability rose from high to midlands and lowlands (CV >30). Besides, the results of the binary logistic regression model analysis showed that, a statistically significant level ($p < 0.05$) the head of the household age, sex, household size, cultivated land size, farming experience, agro ecological zone, number of cattle, level of education, distance from the market and receipt of food aid all positively contribute to household food security. But access to credit, marital status, and access to drought resistant crops is less likely to indicate a household's food security.

Continuous innovation in agricultural research is necessary because without expanding agricultural production it is difficult to improve food security of SFHH. On the other hand, in the highland AEZ improving the transportation infrastructure promotes vegetable waste reduction and smallholder farmer' involvement in agricultural markets. Early detection of the situations of rainfall variability and drought in the locality minimizes the adverse effect on food security of smallholder's households. The government is anticipated to improve the early warning system. The impact will be lessened if such information is appropriately disseminated. Accordingly, the findings of this study are expected to contribute toward the alleviation of the impact of rainfall variability and drought on the food insecurity of households found in the different AEZ of Guji Zone. It follows that in the mid and lowland AEZs, greater attention must be given to the adaptation of the food-system to rainfall variability and drought. Besides, by assessing the level of vulnerability of SFHH food assistance should be provided in the midland and lowland AEZs.

CHAPTER SIX

FARMERS PERCEPTION OF THE IMPACT OF RAINFALL VARIABLITY AND DROUGHT AND DETERMINANTS OF THEIR ADAPTATION STRATEGIES IN GUJI ZONE, OROMIA REGIONAL STATE, ETHIOPIA

ABSTRACT

The research focuses on perception of farmers and the determinants adaptation strategies towards the impacts of rainfall variability and drought. The purpose of this study was to examine farmers' perception of rainfall variability and drought adaptation strategies used as well as variables influencing decisions of adaptation of SFHH in Guji Zone. A concurrent research design is applied in the study where quantitative and qualitative approaches were combined. Quantitative data of climate variables were collected from the Ethiopian Mereological Institute for the period of 1990-2020. A survey was conducted in the three districts of each of the AEZ of the study area. The household survey was supplemented by FGD and KII. A combination of primary and secondary sources of data were used. Meteorological data were analyzed through Coefficient of Variation (CV), Precipitation Concentration Index (PCI) and Reconnaissance Drought Index (RDI). Trend analysis was also held using Mann Kendall trend test and Sen's Slope Estimator. An econometric binary logit regression model was applied to identify factors influencing adaptation methods used by farm households over three agro ecological zones (AEZs). The finding of the study indicated that 80 % of the sampled SFHH perceived increasing temperatures while 71% perceived decreasing rainfall. The most popular adaptation strategies pursued by the smallholder farmers of the study area were crop diversification, mixed cropping, the use of drought-resistant crop types, and planting eucalyptus trees in place of food crops. Econometric analysis revealed that AEZ, HH's sex, household size, the size of the tropical livestock unit, the HH’s educational attainment, having enough food, getting food assistance, and the time it took to get to the local market had a significant impact on the household adaptation strategy. This implies that policies should be geared towards strengthening farmers' efforts to adaptation to rainfall variability and drought and improving the assets to promote adaptation strategies for enhancing productivity.

Keywords: Adaptation strategies; Government; Perception; Smallholders householder farmers

6.1. Introduction

Africa is experiencing the effect of climate change, which includes increase in temperature, rises in sea level, and changes in rainfall pattern (Schwarz-Herion, 2018).The effect is observed in the environmental system as a whole, and in water and agriculture (Matondo *et al.*, 2020). Africa is affected by climate change due to its geographical location (already a warm region), heavy reliance on the most climate-sensitive sector (agriculture) and the limited ability for adaptation because of poverty and low level of technological development (Stern 2007; Collier *et al.*, 2008; World Bank, 2009). Similarly, Ethiopia has experienced the effects of climate change events like increasing temperature and variable precipitation along with recurrent droughts and frequent floods, which adversely affected the agricultural sector (Conway and Schipper, 2011; Karthikeyan and Tadesse, 2014)

Even with the problem of high rainfall variability and recurrent droughts, agriculture remains the main driver of the Ethiopian economy (World Bank 2010; Conway and Schipper 2011; EPCC, 2015). Agriculture is crucial for the Ethiopian economy, contributing 40% of the GDP, 80% employment, and 90% exports. Besides, 79% of the income of the population depends on rain-fed agriculture (Tafesse and Tewodroso, 2019; Young and Klingaman, 2020). Moreover, agricultural practice is dominated by small-scale farmers who rely on low input and low output rain-fed mixed farming with traditional technologies (BoFED, 2008; CEEPA, 2006). Thus, smallholder farmers in Ethiopia are the most vulnerable to the effects of rainfall variability and drought due to low resilience and poor adaptation capabilities.

Adaptation is the process of adjustment to actual or expected climate stimuli and its effects in order to either lessen or avoid harm or exploit beneficial opportunities (IPCC, 2014). The process of adapting to climate change is a two-step process: the first is recognizing that the climate is changing and then responding to changes by taking action to adapt to those changes. Farmers' perception of climate change and variability is a primary step required to take adaptation measures (Apata, 2011; Maddison, 2006; Temesgen *et al*., 2011; Poulos and Belay, 2017). It takes time for farmers to fully comprehend the effect of rainfall variability and drought on their livelihood. Following their observation of the consequences, they modify their farming practice to deal with the effect of rainfall variability and drought. Besides, farmers' decision to adapt to climate change is made based on both climatic stimuli as well as on other issues, such as their personal, economic and policy motivations (Smith, 1996).

Because it is difficult to reverse the previously altered climate condition by mitigation, adaptation is the only practical way to address the impact of climate change (Israel and Belay, 2019). Farmers can lessen their susceptibility to negative effects of climate change and variability through adaptation. It helps rural communities cope and adjust with the negative impact of climate change and variability (Temesgen *et al.,* 2011; IPCC 2014).

Numerous studies have looked at the significant linkage between perception and practice of adaptation to rainfall variability and drought (Temesgen *et al.,* 2011; Poulos and Belay, 2017; Abrham *et al.,* 2022). However, empirical evidence which assessed farmers' perception towards adaptation to the impact of rainfall variability and drought across the different AEZ were very few (Zelalem and Belay, 2021; Israel and Belay, 2021). The study adds knowledge by assessing the perceptions and adaptation to the impact of rainfall variability and drought across the three AEZ of Guji zone. Therefore, the objective of the study was to examine perceptions of SFHH and the factors affecting adaptation of smallholder farmers to the impact of rainfall variability and drought across the three AEZ of Guji Zone.

6.2. Materials and Methods

6.2.1. Descriptions of the Study Area

This study was conducted in East Guji Zone. The area is situated in the Southern part of Oromia National Regional State, Ethiopia. Geographically, the East Guji Zone is located between 4^0 30′ N - 6^0 30′ N and 38^0 15′ E-40^0 5′ E (Figure 3.1) and covers a total area of about 18,577 Km^2. It shares a border with Gedeo and Sidama in the North, Somali Regional State in the South, Bale Mountain in the East, and Borena Zone in the West.

The total population of the area as projected by CSA, (2022) was 2,030,667 in 2022.They are predominantly pastoralists, agro-pastoralists, and farmers (Teshome, 2016). Coffee is an important cash crop in the Guji zone (Lazzari *et al.,* 2021). Guji zone has an average household size of 5.1, consisting of 3.9 in urban areas and 5.3 in rural areas. These are 4.8, 3.8 and 4.9 for Oromia region, and 4.8, 3.8 and 4.9 for Ethiopia (CSA, 2007).

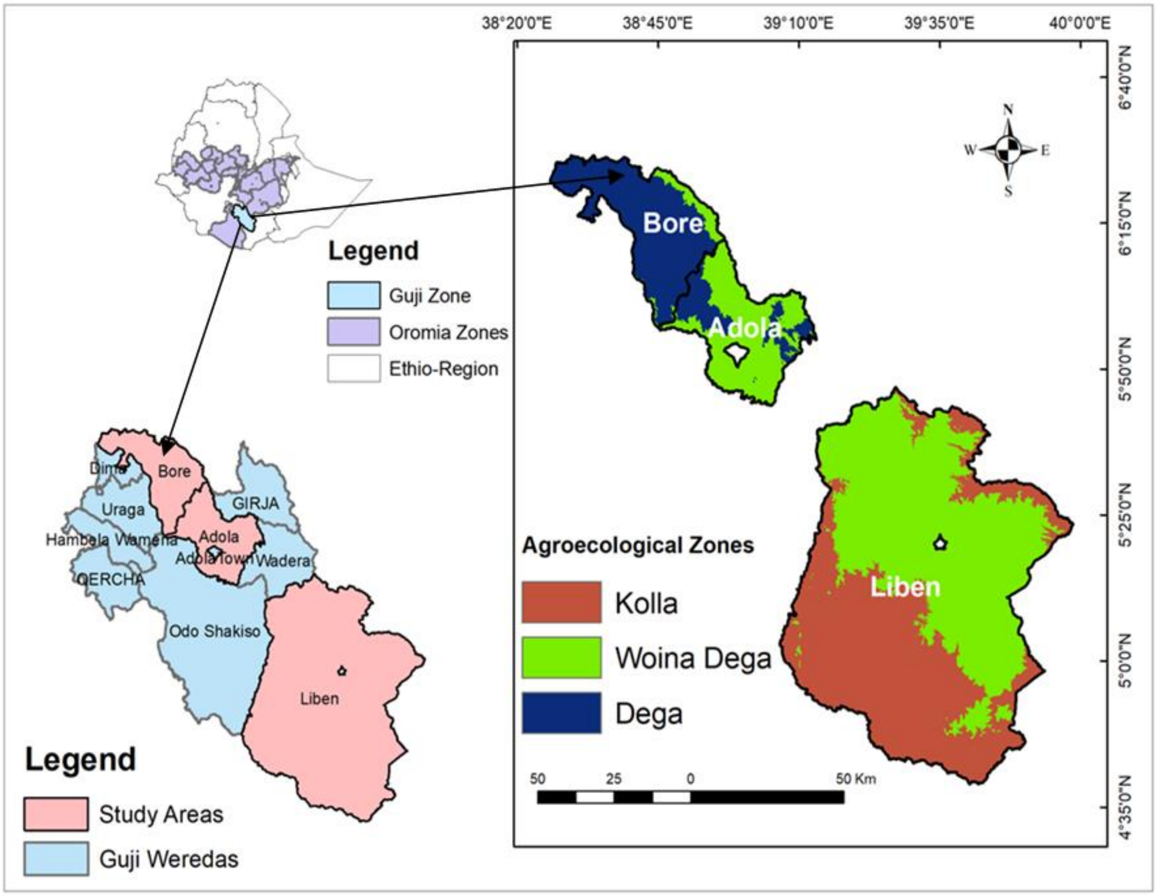


Figure 6. 1.Map of the Selected Districts

6.2.2. Sampling techniques and sample Size

6.2.2.1. Sampling techniques

The East Guji Zone is the study's targeted population (See Figure 3.1). There are thirteen political administrations in the Guji Zone. The study area's altitude varies greatly, from 632 meters to 2960 meters (Figure 6.1). As a result, the zone has three AEZs, which are significant for illustrating the spatial dimension of rainfall variability and drought (Figure 3.2). The three AEZ in the study area were represented by the selected three districts for AEZ-based examination. The household survey was undertaken in three districts at the lower administrative unit, or kebeles.

Table 6. 1.Data Collection Methods by the Respective AEZs

Basic features	Agro Ecological Zone (AEZs)		
	Highlands (*Dega*) 2300m-3300m	Midlands (*Weinadega*) 1500m-2300m	Lowland (*Kola*) 500m-1500m
Fieldwork carried out	2021 August-October	2021 August-October	2021 August-October
Spatial coverage of each AEZ	21%	51.5%	28.%
Main meteorological stations	Bore and Solemo (Uraga)	Odo Shakiso, Adola Harekello (Goro Dola), Wadera and Kercha	Chembe, Dawa, Negele and Bitata
Selected district	Bore	Adola (Kiber Menigist)	Negele (Liben)
Climate Database Period	1990-2020	1990-2020	1990-2020
Field data collected.	90 household surveys, FGD and KII	200 household surveys, FGD and KII	110 household surveys, FGD and KII
Average Annual rainfall of 30 year	1232.4mm	932mm	747mm
Average Temperature	15.8^{0}c	19.4^{0}c	22.1^{0}c
Climate System	Temperate rainy climate: the warm humid temperate, the warm temperate per humid and the cool highland climates	The tropical humid and tropical sub-humid climates	dry climate: the hot arid, semi-arid, dry sub-humid climates
Main growing Seasons	Single growing period: uni modal growing period	Bi modal growing period: Spring (April-may) and Autumn (September-November)	Bi modal growing period: Spring (April-may) and Autumn (September-November)
Farming system	Barley, Pea, Beans, wheat, highland oilseeds, highland pulses	Wheat, Teff, barely, maize, Sorghum, chickpeas, and haricot beans	Sorghum, finger Millet, caw peas, Sesame, ground nuts

Data Source: Extracted from Ethiopian Meteorological Institute (1990-2020)

The study employed a multi-stage sampling approach. A probability and non-probability sampling technique was employed to choose a suitable sample for the research. Because the Guji Zone has lowlands, midlands and highlands that illustrate the geographical aspects of rainfall variability and drought and are particularly susceptible to both, the study area was chosen using non-probability purposive sampling. Then the study area was stratified under the three AEZs (Figure 3.2). AEZs are regarded as strata in the study. Subsequently, the necessary groups or strata for further investigation were chosen using a stratified simple random selection process (Figure 3.2).

Districts for field data collection were chosen at random for the study from the stations mentioned under each AEZ (Table 6.1). Thus, from the lowlands, midland and highland AEZs, respectively, Negele, Adola and Bore were chosen at random. In proportion to their spatial coverage 90, 200,110 heads of the household were chosen from the highland (Bore), midlands (Adola), and lowland (Negele) respectively. The household survey was conducted at the lower-level administration unit named *Kebele.* Then, based on their proportion, *Kebeles* were assigned at random from each AEZ. The summary of the data collection processes by the respective AEZs in the study area was described in Table 6.1**.**

6.2.2.2. Sample size determination

The study was undertaken in the three AEZ in Guji Zone. Given that the study is an AEZ-based assessment three representative woredas from Guji Zone were chosen at random to serve as typical AEZs. Thus, the household survey was conducted in representative rural kebeles of the three AEZs. There were 55632 SFHH in the districts of the three AEZs. There are various methods for figuring out sample sizes. Equation 1 illustrates the sample size determination utilized for the investigation, which was based on Yamane (1967). As a result, the confidence level (Z) is 95 % and the degree of precision (e) is 5%,

$$\mathbf{n} = \frac{N}{1+N(e)^{2}} \qquad \text{Equation (1)}$$

n = Sample size to be studied

N= the Population of the study

e = margin of error in the calculation

$$n \; \frac{N}{1+N(e)^{2}} \qquad \mathbf{n}= \frac{55632}{1+55632(0.05)^{2}}$$

n = 397 farm households were selected sampled for the study

A total of 400 heads of households were enumerated and survey questionnaires were proportionally distributed in the midlands, lowlands, and highlands AEZ as 200, 110 and 90 respectively. Besides, three FGD were held at the selected districts, each comprising six to eight members. Furthermore, three KII were undertaken at each AEZ 3*3=9.

6.2.3. Methods of data collection

Mixed data sources were employed in the study. For the study, a combination of primary and secondary data sources was used. Key informant interviews (KII), Focus group discussion (FGD), and the household survey (HHS) were the methods used to gather primary data. To undertake the study both qualitative and quantitative methods of data collection techniques were used. The household survey was carried out using a structured open and closed-ended questionnaire. The survey evaluated the sampled households' perceptions and methods for adaptation to rainfall variability and drought. Besides, secondary data from the EMI was gathered on temperature and rainfall. Lastly, the perception data from households was associated with meteorological data to examine the adaptation methods used by SFHH in the Guji Zone.

6.2.3.1. Primary data collection instruments

To conduct the research, key informant interviews, focus group discussions and household surveys were among the primary data gathering instruments used. The household survey contains assessment tools to evaluate perception of SFHH on the effects of rainfall variability and adaptation tactics. Several data gathering tools such as KII and FGD were employed to collect information from different sources and conduct triangulations to validate the study objectives. This section provides an overview of the fundamental ideas behind the key data collection tools that were employed in this study.

Household survey

A field survey was conducted in-person interviews, and it was carried out at the household level. The surveys were used to evaluate household head perceptions and methods of adaptation to rainfall variability and drought.

The purpose of the questionnaire was to gather information about household perception, and adaptation strategies to the impact of rainfall variability and drought. Data about the perception of SFHH to rainfall variability and drought were gathered based on the instrument. The modified

Likert scale perception measuring tools were used to assess household perceptions of rainfall variability and drought (Jaishi *et al.*, 2018). Based on the Likert scale measure of perception, instruments have been designed to assess perception of rainfall variability and drought and its influence. In addition, the survey included questions about SFHH's adaptation methods to the effects of rainfall variability and drought.

Focus Group Discussion (FGD)

Focus group discussion brings together individuals from similar experiences or backgrounds to talk about a particular topic of interest. It is a type of qualitative research methodology in which participants were questioned regarding their attitudes, beliefs, opinion, and ideas. Participants in focus group discussions are free to converse with one another. The FGD fosters conversations among participants on a range of interesting themes. A moderator or an interviewer led a group interview in this process. Every participant has an equal opportunity to contribute information during the FGD. A moderator, often known as an interviewer, facilitates free-flowing discussions on a range of interesting topics. Because it guarantees that every participant in the FGD gets an equal opportunity to provide information and assess it accurately and consistently.

Moreover, FGD was utilized as an additional compressive primary data source to complement the other data sources. Information gathered from secondary sources is confirmed by FGD. More precisely, each AEZ hosted one focus group discussion with six to eight participants in each and three in total. A carefully chosen group of people participated in FGD, including two local government official leaders, one model farmer, one agriculture and rural development expert, one food security expert, one expert in climate change and forestry as well as one local elderly. In FGD the elderly were incorporated to offer their experiences with rainfall variability and drought in the study area. Their experience with rainfall variability and drought, the type of adaptation methods they have used, and the variables influencing their adaptation techniques are among the qualitative data gathered through FGD.

Key Informant Interview

The goal of Key informant interviews is to gather information from a wide range of people, including community leaders, professionals, or residents who have firsthand knowledge about the issue of rainfall variability and drought. Key informant interviews are qualitative in-depth interviews with people who know what is going on in the community concerning rainfall variability and drought.

The individuals chosen for knowledge and information exchange in KII are those who can supply the necessary knowledge, concepts and insights on a given subject. The main subject covered in the KII includes the history of rainfall, temperature, drought, and adaptation methods used by SFHH. In addition, the KII raised questions about the effects of rainfall variability and drought and adaptation measures.

Experts in food security, forestry, climate change, and agriculture and rural development participated in the key informant interview. Interview data on their many years' experience of unpredicted rainfall and drought, as well as the effects on household food security and adaptation tactics were gathered. In addition, the study 3*3=9 included three key informant interviews with participants from each AEZ**.**

6.2.3.2. Secondary data collection instruments

Secondary data was used to evaluate the perceptions of SFHH towards rainfall variability and drought on farmers and their methods of adaptation. Secondary data, about rainfall, temperature, altitude, latitude, and longitude, were gathered from the sources of registered meteorological data (Table 3. 1). Gridded daily rainfall data with a grid cell size of 0.04 degrees, or 4 km ×4 km was acquired from the EMI for the study period of 1990-2020. A wide range of sources, including academic journals, books that have been published, unpublished working papers, research and thesis papers, government policy papers and reports, and regional agricultural and climatic documents, were also consulted for valuable information. Lastly, the perception data from households was compared with the finding of empirical data analysis of meteorological variables on rainfall variability and drought.

6.2.4. Methods of data analysis

6.2.4.1. Descriptive statistics

Descriptive statistics such as frequencies, means, percentages and standard deviation were also employed in the study. The perceptions of smallholder farmers in the three AEZ of Guji zone and their adaptation strategies to the effects of rainfall variability and drought were mainly analyzed using descriptive statistics. The results were then arranged in tables and figures and appropriate debates followed.

6.2.4.2. Binary logistic regression model

In addition, the binary logistic regression model (BLRM) is applied to identify the socio-economic and demographic profile of the household that determines household food security in the study area. The BLRM was used to analyze the factors that influence SFHH adaptation strategies of SFHH. Logistic regression allows you to test models to predict categorical outcomes with two or more categories. Your predictor (independent) variables can be either categorical or continuous, or a mix of both in the one model. BLRM allows you to assess how well your set of predictor variables predicts or explains your categorical dependent variable. The Binary logistic regression model deals with binary replies. The binary logit econometric model was used to analyze the factors that influence SFHH adaptation. The use of linear regression is limited when the dependent variables are not continuous in nature. The underlying assumption of binary choice is that individuals express their preference between two alternatives; that is, there is a chance of choosing one whether the SFHH uses adaptation or not. Moreover, binary logistic regression is a common statistical procedure that has been widely used in adaptation studies to relate the probability of a dichotomous outcome (using adaptation or not using adaptation) to a set of explanatory variables. Thus, the adaptation of SFHH was used as a dummy dependent variable to assess factors affecting household adaptation. Because the dependent variable in this study is dichotomous, we assign a value of 0 to not-using adaptation methods and a value of 1 for using adaptation. Functionally, the logit regression model can be specified as:

$$P_i = \text{Prob}(y_i = \frac{1}{x_i}) = \frac{1}{1+e^{-zi}} \qquad \text{Equation (2)}$$

Equation 2 can be simplified as : $P_i = \text{Prob}(y_i = \frac{1}{x_i}) = \frac{1}{1+e^{-(B_O+B_iX_i)}}$

Where P_i = chance of a household taking an adaptation measure (i.e., probability of the event occurring)

1-P = chance of a household not taking adaptation (i.e., probability of an event not occurring)

P_i = is the probability or risk of the event occurring which is the odds 1- P_i

$$P=\beta o+\beta_1X_1+\beta_2X_2+\beta_3X_3 \ldots\ldots \beta zXz, + e \qquad \text{Equation (3)}$$

Xi = X_1, X_2, X_3, X_4………. x_n are the independent variables used in the model

B_o =is the intercept $\beta+\beta_2+\beta_3\ldots\ldots\beta z$ are the slope parameter. The slope shows how the log odds in favor of being willing to take on adaptation practice as corresponding independent variable changes.

The factors influencing smallholder households' strategies for adaptability were examined using the binary logistic regression model. Household characteristics such as: Agro Ecological Zones, heads of the household age, head of the household sex, marital status, education level, farm size, household size, number of cattle, farming experiences in a year, credit availability, food assistance availability, use of contemporary drought-resistant crops and proximity to the closest market were used as a set of predictor variables in the model. The socio-economic factors which affect SFHH adaptation methods were determined by the output of the binary logistic regression model. The model was applied to examine the degree to which a set of socio-economic factors influence adaptation strategies of SFHH.

