Synergetic Impact of Drought and Land Use and Land Cover Change on Livelihood Systems in the Northwestern Escarpment of Ethiopian Rift Valley

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Statement of the Author

I have followed all ethical research principles in this study's processing. I affirm that this dissertation is my original work with my signature below. I have never given a presentation at this or any other university, and the dissertation tools and materials were uninspiring.

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This dissertation has been submitted for examination with my approval as University supervisor.
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Dissertation Approval

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This is to certify that the dissertation prepared by Jemal Nasir Ahmed, entitled "Synergetic Impact of Drought and Land Use and Land Cover Changes on Livelihood Systems in the Northwestern Escarpment of Ethiopian Rift Valley" and submitted in fulfillment of the requirement for the Degree of Doctor of Philosophy (Environment and Development Studies) compiles with the regulations of the University and meets the accepted standards concerning originality and quality.

Signed by the Examining Committee:

Chair, Examining	Committee Signature	Date
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Lists of original papers

The following five original papers serve as the foundation for this dissertation.

Chapter 2 **(Paper 1)**: Modeling seasonal and annual climate variability trends and their characteristics in the northwestern Escarpment of Ethiopian Rift Valle. This article was published on July 31/2021, in the Journal of Modeling Earth Systems and Environment (Springer). https://doi.org/10.1007/s40808-021-01247-9

Chapter 3 **(Paper 2):** Meteorological Drought in Northwestern Escarpment of Ethiopian Rift Valley: detection seasonal and spatial trends. This article was also published on February 12/2021, in the Journal of Environmental System Research (Springer). https://doi.org/10.1186/s40068-021-00219-3

Chapter 4 **(Paper 3)**: Analyzing trends and drivers of land use and land cover dynamics in drought-prone livelihood zones of the Northwestern Escarpment of Ethiopian Rift Valley. This article was published on May 19 /2022, in the Journal of Papers in Applied Geography (Taylor and Francis). https://doi.org/10.1080/23754931.2022.2074304

Chapter 5 **(Paper 4):** Modeling the vulnerability of livelihood systems to drought along livelihood zones in the Northwestern Escarpment of Ethiopian Rift Valley. This article was published on May 3/2022 in the Journal of Papers in Applied Geography (Taylor and Francis). https://doi.org/10.1080/23754931.2022.2068352

Chapter 6 **(Paper 5)**: Analyzing Synergetic Impact of Drought and Land Use and Land Cover Changes on Livelihood Systems Across Three Livelihood Zones in the Northwestern Escarpment of Ethiopian Rift Valley. This article is **accepted** in theJournal of Geomatics, Natural Hazards, and Risk (Taylor and Francis).

Table of Contents

Contents

List of Tables

List of Figures

Acronyms

ALOFLZ	Alagie-Offla Livelihood Zone
ARC	Annual Rate Change
BA	Built-Up Area
BE	Biophysical Exposure
BL	Bare Land
CC	Cumulative Changes
CE	Climate Extreme Exposure
CHIRPS	Climate Hazards Group InfraRed Precipitations with Station data
ENACTS	Enhancing National Climate Service
CL	Cultivation-land
CMIP5	Coupled Model Intercomparsion Project Phase5
CRED	Center for Research on the Epidemiology Disasters
CSAC	Copying Strategy Adaptive Capacity
CV	Coefficient of Variation
CVS	Climate Variability Sensitivity
DF	Drought Free
DVI	Drought Vulnerability Index
EE	Ecosystem Exposures
EM-DAT	Emergency Events Database
ES	Ecosystem Sensitivity
ESD	Extremely Severe Drought
FGD	Focus Group Discussions
FL	Forest Land
FP	Flood Plain
GIS	Geographical Information Systems
GL	Grassland
GPS	Global Positioning Systems
Hg	Hargreaves
IDM	Inverse Weighting Methods
IE	Institutional Exposures
IS	Institutional Sensitivity
L5	Landsat5 Thematic Mapper
L7 ETM+	Landsat7 Enhancement Thematic Mapper Plus
L8 OLI/TIRS	Landsat8 Operational Land Imager and Thermal Infrared Sensor
LSAC	Livelihood Strategy Adaptive Capacity

LSS	Livelihood System
LULC	Land Use and Land Cover
LZ	Livelihood Zone
MC	Magnitude of Change
MD	Mild Drought
MKT	Mann Kendal Test
MOD	Moderate Drought
MP	Penman-Monteith
NB	Number of Bands
NRCAC	Natural Resource Conservations Adaptive Capacity
PC	Percentage of Change
PRC	Proportional Change
PET	Potential Evapotranspiration
RCPs	Representative Concentration Pathways
REST	Relief Society of Tigray
RVLZ	Raya Valley Livelihood Zone
SA	Sun-Azimuth
SBL	Shrub and Bushland
SCE	Socio-Cultural Exposures
SD	Severe Drought
SD	Standard Deviation
SE	Sun-Elevation
SNAC	Social Networks’ Adaptive Capacity
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Standardized Precipitation Index
SPSS	Statistical Package for the Social Sciences
SR	Spatial Resolution
SSE	Sen’s Slope Estimators
TCLZ	Tsirare Catchment Livelihood Zones
Th	Thornthwaite
Tmax	Maximum Temperature
Tmin	Minimum Temperature
UNDRR	United Nation Disaster Risk Redaction
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VRDVI	Variables Relationship with Drought Vulnerability Indexes
WB	Waterbody

WDRPs	Woreda Disaster Risk Profiles
WL	Wetland
WMO	World Meteorological Organizations

Abbreviation

ºC	Decree Celsius
E	East
Ha	Hectare
Km	Kilometer
Km^2	Kilometer Esquire
N	North

1. Chapter One: General Introduction

1.1. Background and Justification

Climate changes and variabilities since 1950 have been increasing globally (IPCC, 2013). As a result, disasters (e.g., drought) have frequently occurred in the last two decades (Ashraf *et al*., 2020; Sadat *et al*., 2020, Sapir & Mami, 2019; Sharafati *et al*., 2019; IPCC, 2013). If extreme climate variability events grow at the current level, human beings will be very unwelcoming in the future (Gujree *et al*., 2017). The severe climate impacts may be long-lasting or irreversible (IPCC, 2007) and never wait for their turns, but consequences new risk drivers. For example, the effects of extreme climate events (precipitation deficits) last for years, and it causes long-term effects on socioeconomic and environmental systems (Guha-Sapir & Mami, 2019; Ishiwatari & Surjan, 2019). Increasing warming temperatures also seriously affected the agricultural sector of smallholder farmers in the arid and semi-arid areas of developing countries (Budhathoki & Zander, 2019; Esayas *et al*., 2019; Gebrechorkos *et al*., 2019; Gebrechorkos *et al*., 2018; Esayas *et al.*, 2018; IPCC, 2018; Bravo-Ureta *et al*., 2015).

Drought is a climate variability phenomenon that may exacerbate by human-induced factors and affects almost every corner of the world, even the wettest and most humid areas (Tian, 2019; Zarei, 2019; Masih *et al*., 2014; Dai, 2011; He *et al*., 2011). It is a disaster with a wide range of negative consequences for the environment and the economy (Chen *et al*., 2020; Yacoub & Tayfur, 2020; Tefera & Bello, 2019; Lu *et al*., 2015). Many individuals in various parts of the world are impacted by endemic drought, while others experience drought regularly (Reichhuber *et al*., 2019; Vernimmen *et al*., 2012). It is the primary cause of global food and water insecurity (Reichhuber *et al*., 2019). Drought frequently has a significantly larger spatial scope, which is non-structural and difficult to quantify (Gunten *et al.*, 2016; Borton & Nicholds,1989). This complex impact extends into many economic sectors and reaches beyond the area experiencing physical drought. While drought may occur in a season or a run of years, its impacts on society and environmental systems may remain for several years (Wilhite & Glantz, 1985). However, the effect depends mainly on society's vulnerability (Maru *et al.* 2021b).

In terms of famine, malnutrition, and food insecurity, drought is a major cause and consequence of poverty and resource depletion (Tsue *et al.*, 2014; Amekawa, 2011). Economically, drought has the highest impact of all-natural disasters, with billions of dollars of losses annually (Rajsekhar *et al.*, 2015). According to the Center for Research on the Epidemiology Disasters (CRED) and United Nations Disaster Risk Redaction (UNDRR)) (UNDRR-CRED, 2020) reports, from 2000 to 2019, 7,348 major disaster events occurred and lost 1.23 million lives, affecting about 4.2 billion people and consequences US$ 2.97 trillion in global economic losses. Between 1980 and 1999, about 4,212 disasters were linked to drought hazards worldwide. These hazards lost approximately 1.19 million lives and affected 3.25 billion people, and the impact was around 1.63 trillion in economic losses (UNDRR-CRED, 2020; Guha-Sapir & Mami, 2019). As the Emergency Events Database (EM-DAT) reports, from 2000 to 2019 worldwide, 1.4 billion people were affected by drought and related hazards. In the same years, different parts of Africa experienced approximately 134 droughts and associated risks. Of the 134 drought events in Africa, 70 have occurred in East Africa alone. These events affect the region more than any other part of the world (Gebrechorkos *et al*., 2019; Haile & Tang, 2019). Since 2005, drought frequencies have doubled in East Africa from once every six years to once every three years. Drought has been one of the causes of socioeconomic instability in the region (Haile & Tang, 2019). For example, frequent drought consequences crop failure, livestock, and human loss in different parts of Ethiopia (Eze *et al*., 2020; Esayas *et al*., 2018). The country will likely be exposed to drought due to climate variability, anthropogenic effects, and low resilience capacity (Eze *et al*., 2020).

On the other hand, parallelly, humans have been altering land cover since prehistory through the clearing of patches of land for agriculture and pastures (Angessa *et al*., 2019, Degife *et al*., 2018; Gollnow *et al*., 2018; Awoke *et al*., 2014; Awange & Kyalo, 2013; Richards & Remot, 2012). However, during the last three centuries, the global human population has increased dramatically, and people’s activities have become essential in global change processes (Dibaba *et al*., 2020; Das & Sarkar, 2019; Frankl *et al*., 2014).

Human activities on land have had a considerable impact and affect the entire landscape (Betru *et al*., 2019; Frankl *et al*., 2014; Meshesha *et al*., 2014; Minale, 2013; Lesschen *et al*., 2005). Human activities ultimately affect the earth's nutrient and hydrological cycles and climate systems (Balabathina *et al*., 2020; Betru *et al*., 2019; Degife *et al*., 2018). And further consequences of land degradation, desertification, and biodiversity loss (Dibaba *et al*., 2020; Gidey *et al*., 2017b; Selassie, 2015; Wolka *et al*., 2015; Minale, 2013). The change in land use profoundly impacts food security and increases human vulnerability worldwide (Chirwa *et al*., 2015). LULC change consequences long-lasting effects on the livelihood systems of the community that depend on rain-fed systems and their essentials (Albert *et al.*, 2020; Deribew & Dalacho, 2019; García-Llamas *et al.*, 2019; Slegers & Stroosnijder, 2008b).

Therefore, if drought and LULC change have a significant impact independently, their synergetic impact is greater on the livelihoods system (Chirwa *et al*., 2015) in the hotspot area for drought and LULC change. Their synergetic effect is not a simple sum of each impact, but it has higher synergetic effects when both are considered (Dosdogru *et al*., 2020). Frequent drought occurrences lead to LULC change with reverse feedback (Slegers & Stroosnijder, 2008). Further, drought impacts can trigger processes of land degradation and desertification (Agidew & Singh, 2017; Chirwa *et al.*, 2015; Tsue *et al*., 2014; Vicente-serrano, 2007) and, in addition, land degradation exacerbates vulnerability to drought (Reichhuber *et al*., 2019; Sahoo *et al*., 2017). Dosdogru et al. (2020) stated that when climate change and LULC change combined, frequent and extreme drought events will happen for hostages. These synergetic stresses and exogenous factors can double exposure and impact local communities' livelihood systems and ecosystem services (Bunce *et al*., 2010).

Synergetic impacts of drought and LULC change depend on the locations of the area, level of vulnerability, and the disadvantaged communities. As a result, proper synergetic risk reduction techniques and equal systemic reactions at the livelihood zone level are necessary. More up-to-date and scientific information about the synergistic effects of drought and LULC change will assist communities in adapting to low-risk agricultural activities and crop productivity through agricultural impute (Budhathoki & Zander, 2019). Therefore, an intensive study needs to capture the synergetic effects of climate variability, the frequencies, severity, duration, and spatial coverage of drought, LULC change impacts, and livelihood system drought vulnerability at the LZ. This study is essential for policymakers to develop synergetic responses on livelihood system levels.

For this purpose, the current research aimed to investigate the synergistic effects of drought and LULC on livelihood systems in three livelihood zones of the Northwestern Ethiopian Rift Valley. The study employs a socioeconomic survey, meteorological data, and LULC change trends, as well as drought vulnerability patterns, to investigate the synergetic impacts of drought and LULC change here on livelihood systems of the three study livelihood zones in Ethiopia's Rift Valley's Northwestern Escarpment.