Before the analysis was carried out, both independent or explanatory and dependent or response variables were identified using different literature. The dependent or response variable is also known as outcome variable, its value is predicted, or its variation is explained by the explanatory variable; this is the outcome which is measured following manipulation of the explanatory variable. The dependent variable adaptation techniques used by SFHH. The set socio-economic and demographic characteristics of the sampled SFHH is considered as an independent variable in the model.

Dependent Variable: The adaptation strategies used are a bivariate dependent variable that takes a value of 1=for households who used adaptation strategies and 0 (zero) for those who are not using the adaptation methods.

Independent Variables (Explanatory Variable)

Also known as the independent or predictor variable, it explains variations in the response variable. The explanatory variable for this model is household characteristics, including age, sex, education level, agro ecological zone, farming experience, household size, land size, number of cattle, distance from the market, access to credit, availability of drought resistant crop, and receipt of food aid, influenced SFHH decision of adaptation practices. The above-mentioned socio-economic and demographic attributes of SFHH serve as the independent variable adaptation methods used by SFHH. The household characteristics determine the adaptation techniques used by SFHH.

Table 6.2.Summary of explanatory variables used in Binary Logistic Regression Model

Variables	Acronym	Measurements	Anticipated result
Age	age	Years	+/-
Sex	sex	Dummy variable (1 and 0)	+/-
Marital Status	maritalstatus	1=married 2 =Single 3=Divorced	+/-
Education	levelofeduca	Years in formal learning	+/-
Agroecology	agroecology	1=Dega 2=Weinadega and Kola	+/-
Farming Experience	farmingexpe	Years in farming	+/-
Household size	households	Members of the household	+/-
Cultivated land size	cultivatedland	Hectares	+/-
Number of livestock	numberofcattle	TLU	+/-
Distance from market	timetoreach	Minutes	+/-
Drought resistant crop	gettingdrought	Dummy variable (1 and 0)	+/-
Extension services	extensionwor	Dummy variable (1 and 0)	+/-
Adaptation strategy	adaptused	Dummy variable (1 and 0)	+/-
Access to credit	accesstocredit	Dummy variable (1and 0)	+/-
obtaining food aid	obtainingfoodaid	Dummy variable (1 and 0)	+/-

Data Source: Household Survey, 2021

Age: is a continuous variable in the model that is measured in years. The household's adaptive techniques might be positively or negatively impacted by Age. Studies show that experienced farmers are more likely to perceive a change in climate risk, and that age can be used as a proxy to farm experience (Madisson, 2006). Older farmers are less likely to be flexible and more likely to be risk averse than younger farmers, which reduces their likelihood of coping. Older farmers are more likely to be able to manage the climate risk because they have more agricultural experience, are better able to evaluate the features of their immediate environment and have more coping options available to them than younger farmers. Several studies also revealed that age positively affects the likelihood of using adaptation strategies (Aemero, 2012; Seid and Tamiru 2016; Abrham *et al.*, 2017). In the study undertaken, age is expected to have either positive or negative effect on the choice of adaptation methods.

Sex: incorporated as a dummy variable in the model, with a value of 0 for women and 1 for men. It is anticipated that the head of the household sex will have an impact on their adaptation choice. Location-specific factors determine how sex influences coping decisions. Research conducted in Africa has revealed that women are less likely than men to have access to, labor and land, which limit their capacity to engage in labor-intensive agricultural innovation. In the same vein, research by Temesgen *et al.* (2009); Aemero, (2012); Seid and Tamiru, (2016); Abrham *et al*.(2017) showed that households headed by men adjust to climate change more easily. Nonetheless, Nhemachen and Hassan, (2007) found women-headed households are more likely to adopt and use adaptation strategies.

Level of education is a continuous variable that is expressed as the head of the household's years of education. It is predicted to enhance one's capacity to acquire, interpret and comprehend information important for making coping decisions. Education is thought to improve a household's coping decision. Higher education level is frequently thought to improve the likelihood of adaptation decisions. The findings were reported by Aemero (2012); Seid and Tamiru (2016); Abrham *et al.* (2017) indicated that as the level of education of the head of the household increases, using different adaptation strategies also enhanced. As to Maddison (2006) findings, farmers with better levels of education and experience should be more knowledgeable about climate change and the agronomic techniques available.

Agro ecological Zone (AEZ) is a continuous variable that the model considers, with 1 denoting highland (*Dega*) AEZs and 2 denoting a combination of midland or *Weinadega* and lowland or *Kola* AEZs. Farmers' usage of adaptation strategies for the impact of rainfall variability and drought are anticipated to be impacted by AEZ setting and local climate. It is anticipated that SFHH located in various AEZ will exhibit varying degrees of exposure and susceptibility to effects of fluctuation in rainfall and drought. Comparing the wet lowland with dry lowland improved awareness and usage of adaptation measures were observed in wet lowland as indicated (Zelalem *et al*., 2022; Esubalew *et al.*, 2023)

Household size (Family size): is a continuous variable that is determined by how many family members live in a home. It is believed to be a representation of the labor required for farm operations. Large households are more likely to shift a portion of their labor force into non farming activities, according to Mano and Nhemachena (2006). However, Hassan and Nhemachena (2008) disputed this claim, arguing that since off-farm opportunities are typically hard to come by the opportunity cost in most smallholder farming systems may be too low. Large-scale farmers have more capital and resources, thus they are more likely to adapt to rainfall variability and drought, according to a number of studies (Hassan *et al*., 2008; Aymone, 2009; Seid and Tamiru 2016; Aemero, 2012; Abrham *et al.,* 2017). Therefore, it is expected in this study that the variable will either positively or negatively affect adaptations to climate change.

Farm Size: Farm size is a continuous variable expressed in hectares. Farm size can affect a household's choice of adaptation strategies in a favorable or negative way. For the SFHH, having a large plot of land is regarded as a sign of wealth. Farm size and the habit of producing alternative crops to meet family requirements are also related. The likelihood that a farmer will use appropriate tactics increases with the size of the farm. It is anticipated in this study that farm size and adaptation to rainfall variability and drought might have positive or negative connections.

Livestock holding in TLU: The total number of cattle, camels, horses, donkeys, mules, sheep and goats in SFHH is represented by the continuous variable known as TLU. To enter TLU, multiply each of the aforementioned entities by their respective values. Farmers mostly drive their wealth from their cattle, which they accumulate over time. Furthermore, Abrham *et al.* (2017) found the positive and significant relationship between TLU ownership and the application SFHH adaptation techniques. In this study TLU will either positively or negatively affect farmers' choice of adaptation strategies.

Distance from the Market: The trip time that SFHH takes to get to the closest market is expressed in minutes is a continuous variable. Because a home closer to the closest local market will have better access to information, expertise and experiences regarding contemporary technologies and innovations. Therefore, the likelihood of gaining access to contemporary technologies and innovations declines with increasing distance from the local market. Similarly, studies by Seid and Tamiru, (2016); Abrham *et al*. (2017) reported the significant and negative correlation between market distance and the application of adaptation techniques.

Access to extension services: This is a reference to the quantity of interactions the farmers who responded made with extension agents. Most writers have found a favorable relationship between farmers' adaptation decisions and contacts with agricultural extension workers. Smallholder farmers in Ethiopia can benefit greatly from the information, expertise, and guidance provided by agricultural extension. Better access to extension services is positively correlated with the likelihood of implementing various adaptation strategies. According to Aymone (2009); Temesgen *et al.* (2009); Seid and Tamiru, (2016) better access to extension services is positively correlated with the likelihood of implementing various adaptation strategies.

Access to credit: For farmers to close financial gaps and buy the necessary farm inputs and technologies to increase agricultural production as well as engage in non-farm revenue-generating activities, access to credit service is crucial (Komba and Muchapondwa, 2015). Numerous studies have shown that having access to credit increases the likelihood of adaptation (Aymone, 2009; Temesgen *et al.,* 2009; Seid and Tamiru, 2016). Therefore, it is expected that this variable either positively or negatively affects farmers' efforts to adapt to rainfall variability and drought in Guji Zone.

Access to drought resistant crops is a dummy variable that is measured as zero (0) for not having access to crop varieties resistant to drought and as one (1) for getting access to drought resistant crop varieties. In the study undertaken the anticipated effect of access to drought resistant crop varieties may favorably or adversely affect farmers' efforts to adapt to rainfall variability and drought.

Access to food Aid is a dummy variable that is assessed as 1 for receiving food assistance and zero (0) for otherwise.

Data reliability and validity

The survey instrument was first translated into the *Oromiffa* language spoken in the area. The accuracy of the translations of various concepts was examined. Next, each woreda's data collectors were counted. They were first-degree holders who were conversant in the community language and custom. The data collectors received one day's instruction on how to fill out the questionnaire with each question and speak with the respondents.

Data Pretesting

Before the real data collection phase began, the questionnaire underwent a pretest. In pilot research, the validity and reliability of the data gathering tools were examined. Certain questions in the pilot research were rewritten to make them clear once they had been pretested. The questionnaire was checked for logical error and completeness based on participant opinions. The questionnaire's consistency was verified and adjusted through cross-checked. Pretesting the data collecting instrument's clarity and dependability was conducted prior to data collection.

Validation

The internal consistency of the questionnaire was checked. The internal validity of the items that measured the SFHH perception of rainfall variability and drought were evaluated using Cronbach's alpha. Cronbach's alpha was used to assess the internal consistency of perception measuring tools used in the data collection process. Cronbach's alpha values were greater than eight (8) were found, indicating a high degree of internal consistency in the items.

The assumption binary logistic regression model was checked before the model applied. Pretesting data for logistic regression entails determining the data's multicollinearity, linearity, and normality. The normality of the data was examined. Variance Inflation Factor (VIF) is also used to diagnose multicollinearity using the SPSS software (Table 9.1.10). Result VIF greater than 10 indicate multicollinearity. However, in the study VIF score below five (< 5) which indicates that there is no issue with multicollinearity among the independent variables. Additionally, the presence of an outlier in the data was detected. The outcome shows that the data does not contain any outlier.

The goodness of fit in BLRM

The goodness of fit test indicated that the model fits the data well. The Omnibus Tests of Model Coefficients and the Hosmer–Lemeshow test of goodness of fit showed the model fits the data well. The Omnibus Tests of Model Coefficients indicate the 'goodness of fit' test results a highly significant whenever value is ($p < 0.05$). In this case the value is .000 which really means $p <. 0005$.The chi-square value is 50.723 with degree of freedom 15. Furthermore, the Hosmer-Lemeshow goodness of fit test is poor when a significance value ($p < 0.05$), the BLRM model in the analysis value ($p > 0.05$). Besides, the chi-square value for the Hosmer-Lemeshow test is 5.727

with a significance level of .678 obtained with a degree of freedom of 8. This value is larger than .05, therefore the model fits data.

The Cox and Snell R Square and the Nagelkerke R Square values provide an indication of the amount of variation in the dependent variable explained by the model, the output varies from a minimum value of 0 to a maximum of approximately 1. These are described as pseudo-R square statistics, rather than the true R square values. In the analysis the two values are .119 and .159, suggesting that between 11.9 % and 15.9 % of the variability is explained by this set of independent variables. The Classification table provides how well the model predicts the correct category for each case. The model correctly classified 62.8% of cases overall is sometimes referred to as the percentage accuracy in classification which indicates an improvement over the 50.3 % (in Block 0) without the inclusion of independent variables.

6.3. Results and Discussions

6.3.1. Smallholder farmers' perceptions of impacts of rainfall variability and drought

The relationship between meteorological data with perception of SFHH was discussed in this section. The meteorological data from three districts were compared with SFHH perceptions because the HHS was conducted on those districts (Figure 6.1). Evaluating the perceptions of smallholder farmers is necessary to determine whether stakeholders share a common understanding of rainfall variability and drought and its consequences. The community's experience should be taken into consideration when valuing climate data. Because empirical analysis of climate variables provides partial information needed to make decisions about adaptation plans. The adaptive reactions of smallholder farmers are determined by their perception of historical changes in rainfall and drought. Therefore, both the empirical analysis of meteorological data and smallholder farmers' perceptions influence the selection of adaptation tactics.

Table 6.3 demonstrated smallholder household perception of rainfall variability and drought together with rainfall distribution, amounts, and temperatures over the past thirty years. The respondents' opinion of the altered climate variables is 66%, 17.8%, and 15.8%, for changes in rainfall, temperature, and wind respectively. Of the respondents, 85% perceived that the area was experiencing rainfall variability and drought, while the remaining15% were unaware of the problem.

Of all the households, 71% perceived that rainfall had decreased in the study area, while 29% thought it had increased. To ascertain whether there were significant differences in the perception behaviors of the household groups located in various AEZs, a one-way Anova was utilized. Compared to households in highland AEZs, a drop in rainfall was observed in the lowland and midland AEZs jointly (90%). As a result, almost all SFHH in the lowland and midland AEZs perceived a notable decline in the trend of rainfall. Their assessment is consistent with meteorological data that showed low and midland AEZs more likely than highland AEZs to experience higher rainfall variability and drought.

Table 6. 3. Farmers Perception of Rainfall Variability and Drought

Variables		Highland		Midland		Lowland		Mean		Sign
		FRQ	%	FRQ	%	FRQ	%	FRQ	%	
Annual RF	Increased	61	52	50	43	6	5	117	29	.000
	decreased	29	10	150	53	104	37	283	71	.000
Spring RF	Increased	36	34.6	57	55	11	10.5	106	27	.249
	Decreased	54	18.3	142	48.3	98	33.3	294	73	.005
Autumn RF	Increased	61	47	59	46	9	7	130	32.5	.000
	Decreased	28	10	41	52	101	38	270	67.5	.005
Temperature	Increased	50	16	160	50	110	34	320	80	.000
	Decreased	40	50	40	50	0		80	20	.979
Drought	Increased	61	17	196	53	110	30	367	92	.000
	Decreased	29	88	4	12	0		33	8	.533

Data Source: Household Survey, 2021

Note: FRQ=Frequency; %=Percentage

On the other hand, 52% of respondents who perceived an increase in annual rainfall were in the highlands AEZs, while 10% observed a decline in annual rainfall. Therefore, their answer was consistent with the meteorological data that confirmed the annual rainfall trend in highland AEZs was significantly increasing.

A significant proportion of respondents, specifically 73%, reported a decline in springtime rainfall, whereas 27% reported an increased springtime rainfall. Of the total respondents, 48.3% in midland and 33% in lowland AEZ thought that they had received a decrease in spring rainfall. In total, 81.3 % of respondents agreed that they observed a decline in the amount of spring rainfall in the midland and lowland AEZ. The outcome is also consistent with the meteorological data output, which showed a statistically significant decreasing trend of spring rainfall in the midland and lowland AEZs (Table 5.14).

Respondents' perception of the historical pattern of autumn rainfall revealed that 67.5% of them observed a decline while 32.5% experienced an increase. Though 10 % of them perceived a drop in autumn rainfall, a considerable number of respondents, 47% experienced an increase in autumn rainfall in the highland AEZ. As the empirical analysis of rainfall confirmed, there is a significant increasing trend of autumn rainfall in the highland AEZ. There was a statistically significant increasing trend at (p <5%) in autumn and annual rainfall in the highland AEZ. On the other hand, some parts of the mid and lowland AEZ showed a similar positive trend in annual rainfall.

In addition, most of the households perceived a noticeable shift in temperature. Out of the total, 80 % of the respondents perceived that the temperature had increased, while 20 % thought it had decreased. According to several studies, the widely held perception of SFHH in various parts of Ethiopia is increasing temperature, and decreasing rainfall (Temesgen *et al.*, 2009; Limantol *et al.*, 2016; Israel and Belay, 2019; Hailay *et al.,* 2019). Out of the total rising temperatures were perceived by 34 %, 50 % and 16 % respondents in the lowland, midland and highland respectively. The empirical analysis of temperature trends showing rising trends in the lowland significantly at (p <10%). There was some intermixing in the minimum and maximum temperature trend at the different AEZ.

The SFHH perception on their historical experience of drought in the lowland, midland and highland increased by 30 %, 53% and 17% of respondents, respectively. In contrast, 88% SFHH in the highland perceived a decline in the frequency of drought. The results of SFHH perceptions align with meteorological data, which indicates that the lowland and midland AEZ experienced more frequent occurrences of droughts.

6.3.2. Major adaptation strategies to rainfall variability and drought

Adaptation has enormous benefits for smallholder farmers who are impacted by rainfall variability and drought. Since adaptability offers advantages locally and temporally. It is a smallholder farmer's way of protecting their system of subsistence from sporadic hardship. Effective adaptation can reduce the vulnerability of smallholder farmers to the effect of rainfall variability and drought. With the help of the local government, smallholder farmers in Guji zone were practicing several adaptation techniques. The potential benefits and challenges of adaptation methods to address the effects of rainfall variability and drought on the lives of SFHH were described in the following section.

6.3.2.1. Adaptation strategies initiated by government

The phenomenon of adaptation is local and situational. The foundation of adaptation responses is shared enabling conditions. According to the (IPCC, 2014) these include effective institutions and governance, innovation and investments in environmentally friendly infrastructure and technology, sustainable livelihoods and behavioral and lifestyle decisions. The local government must be involved in the development of various adaptation measures for SFHH. Given their role in managing risk information and finance, scaling up households' adaptation and other related responsibilities, local governments are increasingly seen as essential to advancement of adaptation (IPCC, 2014). Additionally, non-governmental organizations can help improve the SFHH resilience by offering various adaptation measures.

The information gained from FGD and KII discussions revealed that local governments of the Guji zone were attempting to handle the effects of rainfall variability and drought by providing several adaptation methods for SFHH. Therefore, the SFHH and governments were working together to identify different approaches to deal with the effects of unpredictable rainfall and drought. Based on the input obtained from FGD and KII the adaptation strategies utilized in the study area were narrated in the next part.

The adaptation strategies initiated by the government in Guji Zone include:

1.**Drought-resilient crops:** Guji zone is one among the marginalized parts of Ethiopia. The Guji zone is inaccessible for some adaptation techniques that are utilized in other parts of Ethiopia. Research suggests that introducing drought-resilient crops can lessen the effects of drought-induced food insecurity in Ethiopia (Lewis, 2017). In low and midland AEZ, one of the adaptation strategies used was drought-resistant seed varieties. However, limited provisions for drought resistant seeds with the help of NGO were undertaken in the lowland AEZ. Nonetheless, the practice of offering drought resistance seed in the midland AEZ was once started with the support of NGO but not sustained. The limited access to drought-resilient crops in the area was verified by the household survey, where 60 % of respondents said there was no access to drought-resistant seed varieties in the area. The FGD and KII discussions confirmed the scarcity in the provision of drought resistant crop varieties in mid and lowland AEZ of Guji Zone. Besides, it is difficult for smallholder farmers to afford drought- resilient crop varieties in the mid and lowland AEZ of Guji Zone.

2. Selected seed varieties: Alternative coping strategies include using selected seed varieties to lessen the effects of rainfall variability and drought. Purchasing crops that are climate change adapted can improve a crop's ability to withstand drought (IPCC, 2014). The selected seed varieties are either produced or brought up from other parts of the country. In Bore Agricultural institutes, selected seed varieties have been produced and distributed. The institute cultivates and multiplies the chosen seed kinds on small holder farmers' land as well as in research centers. Subsequently, the seed was allocated to smallholder farmers in Guji zones.

As per the output FGD and KII discussions they faced great challenges related with the provision of the selected seed varieties that were acquired from other parts of Ethiopia. They contend that the seeds provided by the agricultural office are inappropriate for the area's AEZ and growing season. Because the seeds were prepared for cropping them in different locations with distinct AEZ and growing seasons with the study area. The requested and delivered seed by SFHH did not match. There are limitations on the chosen seed variety's delivery time. Since the lowland and midland AEZ have a bimodal growing season. They need the seed before sowing in the spring and autumn season. However, they did not receive the seeds within the requested time frame. Considering that those seed varieties were ready for delivery of plantations in other parts of the country during the summer season. It distressed the situation of smallholder farmers.

3.Small scale irrigation

The local government was initiating small scale irrigation practices with clustering the SFHH in the lowlands and midland AEZs. Smallholders farm households who share boundaries were organized to practice irrigation with the assistance of agricultural extension workers. The agricultural office supplies the necessary inputs, including water pumps, the selected seed varieties, fertilizers, and pesticides and other necessary equipment for small scale irrigation.

4.Destocking

According to the discussion in FGD and KII, previously SFHH in the lowland raised big herds of cattle. Because there were better pasture and grazing areas in the lowland AEZ than at present. Gradually, due to the ongoing drought, their livestock population was reduced. Currently they are engaged in mixed agriculture. However, both crop farming and livestock rearing faced another challenge from shortage of rainfall water and short growing season in the lowland AEZ. As a result, their crop production has declined. Destocking or reducing the quantity of livestock is a key adaptation method advocated by local governments to lessen loss of their livestock due to recurrent drought in the lowland AEZ. Small-holder farmers reduce their livestock population by selling. They sell their cattle for two main reasons: to reduce the number of cattle deaths due to recurrent drought and accumulate capital for investment.

5.Food aid

Particularly, the SFHH in the midland and lowland AEZs, were experiencing worsening drought and hunger. Consequently, food assistance was often provided in the low and midland AEZ. Since the impact of erratic rainfall and drought on food security in SFHH has been worse. Smallholder farmers were then requesting food assistance from the government since it was not feasible to feed everyone. Currently, because of the intensity of the problems, there are more requests for food assistance for SFHH. To put simply, the demand for food helps outweigh the supply.

In summary, the above-mentioned adaptation initiative did not address the problem of smallholder farmers at the expected grassroots level. The concern given by the government was insufficient with the severity of the problem on SFHH in the area. As a result, the regional and zonal level of government ought to work together to develop alternative adaptation plans that will enhance the SFHH livelihood situation in the East Guji zone.

6.3.2.2. Adaptation methods of smallholder farmers' households

In order to deal with the effects of rainfall variability and drought in the research area, SFHH who perceived these phenomena were employing the following adaptation mechanism. In the survey smallholders were asked to list the primary adaptation strategies they used to address the effects of unpredictable rainfall and drought. Summary of the response of the main adaptation mechanisms used by SFHH is provided at Table 6.4. Crop diversification, mixed cropping, the use of drought-resistant crop types, and planting eucalyptus trees in place of food crops were the most employed adaptation measures by smallholder farmers in the Guji zone.

Table 6. 4. Major Adaptation Strategies of Smallholders Farmers

Adaptation Strategies	Frequencies	Percentage
Changing crop variety	6	2.9
Changing planting date (Sowing period)	15	7.2
Use drought resistant crop varieties	21	10.1
Mixed cropping	32	15.4
Crop diversification	61	29.3
Planting early maturing crops	20	9.6
Selling cattle	14	6.7
Irrigation	8	3.8
Replacing food crops with eucalyptus (Planting trees)	21	10.1
Receiving credit	5	2.4
Seek off farm employment	4	1.9
Temporary migration	1	.5
Total	208	100

Data Source: Household Survey, 2021

To address the issue, SFHH in the study area planted a variety of crops, including drought-resistant selected seeds and short-term growing crop varieties. Furthermore, SFHH decided to plant trees in place of crops because crops were more negatively impacted by rainfall variability and drought than grasses and trees.