1.2. Statement of the problem and rationale of the study

East Africa is the most vulnerable region to climate variability and extreme weather events, which are the main risks to agricultural activities and productivity (IPCC, 2007; Haile, 2005) and chronic crises rooted in socioeconomic issues (Gebrechorkos *et al*., 2019; Haile & Tang, 2019). For instance, due to climate variability events, Ethiopia is one of the most drought-prone countries in the world (Birara *et al*., 2020). This exposure is most likely due to climate variability, anthropogenic effects, and the low adaptive capacity of the community. The country is ranked the 22nd most vulnerable to address the impacts on agriculture (Teshome & Zhang, 2019; MOFA, 2018). Farmers in Ethiopia are susceptible to the threat caused by climate variability since most of their livelihood systems rely on weather-depending agricultural systems (Esayas *et al.*, 2019). An increasing dry spell (Maru *et al*., 2021), high rainfall variability (Eze *et al*., 2020), a significant increase in mean temperature (Esayas *et al*., 2018) and recurrent drought (Eshetu *et al*., 2014) significantly challenge the agricultural production and productivities of the country.

Frequently extreme climate variability has consequences of severe and frequent drought that drifts crop failure, livestock, and human loss in different parts of the country (Eze *et al*., 2020; Esayas *et al*., 2018). Droughts have struck the country regularly at ten-year intervals since 1965 (Andargie, 2014). However, droughts have been happening in two to three-year intervals in recent years (since 2000) (Gidey *et al*., 2018a,b). For example, according to the UN Office for the Coordination of Humanitarian Affairs (OCHA) drought report on 2-March 2022 https://reliefweb.int, in Ethiopia, about 6.8 million people have been affected, and more than 1.5 million livestock have died by the prolonged drought (from late 2020 to the report date march 2/ 2022) in Oromia, SNNP, and Somalia. The country is still susceptible to extreme climate impacts in the future due to climate variability, anthropogenic effects, and low capability.

Similarly, drought increases as a risk for farmers in Northern Ethiopia (Eze *et al*., 2020). Drought impact has been, and still is, the leading driving cause and exposure to periodic famine in Northern Ethiopia (Andargie, 2014; Kiros, 1991; Webb & Braum, 1990). Approximately 26 mild-to-severe droughts occurred between 1973 and 2016 in Northern Ethiopia (EM-DAT, 2017; Gebru & Beyene, 2012). Drought events have been happening for two to three years (since 2000) (Gidey *et al*., 2018a,b; Gidey, 2012). Drought is thus one of the strategic challenges in Northern Ethiopia that require serious mitigation measures at the local level.

Some authors, including Kenawy *et al*. (2016) across Ethiopia, Mohammed (2018) in Ethiopia's North East Highland, and Gidey (2012) in Tigray Regional State, confirmed the presence of locally embedded characters dry events. They recommend detailed climate extreme event studies at small-scale areas required to provide evidence for policymakers. The Raya Valley livelihood Zone (RVLZ), Alagie–Ofla livelihood Zone (ALOFLZ), and Tsirare Catchment Livelihood Zones (TCLZ) are among the most sensitive to climate variability, frequent drought impacts, and uncertainty. These livelihood zones (LZs) are vulnerable to extreme weather events and have limited capacity to adapt low–risk agricultural activities and increase crop productivity (Budhathoki & Zander, 2019). Since 2000, extreme dry events have become routine in the three LZs. Apart from the wet seasons, the area is dominated by dry weather, with severe dry events (Tefera & Bello, 2019; Gidey *et al*., 2018a,b,c; Gidey, 2012). Consequently, agriculture and livestock are frequently affected by extreme dry climate events in the study area (Tefera & Bello, 2019; Abrha & Simhadri, 2015).

On the other hand, due to LULC change in Ethiopia, the long-term biological productivity of the country was seriously affected (Kidane *et al*., 2019; Alemu *et al*., 2015; Masih *et al*., 2014). Centuries of land exploitation vastly reduced the productive capacity and diminished the ability of the land to withstand climatic anomalies (Balabathina *et al*., 2020, Emiru *et al*., 2018). The northern provinces of Ethiopia are areas where sedentary agriculture has been practiced for thousands of years (Andargie, 2014). Mainly, the northwestern escarpment of the Ethiopian Rift Valley is among the most drought-vulnerable, and centuries of relentless exploitation of the land have resulted in severe environmental alterations and destructions (Gidey *et al*., 2017a). Communities suffer from scarce grazing land, access to raw materials, fuelwood, and free space due to conversions to farmland. Cropland expansion (both big and small-scale farms) converted natural vegetation and grasslands in the RVLZ's northwestern escarpment areas. This conversion will have an impact on groundwater once more. It also can cause and exacerbate extreme climate events such as droughts.

Recent research has shown climate-related extreme events as the main drivers of LULC change and vice versa (Reef *et al*., 2015). Local alterations through land use and land cover occur in ways that frequently escape our notice (Betru *et al*., 2019; Degife *et al*., 2018; Selassie, 2015; Minale, 2013a). Studies in different parts of Ethiopia on LULC change (Balabathina *et al*., 2020; Betru *et al*., 2019; Gidey *et al*., 2017b; Selassie, 2015; Wolka *et al*., 2015) have addressed the urgent attention needed for LULC change problems.

Most studies in Tigray, particularly in southern Tigray (the current study area), focused on regional or zonal scales. Some studies focused on climate change, local community perceptions, food security, and drought. These studies revealed that rapid LULC changes exacerbated food insecurity and had social, environmental, and financial repercussions. Annys *et al.* (2016) and Demissie (2016) looked at the relationship between rainfall variability and land cover change due to spatial-temporal rainfall variability along the Ethiopian Rift Valley escarpment. Gidey *et al*. (2017a, 2017b) explored the modeling of spatial-temporal dynamics and evolution of land use and land cover (1984-2015) as well as future land use and land cover scenarios in Raya, Northern Ethiopia (2015-2033).

To summarize, drought and a change in LULC have long been recognized as the primary threat to Ethiopian food security (Berhe, 2011). Human environmental exploitation was to blame for the drought that precipitated the famine in Ethiopia between 1984 and 1985 (Andargie, 2014). Ethiopia's LULC change and drought trends imply additional hazards that will significantly impact the community's livelihood system (Betru *et al.*, 2019; Agidew & Singh, 2017). As a result, scientific evidence of synergistic effects of drought and LULC change on livelihood systems is critical for effective and proactive drought management and a sustainable land-use system in Ethiopia, especially for studying livelihood zones (Reichhuber *et al*., 2019).

Many synergy studies around the globe focused on climate policy are concerned with performances of single systems (mitigation or adaptations) aimed at simultaneously reducing climate impact with different regulatory levels. Makate *et al*. (2019) studied the effects of access to credit only, access to extension service, and the possible synergetic impacts of simultaneous access to credit and extension on adopting climate-smart agricultural technologies. Some studies (Bergh *et al*., 2021; Drews *et al*., 2020) use policy mix for synergy of mitigation and adaptations for climate impact reductions. Studying policy mix (mitigation and adaptation) has advantages for accomplishing multiple objectives with effectiveness, efficiency, and equity (Bergh *et al*., 2021). Adolph *et al*. (2020) studied supporting smallholders' decision making: managing trade-offs and synergies for sustainable agricultural intensification. Adolph *et al*. (2020) stated that addressing current and future global environmental change requires understanding the multifaceted interface between human and natural systems. Golfam and Ashofteh (2021) investigated the water-climate-agriculture nexus to determine synergies, trade-offs, benefits, and drawbacks regarding water management, food production, and climate change impacts. Huang *et al*. (2020) studied the synergetic effects of no-tillage and cover crops on soil carbon dynamics in a long-term maize cropping system under climate change. Lee *et al*. (2017) also identified the synergy effects of products, processes, marketing, and organizational innovations, considering the levels of innovation and industrial categories. Mckenna *et al*. (2019) found the synergistic interaction of the climate and land use driver that alters the function of wetland ecosystems.

Similarly, Orchard *et al*. (2020) investigated the synergies and trade-offs among the sustainable development goals. In the forest sector, Shari (2021) looked into the synergies and co-benefits of urban climate change mitigation and adaptation strategies. Rasul and Sharma (2016) also investigated the relationship between water, energy, and food security as climate change adaptation alternatives. Rahn *et al*. (2013) looked at potential synergies between climate change mitigation and adaptation in smallholder coffee production systems. Furter, Ravindranath (2007) explores and promotes synergy between mitigation and adaptation while addressing climate change. And Wang *et al*. (2020) uncover the synergistic effects of the main climatic factors and drought on maize yield.

Studying synergy is essential for reducing operating costs and efficient outcomes (Vinca *et al.*, 2021; Tong & Zhu, 2020; Beg *et al.*, 2011). I appreciated the studies I reviewed for their scientific contribution based on their priority areas. However, Schulte et al. (2020) stated that most studies on climate change and LULC change focused on either climate or land use domain effects on biodiversity sciences. They found synergetic effects cases in which climate change increases the impacts of LULC change on biodiversity. However, studies conducted so far did not systematically evaluate the synergetic effects of drought and LULC change on livelihood systems. They did not even cover all of the parameter combinations this study discussed. In addition, this study differs since it uses comprehensive data covering meteorological, Landsat images, ground surveys, socioeconomic data, reports, and reviews from scientific documents. Also, this study focuses on the livelihood systems at livelihood zone levels rather than most researchers did their study on agro-ecological zones only.

This study hypothesized that the synergistic drought and LULC change impacts on the livelihood system would be more significant than alone or as the sum of their results. Because drought and LULC change have feedback effects, their impact's frequency, magnitude, and geographic coverage are greater than the sum of independent or isolated influences. However, drought, LULC change, and the livelihood system have multiple dimensions, interactions (synergy), and biophysical and socioeconomic contexts that are not always directly comparable. There is no standard approach to define the interactions between drought, LULC change, and livelihood systems. The challenge is that the interaction and synergy impacts of drought and LULC change on the livelihood system of the local community are difficult to synthesize using an empirical formula that can ideally produce measurable outcomes.

Drought and LULC change offer a threat that requires a proactive policy strategy rather than a reactive one to handle. The overall purpose of such a strategy is to synergistically explore the impacts on the livelihood systems to reduce risks. Reducing the potential synergies and effects of drought and LULC change calls for a shift in strategy from a sector-specific emphasis to an integrated approach with policy coherence across sectors to maximize benefits and avoid negative consequences (Rasul & Sharma, 2016). This study can assist us in obtaining a comprehensive picture of possible combinations of drought and LULC change inputs for policy instruments that can aid in reducing their synergistic impacts on livelihood systems that directly influence household livelihoods. Therefore, our research generates new scientific inputs while adding to the existing literature of study disciplines.

1.3. Research Questions

1. What are the seasonal and annual climate variability trends and characteristics across and within the study livelihood zones? How do local communities perceive the climate variability trends (Temperature and Rainfall) in each livelihood zones?
2. What are seasonal and spatial meteorological drought frequencies, magnitudes, and duration trends across and within the three livelihood zones? How do local communities perceive the drought frequency and its impacts in each livelihood zones?
3. What are the trends and drivers of land use and land cover dynamics along the three livelihood zones? Are there any trends and drivers differences along the three livelihood zones?
4. How vulnerable are the livelihood systems to climate variability trends, drought impacts, and LULC changes along and within the three livelihood zones?
5. How does the synergy of drought, land use, and land cover changes affect livelihood systems within the three livelihood zones?

1.4. The objective of the Study

1.4.1. General Objective

The main objective of this study is to examine the synergetic impact of drought and land use and land cover changes on livelihood systems in the northwestern escarpment of the Ethiopian rift valley.

1.4.2. Specific Objectives

1. To investigate seasonal and annual climate variability trends and their characteristics across three livelihood zones of the study area
2. To characterize seasonal and spatial meteorological drought trends across three livelihood zones
3. To explore trends and drivers of land use and land cover dynamics in drought-prone livelihood zones along the three livelihood zones
4. To evaluate the vulnerability of livelihood systems to drought across three livelihood zones
5. To analyze the synergetic impact of drought and land use and land cover changes on livelihood systems along three livelihood zones

1.5. Scope of the Study

This study intended to see the interaction of four broad research areas: climate variability trends, metrological drought, land use and land cover change, and drought vulnerability and their synergetic impacts on livelihood systems at the level of livelihood zones. These areas are independently complex and broad to study in-depth. They need a deep understanding of their concept, knowledge in the area, and more research experiences. There are many ways to explore, with one “driving” the other “feedback” relationship of climate variability within drought, LULC change, drought vulnerability, and then reverses. There are also ways to study these four areas independently (Carr & McCusker, 2017).

The author applied four data sources in the study area's three livelihood zones to analyze the synergistic impacts of drought and LULC change on livelihood systems. Although this study is concerned with four major areas, the synergetic impact section used drought and LULC change as the main pillars, with climate variability trends and drought vulnerability as additional factors. This study looked at the common characteristics of livelihood stems influenced by those above four primary components synergistically. Not only do the four elements have a high synergistic effect, but they imply that a feedback relationship exacerbates the impacts. Areas that are only vulnerable to drought or LULC change do not have the same vulnerability as those susceptible to drought and LULC change.

Ethiopia's rural settings comprise pastoral, agro-pastoral, and agricultural livelihood zones, making it a land of contradictions. Based on economic geography, these three major livelihood zones are subdivided into 175. This study was limited to three livelihood zones that are more vulnerable to climate variability events, are frequently visited by drought impacts, and are considerably more susceptible to the effects of LULC change in the Northwestern Escarpment of Ethiopian Rift Valley. Livelihood zones are areas that have been grouped based on geographic similarities where households broadly share similar livelihood patterns, such as income sources and market opportunities, as well as demographic patterns rather than administrative boundaries (Zone & Teshale, 2019, Pricope *et al*., 2013). Since the perception levels, the decision of individuals, and the communities are affected by socioeconomic, geographical locations, and technological inputs, livelihood zones are fundamental to including these parameters under one umbrella. According to Maru *et al*. (2021b) and Mekonen and Berlie (2021), livelihood-based climate adaptation strategies are necessary to reduce agricultural susceptibility to climate change. Also, Mekonen & Berlie (2021) stated that livelihood-based adaption interventions are essential to mitigate agrarian livelihood system vulnerability to climate change. Therefore, studying the synergetic impacts of drought and LULC change on livelihood systems at the livelihood zone level is critical to cluster the exposure and susceptibility inductors to intervene with appropriate adaptation strategies in the livelihood systems.

Favorable meteorological conditions are essential for agricultural activities and sustainable livelihood developments. Measuring and forecasting the magnitude, intensity, spatial coverages, and frequencies of the meteorological conditions are crucial for farm activities. However, due to the small number of gauges and their distribution along the main roadways, Ethiopia has had difficulty measuring long-term historical meteorological data (Dinku *et al*., 2014). There are three early1980 and five since 1992 established metrological stations in the study area. However, there are missed records of metrological data for years from the early 1980 stations because of the long civil war in the area and recording errors (Dinku et al., 2014). Therefore, to analyze the vulnerability for drought frequency, drought intensity, temperature trends, rainfall trends, and rainfall variability, Climate Hazards Group InfraRed Rainfall with Station data (CHIRPS) as well as Enhancing National Climate Service (ENACTS) maximum temperature and minimum temperatures data at 4km–by–4km were collected from Ethiopian National Meteorological Agency. However, the availability of data, particularly metrological data, affected the length of years of this study. There was no grid data before 1983, and after 2016 the Ethiopian National Meteorological Agency is currently processing it. As a result, the author had to limit themselves to gridded meteorological data from 1983 to 2016. The used data sets were free of missing values to compute the rainfall and temperature trends. I collected the data from 231 gridded meteorological stations to deal with climate variability trends and their characteristics and metrological drought trends based on the magnitude and intensities of temperature and rainfall trends for Belg, Kiremt, combined rainy season (Belg and Kiremt), and annual time scales. Rain feed farming activities and productivities of the study area depend on the two seasonal precipitations (Endale *et al.,* 2020).

The SPI and SPEI index for drought measurements are widely used across the globe. SPI is a drought measuring index which requires only long recorded precipitation data as input requirements (Liu et al.,2016) which is important to study the relative departure of precipitations from normality (Zeleke, 2017). Besides its advantages, practical applications of SPI have some limitations where it uses only a single meteorological element to describe a complex event. In addition, it does not consider other meteorological parameters influencing drought severity (Zeleke, 2017). Therefore, the SPEI index was used for this study to fulfill the SPI index gaps. SPEI index is used to calculate climate water balances and drought assessments. The SPEI combined the Palmer Drought Severity Index (PDSI) with the simplicities of calculation and the multi-temporal nature of the SPI (Vicente-Serrano et al., 2012).

Landsat image has high positive implications for monitoring spatiotemporal landscape changes globe-wide (Alawamy *et al*., 2020; Hailu *et al*., 2020; Angessa *et al*., 2019; Alemu *et al*., 2015). For studying the LULC dynamics of the study area, Landsat images were downloaded (1985, 2000, 2010, and 2019) from the United States Geological Survey (USGS. The author considered Landsat images (study years), the interval of the years, and seasons with required image quality and those more likely cloud-free and less affected by moisture between December and February. In addition, Landsat 7 ETM+ Images after May 2003 had scanline errors. To avoid data gaps, the researchers used the 2010 Landsat image. Due to the lack of full satellite images for the study area on the same day, the author used different paths and rows of satellite images.

1.6. Literature Review

1.6.1. Conceptualizing Drought

Drought is indiscriminate in terms of geography, climate, and political boundaries. It happens in virtually all climatic zones and most parts of the world. Still, their characteristics and impacts on society vary significantly by region and country (Au, 2011). The existing tendency among professionals, politicians, managers or ordinary people is to consider drought a natural hazard. However, it results from a combination of biophysical factors that anthropogenic influences can enhance. The primary cause of any drought event is a deficiency in precipitation and, in particular, the timing, distribution, and intensity of this deficiency with the existing water storage, demand, and use (Nosrati & Zareiee, 2011).

Droughts are regional, and each region has specific climatic characteristics (WMO, 2012). While it might appear attractive for all agencies to adopt a standard operational definition of drought, it cannot account for physical, economic, and social differences between areas and countries (Borton & Nicholds, 1989). Thus, it should be considered a relative rather than absolute condition. Therefore, a generally accepted definition of drought in this study is a dry weather period that lasts several weeks to months, with little or no accumulated rainfall (Vernimmen *et al.,* 2012). Such dry weather events significantly impact water resources, agriculture, forestry, hydropower, health, and socio-economic activities (Rajsekhar *et al.,* 2015).

Rajsekhar *et al.* (2015) classified droughts into meteorological, hydrological, agricultural, and socioeconomic. The first three physical drought types are associated with a deficiency in a characteristic hydro-meteorological variable (WMO, 2012; Lu, 2011; Borton & Nicholds, 1989). Meteorological definitions of drought are the most prevalent (Wilhite & Glantz, 1985). It is the earliest and the most explicit event in the occurrence and progression of drought conditions (Kumar *et al.*, 2009). Meteorological drought occurs when there is a shortage of rainfall in a specific area (Gunten *et al.*, 2016; Tsue *et al.*, 2014). It is a month to a year with below-normal precipitation (Dai, 2011) and prolonged dry weather conditions due to precipitation departure (Rossi, 2011).

On the other hand, hydrological drought happens when a river, streamflow, and water storage in aquifers, lakes, or reservoirs fall below long-term average levels (Rajsekhar *et al.*, 2015). Rather than the meteorological cause for the event, hydrologic droughts are concerned with the effects of dry spells on surface or subsurface hydrology (Tsue *et al.*, 2014; Wilhite & Glantz, 1985). The frequency and severity of hydrologic drought often influence river basins. Groundwater droughts can occur as a result of complicated hydrological processes. Due to excessive consumption, the aquifer may be exhausted (Narasimhan, 2004). Geological changes that shut off parts of the aquifer, areas that draw water from underground aquifers through wells and holes may experience hydrological drought (Gunten *et al.*, 2016; Mavromatis, 2012; Dai, 2011).

Further, agricultural drought results from meteorological and hydrological droughts (Borton & Nicholds, 1989). The onset of a meteorological drought may flow agricultural drought depending on the prior moisture status of the surface soil layers. Dryness in the surface layers, which occurs at a critical time during the growing season, can result in an agricultural drought (Rajsekhar *et al.*, 2015). Therefore, agricultural drought is when dry soils result from below-average precipitation, severe but fewer rain episodes, or above-normal evaporation, resulting in decreased agricultural yield and plant development (Gunten *et al.*, 2016). The total amount of rainfall may be average within a year, yet extended dry spells within the rainy season may cause complete or partial crop failure (Slegers & Stroosnijder, 2008). When rainfall inputs and soil moisture are inadequate to support healthy crop growth conditions, the prevalence of crop stress and crop yield losses will increase (Contreras & Hunink, 2015). Understanding the linkages between meteorological and agricultural drought is critical for understanding the effects of water scarcity on crop production and triggering actions to prevent and mitigate their impacts timely (Narasimhan, 2004).

Crops have a particular temperature, moisture, and nutrient requirements during their growth cycle to achieve optimum growth. The weather circumstances determine the amount of water required by a plant, the biological physiognomies of the specific plant, its stage of development, and the physical and biological properties of the soil (Wilhite & Glantz, 1985). In the plant’s emergence stage and the locations of crop development, a plant is especially vulnerable to dry weather conditions. The timing of dry spells during a crop season is crucial for later crop development or survival. However, if subsurface moisture shortages persist, crop growth will be hampered, resulting in a significant yield loss (Nairizi, 2017).

As mentioned above, understanding the linkages between meteorological and agricultural drought is critical. Agricultural drought impact is difficult to measure because of its interactions with different factors (Borton & Nicholds, 1989). A fall in products may be due to insufficient moisture. Still, it may also stem from, or have been exacerbated by, such factors as the unavailability of fertilizers, lack of weeding, pests and crop diseases, the lack of labor at critical periods in the growth cycle, and unattractive crop prices. Also, these factors can interact with each other and exacerbate conditions (Nairizi, 2017).

Socio-economic drought expresses the socio-economic effects of drought and can also incorporate the above three drought types (Amekawa, 2011). On the other hand, socioeconomic drought impact is distinct from the three drought types. It represents the supply and demand for a product or economic goods dependent on precipitations ((Tsue *et al.*, 2014). Socio-economical droughts also deal with water-resources management failing to meet water supply and demand (Gunten *et al.*, 2016).

To sum up, meteorological drought is a cause of all drought types and their impacts (Tsue *et al.*, 2014; Amekawa, 2011). Therefore this study preferred to study meteorological drought types at seasonal and annual time scales to see their effects on the livelihood systems of the study livelihood zones.

1.6.2. Conceptualizing Land Use and Land Cover Change

The goal of the application and the context of their use influence the definition and description of land, land cover, and land use (Awange &Kiema, 2013). The direct relationship and essential characteristics and processes of land use and land covers, such as land productivity, the diversity of plant-animal species, and the biochemical and hydrological cycles, have piqued the public's attention (UNCCD, 2012; Steve, 2001). Levin (1999) defines land cover as the biophysical state of the earth’s surface and immediate subsurface, including biota, soil, topography, surface and groundwater, and human modifications such as the construction of roads and buildings (Minale, 2013a). Land-use changes continue to shape and reshape land cover. The purposes for which humans exploit land cover are called land use (Eric *et al.*, 2014). It entails how to land's biophysical properties are modified and manipulated, such as why the land is used (Awange & Kiema, 2013).

LULC change is a general term for the human modification of the earth’s terrestrial surface (Li *et al.*, 2014). LULC is always dynamic when it constantly changes the dynamic interaction between underlying drivers and proximate causes (Damtew *et al.*, 2021). Multiple interacting causes emanating from different levels of organization of the coupled human-environment systems constantly induce land-use change (Awange & Kiema, 2013). Conversion and modification are the two most typical LULC changes (Awoke *et al.*, 2020). Agricultural development and deforestation are examples of land conversion, which involves replacing one land cover type with another. On the other hand, land cover modification refers to changes to the land's character that do not impact its overall classification (Awoke *et al.*, 2014; Minale, 2013a).

1.6.3. Conceptualizing Livelihood Systems

The concept of livelihood is about individuals, households, or groups making a living, attempting to meet their various consumption and economic necessities, coping with uncertainties, and responding to new opportunities (Niehof, 2004). As cited by Niehof (2004), Chambers and Conway (1992) describe livelihood as the capabilities, assets (natural, physical, human, financial, and social capital), and access to these assets (mediated by institutions and social interactions) that all contribute to the individual or household's standard of living. These definitions reveal that livelihood is a multifaceted concept, being both what people do and what they accomplish by doing it (Chirwa *et al.*, 2015). According to the Niehof & Price (2001) definition, livelihood is a system (livelihood systems) that may entirely depend on agriculture, linked agriculture, and non-linked agriculture. For example, in drylands, agroecosystems are a complex mix of pastoral, agro-pastoral, rain-fed, and irrigated farming methods (Ginkel *et al.*, 2013). Based on these concepts, livelihoods encompass mainly assets, activities, and access to these assets.

Therefore livelihoods encompassed different kinds of livelihood systems. Furthered according to (Niehof, 2004), livelihood systems are composed of various components: inputs (resources and assets), output (sustainable livelihood), purpose (meeting basic needs), activities (livelihoods generation or composition), agency (efforts to achieve livelihood adequacy), quality (degree of vulnerability the livelihood produced), environment (context within which livelihood system functions interfaces with other systems and institutions) and locus (the household as the locus of livelihoods generations).