Furthermore, as the FGD and KII discussion demonstrated, the Guji community possessed an innate coping strategy known as *"Kello"* to lessen the effect of rainfall variability and drought on their cattle. The Guji community uses *"Kello"* as a traditional adaptation method. It is keeping a vast expanse of land from grazing by the local community's livestock. The indigenous population consented to donate enormous tracts of land. During a period of severe drought, the territory set aside through "*Kello"* was used as a relief. The small holder farmers protect the grazing area in the event of a major calamity, grazing land is reserved with *"Kello"*. Nevertheless, the practice offers little real advantage to the community because of the current security issue in the area.

6.3.3. Determinants of farmer's adaptation to rainfall variability and drought

To identify the determinant factor influencing the adaptation techniques of SFHH in Guji Zone the binary logistic regression model was utilized. The binary logistic regression model's assumption was checked before the analysis was performed. Then, the variables that were thought to have an impact on household adaptation techniques were investigated in the model. The model output revealed that out of fifteen variables eight of them were determined to be significant. The variables which have significant impact on the household adaptation strategies includes: AEZ, HH's sex, household size, the size of the tropical livestock unit, the HH's of educational attainment, having enough food, receiving food assistance, and the time it took to get to the local market were among the variables that were fitted into the model.

The study found that the decision to use adaptation measures by SFHH was not statistically significantly influenced by factors such as age, farming experience and access to drought-resistant crops. In addition, the practice of adaptation was negatively correlated and non-significantly affected by marital status, the quantity of cultivated land, access to credit and obtaining agricultural extension services.

AEZ is significantly and positively correlated with households' adaptation tactics. Considering all other variables constant, each unit rise in AEZ increases, SFHH uses the adaptation approach at an odd ratio of 2.044 times. The model revealed that utilization of adaptation techniques increases with increase in altitude. In other words, SFHH in the highland use more adaptation techniques compared to the mid and lowlands AEZs. Farmers in different agro-ecologies have different choices of adaptation. Comparing the wet lowland with dry lowland improved awareness and usage of adaptation measures were observed in wet lowland as indicated (Esubalew *et al.*, 2023). Similarly, Zelalem *et al.* (2022) reported agro-ecological location positively influence soil and water conservation practices and improved crop varieties in the study area.

Table 6. 5.Determinants of Adaptation Strategies of SFHH

Variable Explanation	B	S.E	Wald	Sig	Exp.(B)	95% C.I EXP(B)	
						lower	Upper
AEZ	.715	.247	8.395	.004**	2.044	1.260	3.314
Age	.134	.392	.116	.733	1.143	.530	2.465
Sex	.783	.259	9.114	.003**	2.187	1.316	3.635
Marital Status	-.012	.126	.008	.927	.989	.772	1.266
Household Size	.91	.40	5.124	.024**	1.095	1.012	1.185
Farming Experience	.120	.087	1.907	.167	1.127	.951	1.336
Size of TLU	.052	.021	6.155	.013**	1.053	1.011	1.097
Level of Education	.067	.025	7.154	.007**	1.069	1.018	1.122
Cultivated Land Size	-.160	.151	1.133	.287	.852	.634	1.144
Enough food	.543	.202	7.236	.007**	1.722	1.159	2.557
Obtaining food aid	.851	.228	13.974	.000***	2.343	1.499	3.661
Access to credit	-.336	.253	1.765	.184	.714	.435	1.173
Time to reach local market	-.006	.002	13.945	.000***	.994	.991	.997
Access to drought resistant crop	.187	.222	.705	.401	1.205	.779	1.864
Agricultural extension services	-.039	.225	.030	.862	.962	.619	1.494

Data Source: Household Survey, 2021
Note: ** Level of significance = <5% and <1% by***

Sex of the household was identified as a significant factor determined using adaptation of SFHH. In addition, considering other factors constant, being male households increases the use of adaptation techniques at an odd ratio of 2.187 times more than being in female headed households. The possible explanation is that living in a household headed by a man facilitates easier access to knowledge about the various adaptation techniques employed. Research by Temesgen *et al.* (2009), Aemero, (2012); Seid and Tamiru, (2016); Abrham *et al.*(2017); Mequannt *et al.* (2020) showed that households headed by men adjust to climate change more easily. Wondimagegn and Lema, (2016) reported that being in male head of the household positively and significantly contributes to farmers' decision to cultivate different crops.

Household size has a significant and positive influence in the application of adaptation techniques. A unit increase in family size enhances the use of adaptation strategy with an odd ratio of 1.095 times. In other words, having large family size influences utilization of adaptation strategies positively. Because large-scale farmers have more capital and resources; thus, they are more likely to adapt to rainfall variability and drought, according to studies (Hassen *et al.* 2008; Aymone, 2009; Temesgen *et al.*, 2011; Seid and Tamiru, 2016; Aemero, 2012; Abrham *et al*., 2017; Mequannt *et al.,* 2020; Zelalem *et al.*, 2022). Productive resources, including money, land, capital, and labor are crucial for adjusting to and overcoming rainfall variability and drought. The study of Wondimagegn and Lema, (2016) revealed that household choice of changing planting dates, adoption of soil and water conservation influenced by family size.

In most parts of Ethiopia SFHH engaged in mixed farming, these kinds of mixed crop-livestock production systems are a crucial risk-management technique for Ethiopian SFHH. Assuming other factors are constant, a unit increase in TLU improves the usage of adaptation techniques with an odd ratio of 1.053. Consequently, SFHH with larger TLU can adjust to the effect of rainfall variability and drought more effectively than SFHH with smaller TLU. Cattle provide SFHH with additional food and revenue streams, enabling them to adapt to the effects of rainfall variability and drought. Abrham *et al.* (2017) and Molla *et al.* (2023) found the positive and significant relationship between TLU ownership and the application SFHH adaptation techniques.

Keeping other factors controlled, a one-year increment in the level of education positively and significantly increases the chance of using different adaptation strategies with an odd ratio of 1.069 times. Possible explanation for this could be that literate farmers are anticipated to adopt new technologies because they understand the potential benefit of adaptation measures. Similar findings were reported by Aemero (2012); Seid and Tamiru, (2016); Abrham *et al.* (2017); Zelalem *et al.* (2022); Esubalew *et al.* (2023) as the level of education of the head of the household increases, using different adaptation strategies also enhanced. As to the findings of Maddison (2006) finding, farmers with better levels of education and experience should be more knowledgeable about climate change and agronomic techniques.

It was discovered that the usage of adaptation techniques was significant and negatively correlated with the distance from the closest market. In other words, as distance from the market increases the likelihood of employing various adaptation techniques declines. In other words, as distance from the local market decreases, adaptation increases because as distance from the market increases access to contemporary technology and input for adaptation decline. In a similar vein, research by Seid and Tamiru, (2016); Abrham *et al.* (2017); Paulos and Belay, (2017) reported the positive influence of decreased distance from the market on the application of adaptation techniques. Similarly, Wondimagegn and Lema, (2016) reported distance from market is found to favor the adoption of planting different crop varieties and choice of changing planting dates. Likewise, Esubalew *et al.* (2023) reported being close to market had a positive and significant impact on adopting crop diversification and adjusting planting dates, and soil and water conservation adaptation measures.

In summary, the binary logistic regression model's result showed that the following factors are less likely to predict the use of adaptation strategies in Guji zone: Age, marital status, farming experience, cultivated land size, access to credit, availability of drought resistant crops, and assistance from agricultural extension workers. Numerous studies have shown that having access to credit increases the likelihood of adaptation (Aymone, 2009; Temesgen *et al.*, 2009; Seid and Tamiru, 2016). One of the main obstacles to adaptation is the lack of sufficient financial resources to buy the required inputs and a variety of possibilities for other related equipment (such as buying seeds, renting a car, or employing temporary labor). Lack of capital is the main factor (33%) that hinders SFHH adaptation practices according to the HHS (Table 6.4). However, the model result indicates access to credit has no significant contribution to SFHH adaptation.

Several studies also revealed that age is a significant variable that positively affects the likelihood of using adaptation strategies Aemero, (2012); Seid and Tamiru, (2016); Abrham *et al.* (2017) however in the study undertaken age and farming experience has no significant contribution with the use of adaptation methods.

Cultivated land size is also found to have negatively and non-significant correlated with the use of adaptation in the model. The finding supported by Temesgen *et al.* (2011) explains that it is not the size of the farm, but the specific characteristics of the farm that dictates the need for a specific adaptation method to climate change. However, a considerable percentage of SFHH who participated in the household survey stated that a lack of land was a barrier to practice adaptation (Table 6.6).

Better access to extension services is positively correlated with the likelihood of implementing various adaptation strategies, according to multiple research by (Aymone, 2009; Temesgen *et al.*, 2009; Seid and Tamiru, 2016; Esubalew *et al.*, 2023). However, the study found the usage of adaptation strategies is negative and non-significant correlated with access to agricultural extension services. According to the discussion in FGD and KII in the lowland AEZ as well as throughout the study area, there were significant security concerns that prevented communication between smallholder farmers and agriculture extension. The prevailing security issues in the lowland AEZ lesser the communication between SFHH and extension workers as mentioned as a challenge for adaptation in FGD and KII. The lack of security and stability in the area for the past several years has prevented the local extension workers from providing information for small-holder farmers, which enables them to address the issue.

The agricultural extension agents did not offer SFHH appropriate services. Farmers that receive better extension services are more likely to be aware of the current conditions related to rainfall variability, as well as to use adaptation strategies to lessen the effect or take advantage of the benefit. The lack of suitable agricultural extension service delivery in the study area may have contributed to the acquired conflicting result.

Challenges of adaptation

The agricultural sector, which the livelihood of smallholders is highly dependent on, needs suitable adaptation techniques. Adaptation reduces the impacts of erratic rainfall and drought on food security of the households. SFHH in the research area employed several adaptation techniques. Socioeconomic factors, however, may make the technically possible adaptation choice less viable. Planning and implementation of adaptation may be hampered by the interaction of constraints. Limited financial and human resources, a lack of government coordination or integration, disparate risk assessment, lack of influential advocates and leaders of adaptation, and lack of methods to assess the efficacy of adaptation are common barriers to implementation (IPCC, 2014)**.**

The study investigates the barriers that make adaptation difficult for SFHH in Guji Zone. Based on the HHS the elements that hinder the practice of SFHH adaptation are outlined in Table 6.6. Accordingly, the following were found to be barriers to adaptation procedures of SFHH in the Guji Zone. The major constraints adaptation of SFHH to the effects of rainfall variability and drought-induced hazards were lack of money, giving less emphasis, lack of information, shortage of farmland, lack of access to input, shortage of water for irrigation, and land scarcity. Consequently, the main reasons SFHH is unable to modify their agricultural practices are because they lack the necessary awareness, funds, expertise or focus on the effect of rainfall variability and drought.

Table 6. 6. Factors Hindering Adaptation practice of SFHH

R.no	Reasons for not undertaking Adaptation	Frequency	Percent (%)
1	Lack of capital (money)	63	32.8
2	Giving less emphasis to rainfall variability and drought	48	25
3	Lack of information and knowledge	45	23.4
4	Shortage of farmland	18	9.4
5	Lack of access to input	18	9.4
	Total	192	100

Data Source: Household Survey, 2021

Shortage of water: according to the FGD and KII discussion shortage of water due to recurrent drought is a major obstacle to adaptation in the lowland. The problem was also confirmed by the empirical analysis of rainfall, temperature and drought. Furthermore, availability of water restricted the efficiency of the adaptation mechanism. Strategies for adaptation must investigate alternative sources of water because of the scarcity of water in the low land. To address the issue of water shortage, the local communities urged the governments to fill the canal built-on river Genale to alleviate the problem of shortage of water. If the government allowed the water to flow through those canals, they would use the water for domestic as well as for irrigation purposes. But the government couldn't supply water via the canals that had been previously constructed. Rather, in the lowland AEZ there were repeated shortages of water and grazing land whenever periodic droughts were exposed. Following a serious drought outbreak, SFHH in the lowland AEZ receives water and grass from the government which they consider inadequate.

6.4. Conclusion

According to the SFHH perception most respondents 71% perceived that rainfall had decreased, while 80 % of the respondents thought the temperature had increased in Guji Zone. Many respondents, 85%, perceived that the area was experiencing rainfall variability and drought, while the remaining 15% were unaware of the problem. According to SFHH responses, the increase in the frequency of drought is perceived by 30 %, 53% and 17% respondents in the lowland, midland and highland, respectively. In contrast, 88% of SFHH in the highland saw a decline in drought trend which is in line with the empirical data analysis which indicates that the lowland and midland

AEZ have faced more frequent droughts. An assessment on the SFHH perception based on agro-ecological principle corresponds with empirical analysis of meteorological variables. In summary, the discussion of FGD and KII with the meteorological data was determined to be in harmony with SFHH perceptions.

Smallholder farmers , who understand the effects of erratic rainfall and drought have used several adaptation techniques. Crop diversification, mixed cropping, the use of drought-resistant crop types, and planting eucalyptus trees in place of food crops were the most frequently employed adaptation measures by smallholder farmers. The finding of the binary logistic regression model revealed that AEZ, HH's sex, household size, the size of the tropical livestock unit, the HH's of educational attainment, having enough food, getting food assistance, the time it took to get to the local market, and the adaptation strategies employed were among the variables that were fitted into the model and had a significant impact on the household adaptation strategy. The study found that the decision to use adaptation measures was less likely to be influenced by factors such as age, farming experience and access to drought-resistant crops of the SFHH. In addition, the practice of adaptation was negatively correlated and non-significantly affected by marital status, the quantity of cultivated land, and access to credit and agricultural extension services.

However, in the Guji zone, the main obstacle to adaptation to the effect of unpredictable rainfall and drought is lack of capital (money), giving less emphasis to rainfall variability and drought and lack of information and knowledge. Shortage of water is also identified as an obstacle to adaptation of the effects of rainfall variability and drought in the lowland. Since in the low and midlands AEZ due to the observed high rainfall variability, (CV >30%) crop production suffered, and food insecurity was intensified. Supplying an additional water source is necessary for small-scale irrigation practice which lessens the negative impact of rainfall variability and drought on food insecurity. Furthermore, it's critical to provide genetically enhanced seed type and short term grown and drought resistant crops in the midland and lowland AEZ.

CHAPTER SEVEN

SUMMARY AND CONCLUSIONS

7.1. Summary

Rain-fed agriculture is the mainstay of smallholder farmers in the study area therefore it is crucial to determine the variability of rainfall in terms of onset and cessation, and distributions and trends across time and in the three AEZs. The general objective of the study was to analyze spatial variability and temporal trend of spring and autumn rainfall and characterize drought, impacts of rainfall variability and drought on food security, household perception and adaptive strategies of the smallholder's farmers in the three AEZs of Guji zone, Oromia Regional State, Ethiopia.

The result shows that the distribution of rainfall in the three AEZs of the study areas varies both spatially and temporally. As a result, the time frame for the study helps to describe the temporal variability in rainfall in the research area. On the other hand, the observed spatial variability in rainfall in Guji zone was mostly caused by the area's varied AEZ, which varied in elevation from 632 meters-2960 meters. Midlands and lowlands experience bimodal rainfall, two distinct onset and cessations and dual LGP in the autumn and spring seasons. In contrast, the highlands received a significant amount of rainfall in spring, autumn and summer. Moreover, variations were noted on the days when rainfall began and ended in the three major AEZs of the study area. There were intricate patterns in rainfall distribution throughout the study area. Insignificant, increasing trends of spring rainfall have been discovered in most parts of the study area. Partially, there was a significant increase in autumn and annual rainfall in some parts of the study area.

As one moved from highlands to lowlands in the study area LGP decreased, rainfall variability increased, and rainfall reliability worsened. As a result, in the lowlands and midlands AEZ of the study areas, SFHH faces significant hurdles from too short LGP, and unpredictable rainfalls. Consequently, the crops will experience a lack of moisture, resulting in inadequate crop yield. So, more consideration is needed for smallholder farmers in the lowland and midland AEZs because their agricultural and livestock production has been negatively impacted by unpredictable rainfall and recurrent drought, lack of water, and late coming and early cessation of the main rainy seasons.

The research area exhibited both temporal and spatial variability in the distribution of monthly, seasonal, and annual rainfall.

The trend drought follows a reciprocals pattern with the trend of rainfall in each AEZs. As a result, drought has a declining trend in places where significant rainfall increases and vice versa. Due to the study area's location in the southern part of the country, there is partial divergence in the drought trend compared to the national average. This is because Ethiopia's southern and the northern and central regions receive rainfall from different moisture sources.

According to the smallholder farmers' perception most respondents viewed an increase in temperature and a decrease in rainfall. Assessments on the SFHH perception based on agro-ecological principle correspond with empirical analysis of meteorological variables. In summary, the empirical analysis of meteorological data, the discussion of FGD and KII are in harmony with the perceptions of SFHH. Thus, as perceived and observed divergent spatial distribution, temporal trend and variability of rainfall were found in the three AEZ of the research area. As a result, each of the three AEZ experienced rainfall variability and drought which have different effects on SFHH food security. Based on HFIAS score the highland Bore is mildly food insecure (8.7). Midland Adola is moderately food insecure (11.3) and there was severe food insecurity (17.5) in the lowland AEZ in Negele. According to HFIAS, the lowland, midland and highland AEZ of the research area had mild, moderate, and severe levels of food insecurity respectively. SFHH, who understand the effects of erratic rainfall and drought, have used several adaptation techniques. Crop diversification, mixed cropping, the use of drought-resistant crop types, and planting eucalyptus trees in place of food crops were the most frequently employed adaptation measures by smallholder farmers. The main obstacle to adaptation to the effect of unpredictable rainfall and drought in Guji zone includes lack of capital (money), giving less emphasis to rainfall variability and drought and lack of information and knowledge.

7.2. Conclusion

The contributions of the seasonal to annual rainfall in the highlands, midlands, and lowland AEZs are different. Accordingly, the midlands and lowland AEZs, which make up more than 78 % of Guji zone, mainly received (84%) of their rainfall in spring and autumn seasons. In contrast, highlands receive similar amounts of rainfall in spring, autumn and summer. As a result, the lowland Negele received (624mm) the smallest and the highland Solemo (1262mm) receives the highest annual rainfall during the study period. In the research area, as one descends from the highlands to the lowland's rainfall decreases, the inter-annual variability of precipitation increases. The finding indicates that the lowland and midland showed moderate, while the highlands exhibited less year-to-year variability of rainfall. High monthly and seasonal variability combined with the late beginning and early cessation of the spring and autumn rainfall adversely affected crop production of the smallholder farmers in the midlands and lowlands AEZ.

The monthly rainfall lacked statistically significant trends in almost all months of the year. The finding of MMR distribution exposed that 38% of the months studied had negative slope or decreasing magnitude. On the other hand, the MMR distribution had a positive magnitude in 62% of the examined months. The implication is an increase in the amount of rainfall in the area. Except for the autumn season, there were no statistically significant trends of seasonal rainfall. The autumn and annual rainfall increased to a statistically significance level of ($p < 0.05$) in highland AEZs. Surprisingly, autumn rainfall showed a significant increasing trend at the station in Bore and Solemo (highlands), Chembe and Dawa (lowland) and in Kercha (midland) at a significant level of ($p < 0.05$). Similarly, annual rainfall showed an insignificant increasing trend in some parts of the study area, a significant increasing trend was noted in the highlands (Bore and Solemo); lowlands (Chembe, Dawa and Bitata) as well as in the midland (Kercha) stations.

Each AEZ in the research area experienced varying degrees of drought, in terms of duration, severity, and spatial coverage. It was discovered that there is correlation between the El Niño in the Pacific and Atlantic oceans and the drought in the studied area. Therefore, the impact on SFHH will be lessened if the incident is accurately predicted using a timely, effective and relevant early warning system. All AEZ in the study areas experienced an increased impact of drought although the lowland AEZ experienced a more severe impact because of lower vegetation cover. This explains why the drought in the lowland *(kola)* causes a serious food scarcity, which is followed by the death of animals and people. However, the effect's severity was lessened in the highland *(dega)* locations. Consequently, it is crucial to manage the negative effects of drought by using various coping techniques that take the local AEZ into account. More attention should be given to adaptation of the agricultural system to rainfall variability in the lowlands and midlands AEZs.

It follows that food insecurity increased in the midlands and lowlands AEZs as seasonal rainfall variability rose from high to mid and lowlands (CV >30). It may be deduced that there were varying degrees of food insecurity in each of the three AEZ in Guji Zone. Nonetheless, the results of the binary logistic regression model analysis at a statistically significant level ($p < 0.05$) showed that, the head of the household age, sex, household size, farming experience, AEZ of the household, number of cattle, cultivated land size, level of education, distance from nearest market and receipt of food aid all positively contribute to household food security. But access to credit, marital status, and access to drought resistant crops is less likely to indicate a household's food security.

Many of the respondents, 85%, perceived that the area was experiencing rainfall variability and drought, while the remaining 15% were unaware of the problem. Of all the households, 71% perceived that rainfall had decreased, while 80 % of the respondents thought the temperature in the study area. The perception of SFHH their historical experience of drought in the lowland, midland and highland increased by 30 %, 53% and 17% of respondents, respectively. In contrast, 88% of SFHH in the highlands perceived a decline in the frequency of drought, which is in line with the empirical analysis of meteorological variables that indicates that the lowland and midland AEZ have faced more frequent droughts.

The binary logistic regression model output revealed that AEZ, HH's sex, household size, the size of the tropical livestock unit, the HH's of educational attainment, having enough food, getting food assistance, and the time it took to get to the local market were among the variables that were fitted into the model and had a significant impact on the household adaptation strategy. The study found that the decision to use adaptation measures was not statistically significantly influenced by factors such as age, farming experience and access to drought-resistant crops of the SFHH. In addition, the practice of adaptation was negatively correlated and non-significantly affected by marital status, the quantity of cultivated land, and access to credit and agricultural extension services.

Smallholder farmers who perceived these phenomena were employing the following adaptation mechanism to deal with the effects of rainfall variability and drought in the research area. The most used adaptation mechanisms used by SFHH in Guji Zone were crop diversification, mixed cropping, the use of drought-resistant crop types, and planting eucalyptus trees in place of food crops.

7.3. Recommendations

- ✓ Overall, the highland AEZ in the study area receives enough rainfall over the three seasons of spring, summer, and autumn. This will be viewed as a great opportunity for the study area to adjust to the effects of variable rainfall and drought. The highland AEZ can provide option rainwater for intensive crop cultivation. It is crucial to make effective use of the highland AEZs comparative advantage.
- ✓ In the highland AEZ, the heavy rainfall induced challenges of flooding, soil leaching, and soil acidification should be alleviated through planting trees and applying chemicals that neutralize soil acidity.
- ✓ Effective adaptation necessitated alternative sources of water, as the supply of water in the mid and lowlands was impacted by high rainfall variability and drought. Therefore, it is necessary to provide access to water from the Genale river through the channels that have already been constructed and other bodies of water in the lowland AEZs. Supplying other water sources from rivers in the midland part of the research area. Furthermore, smallholder farmers in the midlands and lowlands AEZs should receive additional help to increase the utilization of water sources to agricultural activities.
- ✓ Choosing and supplying suitable short-cycle produced and drought-tolerant crops, small-scale irrigation pumps in the midlands and lowlands AEZs within the study area.
- ✓ To prevent planting crops on the false onset date, the community should also have access to timely, accurate and reliable information regarding the beginning and end of rainfall seasons. Therefore, to reduce the risk associated with extreme drought, the government must give SFHH access to and disseminate early warning information. Enhancing the early warning system and the method used to inform the smallholders' farmers.
- ✓ The econometric model result showed that the household's socio-economic and demographic status determines how to improve SFHH food security and adaptation strategies. As a result, building assets and having access to information and knowledge are necessary to increase SFHH's resilience.
- ✓ Expanding small-scale milk and meat processing sectors in low and midland AEZ. As a result, the rain-fed agricultural economy will be transformed to a small industries-based economy based on local available raw materials.