Rural livelihood systems are studied in different nomenclatures by scholars (agricultural livelihood heterogeneity (Le, 2015), livelihood system assessment (Petare *et al.*, 2016), smallholder mixed crop-livestock systems (Amejo *et al.*, 2019), and agricultural livelihood systems (Meylan *et al.*, 2021). The livelihood systems of the study communities are mainly dependent on mixed crop-livestock systems. As a result, the author established the components of the current research on livelihood systems based on the mixed crop-livestock methods of the study livelihood zones. Therefore, since this study used a sustainable development framework, the author used the three main components of livelihoods systems (assets, activities, and access to these assets) to analyze the synergetic impacts of drought and LULC changes on the livelihood zones of the study.

1.6.4. Conceptualizing Synergy

Nature is surrounded and sustained by many synergetic phenomena (Eye *et al*., 2015). Synergetic phenomena are everywhere around us (Corning, 1995). However, the idea is more holistic than segregated measures (Wanga *et al*., 2019). In recent years, there has been a rising quest to study the synergy, for example, between mitigation and adaptation for policy efficiency and effectiveness for climate change issues (Duguma *et al*., 2014). Drews *et al*. (2020) compared the effectiveness of incentives and nudges in the energy policy mix. They observed behaviors using a price incentive alone, a nude alone, a price incentive and nudge, and control group treatments. They stated that the effects of combining the two instruments are higher than the exact sum of the isolated impacts (Etana *et al*., 2021). According to (Bergh *et al.*, 2021; Drews *et al.*, 2020; Schulte *et al.*, 2020; Duguma & Minang, 2014; Eye *et al.*, 2015;), there are two synergies: additive and nonadoptive synergy types. According to them, additive synergy is the type of synergy in which the desired effect or outcome is the sum of the independent products of the parts or systems (Equ.1.1). In synergetic impacts, where it is positive or negative, two or more components are working together to achieve jointly defined or undefined goals that match all involved parts/systems (Dosdogru *et al.*, 2020).

$$V(X_1) + V(X_2) + \cdots V(X_n) = V(X_1 + X_2 + \cdots X_n) + I \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..1$$

Where x_1, x2,….,x_n represent intervention/(systems in our cases), V stands for values/ outcome effects, and for the additive synergy case, I is an interaction term that is zero.

There are three types of nonadoptive synergy: super-additive, sub-additive, and isolated. In super-additive synergy ($I>0$ in Euq.1.1), the underlying principle is that the whole concept is greater than the sum of the parts. There is a more significant outcome when the components interact (Drews *et al.*, 2020; Schulte *et al.*, 2020). In the sub-additive synergy model ($I<0$ Euq.1.1), the aggregate effect when the intercessions act together is less than the amount of the outcomes of the individual intervention (Bergh *et al*., 2021). The third nonadditive synergy type is that isolated synergy (I depends on the specific set of X considered in Euq.1.1) involves interaction between agents, irrespective of their particular effects (Eye *et al*., 2015). Therefore, the current study used the super-additive synergy theory to investigate the synergetic impact of drought and LULC change on livelihood systems in the study zones.

The study hypothesized the synergetic impacts of drought and LULC change on livelihood systems (Figure1.1) in three livelihood zones, with four examples, using Drews *et al*. (2020) and Bergh *et al*.(2021) paradigms. I. No synergy (Additive separable): Total impacts on the livelihood system are the impacts of the sum of the drought and LULC change impacts when other factors are constant, meaning that there are no synergistic interactions (the methods are independent and complementary). II. Positive synergy (Supper additive): Drought influences exacerbate LULC change and other factors in this situation (e.g., vulnerability). LULC change reverses induce drought and other factors that affect the livelihood systems (A positive interaction effect is at stake). III. Weak negative synergy: This case reflects that drought impacts or LULC change weaken one another (reducing the impacts of one another on the livelihood system). The interaction between drought and LULC change is negative, and the results are variably known as substitutability. In this case, appropriate and intelligent land use management can reduce drought impacts. These systems can partially replace each other. IV. Strong negative synergy (backfire): Here, the assumption is that the synergy impacts of drought and LULC change on the livelihood system signify that one of the systems offsets the effects of the other, resulting in the joint system reducing the impacts to zero, compared to the impacts of drought or LULC acting alone.

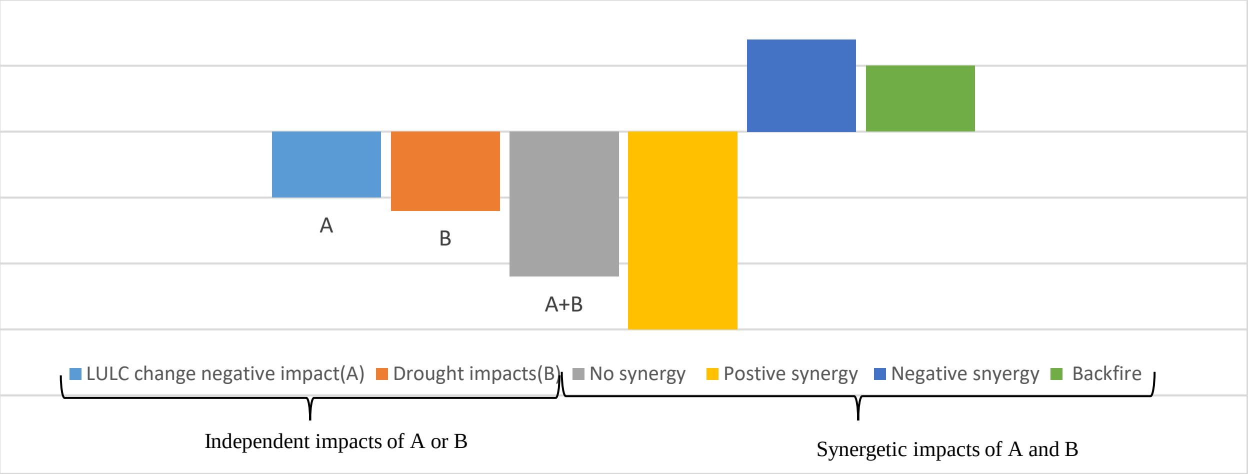

Figure 1.1. Framework for synergetic impacts of drought and land cover change in the livelihood system at the level of the livelihood zone. Adapted from Drews et al.(2020) and Bergh et al. (2021).

1.7. Description of the Study Area

1.7.1. Biophysical Settings

Three livelihood zones in four southern Tigray districts comprise the research area, covering 3809 km^2. In the Northwest escarpment of the Ethiopian rift valley, the area is located between 12^{o} 20'0" and 12^{o} 50'0" N latitude and 39^{o} 10'0" -39^{o} 53'41.7" E longitude (Figure 1.2). The RVLZ is located in the Alamata and Raya Azebo woredas administrative regions. However, the ALOFLZ is found in the administrative regions of Ofla, Endamehoni, and Alaje woredas. Further, the administrative regions of the TCLZ are Ofla, Endamehoni, Alamata, and Alaje woredas. The study area's main source of revenue is mixed agricultural production (Abrha & Simhadri, 2015). The rainfall distribution of the study area is bimodal and receives relatively high rainfall in July and August, with medium rainfall from March to May.

Topography

The study area's topography includes mountains, plateaus, valleys, and gorges. The area is characterized by semi-arid and sub-humid climates and consists of dry Kola (500–1500 m.a.s.l), dry Woinadega (1500–2300 m.a.s.l), dry Dega (2300–3200 m.a.s.l) and High Dega (wurch) (above 3200 m.a.s.l) agro-climatic zones (Hurni & Zeleke, 2018)**.**

The RVLZ has dry Woinadega and dry Kola agro-climatic zones with 1447 Km^2 and 386 Km^2**,** respectively. RVLZ is a flat plain dominated by deep undifferentiated alluvial, lacustrine, and beach sediments. These sediments are bounded east and west by Ashangi formation, a series of volcanic rocks characterized by deeply weathered alkaline (olivine) and transitional basalt flows with tuff intercalations, rare rhyolites from fissures and dissected by dikes and sills (Tadesse *et al.*, 2015). The soil texture at the site is predominantly clay loam, deep black, and has a higher capacity to hold water and nutrients (Mehari & Hailu, 2019). The primary soil types in the research area are Vertisols, Leptosol, Cambiosol and Fluvisols, which are abundant in farmlands (Figure1.3).

The ALOFLZ has dry dega and high dega agro-climatic zones, respectively, with 1035 Km^2 and 52 Km^2. Tertiary basalt, alkali-alluvial basalt, and tuff make up the underlying geology of ALOFLZ (Birhane et al., 2020). Slightly dissected to mountainous terrain, sloping to fairly plunged mountain terrain, severely dissected valley, and gently sloping valley describes the area's topography. Exposed rocks appear as boulders and rock outcrops in degraded areas. Leptosols, which are shallow and found on the slopes, and Regosols, heavy deposits found in valley bottoms, are the geology of the most common soil (Birhane *et al.*, 2020). With a 933.56 km^2, TCLZ contains dry Woinadega and dry dega agro-climatic zones. With mild acacia shrub scrub, the environment is uneven and rocky in TCLZ.

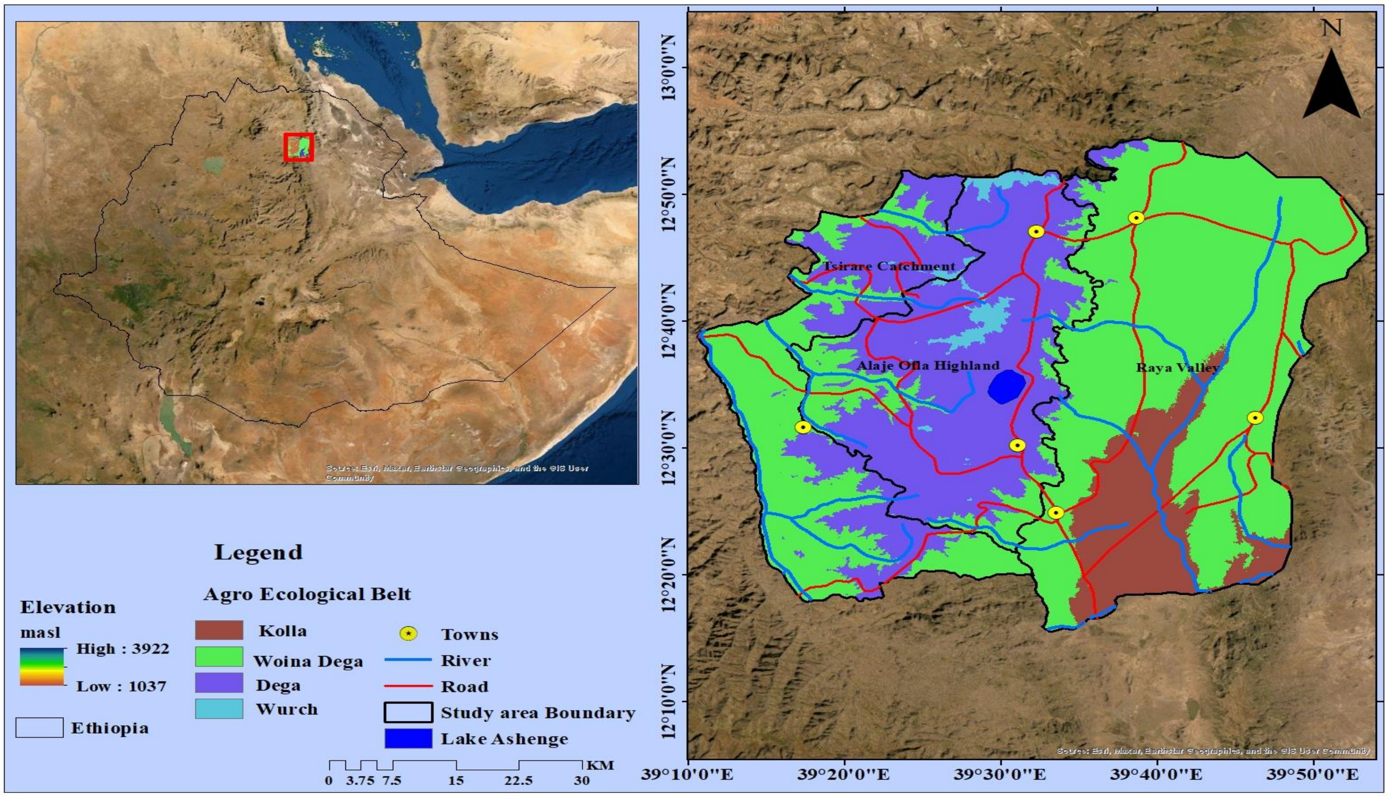

Figure 1.2. The geographical location of the study area

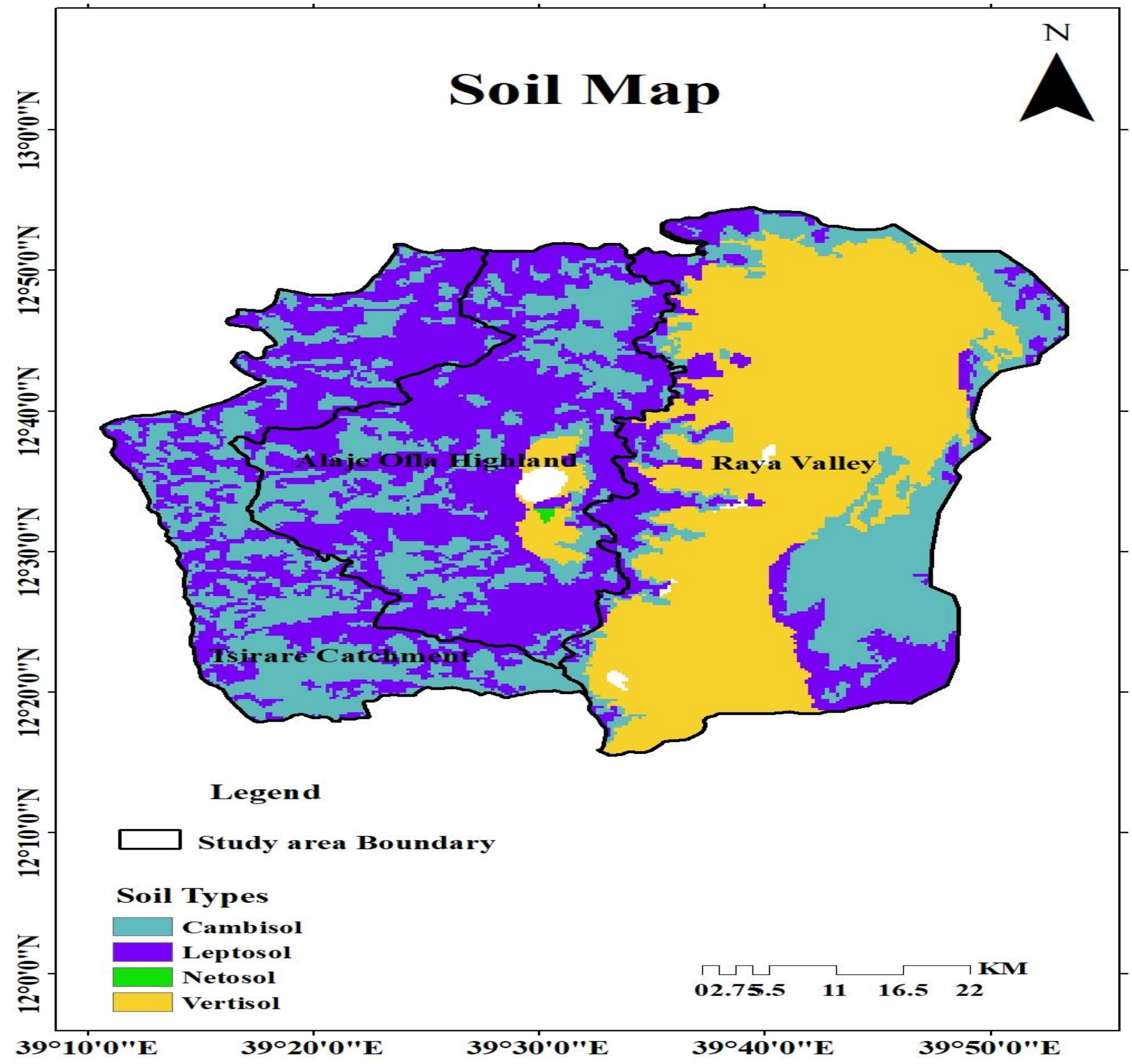

Figure 1.3. The major soil type of the study area. Source: Water and Land Resources Information System (WALRIS) at www.wlrc-eth.org through the MapServer Ethiopia platform.

Climate

The rainfall distribution pattern of the study area is bimodal and receives relatively high rainfall in July and August, with medium rainfall from March to May (Figure 1.4). The Belg (short rainy season), which lasts from March to May, and the Kiremt (major rainy season), which lasts from June to August, are the two rainy seasons (Amha *et al.*, 2018). The annual average maximum temperature of the RVLZ is 27.9 °C, with an annual average minimum of 13.5 °C (Nasir *et al.*

2021b). Rainfall and temperature vary depending on the altitude of the RVLZ (Fenta & Kifle, 2015). Besides, the RVLZ receives an annual rainfall of 164-972 mm (Nasir *et al*. 2021b). The ALOFLZ receives an annual rainfall of 126-1037 mm (Nasir *et al.* 2021b). The maximum annual mean temperature of the LZ is 22.116°C, with a minimum mean annual temperature of 9.753 °C. The ALOFLZ receives yearly rainfall of 119-932mm. The maximum annual mean temperature of the TCLZ is 24.9 °C, with a minimum mean annual temperature of 11.2 °C. The TCLZ receives yearly rainfall of 119-932mm.

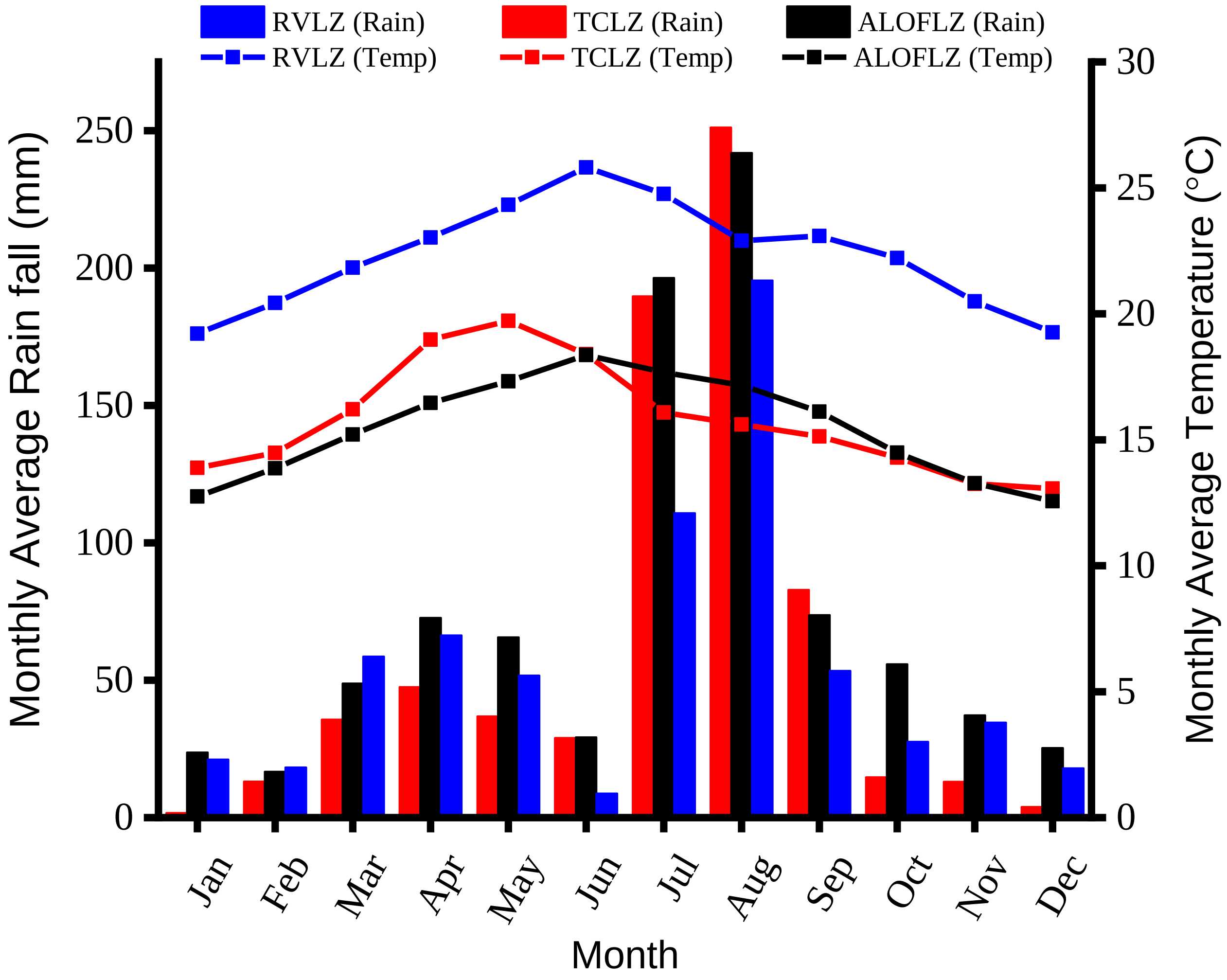

Figure 1.4. Mean monthly rainfall and temperature of the study livelihood zones. Source: observed data from Ethiopian Meteorology Agency. Note: The meteorological data were from 1987-2019 in RVLZ, 1989-2019 in ALOFLZ and only 2008-2019 in TCLZ.

1.7.2. Socioeconomic settings

Mixed agricultural production is the main income source in the study area (Abrha & Simhadri 2015) (Table 1.1). Based on Ethiopian Central Statistical Authority (CSA) census (2007), the RVLZ had 281416 populations with 154 population density (population number /Km^2) in 2019. For spatial population density of the study area, see (Figure1.5). A groundwater resource is supposed to be the vast water resource in the area. Crop and animal production are crucial to the area residents' survival. Sorghum, maize, barley, and teff are the predominant crops grown in the zone during the Kiremt (main rain) and Belg (small rain) seasons. Chat, red onion, coffee, tomato, and citrus fruits are also farmed (Sertse *et al.*, 2021). At the same time, the RVLZ produces high-value tree crops such as Mangifera indica, Persea Americana, Papaya crack, and Psidium guajava (Hagos *et al.*, 2018). The weeding and harvesting season, which runs from August to December, is also a source of labor for immigrants. Animals raised in RVLZ include cattle, camels, goats, sheep and chickens. Climate change has jeopardized rural livelihoods (Sertse *et al.*, 2021). The frequency of droughts and intra-seasonal rain variations is increasing. The combination of high temperatures and strong solar radiation resulted in extremely high potential evapotranspiration, which far outweighs rainfall in all months (Mehari & Hailu, 2019).

Based on Ethiopian Central Statistical Authority (CSA) census (2007), the ALOFLZ had 270388 populations with 249 population density (population number /Km^2) in 2019. The ALOFLZ's main agricultural activity is a mixed farming system, including crop and livestock production (Gebru *et al.*, 2019). Teff, sorghum, barley, wheat, maize, millet, and pulses like pea and chickpea are the most common food crops planted in the study areas (Hagos *et al.*, 2018; Hurni & Zeleke, 2018). Mekuriaw *et al*. (2018) also reported that potatoes are sometimes cultivated in the high-dega (wurch) areas. In ALOFLZ, Malus pumila (Domestica apple) is simultaneously generated in huge quantities (Hagos *et al.*, 2018). Cattle, sheep, goats, and equines such as donkeys, horses, and mules are among the most common animals raised in the zone (Gebru *et al.*, 2019).

Based on Ethiopian Central Statistical Authority (CSA) census (2007), the livelihood zone had 70,843 populations with 76 population density (population number /Km^2) in 2019**.** Short April rains precede the main rainy season in June in TCLZ. In May, the short rains facilitate planting long cycle sorghum varieties. In July, short cycle barley, wheat, teff, and bean are planted **(**Source: Disaster profile of Almata Woreda). Livestock is valuable as a source of income as well as food. Cattle and goats are the most popular livestock.

Hand-dug wells, springs, and rivers collect water used for human consumption in TCLZ. Poor production and a high reliance on the market for household food consumption demands define this livelihood zone. This zone is food insecure because of weak soil fertility and irregular rainfall patterns. Migrant labor and honey production are other major livelihood choices in the area. Land degradation is the riskiest to crop production in the zone. Soil erosion and poor soil conservation efforts are causing declining soil fertility. Land deterioration is exacerbating the zone's overall paucity of cultivable land. Pest infestations are also a constant threat. Shoot fly attacks teff, stalk borer, which attacks sorghum, and aphids and rodents, which target barley and wheat, are the most prevalent pests that assault crops. Internal parasites and bovine and ovine pasteurellosis are the most common livestock diseases. Newcastle disease wreaks havoc on chickens.