- ✓ Investments in agricultural research and development from the public and private sector can support the agricultural industry's ongoing innovation. Because it is impossible to improve food security without increasing the agricultural production in the area.
- ✓ Enhancing the transportation infrastructure promotes vegetable waste reduction and smallholder farmers' participation in agricultural markets in the highland AEZ.
- ✓ It is essential to accurately determine the degree of vulnerability of the SFHH to supply food assistance to smallholders' farmers in the mid and lowland AEZs.
- ✓ Programs of afforestation and reforestation should be encouraged to mitigate the current variability in rainfall and drought through planting trees. The Redd^{++}calm project already-started mitigation effort should be expanded and reinforced to include additional areas in the Guji zone.

7.4. Future research outlook

- ➢ Further research should be conducted on identifying the irrigation potential of the study area together with the challenges and opportunities of water resources in Guji zone.
- ➢ Future research is needed on the spatial distribution and temporal trends of the water-soil system with the rate of evaporation throughout the three AEZ in the study area.
- ➢ Future research on agricultural drought and the impact on SFHH in Guji zone is required.
- ➢ Future research should be conducted assessing the level of vulnerability of smallholders to climate change in the Guji zone.

8. REFERENCES

Abebe, A. M., and Arega, B. B. 2020. Spatiotemporal variability and trends of rainfall and temperature in the Northeastern Highlands of Ethiopia. *Modeling Earth Systems and Environment*, *6*(1), 285–300. https://doi.org/10.1007/s40808-019-00678-9

Abebe, A. M., Berlie, Arega. B., and Mehrete, B. F. 2020. Spatial and temporal drought incidence analysis in the northeastern highlands of Ethiopia. *Geoenvironmental Disasters*, *7*(1). https://doi.org/10.1186/s40677-020-0146-4

Abebaw, H. F., and Mesele, B. Z. 2022. Determinants of Rural Household Food Security Status in North Shewa Zone, Amhara Region, Ethiopia. *Scientific World Journal*, *2022*. https://doi.org/10.1155/2022/9561063

Abera, H., Girma, M., Walelign, W., Dereje, A., and Gayler, S. 2021. Spatial Variability and Temporal Trends of Climate Change in Southwest Ethiopia: Association with Farmers' Perception and Their Adaptation Strategies. *Advances in Meteorology*, *2021*. https://doi.org/10.1155/2021/3863530

Abera, H., Walelign, W., Girma, M., Dereje, A., and Gayler, S. 2023. Rainfall variability and its seasonal events with associated risks for rainfed crop production in Southwest Ethiopia. *Cogent Food and Agriculture*, *9*(1). https://doi.org/10.1080/23311932.2023.2231693

Abrham, B., Teferi, D., Recha, J. W., Oludhe, C., Osano, P. M., Olaka, L. A., Solomon, D., and Berhane, Z. 2021. Analysis of climate variability and trends in Southern Ethiopia. *Climate*, *9*(6), 1–17. https://doi.org/10.3390/cli9060096

Abrham, B., Recha, J. W., Teshale, W., and Morton, J. F. 2017. Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia. *Agriculture and Food Security*, *6*(1). https://doi.org/10.1186/s40066-017-0100-1

Adanech, B., Marisennayya, S., and Elias, B. 2023. Status of household food security, its determinants, and coping strategies in the Humbo district, Southern Ethiopia. *Journal of Agriculture and Food Research*, *11*. https://doi.org/10.1016/j.jafr.2022.100461

Adisu, M., Tessema, A., Ganewo, Z., and Haile, A. 2021. Climate change impacts on household food security and adaptation strategies in southern Ethiopia. *Food and Energy Security*, *10*(1), 1–14. https://doi.org/10.1002/fes3.266

Adger, W. N., Huq, S., Brown, K., Declan, C., and Mike, H. 2003. Adaptation to climate change in the developing world. *Progress in Development Studies*, *3*(3), 179–195. https://doi.org/10.1191/1464993403ps060oa

Adhyani, NL; June, T; Sopaheluwakan, A 2017. Exposure to Drought: Duration, Severity and Intensity (Java, Bali and Nusa Tenggara). IOP Conf. Ser. Earth Environ. Sci. 58(2): 012 - 040.

Aemro, T., Jema, H., and Mengistu, K., 2012. Climate change adaptation strategies of smallholder farmers: the case of Babile district of East Hararghe zone of Oromiya regional state of Ethiopia. Journal of Economics and Sustainable Development, 3 (14): 1-12.

Aklilu, M., Kindie, T., and Duncan, A. J. 2014. Trends in daily observed temperature and precipitation extremes over three Ethiopian eco-environments. *International Journal of Climatology*, *34*(6), 1990–1999. https://doi.org/10.1002/joc.3816

Akinnagbe, O., and Irohibe, I. 2015. Agricultural Adaptation Strategies to Climate Change Impacts in Africa: A Review. Bangladesh Journal of Agricultural Research, 39, 407-418. https://doi.org/10.3329/bjar.v39i3.21984

Alem meta, A., and Singh, K. N. 2018. Determinants of food insecurity in the rural farm households in South Wollo Zone of Ethiopia: the case of the Teleyayen sub-watershed. *Agricultural and Food Economics*, *6*(1). https://doi.org/10.1186/s40100-018-0106-4

Almeida, C. S. de, Miccoli, L. S., Andhini, N. F., Aranha, S., Oliveira, L. C. de, Artigo, C. E., Em, A. A. R., Em, A. A. R., Bachman, L., Chick, K., Curtis, D., Peirce, B. N., Askey, D., Rubin, J., Egnatoff, D. W. J., Uhl Chamot, A., El-Dinary, P. B., Scott, J.; Marshall, G., Prensky, M., … Santa, U. F. De. 2016 https://revistas.ufrj.br/index.php/rce/article/download/1659/1508%0Ahttp://hipatiapress.com/hpjournals/index.php/qre/article/view/1348%5Cnhttp://www.tandfonline.com/doi/abs/10.1080/09500799708666915%5Cnhttps://mckinseyonsociety.com/downloads/reports/Educa

Alves, L. M., Marengo, J. A., Chadwick, R., Moise, A., and Brown, J. 2021. *Assessment of rainfall variability and future change in Brazil across multiple timescales*. *December 2019*, Anderson, W., Cook, B. I., Slinski, K., Schwarzwald, K., McNally, A., and Funk, C. 2023. Multiyear La Niña Events and Multiseason Drought in the Horn of Africa. *Journal of Hydrometeorology*, *24*(1), 119–131. https://doi.org/10.1175/JHM-D-22-0043.1

Amogne, A., Amare, B., Belay, S., and Ali, H. 2021. Smallholder farmers' livelihood vulnerability to climate change-induced hazards: agroecology-based comparative analysis in Northcentral

Ethiopia (Woleka Sub-basin). *Heliyon*, *7*(4), e06761. https://doi.org/10.1016/j.heliyon.2021.e06761

Amogne, A., Belay, S., Ali, H., and Amare, B. 2017. Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia : A case study in Woleka sub-basin . *Weather and Climate Extremes*, *19*(December), 29–41. https://doi.org/10.1016/j.wace.2017.12.002

AMS, 1997.Bulletin of the American Meteorological Society .Volume.78 1997: Issue 2 (Feb 1997

Ansarifard, S., and Shamsnia, S. A. 2018. *Monitoring drought by Reconnaissance Drought Index (RDI) and Standardized Precipitation Index (SPI) using DrinC software*. 29–35.1875–1888. https://doi.org/10.1002/joc.6818

Aragaw, A., and Weldeamlak, B. 2016. Local climate variability and crop production in the central highlands of Ethiopia. *Environmental development*, *19*, 36-48.

Arragaw, A., Molla, M., Weldeamlak, B., and Mohammed, A. 2020. Spatiotemporal variability and trends in rainfall and temperature in Alwero watershed, western Ethiopia. *Environmental Systems Research*, *9*(1). https://doi.org/10.1186/s40068-020-00184-3

Asaminew, T. G. 2015. Recent Changes in Rainfall, Temperature and Number of Rainy Days over Northern Oromia Zone, Ethiopia. *Science Discovery*, *3*(6), 62. https://doi.org/10.11648/j.sd.20150306.1

Aschalew, S. 2014. Smallholder Farmers Adaptation Strategies to Climate Change in Ethiopia: Evidence from Adola Rede Woreda, Oromia Region. *Journal of Economics and Sustainable Development*, *5*(7), 162–181. https://www.iiste.org/Journals/index.php/JEDS/article/view/12586

Ashenafi, H.S., Arega, B. B., and Yechale, K. Biferaw. 2022. Variability and trends of temperature and rainfall over three agro-ecological zones in North Shewa, Central Ethiopia. *Arabian Journal of Geosciences*, *15*(18). https://doi.org/10.1007/s12517-022-10674-6

Ault, T. R., Mankin, J. S., Cook, B. I., and Smerdon, J. E. 2016. Relative impacts of mitigation, temperature, and precipitation on 21st-century megadrought risk in the American Southwest. *Science Advances*, *2*(10), 1–8. https://doi.org/10.1126/sciadv.1600873

Ayanlade, A., Radeny, M., Morton, J. F., and Muchaba, T. 2018. Rainfall variability and drought characteristics in two agro-climatic zones : An assessment of climate change challenges in Africa Science of the Total Environment Rainfall variability and drought characteristics in two agro-climatic zones : An assessment. *Science of the Total Environment*, *630*(February), 728–737. https://doi.org/10.1016/j.scitotenv.2018.02.196

Aymone, G., 2009. Understanding farmers' perceptions and adaptation to climate change and variability: The case of the Limpopo basin, South Africa. IFPRI Discussion paper 00849, International Food Policy Research Institute: Washington DC.

Bates, B.C., Kundzewicz, Z.W., Wu, S. and Palutikof, J.P. 2008 Climate Change and Water. Technical paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat. Intergovernmental Panel on Climate Change, Geneva.

Barana, B. 2017. Spatial and Temporal Rainfall Trend Analysis : A Case Study of. *Civil and Environmental Research, 9*(8), 1–9.

Bartel, P. 2007. Horn of Africa Natural Hazard Probability and Risk Analysis. *Humanitarian Information Unit*, 1–17.

Befikadu, E., Belay, S., Ermias, T., Ongoma, V., and Nigussie, T. 2018. Trends in extreme climate events over three agroecological zones of Southern Ethiopia. *Advances in Meteorology*, *2018*(October). https://doi.org/10.1155/2018/7354157

Belay, Z., and Getaneh, G. 2016. Climate Change in Ethiopia Variability , Impact , Mitigation , and Adaptation Journal of Social Science and Humanities Research. *International Journal of Science and Humanities Research*, *2*(May),66–84. https://doi.org/10.13140/RG.2.2.16782.46408

Belay., S, Hunachew.,B, Wakgari., D, Abera., K, Kiros., B, and Jonathan Samet. 2016. Review of climate change and health in Ethiopia: Status and gap analysis. *Ethiopian Journal of* Health Development, 3*0*(SpecialIssue1), 28–41.

Belaineh Legesse, Yared Ayele and Woldeamlak Bewket, 2013. Smallholder farmers' perceptions and adaptation to climate variability and climate change in Doba district, west Hararghe, Ethiopia. Asian Journal of Empirical Research 3(3):251-265.

Bereket, Y. K., Seifu, H. G., Eskindir, L., and Lindtjørn, B. 2019. Performance of an adapted household food insecurity access scale in measuring seasonality in household food insecurity in rural Ethiopia: A cohort analysis. *BMC Nutrition*, *5*(1), 1–10. https://doi.org/10.1186/s40795-019-0323-6

Black, E. 2005. The relationship between Indian Ocean sea-surface temperature and East African rainfall. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *363*(1826), 43–47. https://doi.org/10.1098/rsta.2004.1474

Bouis, H., and Hunt, J. 1999. *A Linking Food and Nutrition Security: Past Lessons and Future Opportunities*.

Bradshaw, B. E. N., Dolan, H., and Smit, B. 2004. Farm-Level Adaptation to Climatic Variablity and Change :Crop Diversification in the Canadian Prairies .

Bureau of Finance and Economic Development (BOFED) 2008 Socio-Economic Profile of Bale Zone: Oromia State Government.

CEEPA 2006 Climate Change and African Agriculture Policy Note No. 10. Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, Pretoria.

Central Statistics Agency CSA 2007 National Population Statistics. Federal Democratic Republic of Ethiopia, Central Statistical Authority, Addis Ababa.

Central Statistical Agency 2022 Agricultural Sample Survey. The 2021/22 National Statistics. Report on Livestock and Livestock Characteristic with Statistical Bulletin 594, Volume II.

Coates, J., Swindale, a, and Bilinsky, P. 2007 . Household Food Insecurity Access Scale (HFIAS) for measurement of food access: indicator guide. *Washington, DC: Food and Nutrition Technical …*, *August*, Version 3.

Coates, J., Swindale, A., Bilinsky, P. 2013. HFIAS for Measurement of Food Access Indicator Guide. *Journal of Chemical Information and Modeling*, *53*(9), 1689–1699. https://doi.org/10.1017/CBO9781107415324.004

Collier, P., Conway, G., and Venables, T. 2008. Climate change and Africa. *Oxford Review of Economic Policy*, *24*(2), 337–353. https://doi.org/10.1093/oxrep/grn019

Conway, D., Mould, C., and Bewket, W. 2004. *OVER ONE CENTURY OF RAINFALL AND TEMPERATURE OBSERVATIONS IN ADDIS ABABA , ETHIOPIA*. *91*, 77–91. https://doi.org/10.1002/joc.989

Conway, D., and Schipper, E. L. F. 2011. Adaptation to climate change in Africa: Challenges and opportunities identified from Ethiopia. *Global Environmental Change*, *21*(1), 227–237. https://doi.org/10.1016/j.gloenvcha.2010.07.013

Crompton, R., Nuttall, N., and UNEP. 2012. *UNEP* annual report 2011 [1972 - 2012 ; serving people and the planet].

Dai, A. 2011. *Drought under global warming :* 45–65. https://doi.org/10.1002/wcc.8

Daniel, G. 2016. *Some Patterns of Altitudinal Variation of Climatic Elements in the Mountainous Regions of Ethiopia Author (s): Daniel Gamachu Source : Mountain Research and*

Development , Vol . 8 , No . 2 / 3 , African Mountains and Highlands (May - Aug ., 1988), pp . 8(2), 131–138.

Daniel, M., Woldeamlak, B., and Lal, R. 2014. Recent spatiotemporal temperature and rainfall variability and trends over the Upper Blue Nile River Basin, Ethiopia. *International Journal of Climatology*, *34*(7), 2278–2292. https://doi.org/10.1002/joc.3837

Davidson, O., Gitay, H., Griggs, D., Halsnaes, K., Houghton, J., House, J., Kundzewicz, Z., Noble, I., Pachauri, R., Pittock, B., Prather, M., Richels, R. G., and Robinson, J. B. 2001. *Climate Change 2001: Synthesis Report*. *September*, 24–29.

Desalegn, C. E., Babel, M. S.,and Gupta, A. Das. 2010. Drought analysis in the Awash River Basin, Ethiopia. *Water Resources Management*, *24*(7), 1441–1460. https://doi.org/10.1007/s11269-009-9508-

Diodato, N., and Ceccarelli, M. 2005. *Geographical Information Systems and Geostatistics for Modelling Radioactively Contaminated Land Areas*. 229–242. https://doi.org/10.1007/s11069-004-5206-7

Diro, G. T., Grimes, D. I. F., and Black, E. 2011. Teleconnections between Ethiopian summer rainfall and sea surface temperature: Part I-observation and modelling. *Climate Dynamics*, *37*(1), 103–119. https://doi.org/10.1007/s00382-010-0837-8

Diriba, K., and Barnston, A. G. 2007. Predictability of June-September rainfall in Ethiopia. *Monthly Weather Review*, *135*(2), 628–650. https://doi.org/10.1175/MWR3304.1

Dong, L., Leung, L. R., Northwest, P., and Song, F. 2018. *Future Changes of Subseasonal Precipitation Variability in North America Future changes of subseasonal precipitation variability in North America during winter under global warming*. *November*. https://doi.org/10.1029/2018GL079900

Dore, M.H.I. 2005 Climate Change and Changes in Global Precipitation Patterns: What Do We Know? Environment International, 31, 1167-1181. http://dx.doi.org/10.1016/j.envint.2005.03.004

Dunning, C. M., E. C. L. Black, and R. P. Allan, 2016: The onset and cessation of seasonal rainfall over Africa. J. Geophys. Res. Atmos., 121, 11 405–11 424, https://doi.org/10.1002/2016JD025428.

EPCC, 2015. Ethiopian panel on Climate Change 2015, First Assessment Report, Working Group I Report on climate change on Ethiopia. In *Physical Science Basis* (Issue August).

Eriksen, S., Aldunce, P., Bahinipati, C. S., Martins, D. A., Molefe, J. I., Nhemachena, C., Brien, K. O., Olorunfemi, F., Park, J., Sygna, L., Martins, D. A., Molefe, J. I., Nhemachena, C., Brien, K. O., Park, J., Sygna, L., Ulsrud, K., Eriksen, S., Aldunce, P., … Ulsrud, K. 2011. *When not every response to climate change is a good one : Identifying principles for sustainable adaptation When not every response to climate change is a good one : Identifying principles for sustainable adaptation*. *5529*. https://doi.org/10.3763/cdev.2010.0060

Esubalew, M., Yoseph, M., and Getnet, D. 2023. Determinants of farmers' adaptation strategies to climate change impacts in northwestern Ethiopia. *Heliyon*, *9*(8), e18514. https://doi.org/10.1016/j.heliyon.2023.e1851

Fikiru, A. A., Kassahun, T. B., Tadesse, T. Z., and Desalegn, Y. A. 2022. Spatiotemporal analysis of droughts characteristics and drivers in the Omo - Gibe River basin, Ethiopia. *Environmental Systems Research*. https://doi.org/10.1186/s40068-022-00246-

Fassil, E. 2020. Determinants of Rural Households Food Insecurity in Southern Ethiopia. *Asian Food Science Journal*, 29–43. https://doi.org/10.9734/afsj/2020/v15i130144

FAS, 2019. Geography of Ethiopia and The Horn. *Manual*.

FAO 1975 Food and Agricultural Organization FAO 1975 World Agriculture

FAO 1996 Food and Agricultural Organization FAO 1996 World Agriculture

FAO 2002 Food and Agricultural Organization FAO 2002 World Agriculture

FAO 2003 Food and Agricultural Organization FAO 2003 World Agriculture

FAO 2008 An Introduction to the Basic Concepts of Food Security. In: Food Security Information for Action: Practical Guides, EC-FAO Food Security Programme.

FAO 2011 The state of food and agriculture: Women in agriculture (executive summary). *Lancet*, *2*(7929), 160. http://www.ncbi.nlm.nih.gov/pubmed/24897208%5Cnhttp://www.fao.org/catalog/inter-e.htm

FAO. 2015. *Climate change and food security: risks and responses. Rome, Italy: FAO. September*, 122. https://www.fao.org/3/i5188e/i5188e.pdf

Few, R., Ahern, M., Matthies, F., and Kovats, S. 2004. Floods, health and climate change: a strategic review. *East*, *November*, 138 pp. http://www.tyndall.ac.uk/publications/working_papers/wp63_summary.shtml%5Cnhttp://tyndall.ac.uk/sites/default/files/wp63.pdf

Federal, T.H.E., and Republic, D. 2007.The Federal Democratic Republic of Ethiopia Climate Change National Adaptation Programme of Action (NAPA) of Ethiopia Climate Change National Adaptation programme of Action (NAPA) of Ethiopia.June

Fedhasa, B., and Megarsa, A. 2019. Trend Analyses of Temperature and Rainfall and Their Response to Global CO2 Emission in Masha, Southern Ethiopia. *Caraka Tani: Journal of Sustainable Agriculture*, *34*(1), 67. https://doi.org/10.20961/carakatani.v34i1.28022

Fekadu, B., and Mequanent, M. 2010. Determinants of food security among rural households of Central Ethiopia: An empirical analysis. *Quarterly Journal of International Agriculture*, *49*(4), 299–318.

Filho, Esilaba, R. and S. 2015. Adapting African agriculture to climate change. In *Climate Change Management*.

Funk, C., Hoell, A., Shukla, S., Bladé, I., Liebmann, B., Roberts, J. B., Robertson, F. R., and Husak, G. 2014. *Predicting East African spring droughts using Pacific and Indian Ocean sea surface temperature indices*. 4965–4978. https://doi.org/10.5194/hess-18-4965-2014

Garrett, J. L., and Ruel, M. T. 1999. Are determinants of rural and urban food security and nutritional status different? Some insights from Mozambique. *World Development*, *27*(11), 1955–1975. https://doi.org/10.1016/S0305-750X(99)00091-1

Gelgelo, W. D., Solomon, T. D., and Tegegn, S. E. 2021. Meteorological Droughts from 1987-2017 in Yabello and ElWoye Areas of Borana, Oromia Region, Ethiopia. Ethiopian Journal of Social Sciences, 7(1).

Getachew, B., Gedamu, A., Getne, A., and Temesgen, G. 2021. Spatiotemporal variability and trends of rainfall and its association with Pacific Ocean Sea surface temperature in West Harerge Zone, Eastern Ethiopia. *Environmental Systems Research*, *10*(1). https://doi.org/10.1186/s40068-020-00216-y

Getachew, M. M., Raju, U. J. P., Stojanovic, M., and Sorí, R. 2024. The phenomenon of drought in Ethiopia: Historical evolution and climatic forcing. *Hydrology Research*, *55*(6), 595–612. https://doi.org/10.2166/nh.2024.192

Getachew, T. M., Degefa, T., and Negussie, S. 2018. Food insecurity of rural households in Boset district of Ethiopia: A suite of indicators analysis. *Agriculture and Food Security*, *7*(1), 1–16. https://doi.org/10.1186/s40066-018-0217-x

Getaneh, G.W., Zewdu, E., and Mekuria, A. 2016. *Temporal and spatial variability of rainfall* *distribution and evapotranspiration across altitudinal gradient in the Bilate River Watershed, Southern Ethiopia*. *10*(6), 167–180. https://doi.org/10.5897/AJEST2015.2029

Gibbs, W. J., and Maher, J. V. 1967. Rainfall Deciles as Drought Indicators. Bureau of Meteorology Bulletin No. 48, Melbourne: Bureau of Meteorology.

Girma, G, G. 2012. Determinants of Food Insecurity among Households in Addis Ababa City, Ethiopia. *Interdisciplinary Description of Complex Systems*, *10*(2), 159–173. https://doi.org/10.7906/indecs.10.2.9

Gitz, V., Meybeck, A., Lipper, L., Young, C., and Braatz, S. 2016. Climate change and food security: Risks and responses. In *Food and Agriculture Organization of the United Nations*. https://doi.org/10.1080/14767058.2017.1347921

Glantz, M. H., and Katz, R. W. 1977. When is a drought a drought? *Nature*, *267*(5608), 192–193. https://doi.org/10.1038/267192a0

Habtamu, T. M., Tadesse, T. M., and Amanual, Z. A. 2018. Farmers' perception of drought and its socioeconomic impact: The case of Tigray and Afar regions of Ethiopia. *Journal of Applied Animal Research*, *46*(1), 1023–1031. https://doi.org/10.1080/09712119.2018.1450752

Hailay, T. K., Dawit, D. G., Belay, S. B., Tagel, G. G., and Routray, J. K. 2019. Farmers' Perceptions of Climate Change Trends and Adaptation Strategies in Semiarid Highlands of Eastern Tigray, Northern Ethiopia. *Advances in Meteorology*, *2019*. https://doi.org/10.1155/2019/3849210

Hassan, R., Nhemachena, C., Hassan, R., and Nhemachena, C. 2008. Determinants of African farmers' strategies for adapting to climate change: Multinomial choice analysis. In *AfJARE* (Vol. 2).

Hare, W. 2003. Assessment of Knowledge on Impacts of Climate Change-Contribution to the Specification of Art. 2 of the UNFCCC: Impacts on Ecosystems, Food Production, Water and Socio-Economic Systems. WBGU Report, Potsdam-Berlin, Germany.

Hayes, M. J., Svoboda, M. D., Wardlow, B. D., Anderson, M. C., and Kogan, F. 2012. Drought monitoring: Historical and current perspectives. *Remote Sensing of Drought: Innovative Monitoring Approaches*, 1–19. https://doi.org/10.1201/b11863

Headey, Derek D. 2013. Developmental drivers of nutritional change: A cross-country analysis. World Development 42(February 2013): 76-88

He, C., and Li, T. 2019. Does global warming amplify interannual climate variability ? *Climate*

Dynamics, *52*(5), 2667–2684. https://doi.org/10.1007/s00382-018-4286-0

Hermes, C., Keller, K., Nicholas, R. E., Segelbacher, G., and Schaefer, M. 2018. *Projected impacts of climate change on habitat availability for an endangered parakeet*. 1–17.

Hurni, H. 1998. Agroecological Belts of Ethiopia. *Explanatory Notes on Three Maps at a Scale of 1*, *1*. http://www.cde.unibe.ch/CDE/pdf/Hurni 1998_Agroecological Belts of Ethiopia.pdf

Ikegwuoha, D. C., and Dinka, M. O. 2020. Drought prediction in the Lepelle River basin, South Africa under general circulation model simulations. *Journal of Water and Land Development*, *45*(September), 42–53. https://doi.org/10.24425/jwld.2020.133044

Indale, N. D., Mitiku, B. M., and Dessalegn, O. G. 2023. Spatiotemporal monitoring of drought using satellite precipitation products: The case of Borena agro-pastoralists and pastoralists regions, South Ethiopia. *Heliyon*, *9*(3), e13990. https://doi.org/10.1016/j.heliyon.2023.e13990

IPCC. 2001. Climate Change 2001: Impacts, Adaptation and Vulnerability. In J. J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Dokken, and K. S. White (Eds.), IPCC Working Group II, Third Assessment Report. Cambridge University Press.

IPCC. 2007. Introduction to the Working Group II Fourth Assessment Report. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, v–6.

IPCC. 2014 . Part A: Global and Sectoral Aspects. (Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change). *Climate Change 2014: Impacts, Adaptation, and Vulnerability.*, 1132. https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-FrontMatterA_FINAL.pdf

Israel, T., and Belay, S. 2019. Vulnerability analysis of smallholder farmers to climate variability and change: an agro-ecological system-based approach in the Fincha’a sub-basin of the upper Blue Nile Basin of Ethiopia. *Ecological Processes*, *8*(1). https://doi.org/10.1186/s13717-019-0159-7

Israel, T., and Belay, S. 2021. Smallholder Farmers’ perception and adaptation to climate variability and change in Fincha sub-basin of the Upper Blue Nile River Basin of Ethiopia. *GeoJournal*, *86*(4), 1767–1783. https://doi.org/10.1007/s10708-020-10159-7

Jaishi, M., Kafle, K., Subedi, R., Khanal, A., Poudel, A., and Paudel, R. 2018. Developing Tools for Measuring Perception on Climate Change and its Impact on Insect-Pests of Major Staple

Food Crops. *Journal of the Institute of Agriculture and Animal Science*, *35*(1), 29–38. https://doi.org/10.3126/jiaas.v35i1.22511

Jemal, A., and Kim, K.-R. (n.d.). Determinants of Household Food Security in Rural Ethioipia: An Emperical Analysis. In *Journal of Rural Development* (Vol. 37, Issue 2). http://www.irinnews.org/coun-

Jury, M. R., and Funk, C. 2013. Climatic trends over Ethiopia: Regional signals and drivers. In *International Journal of Climatology* (Vol. 33, Issue 8, pp. 1924–1935). https://doi.org/10.1002/joc.3560

Kassahun Bokretsion, 1999. Ye'ayer Mezabat'na tinbi'ya k'Itiopia Antsar (Climate Change and Forecast in Ethiopia, in Amharic). Paper Presented at a Meeting organized by the DPPC on Climate Change, Drought and Disaster Prevention in Ethiopia, Addis Ababa, Ethiopia, August 1999.

Kabubo-mariara, J., and Kabara, M. 2023. *Climate change and food security in Kenya * Environment for Development Initiative Climate Change and Food Security in Kenya Author (s): Jane Kabubo-Mariara and Millicent Kabara Environment for Development Initiative (2015)* (Issue March 2018). https://doi.org/10.4324/9781315149776-4

Karthikeyan, M., and Tadesse, M. 2014. Assessing the Effect of Climate Change on Crop Production and Adaptation Strategies in Dendi District, Ethiopia. *Journal of Science and Sustainable Development (JSSD)*, *1*(3), 31–41. https://doi.org/10.20372/au.jssd.2.1.2014.024

Khalid, M., and Schilizzi, S. 2013. *Determinants of rural household food security : a comparative analysis of African and Asian studies*. *January*, 1251–1258. https://doi.org/10.1002/jsfa.6038

Kim, K.(2014).Determinants of Household Food Security in Rural Ethiopia:An Empirical Analysis.*Journal of Rural Development* /*Nongchon-Gyeongie*,37(32),1-29.

Komba, C. and Muchapondwa, E. 2015 Adaptation to Climate Change by Smallholder Farmers in Tanzania. Discussion Paper Series, Environment for Development (EfD) 15-12.

Kogan, F., Guo, W., and Yang, W. 2019. Drought and food security prediction from NOAA new generation of operational satellites. *Geomatics, Natural Hazards and Risk*, *10*(1), 651–666. https://doi.org/10.1080/19475705.2018.1541257

Korecha, D. and Barnston, A.G. 2007 Predictability of June-September Rainfall in Ethiopia. Monthly Weather Review, 135, 628-650. http://dx.doi.org/10.1175/MWR3304.1

Kourouma, J. M., Eze, E., Kelem, G., Negash, E., Phiri, D., Vinya, R., Girma, A., and Zenebe, A.

2022. Spatiotemporal climate variability and meteorological drought characterization in Ethiopia Spatiotemporal climate variability and meteorological. *Geomatics, Natural Hazards and Risk*, *13*(1), 2049–2085. https://doi.org/10.1080/19475705.2022.2106159

Kurukulasuriya, P., and Mendelsohn, R. 2008. Give to AgEcon Search A Ricardian analysis of the impact of climate change on African cropland. In *AfJARE* (Vol. 2). http://ageconsearch.umn.edu

Lazzari, E., Anker, M., and Anker, M. 2021.Living Income for Guji Zone (Oromia Regiona State), Ethiopia 2021.Living Income for Guji Zone (Oromia Regional State),.5

Lewis, K. 2017. Understanding climate as a driver of food insecurity in Ethiopia. *Climatic Change*, *144*(2), 317–328. https://doi.org/10.1007/s10584-017-2036-7

Liebmann, B., Hoerling, M. P., Funk, C., Bladé, I., Dole, R. M., Allured, D., Quan, X., Pegion, P., and Eischeid, J. K. 2014. Understanding recent eastern Horn of Africa rainfall variability and change. *Journal of Climate*, *27*(23), 8630–8645. https://doi.org/10.1175/JCLI-D-13-00714.1

Limantol, A. M., Keith, B. E., Azabre, B. A., and Lennartz, B. 2016. Farmers' perception and adaptation practice to climate variability and change: a case study of the Vea catchment in Ghana. In *SpringerPlus* (Vol. 5, Issue 1). Springer International Publishing. https://doi.org/10.1186/s40064-016-2433-9

Linderman, M., Rowhani, P., Lobell, D. B., Linderman, M., and Ramankutty, N. 2011. Climate variability and crop production in Tanzania Agricultural and Forest Meteorology Climate variability and crop production in Tanzania. *Agricultural and Forest Meteorology*, *151*(4), 449–460. https://doi.org/10.1016/j.agrformet.2010.12.002

Lyon, B. 2014. Seasonal drought in the Greater Horn of Africa and its recent increase during the March-May long rains. *Journal of Climate*, *27*(21), 7953–7975. https://doi.org/10.1175/JCLI-D-13-00459.1

Lyon, B., and Dewitt, D. G. 2012. A recent and abrupt decline in the East African long rains. *Geophysical Research Letters*, *39*(2), 1–5. https://doi.org/10.1029/2011GL050337

Maddison, D. 2006 . The Perception of and Adaptation to Climate Change in Africa. CEEPA Discussion Paper No. 10. *Centre for Environmental E Conomics and Policy in Africa, University of Pretoria, South Africa.*, *10*, 1–47.

Malla, S.,Tsegaye, D., Berket, Y., and Mulugeta, Y. 2017. Household food insecurity and associated factors in West Abaya district, Southern Ethiopia, 2015. *Agriculture and Food*

Security, *6*(1), 1–9. https://doi.org/10.1186/s40066-016-0080-6

Makula, E. K., Umutoni, M. A., Japheth, L. P., Lipiki, E. J., Kebacho, L. L., and Limbu, P. T. S. 2020. The Covariability of Sea Surface Temperature and MAM Rainfall on East Africa Using Singular Value Decomposition Analysis. *Geographica Pannonica*, *24*(4), 261–270. https://doi.org/10.5937/GP24-27577

Marie, M., Yirga, F., Haile, M., and Tquabo, F. 2020. Heliyon Farmers' choices and factors affecting adoption of climate change adaptation strategies : evidence from northwestern Ethiopia. *Heliyon*, *6*(April), e03867. https://doi.org/10.1016/j.heliyon.2020.e03867

Markos, B. W., Tafesse, M., Mekuria, G., Abiyot, L., and Yimer, M. 2023. Spatiotemporal variability and trend of rainfall and temperature in Sidama Regional State, Ethiopia. *Theoretical and Applied Climatology*, *153*(1–2), 213–226. https://doi.org/10.1007/s00704-023-04463-8

Marta, G. 2020. Historical Drought Characterization in Awash River Basin, Ethiopia. *International Journal of Environmental Sciences and Natural Resources*, *26*(3). https://doi.org/10.19080/ijesnr.2020.26.556186

Marta, G., Abreham , C., Mogos, M., Tefera, A., and Goitom, K. 2020. *Drought Characterization Using Reconnaissance Drought Index (RDI): In the case of Awash River Basin , Ethiopia*. *26*(3). https://doi.org/10.19080/IJESNR.2020.26.556186

Matios, H., Mitiku, E., Melesse, M., Dereje, A., and Abiyot, L. 2022. Effects of climate variability on livestock productivity and pastoralists perception : The case of drought resilience in Southeastern Ethiopia. *Veterinary and Animal Science*, *16*, 100240. https://doi.org/10.1016/j.vas.2022.100240

Matondo, J. I., Alemaw, B. F., and Sandiwidi, J. P. (n.d.). *Edited by Sustainable Development Goals Series*.

Maxwell, D., Coates, J., and Vaitla, B. 2013. How do different indicators of household food security compare ? Empirical evidence from Tigray. *Feinstein International Center*, *August*, 1–19.

McMahon, T. A., Peel, M. C., and Szilagyi, J. 2013. Comment on the application of the szilagyi and ndash;jozsa advection–aridity model for estimating actual terrestrial evapotranspiration in "estimating actual, potential, reference crop and pan evaporation using standard meteorological data: A pragmatic . *Hydrology and Earth System Sciences*, *17*(12), 4865–4867. https://doi.org/10.5194/hess-17-4865-2013

McSweeney, C., New, M., Lizcano, G., and Lu, X. 2010. The UNDP climate change country profiles. *Bulletin of the American Meteorological Society*, *91*(2), 157–166. https://doi.org/10.1175/2009BAMS2826.1

Mekonnen, A., David, D., and Woldeamlak, P. R. 2016. Teleconnections between Ethiopian rainfall variability and global SSTs : observations and methods for model evaluation. *Meteorology and Atmospheric Physics*. https://doi.org/10.1007/s00703-016-0466-9

Mekonnen, A. D., and Woldeamlak, B. 2015. Trends and spatial patterns of drought incidence in the Omo-Ghibe River Basin, Ethiopia. *Geografiska Annaler, Series A: Physical Geography*, *97*(2), 395–414. https://doi.org/10.1111/geoa.12080

Mekonnen, A. D., Rowell, D. P., and Weldeamlak, B. 2017. Teleconnections between Ethiopian rainfall variability and global SSTs: observations and methods for model evaluation. *Meteorology and Atmospheric Physics*, *129*(2), 173–186. https://doi.org/10.1007/s00703-016-0466-9

Melese, G. 2019. Farmer's response to climate change and variability in Ethiopia : A review Farmer ' s response to climate change and variability in Ethiopia : A review. *Cogent Food and Agriculture*, *5*(1). https://doi.org/10.1080/23311932.2019.1613770

Mendelsohn, R., and Williams, L. 2006. *The distributional impact of climate change on rich and poor countries*. *1992*, 159–178. https://doi.org/10.1017/S1355770X05002755

Menbere, S., Solomon, T., Yimer, M., Tegeng, S., Haji, K., and Solomon, A. 2024. Spatiotemporal trends and variability of rainfall across agro-ecologies in East Guji Zone, Southeast Ethiopia. *PLOS Climate*, *3*(3), e0000361. https://doi.org/10.1371/journal.pclm.0000361

Mequanent, M., Birara, E., and Tesfalem, K. 2014. Determinants of Household Food Security among Southwest Ethiopia Rural Households. *Food Science and Technology*, *2*(7), 93–100. https://doi.org/10.13189/fst.2014.020701

Merabtene, T., Siddique, M., and Shanableh, A. 2016. Assessment of Seasonal and Annual Rainfall Trends and Variability in Sharjah City, UAE. *Advances in Meteorology*, *2016*. https://doi.org/10.1155/2016/6206238

Merabti, A., Martins, D. S., Meddi, M., and Pereira, L. S. 2018. Spatial and Time Variability of Drought Based on SPI and RDI with Various Time Scales. *Water Resources Management*, *32*(3), 1087–1100. https://doi.org/10.1007/s11269-017-1856-6

Mesfin, M., Minyahel, T., and Mebratu, A. 2021. Household food insecurity and coping strategies in Southern Ethiopia. *Agriculture and Food Security*, *10*(1), 1–13. https://doi.org/10.1186/s40066-021-00296-8

Mesfin, W. 2014. Determinants of Households Vulnerability to Food Insecurity in Ethiopia: Econometric analysis of Rural and Urban Households. In *Journal of Economics and Sustainable Development www.iiste.org ISSN* (Vol. 5, Issue 24). www.iiste.org

Messay Abebe, 2006. The Onset, Cessation and Dry Spells of the Small Rainy Season (Belg) of Ethiopia. National Meteorological Agency, Addis Ababa, Ethiopia

Metadel, F., and Yihunie, B. 2020. Climate Change Impacts on Household Food Security and Its Adaptation Options in Rural Ethiopia: A Systematic Review. EPRA International Journal of Research and Development, 5, 2455-7838. https://doi.org/10.36713/epra4142

Millner, A., and Dietz, S. 2015. Adaptation to climate change and economic growth in developing countries. *Environment and Development Economics*, *20*(3), 380–406. https://doi.org/10.1017/S1355770X14000692

Mishra, A. K., and Desai, V. R. 2005. Drought forecasting using stochastic models. *Stochastic Environmental Research and Risk Assessment*, *19*(5), 326–339. https://doi.org/10.1007/s00477-005-0238-4

Misrak, T. H., Teshale, W., and Menfese, T. 2019. Spatial and temporal climate variability and change in the bilate catchment, central Rift Valley lakes region, Ethiopia. *Physical Geography*, *42*(3), 199–225. https://doi.org/10.1080/02723646.2019.1698094

Mitiku, A. W., Gudina, A. F., Kassahun, T. B., and Garbolino, E. 2022. Rainfall variability and trends in the Borana zone of southern Ethiopia. *Journal of Water and Climate Change*, *13*(8), 3132–3151. https://doi.org/10.2166/wcc.2022.173

Mintesinot, T., Belay, S., Zaitchik, B. F., Yehenew, G. S., and Shimeles, S. 2019a. Rainfall variability across the agro-climatic zones of a tropical highland: The case of the jema watershed, northwestern ethiopia. In *Environments - MDPI* (Vol. 6, Issue 11). https://doi.org/10.3390/environments6110118

Mosunmola, I. A., Samaila, I. K., Emmanuel, B., and Adolphus, I. 2020. Evaluation of Onset and Cessation of Rainfall and Temperature on Maize Yield in Akure, Ondo State, Nigeria. *Atmospheric and Climate Sciences*, *10*(02), 125–145.

https://doi.org/10.4236/acs.2020.102006

Murendo, C., Keil, A., and Zeller, M. 2011. Drought impacts and related risk management by smallholder farmers in developing countries: Evidence from Awash River Basin, Ethiopia. *Risk Management*, *13*(4), 247–263. https://doi.org/10.1057/rm.2011.17

Negash, W., Goel, N. K., and Jain, M. K. 2013. Variabilité temporelle et spatiale des précipitations annuelles et saisonnières sur l'Ethiopie. *Hydrological Sciences Journal*, *58*(2), 354–373. https://doi.org/10.1080/02626667.2012.754543

Naumann, G., Spinoni, J., Vogt, J. V., and Barbosa, P. 2015. Assessment of drought damages and their uncertainties in Europe. *Environmental Research Letters*, *10*(12). https://doi.org/10.1088/1748-9326/10/12/124013

National Meteorological Agency NMA 2007 Climate Change National Adaptation Program of Action of Ethiopia. Addis Ababa.

National Meteorological Services Agency NMSA 2005 Annual Climatic Bulletin. Ministry of Water Resources.

Nega, D., Caroline, M., Kerry, B., Ross, Corkrey., and McNeil, D. 2015. Perception of climate change and its impact by smallholders in pastoral/agropastoral systems of Borana, South Ethiopia. *SpringerPlus*, *4*(1). https://doi.org/10.1186/s40064-015-1012-

New, M., Hulme, M., and Jones, P. 2000. Representing twentieth-century space-time climate variability. Part II: Development of 1901-96 monthly grids of terrestrial surface climate. *Journal of Climate*, *13*(13), 2217–2238. https://doi.org/10.1175/1520-0442(2000)013<2217:RTCSTC>2.0.CO;2

Nhemachena, C., and Mano, R. 2007. Assessment of the Economic Impacts of Climate Change on Agriculture in Zimbabwe A Ricardian Approach. In *World* (Issue July). http://0-search.ebscohost.com.catalog.library.colostate.edu/login.aspx?direct=true&AuthType=cookie,ip,url,cpid&custid=s4640792&db=lah&AN=20083213535and site=ehost-live

Nicholson, S. E. 2017. Climate and climatic variability of rainfall over eastern Africa. *Reviews of Geophysics*, *55*(3), 590–635. https://doi.org/10.1002/2016RG000544

NMSA 1996 Climate and Agro Climate Resources of Ethiopia. NMSA Meteorological Research Report Series, Vol. 1, No. 1, and Addis Ababa.

NMA Ethiopian National Meteorology Agency 2014 Climatic Bulletin.

Oceanic, N., and Science, A. 2006. *Robust Responses of the Hydrological Cycle to Global*

Warming.

Oliver, J.E. 1980 Monthly Precipitation Distribution: A Comparative Index. Professional Geographer, 32, 300-309. https://doi.org/10.1111/j.0033-0124.1980.00300.x

Olaniran, O.J. and Sumner, G.N. 1989 A Study of Climate Variability in Nigeria Based on the Onset, Retreated and Length of the Rainy Season. International Journal of Climatology, 9, 253-269. http://dx.doi.org/10.1002/joc.3370090304

Omuru, E., and Kingwell, R. 2006. Funding and managing agricultural research in a developing country: A Papua New Guinea case study. *International Journal of Social Economics*, *33*(4), 316–330. https://doi.org/10.1108/03068290610651634

Otieno, V. O., and Anyah, R. O. 2013. CMIP5 simulated climate conditions of the Greater Horn of Africa (GHA). Part 1: Contemporary climate. *Climate Dynamics*, *41*(7–8), 2081–2097. https://doi.org/10.1007/s00382-012-1549-z

Palmer, P. I., Wainwright, C. M., Dong, B., Maidment, R. I., Wheeler, K. G., Gedney, N., Hickman, J. E., Madani, N., Folwell, S. S., Abdo, G., Allan, R. P., Black, E. C. L., Feng, L., Gudoshava, M., Haines, K., Huntingford, C., Kilavi, M., Lunt, M. F., Shaaban, A., & Turner, A. G. 2023. Drivers and impacts of Eastern African rainfall variability. *Nature Reviews Earth and Environment*, *4*(4), 254–270. https://doi.org/10.1038/s43017-023-00397-x

Parry, M. L., Rosenzweig, C., Iglesias, A., Livermore, M., and Fischer, G. 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change*, *14*(1), 53–67. https://doi.org/10.1016/j.gloenvcha.2003.10.008

Paulos, A., and Belay, S. 2017. Adapting Smallholder Agriculture to Climate Change through Sustainable Land Management Practices: Empirical Evidence from North-West Ethiopia. *Journal of Agricultural Science and Technology A*, *7*(5). https://doi.org/10.17265/2161-6256/2017.05.001

Pinstrup-Andersen, P. 2009. Food security: definition and measurement. *Food Security*, *1*(1), 5–7. https://doi.org/10.1007/s12571-008-0002-y

Palmer WC. 1965. Meteorological droughts. U.S. Department of Commerce Weather Bureau Research Paper 45, 58.