Source: https://www.yumpu.com/en/document/view/28046738/tsirare-catchment-livelihood-zone-report

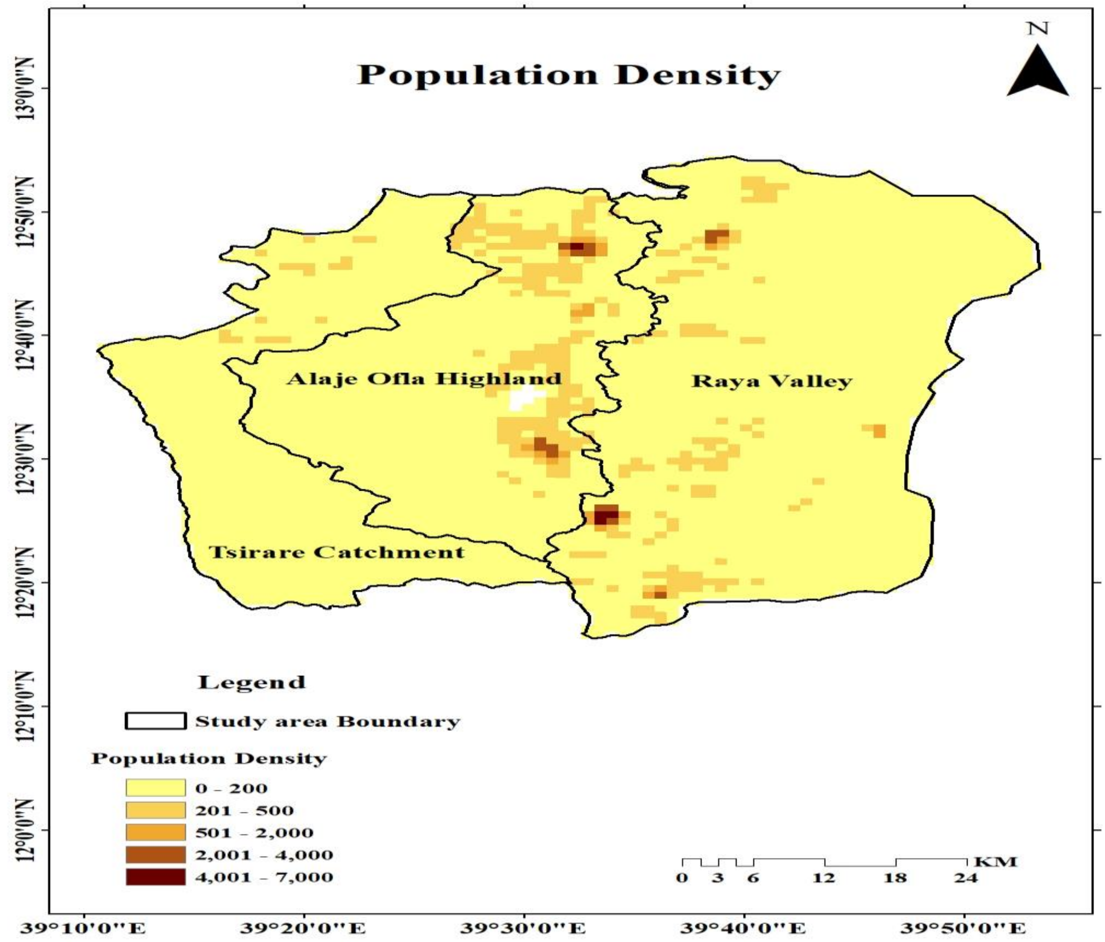

Figure 1. 5. Population density of the study area in 2016 source: Ethiopian Central Statistical Authority (CSA*)*

Table 1.2 Summer of the study livelihood zones biophysical and socioeconomic characteristics

Characteristics	Sub Characteristics		Livelihood zones		
			ALOFLZ	RVLZ	TCLZ
Biophysical Settings	Topography		Mainly Highlands	Mainly Lowland	Mainly Midland
	Major Soil types		Mainly, Cambiosol, followed by Leptosol, Vertisols, and Netosol,	Mainly Vertisols followed Leptosol, Cambiosol, and Fluvisols,	Vertisols and Leptosol
	Climates				
		Agro-climatic zones	(Dry Dega and High Dega)	(Dry Woinadega and dry Kola)	Dry Woinadega
		Annual rainfall	126-1037 mm	164-972 mm	119-932mm
		Annual average maximum temperature	22.116°C	27.9 °C	24.9 °C
Socioeconomic settings	Population number in 2019		270388	281416	70,843
	Population density/Km^2 in 2019		249	154	76
	livelihoods	Mixed system	Crop dominate systems	Crop and livestock	Crop and livestock
		Water sources for farming	Mainly Rain feed	Rain feed, spate/ traditional irrigation, and drip irrigations	Mainly Rain feed
		Mainly cultivated crops	Teff, sorghum, barley, wheat, millet, and pulses	Sorghum, maize, barley, teff, Chat, red onion, coffee, tomato, and citrus fruits	Barley, wheat, teff, and bean
		Mainly reared livestock	Cattle, sheep, goats, and equines	Cattle, camels, goats, and chickens	Cattle, goats and apiaries
	Major threats		Land degradation and high population pressures	Droughts and intra-seasonal rain variations	Irregular rainfall patterns, Land degradation and Pest infestations

1.8. Structure of the Dissertation

There are six chapters in this dissertation. Chapter one discusses the background, literature review, statement of the problem and rationale of the study, research questions, general objective, specific objectives, the scope of the study, description of the study area and dissertation organization. Independent publications are presented in chapters two through six, with an abstract, introduction, materials, methods and data settings, results and discussions, conclusion, and recommendations.

Chapter 2 is concerned with modeling seasonal and annual climate variability trends and their characteristics within and across the study livelihood zones. This chapter contributes to discovering the maximum and minimum temperature and rainfall trends and variability at seasonal and annual time scales. Chapter 3 investigates seasonal and spatial patterns of meteorological drought across the three livelihood zones. Chapter 4 looked at the trends and drivers of land use and land cover dynamics in three drought-prone livelihood zones.

The study model the vulnerability of livelihood systems to drought along with and within livelihood zones in chapter 5 using the results of Chapters 1, 2 and 3 and other internal and external factors. This chapter adds to understanding how communities' livelihood systems are sensitive to drought based on integrated data directly affecting their livelihoods. Chapter 6 analyses the synergetic impacts of drought and LULC changes on livelihood systems at livelihood zone levels. This chapter used four key results (chapters 1,2,3, and 4) to discover synergistic effects on the livelihood systems of the community. The dissertation discussed major findings and ramifications in the final chapter (chapter 7). The final chapter also elucidated policy and strategy implications and contributions from science and society. This chapter summarized the study's scientific contributions to policy implications and future research directions for scientific communities.

2. Chapter Two: Modeling seasonal and annual climate variability trends and their characteristics in the Northwestern Escarpment of Ethiopian Rift Valley

Abstract

Climate variability is a serious threat to the livelihood of smallholder farmers in the Northwestern Escarpment of the Ethiopian Rift Valley. Raya Valley livelihood Zone (RVLZ), Alagie-Offla livelihood Zone (ALOFLZ), and Tsirare Catchment Livelihood Zones (TCLZ) are among the most chronically food-insecure livelihood zones of the area due to climate variability events and other anthropogenic factors. This study aimed to analyze the seasonal and annual climate variability trends and their characteristics in the three livelihood zones (LZ). To analyze trends of temperature and rainfall as well as rainfall variability, both the monthly Climate Hazards Group InfraRed Rainfall with Station data (CHIRPS) and Enhancing National Climate Service (ENACTS) Maximum (Tmax) and minimum (Tmin) temperature at moderate spatial resolution (4km–by–4km) acquired from the National Meteorological Agency of Ethiopia (1983–2016). The Mann Kendal Test (MKT), Sen's Slope Estimators (SSE), and coefficient of variation (CV) statistical tests were applied to analyze the data. The findings revealed temperature trends in the study area that corresponded to the expected global temperature shift of 0.3 °C in 2016 to 0.7 °C in 2035. Annual *T*min of MKT and SSE indicated minimum temperature increased with statistical significance in all study LZ. The MKT annual *T*min was 0.319, 0.301, and 0.273 °C in ALOFLZ, TCLZ, and RVLZ, respectively. Besides, statistical significance annual *T*max is rising 0.323 °C per year in the TCLZ and 0.419 °C per year in the RVLZ. The Belg MKT records show that the *T*max trend increased significantly by 0.301, 0.401, and 0.430 °C in ALOFLZ, TCLZ, and RVLZ, respectively. Besides rainfall trends, only the Kiremt rainfall shows significant trends with SSE magnitudes of 8.081 in the RVLZ and 8.511 in the TCLZ. However, high seasonal and annual rainfall variability was recorded in all LZ. The Belg rainfall variability (i.e., 64.01, 69.66, and 64.85%) was higher than Kiremt (45.71, 43.95, and 46.31%) and annual (34.4, 35.12, and 31.62%) rainfall variability in ALOFLZ, TCLZ, and RVLZ correspondingly. Analysis of climate variability trends using MKT and SSE and long recorded data from uniformly distributed meteorological grids have high implications for revealed trends and characteristics of climate variability at LZ levels. The combined rapidly warming temperatures and increased rainfall irregularities imply possible future effects on agricultural productivity and increasing evapotranspiration demands that will affect the agricultural productivity of smallholder farmers. Thus, agriculture development practitioners and policymakers should consider the seasonal variability of the rainfall in the livelihood zones for future productivity improvement.

Keywords: Belg, Climate variability, Kiremt, Livelihood zones, Rainfall, Temperature

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2.1. Background

Climate changes and variabilities since 1950 have been increasing globe-wide (IPCC, 2013). As a result, disasters (e.g., drought and floods) have frequently occurred due to climate change and variability in the last two decades (Ashraf *et al*., 2020; Sadat *et al*., 2020; Sapir & Mami, 2019; Sharafati *et al*., 2019; IPCC, 2013). If the extreme weather events grow at the current level, the human being will be very unwelcoming in the future (Gujree *et al*., 2017). Studies (Djalante, 2019; IPCC, 2018) reported an average of 1.5 ⁰C temperature increases globally. Increasing warming temperature and climate variability seriously affect smallholder farmers' agricultural sector in developing countries' arid and semi-arid areas (Budhathoki & Zander, 2019; Esayas *et al*., 2018, 2019; Gebrechorkos *et al*., 2018, 2019; IPCC, 2018; Bravo-Ureta *et al*., 2015). East Africa is the most vulnerable region to climate variability and extreme weather events, which are the main risks to agricultural activities and productivity (IPCC, 2007; Hail, 2005) and chronic crisis roots in socioeconomic issues (Gebrechorkos *et al*., 2019; Haile & Tang, 2019). For instance, Ethiopia is one of the most drought-prone countries globally (Birara *et al*., 2020). The country is ranked the 22nd most vulnerable to address the impacts on agriculture (Teshome & Zhang, 2019; MOFA, 2018). Farmers in Ethiopia are vulnerable to the threat caused by climate variability since most of their livelihood systems rely on weather-dependent rain-fed agricultural systems (Esayas *et al*., 2018, 2019). An increasing dry spell (Maru *et al*., 2021), high rainfall variability (Eze *et al*., 2020), substantial rise in mean temperature (Nnaemeka *et al*., 2020), and frequent extreme events (Eshetu *et al*., 2014) significantly challenge the agricultural production and productivities.

The rainfall condition of northern Ethiopia is complex in terms of seasonal and spatial climate patterns and uncertainties (Haile & Tang, 2019) which is one of the most determinants of the livelihood system in the area (Esayas *et al*., 2018). The three livelihood zones of the study area include the Raya Valley livelihood Zone (RVLZ), Alagie–Ofla livelihood Zone (ALOFLZ), and Tsirare Catchment Livelihood Zones (TCLZ), are among the most vulnerable area to climate variability events and uncertainties. These livelihood zones (LZs) are prone to extreme climate events and adapt to low–risk agricultural activities and crop productivity (Budhathoki & Zander, 2019).

Scientific climate information helps communities adapt to low-risk agricultural and crop production practices through agricultural technology impute (Budhathoki & Zander, 2019).

Updated climate variability study at the livelihood zone level has positive implications for climate-resilient farm development and sustainable ecosystem services (Djalante, 2019). Therefore, it is necessary to combine appropriate strategies and technology in livelihood zones (Haile 2005; UNDRR-CRED, 2020). The integrated measures should be designed based on predicted and continued active response for risk management rather than actions during the crisis (Haile & Tang, 2019). Measuring and predicting rainfall and temperature patterns are crucial for agriculture developments (Koech *et al*., 2019). Temperate and rainfall patterns are the main factors for the study area's agricultural activities and household sustainability.

Several studies have been conducted on climate change perceptions, historical and future drought frequencies, intensities, durations, and impacts in different parts of the country (e.g., Ademe *et al*., 2020; Deressa, 2020; Eze *et al*., 2020; Ndehedehe *et al*., 2020; Obsi *et al*., 2020; Singh, 2020; Tesfaye & Gosain, 2020; Gebrechorkos *et al*., 2019; Hadria *et al*., 2019; Haile & Tang, 2019; Ishiwatari & Surjan, 2019; Lemma *et al*., 2019; Tefera & Bello, 2019; Esayas *et al*., 2018; Gidey *et al*., 2018; Juma & Mulungu, 2018; Sci *et al*., 2018; Elum *et al*., 2017; Region *et al*., 2016; Shikuku *et al*., 2017; Teklegiorgis *et al*., 2016; Melka *et al*., 2015; Funk *et al*., 2014; Haile, 2005). However, most of these studies did not show climate variability trends at livelihood zone levels.