Poterie, A.T. and Baudoin, M.A. 2015 From Yokohama to Sendai: Approach to Participation in

International Disaster Risk Reduction Frameworks. International Journal of Disaster Risk Science, 6, 128-139. https://doi.org/10.1007/s13753-015-0053-6

Poudel, S., and Shaw, R. 2016. *The Relationships between Climate Variability and Crop Yield in a Mountainous Environment : A Case Study in Lamjung District , Nepal*. https://doi.org/10.3390/cli4010013

Rani, S., and Sreekesh, S. 2019. Evaluating the Responses of Streamflow under Future Climate Change Scenarios in a Western Indian Himalaya Watershed. *Environmental Processes*, *6*(1), 155–174. https://doi.org/10.1007/s40710-019-00361-2

Recha, C. W., Makokha, G. L., and Shisanya, C. A. 2017. Climate variability and causes: from the perspective of the Tharaka people of eastern Kenya. *Geoscience Letters*, *4*(1), 4–11. https://doi.org/10.1186/s40562-017-0088-1

Regassa, N., and Stoecker, B. J. 2012. Household food insecurity and hunger among households in Sidama district, southern Ethiopia. *Public Health Nutrition*, *15*(7), 1276–1283. https://doi.org/10.1017/S1368980011003119

Report, T. S. 2007. *Chapter 1. conceptual framework*. 29–35.

Rosell, S., and Holmer, B. 2007. Rainfall change and its implications for Belg harvest in South Wollo, Ethiopia. *Geografiska Annaler*, *Series A: Physical Geography*, *89 A*(4), 287–299. https://doi.org/10.1111/j.1468-0459.2007.00327.x

Rowell, D. P., Booth, B. B. B., Nicholson, S. E., and Good, P. 2015. Reconciling past and future rainfall trends over East Africa. *Journal of Climate*, *28*(24), 9768–9788. https://doi.org/10.1175/JCLI-D-15-0140.1

Saji, N. H., Goswami, B. N., Vinayachandran, P. N., and Yamagata, T. 1999. A dipole mode in the tropical Indian ocean. *Nature*, *401*(6751), 360–363. https://doi.org/10.1038/43854

Salvador Castell, G., Pérez Rodrigo, C., Ngo de la Cruz, J., and Aranceta Bartrina, J. 2015. Household food insecurity access scale (HFIAS). *Nutricion Hospitalaria*, *31 Suppl 3*, 272–278. https://doi.org/10.3305/nh.2015.31.sup3.8775

Schmidhuber, J., and Tubiello, F. N. 2007. Global food security under climate change. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(50), 19703–19708. https://doi.org/10.1073/pnas.0701976104

Schwarz-Herion, O. 2018. The impact of the climate change discussion on society, science, culture, and politics: From The Limits to Growth via the Paris agreement to a binding global policy? In *The Impact of Climate Change on Our Life: The Questions of Sustainability*. https://doi.org/10.1007/978-981-10-7748-7_1

Sciences, O., Physics, P., Angeles, L., Angeles, L., and Shan, Y. 2008. *Evaluating the '" Rich-Get-Richer "' Mechanism in Tropical Precipitation Change under Global Warming*. 1982–2005. https://doi.org/10.1175/2008JCLI2471.1

Segele, Z. T., Lamb, P. J., and Leslie, L. M. 2009. Seasonal-to-interannual variability of Ethiopia/horn of Africa monsoon. Part I: Associations of wavelet-filtered large-scale atmospheric circulation and global sea surface temperature. *Journal of Climate*, *22*(12), 3396–3421. https://doi.org/10.1175/2008JCLI2859.1

Seid, S., and Tamiru, Celeshi. 2016. Farmers' Perception, Impact andAdaptation Strategies to ClimateChange among Smallholder Farmersin Sub-Saharan... *Journal of Resources Development and Management, 26* (January 2016), 1–8. www.iiste.org

Saeid Eslamian et al. Investigation and Comparison of the Quantitative and Qualitative Frequency Distribution of the Rivers. American Journal of Engineering and Applied Sciences 2017, 10 (4): 799.805 DOI: 10.3844/ajeassp.2017.799.805

Sen, P. K. 1968. Estimates of the Regression Coefficient Based on Kendall's Tau. *Journal of the American Statistical Association*, *63*(324), 1379–1389. https://doi.org/10.1080/01621459.1968.10480934

Seo, K. W., Wilson, C. R., Han, S. C., and Waliser, D. E. 2008. Gravity Recovery and Climate Experiment (GRACE) alias error from ocean tides. *Journal of Geophysical Research: Solid Earth*, *113*(3), 1–10. https://doi.org/10.1029/2006JB004747

Shishay, K. W., and Dawit, G. T. 2018. Impact of climate variability on household food availability in Tigray, Ethiopia. *Agriculture and Food Security*, *7*(1), 1–10. https://doi.org/10.1186/s40066-017-0154-0

Shongwe, M. E., van Oldenborgh, G. J., van den Hurk, B., and van Aalst, M. 2011. Projected changes in mean and extreme precipitation in Africa under global warming. Part II: East Africa. *Journal of Climate*, *24*(14), 3718–3733. https://doi.org/10.1175/2010JCLI2883.1

Singh, G. K., and Siahpush, M. 2006. *Widening socioeconomic inequalities in US life expectancy , 1980 – 2000*. *May*, 969–979. https://doi.org/10.1093/ije/dyl083

Sisay, Y., Degsew, M., and Wuletaw, M. 2018. The Status of Household Food Insecurity: The

Case of West Belesa, North Gondar, Amhara Region, Ethiopia. *International Journal of Scientific Research and Management (IJSRM)*, *6*(06). https://doi.org/10.18535/ijsrm/v6i6.ah02

Solomon, H. G., Hülsmann, S., and Bernhofer, C. 2019. Long-term trends in rainfall and temperature using high-resolution climate datasets in East Africa. *Scientific Reports*, *9*(1), 1–9. https://doi.org/10.1038/s41598-019-47933-8

Smit, B., and Wandel, J. 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, *16*(3), 282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

Smith, J. B., and Lenhart, S. S. 1996. Climate change adaptation policy options. *Climate Research*, *6*(2), 193–201. https://doi.org/10.3354/cr006193

Sousa, P. M., R. M. Trigo, P. Aizpurua, R. Nieto, L. Gimeno, and R. García-Herrera, 2011: Trends and extremes of drought indices throughout the 20th century in the Mediterranean. Nat. Hazards Earth Syst. Sci., 11, 33–51, https://doi.org/ 10.5194/nhess-11-33-2011.

Stagge, J. H., Tallaksen, L. M., Xu, C. Y., and Van Lanen, H. A. J. 2014. Standardized precipitation-evapotranspiration index (SPEI): Sensitivity to potential evapotranspiration model and parameters. *IAHS-AISH Proceedings and Reports*, *363*(October), 367–373.

Stern, B. N. 2008. *The Economics of Climate Change*.

Stocker, T., Ed. 2014 Climate Change 2013: The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, UK.

Swain, D. L., Langenbrunner, B., Neelin, J. D., and Hall, A. 2018. Increasing precipitation volatility in twenty-first- century California. *Nature Climate Change*, *8*(May). https://doi.org/10.1038/s41558-018-0140-y

Tafesse, M., and Tewodroso, T. 2019. *Local level rainfall and temperature variability in drought-prone districts of rural Sidama , central rift valley region of Ethiopia*. *3646*. https://doi.org/10.1080/02723646.2019.1625850

Tagel, G., and van der Veen, A. 2013. Climate change vulnerability in Ethiopia: disaggregation of Tigray Region. *Journal of Eastern African Studies*, *7*(4), 607–629. https://doi.org/10.1080/17531055.2013.817162

Tagel, G., van der Veen, A., and Maathuis, B. 2011. Spatial and temporal assessment of drought in the Northern highlands of Ethiopia. In *International Journal of Applied Earth Observation* *and Geoinformation* (Vol. 13, Issue 3, pp. 309–321). https://doi.org/10.1016/j.jag.2010.12.00

Tannehill, I. R. 1947. Drought, Its Causes and Effects. Princeton, NJ: Princeton University Press

Taylor, J.G., Steward, T.R. and Downton, M. 1988 Perceptions of Drought in the Ogallala Aquifer Region. Environment and Behaviour, 20, 150-175. https://doi.org/10.1177/0013916588202002

Technological, institutional and policy options. *Weather and Climate Extremes*, *3*(June), 67–79. https://doi.org/10.1016/j.wace.2014.04.004

Temam, D., Uddameri, V., Mohammadi, G., and Hernandez, E. A. 2019. *Long-Term Drought Trends in Ethiopia with Implications for Dryland Agriculture*. 1–22.

Temesgen, T. D. 2007. Measuring the Economic Impact of Climate Change on Ethiopian Agriculture: Ricardian Approach. *Social Science Research Network*, *4342*(July), 32-pp. http://ssrn.com/paper=1012474

Temesgen, T. D., Hassan, R. M., and Ringler, C. 2011. Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. *Journal of Agricultural Science*, *149*(1), 23–31. https://doi.org/10.1017/S0021859610000687

Temesgen, T. D., Hassan, R. M., Ringler, C., Alemu, T., and Yesuf, M. 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, *19*(2), 248–255. https://doi.org/10.1016/j.gloenvcha.2009.01.002

Teshome, A. 2016. Contribution of Indigenous Knowledge to Climate Change and Adaptation Response in Southern Ethiopia. *Journal of Earth Science & Climatic Change*, *7*(11). https://doi.org/10.4172/2157-7617.1000377

Thomas B. McKee, N. J. D. and J. K. 1993. Analysis of Standardized Precipitation Index (SPI) data for drought assessment. *Water (Switzerland)*, *26*(2), 1–72. https://doi.org/10.1088/1755-1315/5

Thomas, T., Jaiswal, R. K., Galkate, R., Nayak, P. C., and Ghosh, N. C. 2016. Drought indicators-based integrated assessment of drought vulnerability: a case study of Bundelkhand droughts in central India. *Natural Hazards*, *81*(3), 1627–1652. https://doi.org/10.1007/s11069-016-2149-8

Thornton, P. 2014. Rainfall and rainfall variability. *Atlas of African Agriculture Research and Development: Revealing Agriculture's Place in Africa*, 38–39. http://ebrary.ifpri.org/cdm/singleitem/collection/p15738coll2/id/128752/rec/17

Thornton, P. K., Ericksen, P. J., Herrero, M., and Challinor, A. J. 2014. Climate variability and vulnerability to climate change: A review. *Global Change Biology*, *20*(11), 3313–3328. https://doi.org/10.1111/gcb.12581

Thornton, P. K., van de Steeg, J., Notenbaert, A., and Herrero, M. 2009. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems*, *101*(3), 113–127. https://doi.org/10.1016/j.agsy.2009.05.002

Tierney, J. E., Ummenhofer, C. C., and DeMenocal, P. B. 2015. Past and future rainfall in the Horn of Africa. *Science Advances*, *1*(9), 1–9. https://doi.org/10.1126/sciadv.1500682

Tigkas, D., Vangelis, H., and Tsakiris, G. 2013. The drought indices calculator (DrinC). *Proceedings of the 8th International Conference of …*, *June*, 1333–1342.

Tigkas, D., Vangelis, H., and Tsakiris, G. 2015. DrinC: a software for drought analysis based on drought indices. *Earth Science Informatics*, *8*(3), 697–709. https://doi.org/10.1007/s12145-014-0178-y

Toni, A. T., Malcherek, A., and Kassa, A. K. 2022. Agroclimatic Zone-Based Analysis of Rainfall Variability and Trends in the Wabi Shebele River Basin, Ethiopia. *Water (Switzerland)*, *14*(22), 1–16. https://doi.org/10.3390/w14223699

Torban, K. M. 2010. Economic and distributional impacts of climate change: The case of Ethiopia. *Global Environmental Change*, *20*(2), 278–286. https://doi.org/10.1016/j.gloenvcha.2009.11.007

Tozier de la Poterie, A., and Baudoin, M. 2015. From Yokohama to Sendai: Approaches to Participation in International Disaster Risk Reduction Frameworks. *International Journal of Disaster Risk Science*, *6*, 128-139.

Trenberth, K.E., et al. 2007. Observations: Surface and Atmospheric Climate Change Climate Change 2007—The Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the IPCC. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M.C., Averyt, K.B., Tignor, M. and Miller, H.L., Eds., Cambridge University Press, Cambridge.

Trenberth, K. E. 2011. Changes in precipitation with climate change. *Climate Research*, *47*(1–2), 123–138. https://doi.org/10.3354/cr00953

Trenberth, K. E., 2014: Climate change and environmental issues. In G7 Summit 2014, S. Trevis publisher, www.PrestigeMediaUSA.com 87pp, 21-31.

Tropp, H., and Jagerskög, A. 2006. Water Scarcity Challenges in the Middle East and North Africa (MENA). *Human Development Report Office OCCASIONAL PAPER*, *August*, 1–25.

Tsegay, W., and Members, T. 2000. *The Case of Ethiopia*. 1–73.

Tsakiris, G., Pangalou, D., and Vangelis, H. 2007. Regional drought assessment based on the Reconnaissance Drought Index (RDI). *Water Resources Management*, *21*(5), 821–833. https://doi.org/10.1007/s11269-006-9105-4

Tsakiris, G., and Vangelis, H. 2005. Establishing a drought index incorporating evapotranspiration. *European Water*, *9*(10), 3–11.

Tsakiris, G., and Vangelis, H. 2014. *Regional Drought Assessment Based on the Reconnaissance Drought Index (RDI) Regional Drought Assessment Based on the Reconnaissance Drought Index (RDI)*. *April*. https://doi.org/10.1007/s11269-006-9105-4

Ubisi, N. R., Mafongoya, P. L., Kolanisi, U., and Jiri, O. 2017. Smallholder farmer's perceived effects of climate change on crop production and household livelihoods in rural Limpopo province, South Africa. *Change and Adaptation in Socio-Ecological Systems*, *3*(1), 27–38. https://doi.org/10.1515/cass-2017-0003

UNISDR. United Nations International Strategy for Disaster Reduc- tion. 2010. Local governments and disaster risk reduction: Good practices and lessons learned. http://www.unisdr.org/we/ inform/publications/13627. Accessed

UNISDR.2015. *Disaster Risk-Disaster risk*. *2020*, 1–12. https://www.preventionweb.net/risk/disaster-risk

United Nations Development Programme (UNDP) 2006. Niger Delta Human Development Report. United Nations Development Programme, UN House, Plot 617/618, Diplomatic Zone, Central Area District, Abuja.

United Nations. 2009. Disaster Risk Reduction in the United Nations. *International Strategy for DisasterReduction,ISDR*,145.https://www.unisdr.org/preventionweb/files/9866_DisasterRiskReductionintheUnitedNat.pdf

United Nations Office for Disaster Risk Reduction 2021. GAR Special Report on Drought 2021. Geneva.

Van Lanen HAJ, E. B. 2014. Assessment of the Impact of Climate Change on Hydrological Drought in Lake Tana Catchment, Blue Nile Basin, Ethiopia. *Journal of Geology and*

Geosciences, *03*(06). https://doi.org/10.4172/2329-6755.1000174

Vedwan, N., and Rhoades, R. E. 2001. Climate change in the western Himalayas of India: A study of local perception and response. *Climate Research*, *19*(2), 109–117. https://doi.org/10.3354/cr019109

Vicente-Serrano SM, Beguer´ıa S, L´opez-Moreno JI. 2010. A multi-scalar drought index sensitive to global warming: the standard-ized precipitation evapotranspiration index – SPEI. J. Clim. 23:1696–1718

Viste, E., Korecha, D., and Sorteberg, A. 2013. Recent drought and precipitation tendencies in Ethiopia. *Theoretical and Applied Climatology*, *112*(3–4), 535–551. https://doi.org/10.1007/s00704-012-0746-3

Wagaye, B. A., and Antensay, M. 2020 . Rainfall Variability and Trends over Central Ethiopia. *Int J Environ Sci Nat Res*, *24*(4). https://doi.org/10.19080/IJESNR.2020.24.556144

Wang, F., Shao, W., Yu, H., Kan, G., He, X., Zhang, D., Ren, M., and Wang, G. 2020. Re-evaluation of the Power of the Mann-Kendall Test for Detecting Monotonic Trends in Hydrometeorological Time Series. *Frontiers in Earth Science*, *8*(February), 1–12. https://doi.org/10.3389/feart.2020.00014

Washington, R., and Preston, A. 2006. Extreme wet years over southern Africa: Role of Indian Ocean sea surface temperatures. In *Journal of Geophysical Research Atmospheres* (Vol. 111, Issue 15). https://doi.org/10.1029/2005JD006724

Webb, B. W., Hannah, D. M., Moore, R. D., Brown, L. E. and Nobilis, F. 2008 Recent advances in stream and river temperature studies. Hydrol. Process. 22, 902–918. (doi:10.1002/hyp.6994)

Webster, P. J., Moore, A. M., Loschnigg, J. P., and Leben, R. R. 1999. Coupled ocean-atmosphere dynamics in the Indian Ocean during 1997-98. *Nature*, *401*(6751), 356–360. https://doi.org/10.1038/43848

Webster, N. 1980 Webster's New Twentieth Century Dictionary of English Language (2nd ed.). London: William Collins Publication.

WFP. 2016. The impacts of climate change on Food Security and Livelihoods in Karamoja 1981-2015.

Wilhite, D. A. 1993. Chapter 1 Drought. *Drought Assessment, Management, and Planning: Theory and Case Studies*, 3–15. http://digitalcommons.unl.edu/droughtfacpub/65

Wilhite, D. A., and Glantz, M. H. 2019. Understanding the drought phenomenon: The role of definitions. *Planning for Drought: Toward A Reduction of Societal Vulnerability*, 11–27. https://doi.org/10.4324/9780429301735-2

Wilhite, D. a, and Svoboda, M. D. 2000. Drought early warning systems in the context of drought preparedness and mitigation. *Early Warning Systems for Drought Preparedness and Drought Management*, 1–21.

Wilhite, D.A. and Buchanan-Smith, M. 2005 Drought as Hazard: Understanding the Natural and Social Context. In: Drought and Water Crises, CRC Press, Boca Raton, 3-20.

Woldeamlak, B., and Conway, D. 2007. *A note on the temporal and spatial variability of rainfall in the drought-prone Amhara region of Ethiopia*. *1477*(May), 1467–1477. https://doi.org/10.1002/joc

Woldeamlak B, Conway D .2009. A note on temporal and spatial variability of rainfall in drought prone Amhara regions of Ethiopia. Int. J. Climatolo., 27: 1467-147.

Worku, E., Zelalem, B. M., Azeb, A., and Akilew, A. A. 2014. Food Insecurity in Farta District, Northwest Ethiopia: A community based cross-sectional study. *BMC Research Notes*, *7*(1). https://doi.org/10.1186/1756-0500-7-130

Wondimu, A., Kefele, E., Genenew, A., and Belete, M. 2022. Determinants of food security status of household in Central and North Gondar Zone, Ethiopia. *Cogent Social Sciences*, *8*(1). https://doi.org/10.1080/23311886.2022.2040138

Wondimagegn, T., Lemma, S. 2016. *Climate change perception and choice of adaptation strategies Empirical evidence from smallholder farmers*. https://doi.org/10.1108/IJCCSM-01-2014-0017

World Bank, 2011.*(World Bank, 2011)- Climate Risk and Adaptation Country Profile Climate Investment Funds Climate Risk and Adaptation Country Profile Ethiopia COUNTRY OVERVIEW*. *April*, 15. https://climateknowledgeportal.worldbank.org/sites/default/files/2018-10/wb_gfdrr_climate_change_country_profile_for_ETH.pdf

WMO 2006 Observations and Forecasts of Rainfall Distribution. Six WMO International Workshop on Tropical Cyclones (IWTC-VI), San Jose, Costa Rica, 21-30 November 2006.

Wu, J., Zhang, N., Hayes, A., Panoutsopoulou, K., and Oliver, S. G. 2004. *Global analysis of nutrient control of gene expression in Saccharomyces cerevisiae during growth and* *starvation*. https://doi.org/10.1073/pnas.0308321100

Yamane, Y. 1967. Mathematical Formulae for Sample Size Determination

Yilma, S., and Zanke, U. 2004. Recent changes in rainfall and rainy days in Ethiopia. *International Journal of Climatology*, *24*(8), 973–983. https://doi.org/10.1002/joc.1052

Yimer, M., and Asnake, Y. 2021. Analysis of meteorological droughts in the Lake's Region of Ethiopian Rift Valley using reconnaissance drought index (RDI). *Geoenvironmental Disasters*, *8*(1), 1–17. https://doi.org/10.1186/s40677-021-00183-1

Yimer, Y., Fantaw, Y., Menfese, T., and Kindie, T. 2018. Meteorological drought assessment in north east highlands of Ethiopia. *International Journal of Climate Change Strategies and Management*, *10*(1), 142–160. https://doi.org/10.1108/IJCCSM-12-2016-0179

Yimer, M., Fantew, F., Menfese, M., and Kindie, K. 2019.Variability and trends of rainfall extreme events in north east highlands of Ethiopia. *International Journal of Hydrology*, *2*(5), 594–605. https://doi.org/10.15406/ijh.2018.02.00131

Young, H. R., and Klingaman, N. P. 2020. Skill of seasonal rainfall and temperature forecasts for East Africa. *Weather and Forecasting*, *35*(5), 1783–1800. https://doi.org/10.1175/WAF-D-19-0061.1

Zarch, M. A. A., Malekinezhad, H., Mobin, M. H., Dastorani, M. T., and Kousari, M. R. 2011. Drought Monitoring by Reconnaissance Drought Index (RDI) in Iran. *Water Resources Management*, *25*(13), 3485–3504. https://doi.org/10.1007/s11269-011-9867-1

Zargar, A., Sadiq, R., Naser, B., and Khan, F. I. 2011. A review of drought indices. *Environmental Reviews*, *19*(1), 333–349. https://doi.org/10.1139/a11-013

Zelalem, D., and Belay, S. 2021. Farmers' perceptions about changes in climate variables: Perceived risks and household responses in different agro-ecological communities, Southern Ethiopia. *Climate Services*, *22*(May), 100236. https://doi.org/10.1016/j.cliser.2021.100236

Zelalem, Y. A., Minale, Amare. S.M., and Solomon, A. L. 2022. Determinants of smallholder farmers' adaptation strategies to climate variability in Suha watershed, Upper Blue Nile basin, Northwest Ethiopia. In *Arabian Journal of Geosciences* (Vol. 15, Issue 23). https://doi.org/10.1007/s12517-022-11004-6

Zhang, W., Furtado, K., Wu, P., Zhou, T., Chadwick, R., Marzin, C., Rostron, J., and Sexton, D. 2021. Increasing precipitation variability on daily-to-multiyear time scales in a warmer world. *Science Advances*, *7*(31), 1–11. https://doi.org/10.1126/sciadv.abf8021

9. APPENDIX

9.1. List of Tables in the Appendix

Table 9.1. 1.Distribution of Annual Rainfall in East Guji

Year	Chembe	Bitata	Negele	Dawa	Adola	Shakiso	Harekello	Wadera	Kercha	Solemo	Bore
1991	734.6	524.6	431.5	555.7	603.2	603.1	516	772.4	602.2	936.7	860
1992	835.4	594.3	574.9	636.7	898	898	573.5	787.6	941	1290.6	1190
1993	963.3	674.1	668.5	658.5	1173.4	1173.3	738.8	1060.3	977.6	1031	1033.3
1994	866.3	639.2	623.1	435	877	877	628.5	796	878.6	1317.1	1386.3
1995	1002.5	689.9	737.9	569	1283.4	1283.4	640.4	1152.6	890.4	1341.1	1224.2
1996	1057.5	796.4	774.9	542.1	1260	1260	863.5	1230.7	1188.3	1379.7	1288.7
1997	1238.9	826.5	623.8	945.2	1008	1007.8	698.7	1061	1006.3	1120.1	1033.7
1998	809.5	540.2	475.2	454.8	1139	1138.8	668.5	993	883.8	1167.5	1167
1999	523.2	370.3	357.6	277.5	607	607	482	544	646.5	976.4	1130
2000	847.2	554.1	512.5	669.4	874	873.8	710.7	624.5	900.1	1011.8	974.8
2001	885.8	664.8	607.4	546.7	930.2	930.1	759.3	851.3	959.2	1212.5	1150.8
2002	864.8	704.8	691.4	530.5	1045.3	1045.3	637	925.1	897.9	1042.4	1021.6
2003	818.01	688.6	615.7	845.6	972.3	972.3	680.1	745	825.9	935.3	829
2004	811.2	768.2	663.3	614.2	1022.7	1022.7	793.4	803.1	716.6	908	930
2005	904.6	823.9	843.1	794.5	1360.7	1360.7	618	845.8	1156.7	1306.1	1138.
2006	1077.2	862.4	793	819	1092.8	1092.7	908.4	987	1119.6	1188.8	1090
2007	951.4	660.2	509.7	620.8	1029	1029	611.5	936.4	1191.	1497.8	1244.7
2008	991.4	774.9	777.3	482.7	883	883	592.8	674.8	1017.6	1011	940.3
2009	913.5	650.6	580.6	285.7	1091	1091.2	563.2	663.9	796.4	948.6	899.3
2010	995.4	520.8	505.4	671.5	1256.2	1256.2	287.0	648.8	1455.9	1588.	1433.1
2011	1155.7	816.4	643.4	888.5	1172.5	1172.5	837.8	1053.7	1256.4	1534.5	1320.7
2012	1175.9	961.5	553.2	600.6	1148.2	1148.2	905.9	962	952.7	1508.8	1344.4
2013	1300.2	970.5	675.3	810.8	812.4	812.4	986.8	930.85	1434.6	1625.5	1435.1
2014	1004.3	1425.6	727.4	778.5	854.2	854.2	1233.6	916.6	1329.3	1383.5	1480
2015	1096.8	673.5	620.5	751.1	1033	1033	1043.1	920.1	799.2	1057.5	1061
2016	989.5	494	435.7	755.8	1003.1	1003.1	517.7	644.	1100.4	1405.4	1190.
2017	845.6	621	530.4	574.6	839.	839.1	647.4	668.5	778.5	1251.9	1493.8
2018	982.8	611.8	490.2	669.4	849.4	849.4	640.3	850.7	1058.6	1541.4	1507.8
2019	1258	811.4	781	1264.7	1292.4	1292.4	927	1052.7	1548.1	1651.6	1719.
2020	1321.7	854.2	794.3	1273.6	1398	1398	964.6	1111.7	1474	1790.7	1705.5

Data Source: Extracted from Ethiopian Meteorological Institute

Table 9.1. 2.Distribution of Temperature in East Guji

Stations	Mean Maximum	Mean Minimum	Mean Annual
Chembe	27.365	14.016	20.691
Dawa	30.559	16.798	23.679
Negele	27.010	15.838	21.424
Bitata	27.805	15.424	21.615
Shakiso	27.176	9.674	18.425
Adola	27.176	9.674	18.425
Harekello	26.310	14.565	20.438
Wadera	26.519	13.802	21.615
Kercha	23.463	12.797	18.129
Solemo	23.496	11.141	17.318
Bore	20.225	8.352	14.288

Data Source: Extracted from Ethiopian Meteorological Institute

Table 9.1. 3.Distribution of Mean Seasonal Rainfall in Guji Zone

AEZs	Center	Winter	Spring	Summer	Autumn
Lowland	Chenbe	49.0	372.1	146.3	407.5
	Dawa	54.2	324.2	87.4	211.3
	Negele	31.8	334.6	29.9	224.6
	Bitata	30.8	398.3	38.2	252.1
Midland	Shakiso	75.2	475.5	110.1	367.2
	Adola	75.2	475.5	110.	367.2
	HareKello	36.6	365.7	65.5	255.5
	Wedera	51.9	406	76.8	341.6
	Kercha	63.9	443.	187.8	331.6
Highland	Solomo	75.5	449.2	372.	368.7
	Bore	79.3	389.0	384.8	353.7

Data Source: Extracted from Ethiopian Meteorological Institute

Table 9.1. 4.Distribution of Annual Drought in Guji Zone using RDI

Year	Chembe	Dawa	Negele	Bitata	Shakiso	Adola	Harekello	Wadera	Kercha	Solemo	Bore
1991	-0.84	-0.81	-0.37	-0.11	-1.31	-1.31	-0.45	-0.14	-1.53	-1.15	-1.13
1992	-1.69	-0.43	-1.55	-1.65	-1.75	-1.75	-1.44	-0.52	-1.29	-1.18	-0.7
1993	0.68	0.44	1.17	0.58	1.25	1.25	0.72	1.11	0.32	0.1	0.69
1994	-0.68	-1.3	-0.25	-0.84	-0.71	-0.71	-0.79	-0.28	-0.9	-0.27	0.86
1995	-0.59	-0.59	0.61	-0.01	0.1	0.1	-0.62	0.37	-0.94	0.01	0.09
1996	1.1	-0.02	0.98	0.67	1.59	1.59	0.77	1.79	0.27	0.5	0.74
1997	-0.48	-1.36	-0.75	-0.55	-1.41	-1.41	-0.86	-0.3	-1.19	-1.22	-1.44
1998	1.1	1.45	1.2	1.16	1.26	1.26	1.27	1.95	0.17	-0.15	0.47
1999	-1.73	-2.4	-2.11	-1.94	-1.04	-1.04	-1.16	-1.09	-1.49	-1.15	-0.32
2000	-2.64	-0.54	-1.22	-1.24	-1.71	-1.71	-0.25	-2.46	-1.28	-1.59	-1.2
2001	1.18	0.1	0.44	0.06	0.22	0.22	0.26	0.4	-0.12	-0.05	0.17
2002	-1.14	-0.6	-0.61	-0.55	-0.38	-0.38	-0.48	-0.05	-0.75	-1.4	-0.91
2003	0.28	0.72	1.58	1.05	0.51	0.51	0.85	1.03	0.2	-0.46	-0.84
2004	-0.53	-0.48	-0.58	-0.32	-0.87	-0.87	-0.45	-1.04	-1.21	-1.32	-1.25
2005	-0.2	0.78	1.85	0.93	1.74	1.74	0.27	0.26	0.68	0.03	-0.38
2006	0.61	-0.13	0.75	0.77	0.3	0.3	0.8	0.13	0.7	0.04	-0.43
2007	0.4	0.85	-0.03	0.1	0.3	0.3	0.1	0.45	0.88	0.67	0.38
2008	-0.66	-0.71	-0.8	-0.59	-1.46	-1.46	-1.27	-0.65	-0.36	-1.29	-1.68
2009	0.29	-1.55	1.02	0.62	0.96	0.96	-0.06	-0.62	-0.15	-0.71	-1.17
2010	0.91	0.38	-0.24	-0.34	1.18	1.18	-1.22	-0.08	1.73	1.55	0.99
2011	-0.43	-0.44	-1.33	-1.21	-0.47	-0.47	-1.65	-1.29	-0.02	1.35	0.17
2012	0.32	0.5	0.5	1.35	0.73	0.73	1.32	0.87	0.43	0.92	-0.11
2013	1.24	0.61	0.04	0.89	-0.81	-0.81	0.19	-0.34	1.33	1.4	0.63
2014	0.62	0.57	0.58	2.54	-0.06	-0.06	2.52	0.67	1.63	1.24	0.81
2015	0.04	0.34	0.5	0.17	0.04	0.04	1.08	0.14	-0.09	-0.11	-0.62
2016	0.03	0.98	-0.79	-0.77	0.68	0.68	0.05	-0.28	0.85	0.69	-0.27
2017	-0.74	-0.78	-1.42	-1.56	-0.65	-0.65	-1.38	-2.19	-1.32	-0.51	0.55
2018	0.99	1.47	-0.03	0.33	0.24	0.24	0.73	1.01	1.03	1.47	2.45
2019	0.81	0.44	-0.58	-0.58	0.24	0.24	-0.34	-0.11	0.54	0.98	1.63
2020	1.78	2.5	1.42	1	1.32	1.32	1.48	1.28	1.86	1.61	1.83

Data Source: Extracted from Ethiopian Meteorological Institute

Table 9.1. 5.Distribution of Autumn Drought in Guji Zone Using RDI

Year	Chembe	Dawa	Negele	Bitata	Shakiso	Adola	Harekello	Wadera	Kercha	Solemo	Bore
1991	-0.72	-1.17	0.11	0.19	-1.44	-1.44	-0.02	0.16	-1.35	-1.4	-1.06
1992	-1.82	-0.26	-2.11	-2.44	-2.42	-2.42	-1.54	-0.45	-1.97	-2.19	-1.61
1993	-0.04	0.38	0.2	-0.07	0.25	0.25	-0.24	-0.71	0.03	0.55	0.88
1994	-1.36	-0.79	-0.83	-1.12	-1.4	-1.4	-1.2	-0.69	-1.5	-1.66	-1
1995	-1.05	-0.42	0.02	0.26	-0.92	-0.92	-0.23	-0.92	-1.22	-0.84	-0.57
1996	0.32	0.02	0.48	0.39	1.05	1.05	0.26	0.64	-0.7	-0.09	0.13
1997	-1.02	-0.99	0.5	0.12	-0.58	-0.58	0.32	0.35	-0.27	-0.23	-0.17
1998	2.15	2.24	1.56	1.89	1.56	1.56	1.49	1.98	0.91	0.44	1.05
1999	-0.7	-1.95	-1.64	-1.47	0.07	0.07	-0.88	-0.03	-0.62	0	0.15
2000	-2	-1.2	-0.64	-1.01	-1.31	-1.31	-0.8	-0.97	-1.44	-0.78	-0.04
2001	1.85	0.53	0.36	0.13	0.63	0.63	-0.01	0.94	-0.08	-0.01	0.35
2002	-0.3	-0.27	-0.1	0.01	-0.36	-0.36	0.29	0.62	-0.52	-0.51	-0.22
2003	0.05	-0.99	0.73	0.37	0.03	0.03	-0.1	0.32	-0.67	-0.39	-0.87
2004	-0.9	-0.83	-1.89	-1.27	-1.33	-1.33	-1.39	-2.27	-1.24	-1.7	-2.03
2005	-0.2	0.53	0.71	0.62	1.33	1.33	0.77	0.09	-0.15	-1.04	-1.45
2006	0.18	0.14	-0.57	0.14	0.09	0.09	0.01	-0.18	0.34	-0.21	-0.36
2007	0.27	1.28	0	0.2	-0.11	-0.11	0.27	0.53	0.39	-0.66	-0.51
2008	-0.15	0.13	-0.85	-0.12	-0.18	-0.18	-0.25	0.94	0.89	0.41	-0.22
2009	1.57	0.07	1.91	1.56	1.28	1.28	0.95	0.75	1.3	0.88	0.57
2010	0.15	-0.74	-0.02	0.03	-0.66	-0.66	-0.18	-0.25	-0.1	-0.03	-0.79
2011	-1.39	-1.24	-0.35	-1.09	-0.78	-0.78	-2.43	-2.25	-0.07	0.65	-0.29
2012	0.55	0.9	1.64	1.76	1.12	1.12	1.56	1.42	1.39	1.19	0.17
2013	0.92	0.61	0.52	0.8	1.08	1.08	0.53	0.43	1.02	1.41	0.96
2014	1.16	0.85	0.88	1.03	1.42	1.42	1.85	1.2	1.77	2.1	1.04
2015	0.13	0.84	0.98	0.89	0.63	0.63	0.73	0.37	1.43	1.4	0.94
2016	0.76	0.83	-0.14	-0.4	0.94	0.94	1.19	0.41	0.59	0.17	-0.15
2017	0.43	-0.25	-1.19	-1.38	-0.34	-0.34	-1.12	-1.74	-0.14	-0.02	-0.28
2018	0.64	1.28	0.15	0.52	0.37	0.37	0.62	0.37	0.95	1.23	2.75
2019	-0.08	-1.42	-1.43	-1.21	-0.68	-0.68	-1.39	-1.38	-0.4	0.36	0.87
2020	0.6	1.8	1.04	0.73	0.67	0.67	1.01	0.37	1.43	0.97	1.74

Data Source: Extracted from Ethiopian Meteorological Institute

Table 9.1. 6.Distribution of Spring Drought in Guji Zone using RDI

Year	Chembe	Dawa	Negele	Bitata	Shakiso	Adola	Harekello	Wadera	Kercha	Solemo	Bore
1991	-0.76	-0.85	-0.81	-0.9	-0.73	-0.73	-0.79	-0.16	-0.91	-0.91	-1.24
1992	-1.25	-0.95	-1.22	-1.12	-0.75	-0.75	-1.13	-0.95	-0.97	-1.29	-0.75
1993	1.13	0.29	1.04	0.56	1.02	1.02	1.03	1.77	0.5	0	-0.16
1994	0.86	-0.67	0.68	-0.16	0.35	0.35	0.13	0.86	-0.07	0.76	1.35
1995	0.37	-0.06	1.22	0.03	0.94	0.94	-0.54	1.39	-0.02	0.97	0.95
1996	1.08	0.17	1.66	1.02	1.52	1.52	0.93	1.9	0.69	0.7	0.65
1997	0.02	-0.97	-1.66	-0.74	-0.88	-0.88	-1.41	-0.17	-1.48	-1.66	-1.76
1998	-1.57	-0.77	-0.66	-0.73	-0.64	-0.64	-0.11	-0.25	-1.21	-1.48	-1.27
1999	-1.25	-1.64	-1.39	-1.7	-0.65	-0.65	-0.59	-0.83	-1.23	-1.15	0.32
2000	-2.33	0.44	-0.86	-0.84	-0.6	-0.6	-0.04	-2.77	-0.49	-1.02	-0.92
2001	0.39	-0.11	0.74	0.23	-0.13	-0.13	0.67	0.07	-0.18	0.19	0.44
2002	-0.83	0.04	-0.29	-0.36	0.56	0.56	-0.32	0.12	-0.12	-0.38	-0.15
2003	-0.05	1.76	1.16	0.79	0.44	0.44	0.7	0.43	0.2	-1.09	-1.75
2004	-0.71	-0.46	-0.01	0.28	-0.74	-0.74	0.44	0.09	-0.93	-0.89	-0.79
2005	0.79	1.41	2.41	1.01	1.87	1.87	-0.22	0.7	1.54	1.79	1.31
2006	0.31	0.07	1.75	1.12	0.41	0.41	1.08	0.31	0.79	-0.23	-0.76
2007	-0.46	0.16	-0.01	-0.12	0.3	0.3	-0.45	-0.12	0.76	0.48	0.05
2008	-0.74	-0.78	-0.13	-0.45	-1.56	-1.56	-1.3	-1.66	-0.62	-1.43	-1.26
2009	-0.81	-2.33	-0.31	-0.46	0.73	0.73	-1.02	-1.56	-0.59	-0.36	-0.86
2010	1.44	1.09	-0.3	-0.71	1.79	1.79	-1.92	0.14	2.48	2.31	1.67
2011	-0.35	-0.13	-1.34	-0.77	-0.78	-0.78	-0.82	-0.49	-0.11	0.75	0.06
2012	1.06	-0.94	-0.54	1.09	0.77	0.77	1.2	0.69	-0.58	0.18	-0.23
2013	0.8	0.95	-0.15	1.08	-2.8	-2.8	0.67	-0.44	1.14	0.68	0.26
2014	-0.47	0.24	0.09	3.54	-1.37	-1.37	3.08	0.44	1.1	0.14	0.27
2015	0.3	0.13	0.25	-0.14	0.01	0.01	-0.08	-0.41	-0.83	-0.28	-0.22
2016	-0.13	1.13	-0.73	-0.56	0.16	0.16	-0.32	-0.17	0.9	0.99	0.13
2017	-0.97	-1.04	-1.01	-1.13	-0.15	-0.15	-0.66	-1.23	-1.99	-0.4	0.54
2018	1.11	1.9	-0.55	-0.26	0.35	0.35	0.26	0.92	1.17	1.13	2.37
2019	1.05	0.19	-0.14	-0.39	-0.13	-0.13	0.1	0.17	0.01	0.29	0.71
2020	2.01	1.72	1.07	0.66	0.72	0.72	1.34	1.22	1.01	1.18	1.03

Data Source: Extracted from Ethiopian Meteorological Institute

Table 9.1. 7.Predictors of household food insecurity in Guji Zone, 2021 (N = 400)

Characteristics N=400	Households' food Insecurity Status		
	Food Insecure N=206 (51.5%)	Food secure N=194(48.5%)	AOR (95% CI)
AEZ			
Dega	33	57	
Weinadega and Kola	173	137	2.207 (1.354-3.596)
Sex of the HHH			
Female	55	26	
Male	151	168	2.354(1.405-3.942)
Age of the HHH			
19-28	34	18	
29-38	73	52	.441(.202-.962)
39-48	58	58	.594 (.313-1.125)
49-58	25	30	.833(.438-1.586)
>59	16	36	1.875(.849-4.143)
Marital status HHH			
Married	181	168	.836(.228-2.706)
Single	25	26	1.393(200-9.711)
Level of Education of the head of the household			
No formal Education	88	40	1.142 (1.085-1.202)
Literate	118	154	
Household size			
1-3			1.151 (1.062-1.248)
4-6			
Cultivated land size			
<1 hectare	158	112	
>1 hectare	48	82	1.933 (1.264-2.955)
Farming Experience			
1-10	98	50	
11-20	34	39	.492 (.199-1.217)
21-30	25	32	.219 (.093-.513)
31-40	40	52	.557 (.230-1.347)
41-50	9	21	.549 (.214-1.404)
Obtaining Food aid			
Yes (1)	96	21	7.190(4.235-12.205)
No (0)	110	173	
Access to drought-tolerant crops	154	133	
Yes	52	61	.736 (.476-1.139)
No			
Access to credit			
Yes	172	149	
No	34	45	1.528 (.930-2.510)

Source: Household Survey, 2021

Table 9.1. 8 . Cronbach's Alpha HFIAS Item's reliability nine indicators of HFIAS

Indicators of HFIAS	Reliability
1.Did you worry that your household would not have enough food?	.857
2.Were your household members unable to eat kinds of foods you Preferred?	.794
3.Did you or any household member have to eat a limited variety of foods?	.789
4.Did you or any household member have to eat some food that you really did not want to eat?	.798
5.Did you or any household member have to eat a smaller meal than you felt you needed?	.790
6.Did you or any other household member have to eat fewer meals in a day?	.808
7.Was there ever no food to eat of any kind in your household? You were	.790
8.Did you or any household members go to sleep at night hungry?	.790
9.Did you or any household member go a whole day and night without eating anything?	.804
Average	0.802222

Source: Household Survey, 2021

Table 9.1. 9. Multicollinearity Diagnosis for independent variable of Food security for BLRM

	Variables	Tolerance	VIF	t	sig
1	level of education in year	.798	1.254	5.339	.000
2	Cultivated land	.541	1.847	3.063	.002
3	Time to reach the nearest market?	.695	1.440	3.851	.000
4	Total number of the household	.687	1.456	-4.174	.000
5	Getting drought resistance crop	.774	1.292	.706	.480
6	Access to credit	.664	1.505	-.417	.677
7	Local extension services	.668	1.496	-.511	.610
8	Total number of livestock per household	.739	1.352	-.382	.702
9	Agro ecological zones	.490	2.041	.326	.744
10	Farming experiences	.728	1.373	-4.821	.040

Source: Household Survey, 2021

Table 9.1. 10 Multicollinearity Diagnosis of independent variable for Adaptation methods in BLRM

	Variables	Tolerance	VIF	t	Significance
1	Level of education in year	.798	1.254	3.598	.000
2	Cultivated land	.541	1.847	1.259	.209
3	Time to reach to nearest market	.695	1.440	-.840	.402
4	Total number of the household	.687	1.456	-2.607	.009
5	Getting drought resistance crop from	.774	1.292	.586	.558
6	Access to credit?	.664	1.505	.555	.579
7	Local extension works services	.668	1.496	2.477	.014
8	Total number of livestock per household	.739	1.352	-.968	.333
9	Agro ecological zones	.490	2.041	2.384	.018
10	Farming experiences of head of the household in year	.728	1.373	-1.476	.141

Source: Household Survey, 2021

9.2. List of Figures in the Appendix

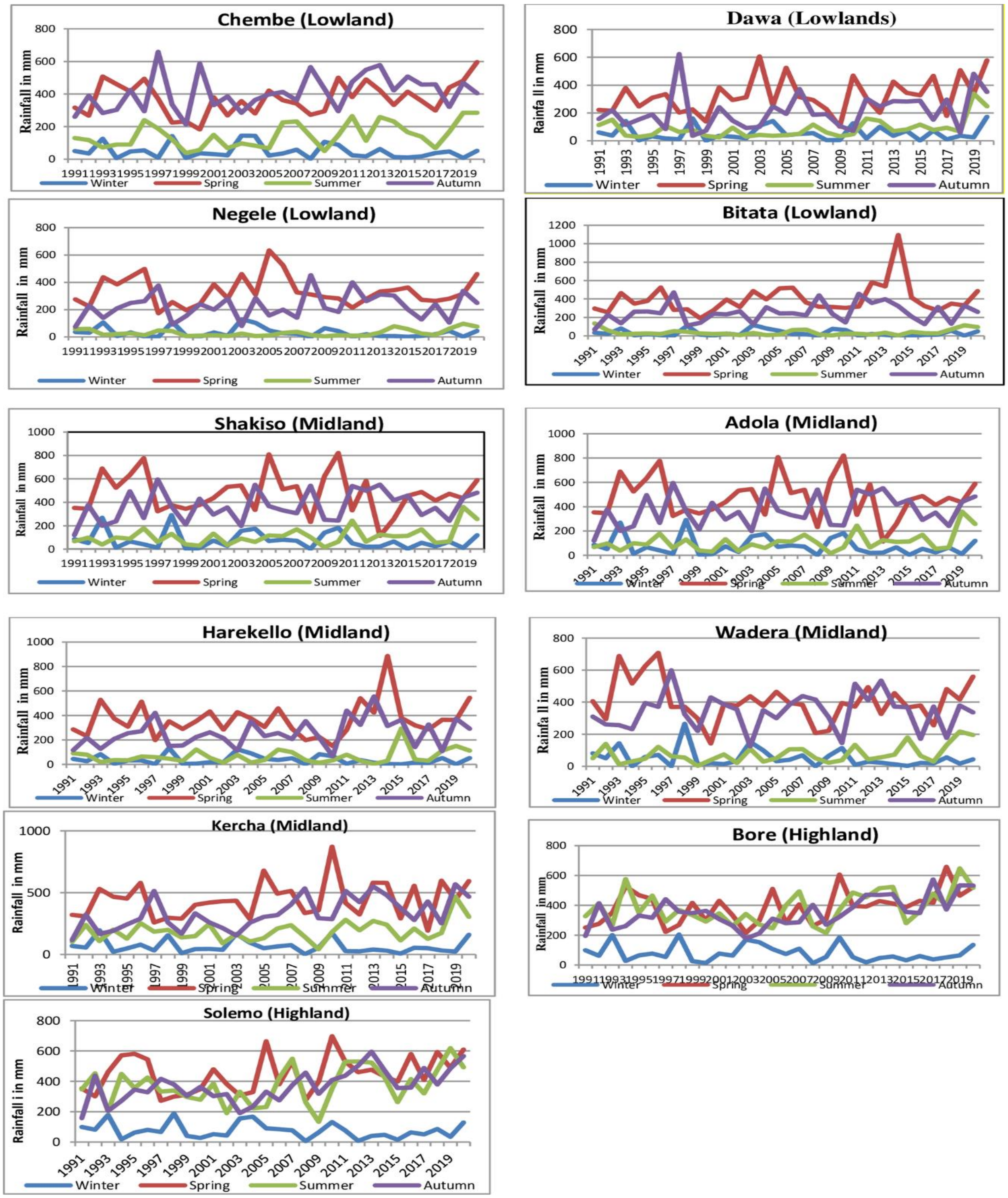


Figure 9. 1.Seasonal Distributions of Rainfall of Individual Stations in the Study Area