Most of the datasets used by the reviewed author in Ethiopia were poor records of meteorological data; gauges are small in number and unevenly distributed in the country (Dinku *et al*., 2007). Therefore, there is a need to use good quality climatic data such as Climate Hazards Group InfraRed Rainfall with Station data (CHIRPS) and Enhancing National Climate Service (ENACTS) to deal with their variability based on the magnitude and intensities of temperature and rainfall trends to adjust the existing agricultural activities in the area. Studying temperature and rainfall variabilities and trends on a large scale could generalize the vulnerable areas' situations that need special focuses and local solutions based on the magnitude of their vulnerabilities. Unrepresentative data could not represent results that vividly put the severity and intensities of temperature and precipitation trends and variabilities.

This study aimed to investigate trends of climate variability during the main rainy seasons (Belg and Kiremt) and in annual timescales in the different livelihood zones of the Northwestern Escarpment of the Ethiopian Rift Valley. The Kiremt (June to August or September) and Belg (March to May) rainy seasons in the study area are the rainfall sources to cultivate the short and long-cycle growing crops. Rain feed agricultural activities and productivities of the study area depends on the two seasonal precipitations. Seasonal and annual rainfall variabilities during the rainy seasons have higher impacts on the rain-fed agriculture systems (Endale et al., 2020).

2.2. Data Sets and Methodology

2.2.1. Data Types and Sources

Both the monthly Climate Hazards Group InfraRed Rainfall with Station data (CHIRPS) and Enhancing National Climate Service (ENACTS) Maximum (Tmax) and minimum (Tmin) temperatures data (1983–2016) at moderate spatial resolution (4km–by–4km) acquired from the National Meteorological Agency of Ethiopia. Before 1983, there was no grid data; after 2016, it is under process in the National Meteorological Agency of Ethiopia. Therefore, the author limited the gridded meteorological data between 1983 and 2016. The collected data sets were free of missing values to compute the rainfall, Tmax, Tmin trends, and variability for the selected three livelihood zones.

2.2.2. Data Processing, Analysis, and Interpretation

In this study, to examine climate variability trends from 1983 to 2016, the Mann-Kendall trend (MKT), Sen's Slope Estimator (SSE), and Coefficient variations (CV) were used. The MKT is widely used to measure climate variability trends and understand the decreases or increases in the long-term climate variability (Lakshmi & Vani, 2019). Moreover, Sen's Slope, developed by Sen (1968), was applied to compute the magnitudes of trends in the long-term climate variability of nonparametric data (Lone, 2020). This study used Arc GIS using inverse distance weight to the measured to map the spatial rainfall variability trends for Belg, Kiremt, and annual time scales. The relationship between the livelihood zones' Tmax, Tmin, and rainfall trends was studied using GraphPad Prism version 8.4.2 software.

Mann Kendall trend (MKT) test for seasonal and annual precipitation and temperatures

MKT test is used to measure climate variability trends globe wide since it is a nonparametric test that does not require normally distributed data. It is low sensitivity to abrupt breaks due to inhomogeneous time series (Mohammad & Goswami, 2019; Vu *et al*., 2018; Tabari *et al*., 2011). It is applied to perceive statistically significant decreasing or increasing daily, monthly, seasonal, and annual climate variability trends (Lakshmi & Vani, 2019). There are two hypothesis tests in the MK trend test. They are the null (H_0) and alternate (H_1) hypotheses. The H_0 expresses the existence of no trend, while H_1 indicates the significance of increasing or decreasing climate variability data (Shawul, 2020; Asfaw *et al.*, 2018; Hamed, 2009).

$$S = \sum_{k=1}^{n-1} \sum_{J=k+1}^{n} \operatorname{sgn}\left(X_{j-}X_i\right) \qquad 2.1.$$

$$\operatorname{sgn}\left(X_{j-}X_k\right) = \begin{cases} 1 \ if \left(X_{j-}X_k\right) > 0 \\ 0 \ if\left(X_{j-}X_k\right) = 0 \\ -1 \ if\left(X_{j-}X_k\right) < 0 \end{cases} \qquad 2.2$$

Where n represents the number of data points, X_j and X_k are the consecutive data values in time series j and k (j>k). When the number of observations is more than 10 (n≥10), the statistics 'S' is approximately normally distributed with mean and Variances as follows(Asfaw *et al.*, 2018).

$$Vas(S) = \frac{n(n-1)\ (2n+5)(x+a)^n = \sum_{t=1}^{m} \ (t_{i-}1)(2t_i+5)}{18} \qquad 2.3$$

Where n is the number of observations, m is the number of tied groups, and t_j is the number of remarks in the i^{th} sample time series. When the sample size is n>10, the standard normal test Z_{KM} is calculated using Equation 2.4.

$$Z_{KM} = \begin{cases} \frac{S-1}{\sigma} & if\ S > 0 \\ 0 & if\ \ S = 0 \\ \frac{S-1}{\sigma} & if\ \ S < 0 \end{cases} \qquad 2.4$$

Using the ZKM value at a 5% significance level and XLSTAT version 22.5.1046.0, the study computed the Tmax, Tmin, and rainfall trends of the study three LZ over the study years. Positive (increasing) or negative (decreasing) values indicate the direction of the trends. Based on the 5% significance level: if the Z_{KM} value ≤ α =0.05, the H_1 hypothesis will accept, but if the value of the Z_{KM} Value≥ α=0.05 H_1 will be rejected instead of the H_0 accepted.

Sen's Slope Estimator (SSE)

The Sen's Slope, developed in the year (1968) has been widely used to compute the magnitudes of trends in long-term climate variability of nonparametric data. Following (Shawul, 2020; Vu *et al.*, 2018; Tabari *et al.*, 2011) and using XLSTAT version 22.5.1046.0, the author used nonparametric procedures to estimate the true Sen's slope (change per unit time) of the linear trends of seasonal rainfall and temperature (maximum and minimum) of the study livelihood zones from the year 1983 to 2016. The positive or negative values of the slope show increasing or decreasing trends, respectively (Geremew *et al.*, 2020). The Sen's Slope estimator of the N pair data is computed by

$$Q_i = \frac{X_{j-}X_k}{j-k} \qquad 2.5$$

Where X_j and X_k are data at time j, and k(j>k), and the median of these N values of Q_i is Sen's Slope estimator.

Coefficient of Variations

Coefficient variation is applied to calculate temporal and spatial rainfall variability trends at seasonal or annual time scales. Coefficient of variation (CV) is countenance acquired through converting the standard deviation (SD) to a % of the mean (Koech *et al.,* 2019; Fitto *et al.,* 2017). So, in this study, the author used CV to reveal seasonal (Belg and Kiremt) and annual rainfall variability at LZ and Grid levels of the study area using equation 2.6.

$$CV = \frac{SD}{Mean} \times 100 \qquad 2.6$$

If the results of CV are less than 20 % (less variable), from 20-30% (moderately variable), and more than 30% indicates high variability of rainfalls (Mekonen & Berlie, 2019).

2.3. Results and Discussions

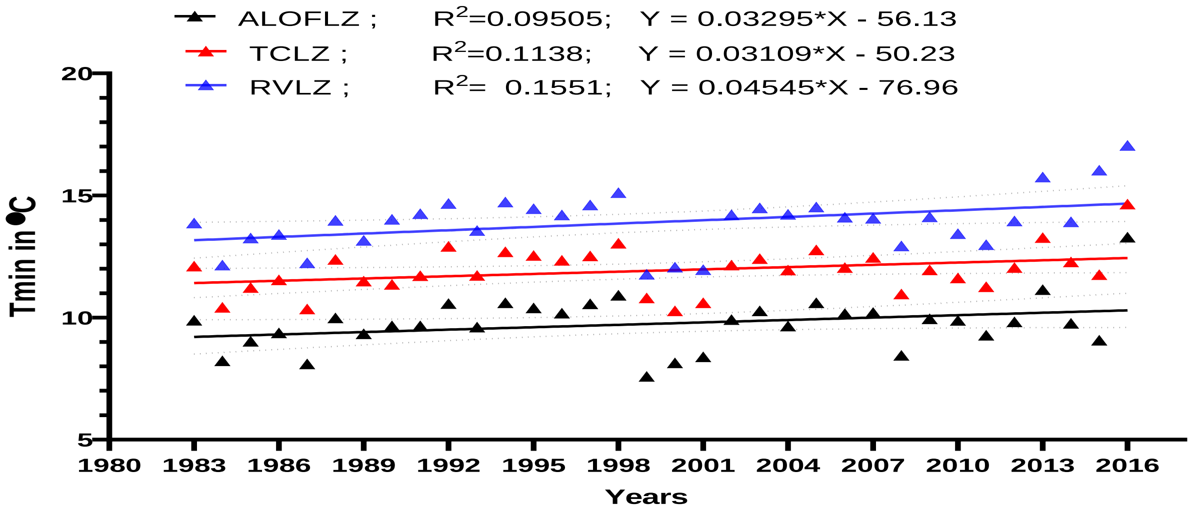
2.3.1. Tmin and Tmax Trends in Seasonal (Belg and Kiremt) and Annual Scales

At 5 % significant levels, the trends of nonparametric seasonal (Belg and Kiremt) and annual time scales Tmin and Tmax for the three studies LZs computed using MKT and SSE statistical tests. Tables 2.1 and 2.2 and Figure 2.1 show the results of MKT and SSE for the seasonal and annual Tmin and Tmax. Except for insignificant negative Tmax (-0.123 ⁰ C) trends in Kiremt season in the ALOFLZ, both significant and non-significant Tmin and Tmax trends were observed at measured time scales in all study LZs. The MKT annual Tmin (0.319, 0.301, and 0.273 ⁰ C) indicated statistically significant trends with the magnitude of SSE (0.026, 0.025, and 0.031) in ALOFLZ, TCLZ, and RVLZ, respectively. Besides, the positive significant MKT annual Tmax (0.323 and 0.419 ⁰ C) and 0.024 and 0.041 magnitudes of SSE were recorded in TCLZ and RVLZ, respectively. Annual Tmin of MKT and SSE indicated minimum temperature increased with statistical significance in all study LZ. However, the magnitude of the increased trends is slightly different between the study LZs with relatively higher at ALOFLZ. The result of statistical significance MKT annual Tmax trends is shown only in TCLZ and RVLZ. Furthermore, the Belg MKT records show that the Tmax trend increased significantly by 0.301, 0.401, and 0.430 ^{o} C with SSE magnitudes of 0.034, 0.056, and 0.082 in the areas of ALOFLZ, TCLZ, and RVLZ, respectively. Tmin in the Belg season showed non-significant but positive trends in all study LZs. Further, Tmax in Kiremt showed non-significant positive trends in TCLZ and RVLZ (Table 2.1 and 2.2 and Figure 2.1**)**. However, the Tmax in ALOFLZ during the Kiremt season shows a negative but not statistically significant trend.

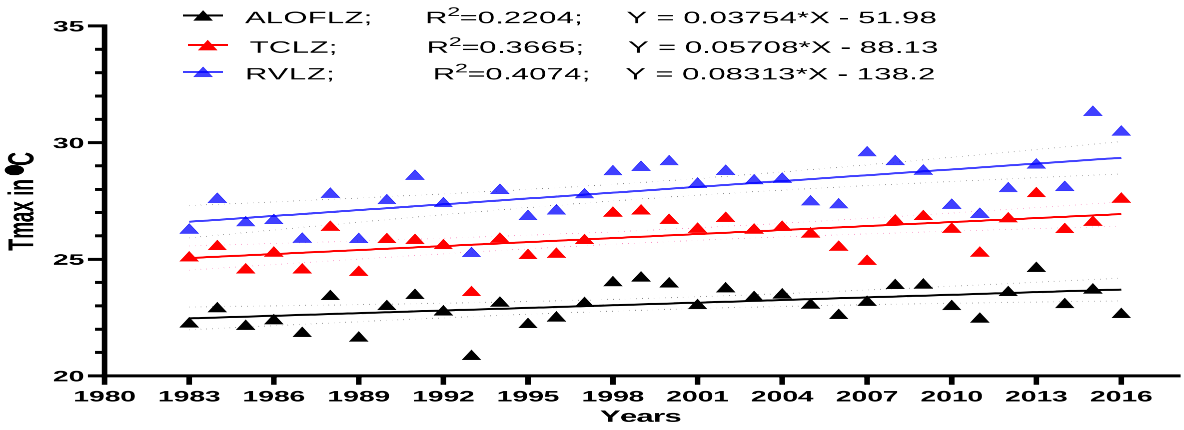
This finding is in line with the expected increasing global temperatures prediction of the new Representative Concentration Pathways (RCPs) scenarios under Coupled Model Intercomparison Project Phase5 (CMIP5) of the World Climate Research Program. The new scenarios stated that, with continuing anthropogenic-induced climate change, global mean surface temperature will likely be in the range of 0.3^{o} C to 0.7 ^{o} C from 2016 to 2035. The current study also coincides with the Ministry of Foreign Affairs of the Netherlands (MOFA, 2018) reports. The report stated that Ethiopia's average temperature increased from 0.2 ^{o} C to 0.28 ^{o} C. Their statement also said that Tmin had risen significantly between 0.3 ^{o} C to 0.7 ^{o} C in Ethiopia.