Data Source: Extracted from Ethiopian Meteorological Institute

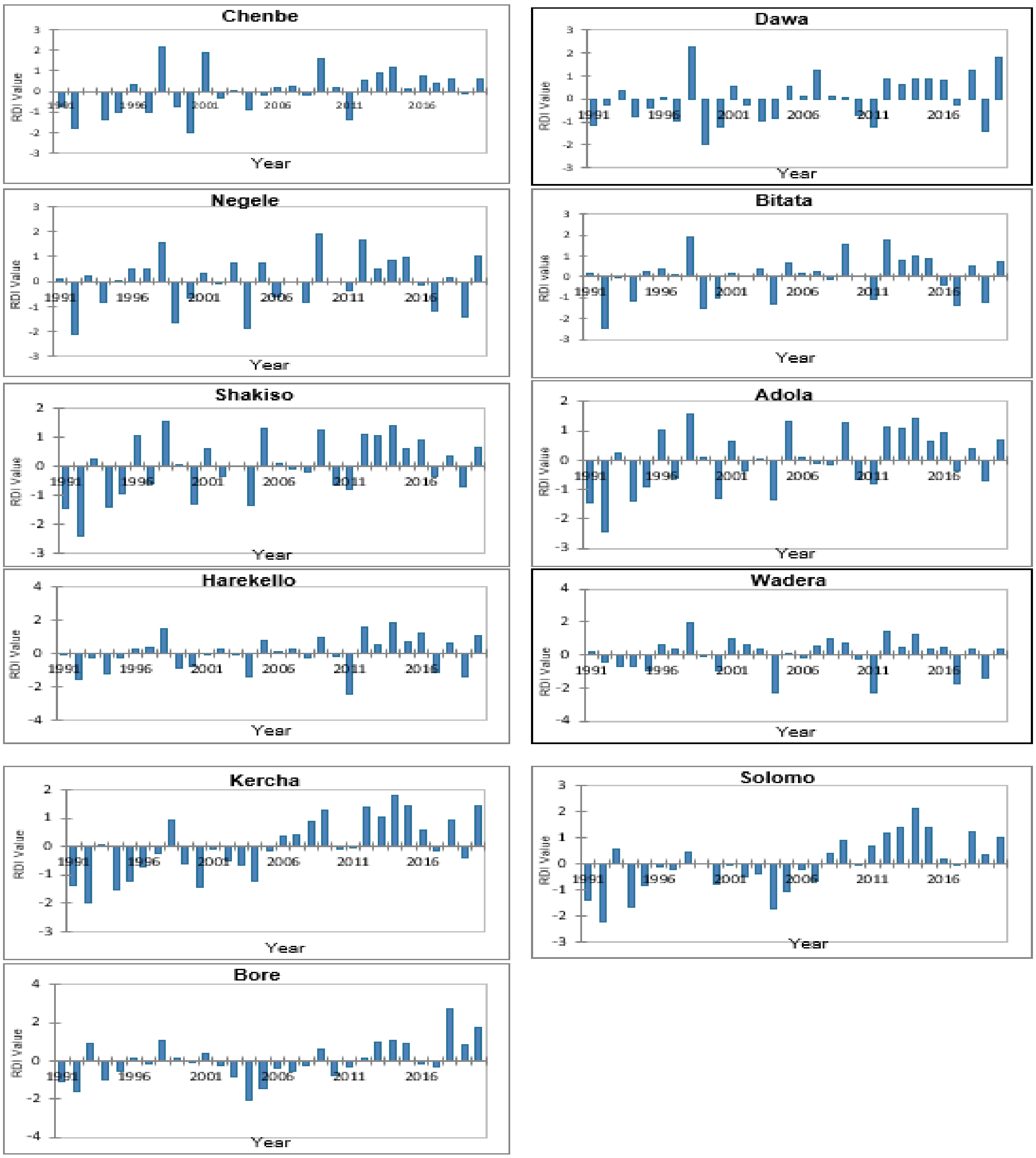


Figure 9. 2.Distributions of Severity of Autumn (3 months) Drought in Guji Zone

Data Source: Extracted from Ethiopian Meteorological Institute

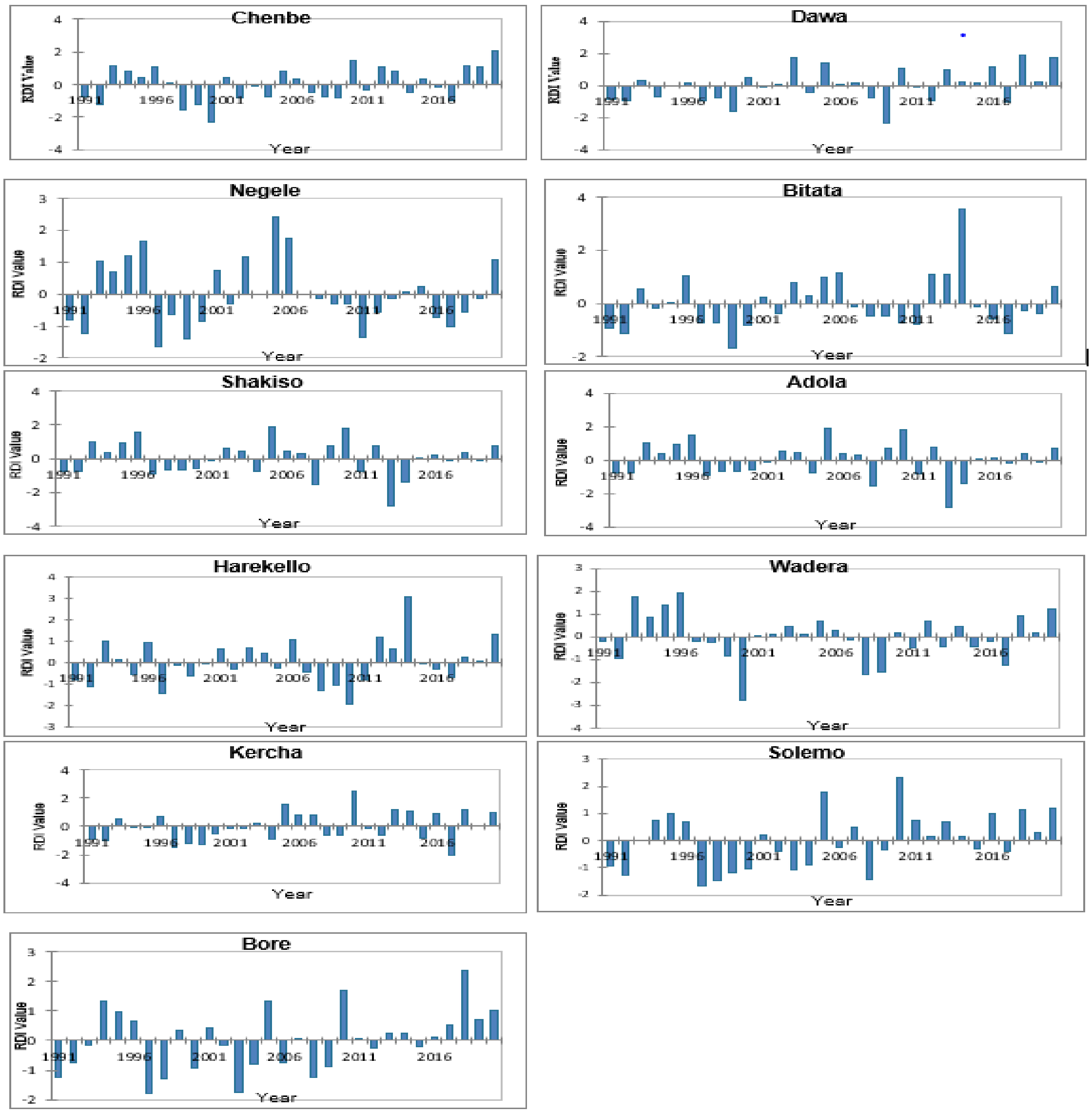


Figure 9. 3. Distributions of Severity of Spring (3 months) Drought in Guji Zone

Data Source: Extracted from Ethiopian Meteorological Institute

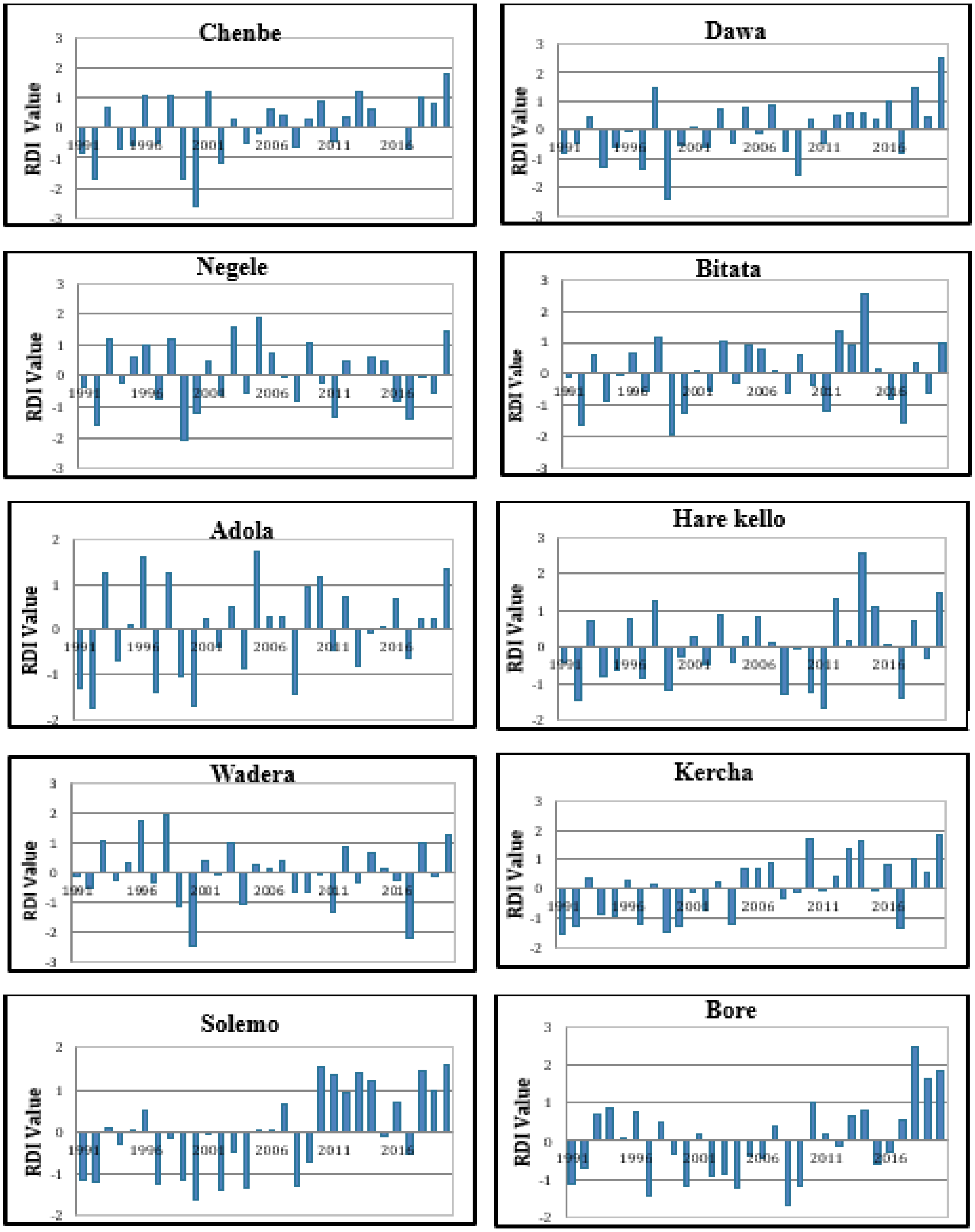


Figure 9. 4. The Distribution of Severity of Annual (12 months) Drought in Guji Zone

Data Source: Extracted from Ethiopian Meteorological Institute

9.3. Instruments of Household Survey

9.3.1. Questionnaire

Part One. Background Information of Farm Households

I. **Code of interviewer: ....II. Questionnaire no. ……………**

III. Date: ..../......../............. IV. Time spent on interviews: From............ to..................

V. Code of respondent..........................

1. Personal information

1	Wereda	
2	Kebele	
3	Age	
4	***sex***	
5	Annual income (birr)	
6	Household size	
7	Farming Experience in year	

2. Number of cattle

1	Oxen	
2	Caw	
3	Horses	
4	Donkey	
5	Mule	
6	Camel	
6	Goat	
7	Sheep	
8	Calf	

3. Marital status: 1. Married 2. Single 3. divorced: 4. widowed 5. Other (specify)_________________

4. Which agro-ecological zones respondent households are found?

1. Dega 2. Weinadega 3. Kola

5. Does your household normally undertake crop farming? 1. Yes 2. No

6. If yes in (2) above, is it done by irrigation or rain fed? 1.Rain fed 2. Irrigation

7. What is your source of income?

1. Farming 2. Salaried employment 3. Business 4. Mining 5. Others…………

8. Have you ever gone to school? 1. Yes 2. No

9. State level of education in years ……………….

10. For how many years do you lived in this area? ....in years.

11. How many plots of land do you have? ....hectare.

12. What is the estimated cultivated land size of the household in hectare? ....

13. Do you have access to market 1.yes 2. No

14. What is the estimated distance you travel to reach to nearest market? ……………in minutes.

NB: Background information was used for analyzing determinants of food security and adaptation strategies of household using binary logistic regression model.

Part II Objective Four: To examine the perception of smallholder farmers towards the impact of rainfall variability and drought.

1. Do you hear about climate change? A. Yes B. No

2. From whom have you heard about climate change? (Sources of information about climate change)

A. Extension workers B. Mass media C. Teachers/School C. Neighbors /friends

D. Scientists E. Experience F. Local leaders

3. Do you understand what rainfall varies? A. Yes B. No

4. Do you believe the rainfall of your locality is changing? A. Yes B. No

5. Which components of climate have you felt as changing mostly?

A. Rainfall B. Temperature C. Wind D. Other, specify……….

6. Content Measurements a change in the parameters of climate change

Ite ms	Parameters of climate variability and drought	Great deal	Much	Less	Little	None
1	How much do you understand about rainfall variability					
2	Do you understand what rainfall variability is					
3	Do you understand what drought is					
4	Do you believe that all people should know something about rainfall variability and drought					
5	Is total annual rainfall in the study area increased					
6	Is total annual rainfall in the study area decreased					
7	Is there increase in amount of Rainfall in autumn					
8	Is there decrease in amount of Rainfall in autumn					
9	Is there increase in amount of Rainfall in spring					
10	Is there decrease in amount of rainfall in spring					
11	Do you think rainfall is coming early					
12	Do you think rainfall is coming late					
13	Do you think the number of dry days increasing					
14	Do you think number of wet or rainy days increasing					
15	Is temperature of the locality increasing					
16	Is temperature of the locality decreasing					
17	Is the pattern rainfall has been changed					
18	Is timing rainfall is changing					
19	Is intensity of rainfall is changing					
20	Is increase in the frequency of occurrence of drought					
21	Is decrease in the frequency of drought					
22	Is increase in duration of drought					

23	Is decrease in duration of drought					
24	Is increase in severity of drought					
25	Is decrease in severity of drought					
26	Do you associate rainfall variability and drought with food shortage					
27	How rainfall variability and drought affected food crop production for your household					
28	Do you believe that rainfall variability and drought has influenced food security in your area					
29	Do you believe that incidence of food insecurity changing from better to worse due to rainfall variability and drought					
30	Do you participate in any activity to adapt to impact of Rainfall variability and drought in your area					
31	do you believe that Government Policy in Ethiopia is concerned on the issue of climate variability and drought?					
32	Do you believe that if rainfall variability and impacts of droughts are not solved now, future generations will suffer					
33	Do you believe that a degraded and devastated? environment is result of rainfall variability and drought					
34	Do you believe that farmers are replacing food crop with exculpates tree due to rainfall variability and drought					
35	Do you believe that problems related to rainfall variability and food security will be reduced if					

	early warning measures were communicated in time					
36	Do you agree that the meteorological department always makes timely the early warning information to farm households					

Objective Three: To investigate the influence of rainfall variability and drought on the food security of smallholder farmers and determinants

1. How has your production overtime been in the last years to now?

1. Increased 2. Decreased 3. Remained the same

2. If the response is # 2 Do you assume that rainfall variability and drought are cause for decease? 1) Yes 2). No

3. Do you think rainfall variability and drought resulted in food insecurity problems?

1. Yes 2. No

4. Do you have enough food for your household currently? 1. Yes 2. No

5. How many times do you take a meal per day?

1. Once 2. Twice 3. Threewise 4. Fourwice

6. Are these foods enough to sustain you? 1) Yes 2) No

7. In the past year, did you worry that your household would not have enough food?

1 = Yes 2= No (skip q.3)

8. Do you take any measures to reduce your exposure to the impacts of rainfall variability and drought on food security risk? 1. Yes 2. No

9. Has there been any project targeted at improving the food insecurity condition in your area?

1. Yes 2. No

10. How often do you face food insecurity problems in your house?

1 = rarely (once or twice in the past year)

2 = Sometimes (three to ten times in the past year)

3 = Often (more than ten times in the past year)

Q.10. During the last 12 months, was there a time when, because of climate variability and drought resulted food shortage: occurrence questions						
		0 = never	1=Rarely	2 = Sometimes	3 = Often	Total
1	Did you worry your household would not have enough food to eat?					
2.	Were your household members unable to eat healthy and nutritious food?					
3.	Do you or any household member have to eat a limited variety of foods?					
4.	Did you or any household member have to eat some foods that you really did not want to eat?					
5.	Did you or any household member have to eat a smaller meal than you felt you needed?					
6.	Did you or any other household members have to eat fewer meals in a day?					

7.	Was there ever no food to eat of any kind in your household? You were hungry but did not eat?					
8.	Did you or any household member go to sleep at night hungry?					
9	Have you or any household member go a whole day and night without eating anything?					

11. How do you overcome the problem of food insecurity of your household? Mention at least three:

i.……………………………………………………………………………………………

ii……………………………………………………………………………………………

iii……………………………………………………………………………………………

12. Do you ever get food aid 1. Yes 2. No

13. If the response of q# 12 is yes. How frequently do received food aid?

1. Always 2. Sometimes 3. Rarely 4. Often

IV. Part Four

Objective Four: To identify the adaptation strategies of smallholder farmers to rainfall variability and drought and determinants.

1. Do you ever use adaptive strategies to minimize or alleviate the effects of rainfall variability and drought? 1. yes 2. No

2. If your answer to #1 is no, why? Identify reasons for not practicing adaptation

	2.Reasons for not taking adaptation	Yes	No
1	Lack of information		
2	Lack of capital (money)		
3	Lack of knowledge		
4	Shortage of farming land		
5	Lack of access to input of adaptation		
6	Giving less emphasis to climate variability and drought as problems		
7	Others		

3. Which of the following major adaptation methods have you ever used? Tick marks only for adaptation strategies the households are using.

	6.Adaptation strategies used by household	✓ tick		Adaptation strategies used by household	✓ Tick
1	Changing crop variety		8	Irrigation	
2	Changing planting dates (changing sowing period)		9	Planting trees	
3	Use of drought-resistant crop varieties		9	Replacing food crop with planting eucalyptus trees	
4	Mixed cropping		10	Receiving credit	
5	Crop diversification		11	Seek off-farm employment	
6	Planting early maturing crop		12	Temporary migration	
7	Selling cattle			Total	

4. Do you have access to credit? 1. Yes 2. No

5. Do you have access to any formal credits (from development banks, microfinances, etc) in time you face shortage of money? 1. Yes 2. No

6. Do you have access to any informal credits (from neighbors, friends, relatives etc)

1. Yes 2. No

7. Are you getting drought resistance crops from Woreda's agricultural offices?

1. Yes 2. No

8. Are the local extension workers providing services related to the problem of climate variability and drought? 1.Yes 2. No

9. What relevant services are provided to your household by Woreda agricultural office and extension workers which helped you to withstand the impact of rainfall variability and drought?

I.…………………………………………………………………………………………

II…………………………………………………………………………………………

III…………………………………………………………………………………………

10. What kind of support should the government or other concerned bodies have to provide SFHH to easily withstand the effects of rainfall variability and drought in the future?

I.…………………………………………………………………………………………

II…………………………………………………………………………………………

III…………………………………………………………………………………………

10. Do you think that if the government or other concerned bodies provided appropriate assistance to withstand the impact of rainfall variability and drought you could easily cope with the impact of rainfall variability and drought in the future? 1.Yes 2. No

9.3.2. Guiding Questions for Focus Group Discussion (FGD)

1.What is your historical experience of rainfall variability and drought for the past thirty years?
2.Do you think that there is rainfall variability in your locality? How do you perceive rainfall?

variability and drought in your locality.

3. How about the experience of drought, intensity and duration and spatial coverage of drought in the locality?

4. Discuss the impact of rainfall variability and drought in your area?

5. Why do you think the reason for replacing food crops with planting of eucalyptus tree in the locality

6. What do you think is the impact of planting eucalyptus in food security in the study area?

7. What is the influence of rainfall variability and drought on household food security?

8. What adaptation techniques have been used to the impacts of rainfall variability and drought?

9.3.3. Guiding Questions for Key Informant Interview (KII)

1. For how many years have you lived in the area? What is your historical experience of rainfall variability and drought?
2. Is there rainfall variability and drought problem in your locality? How do you perceive rainfall variability and drought?
3. What change have you observed for the past thirty years concerning rainfall variability and? drought? Which parameters (rainfall, temperature and wind) are increasing or decreasing?
4. What are the impacts of rainfall variability and drought in the locality?
5. Why do you think the reason for replacing food crops with planting of eucalyptus tree in relation to food security in the locality?
6. What do you think is the impact of planting eucalyptus tree on the food security of smallholder farm household in the study area?
7. What are the influences of rainfall variability and drought on household food security?
8. What adaptation methods have been used to the impact of rainfall variability and drought in your locality?