Many studies on climate variabilities trends in different parts of Ethiopia revealed various reports. Teklegiorgis *et al*. (2016) reported an increasing Tmax and Tmin in Ziway and Tmax in the Holleta site. Esayas *et al*. (2019) stated that Tmin has significantly increased in Southern Ethiopia. The Benti and Abara (2019) study in Masha, southern Ethiopia, revealed seasonal temperature increased from 1980 to 2015. Dechassa *et al*. (2020) pointed out that the mean temperature increased by an average of 0.181^{o} C in the Didessa sub-basin of Blue Nile River, Ethiopia. Ademe *et al*. (2020) also reported higher temperature trends in the agricultural region of the Ethiopian Highlands. The Asfaw *et al*. (2018) study showed trends for Tmax exhibited a non–significant increase trend, but Tmin increased in north-central Ethiopia. Gebrehiwot and Veen (2013) and Hadgu *et al*. (2015) revealed that the annual Tmin and Tmax significantly increased in Tigray northern Ethiopia, respectively, over the study years (1954–2008) and (1980–2009). Over the study years, the author of the current investigation discovered rapidly warming seasonal (Belg and Kiremt) and annual Tmin and Tmax in all studies LZ (1983).

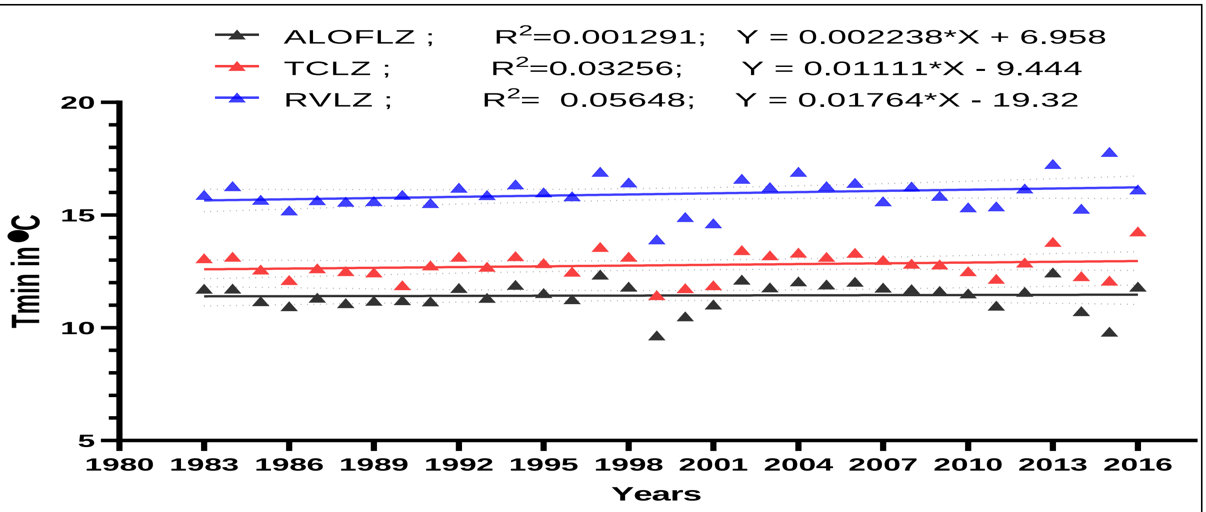
Temperature rising may reduce frost and its impact on crops, thereby fasting crop growth within a short period in most parts of ALOFLZ. This warming trend implies possible future impacts of extreme events for agricultural and forage productivities exposed to temperature stress, increasing evapotranspiration demands, and economic loss for local communities and disrupts the ecosystem of the study areas. However, the study LZs have not the same exposure, trends, and magnitude of temperature changes.



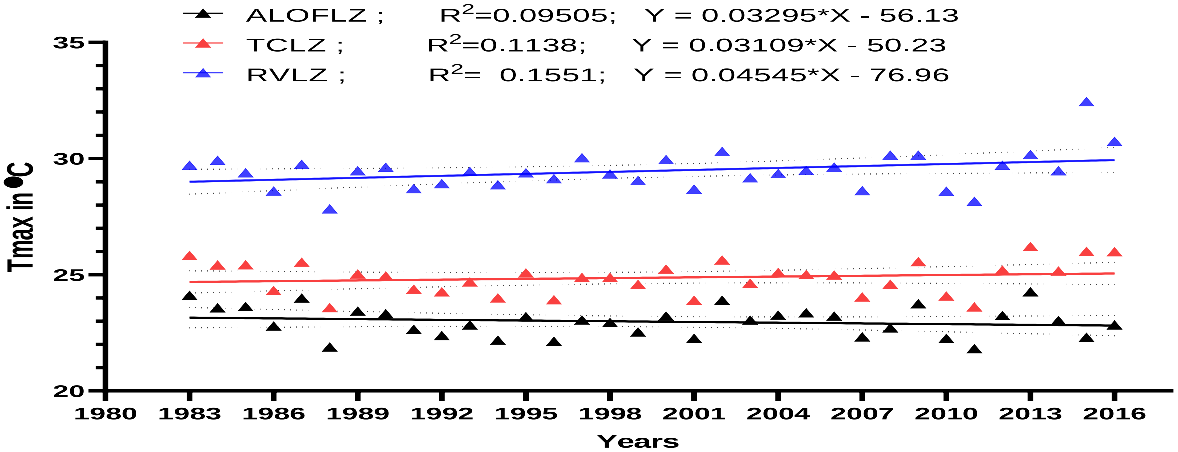
Belg minimum temperature trends



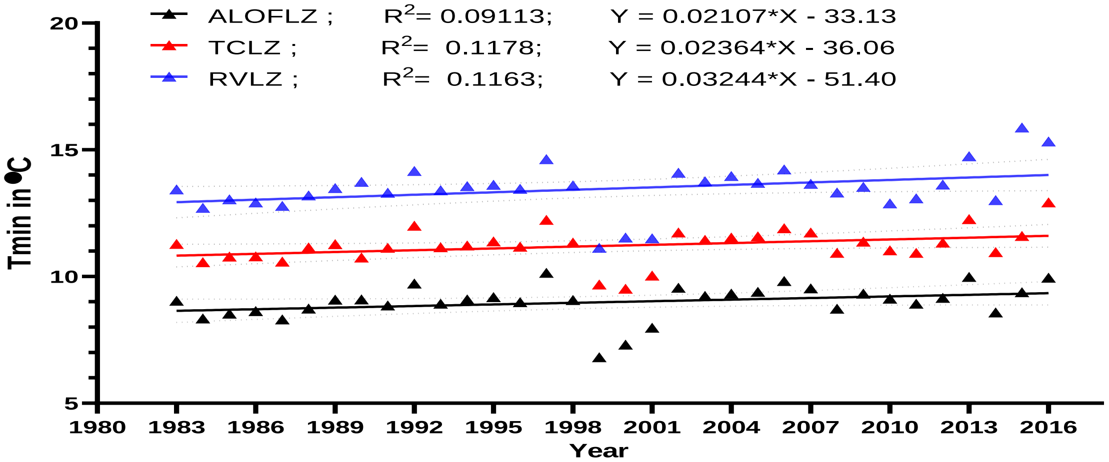
Belg maximum temperature trends



Kiremt minimum temperature trends



Kiremt maximum temperature trends



Annual minimum temperature trends

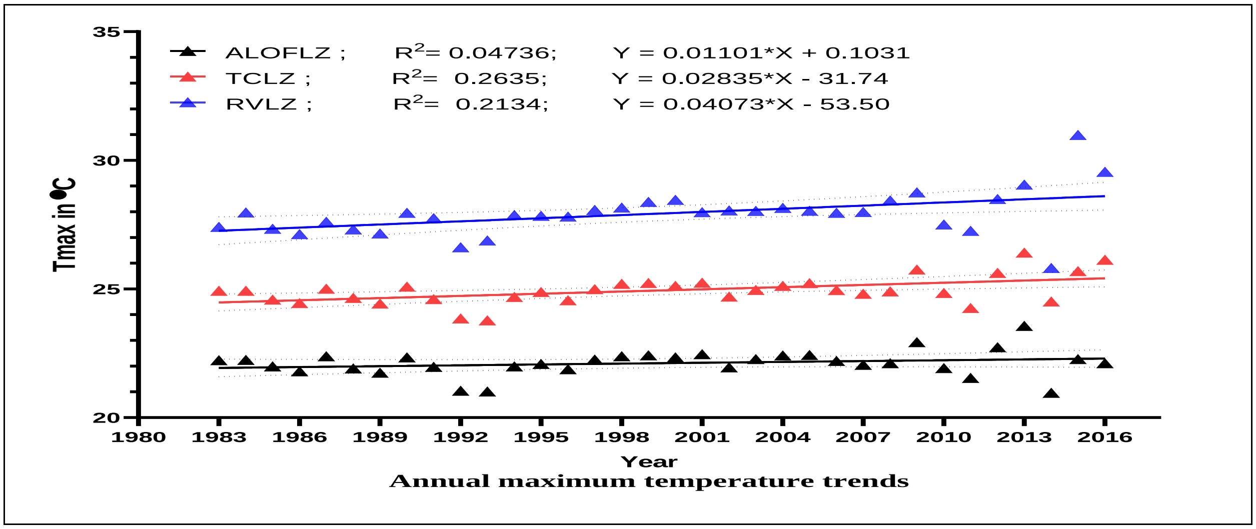


Figure 2.1.Temporal Seasonal Tmin and Tmax trends in Belg, Kiremt, and annual from 1983–2016

Table 2.1 Tmin trends using the MKT and Sen's slope in Belg, Kiremt, and annual from 1983–2016

Series	**LZs**	**Min in (°C)**	**Max in (°C)**	**Mean in (°C)**	**Std. deviation**	**Sen's slope**	**Kendall's tau**	**P value at (alpha = 0.05) (Two tailed)**	
								P-value	Trends
Tmin -Belg	ALOFLZ	7.587	13.285	9.753	1.064	0.021	0.159	0.192	+ve
	TCLZ	10.272	14.640	11.928	0.917	0.025	0.184	0.131	+ve
	RVLZ	11.774	17.048	13.918	1.149	0.035	0.212	0.080	+ve
Tmin- Kiremt	ALOFLZ	9.661	12.451	11.433	0.620	0.008	0.091	0.436	+ve
	TCLZ	11.443	14.273	12.779	0.613	0.009	0.087	0.455	+ve
	RVLZ	13.924	17.799	15.942	0.738	0.018	0.127	0.299	+ve
Tmin- Annual	ALOFLZ	6.813	10.136	8.992	0.694	0.026	0.319	0.008*	+ve
	TCLZ	9.506	12.924	11.212	0.686	0.025	0.301	0.013*	+ve
	RVLZ	11.132	15.872	13.465	0.947	0.031	0.273	0.024*	+ve

*Significant at P< 0.05, (+ve) positive trends

Table 2.2 Tmax trends using the MKT and Sen's Slope in Belg, Kiremt, and annual from 1983–2016

Series	**LZs**	**Min in (°C)**	**Max in (°C)**	**Mean in (°C)**	**Std. deviation**	**Sen's slope**	**Kendall's tau**	**P value at (alpha = 0.05) (Two tailed)**	
								P-value	Trends
Tmax– Belg	ALOFLZ	20.899	24.682	23.084	0.797	0.034	0.301	0.013*	+ve
	TCLZ	23.644	27.884	25.995	0.939	0.056	0.401	<0.0001*	+ve
	RVLZ	25.311	31.374	27.980	1.297	0.082	0.430	<0.0001*	+ve
Tmax– Kiremt	ALOFLZ	21.819	24.261	22.984	0.641	–0.014	–0.123	0.313	–ve
	TCLZ	23.583	26.211	24.873	0.700	0.011	0.091	0.459	+ve
	RVLZ	27.832	32.453	29.468	0.827	0.021	0.187	0.123	+ve
Tmax- Annual	ALOFLZ	20.96	23.559	22.116	0.504	0.009	0.169	0.163	+ve
	TCLZ	23.78	26.406	24.94	0.550	0.024	0.323	<0.0001*	+ve
	RVLZ	25.812	30.981	27.934	0.878	0.041	0.419	0.001*	+ve

*Significant at P< 0.05, (+ve) positive trends

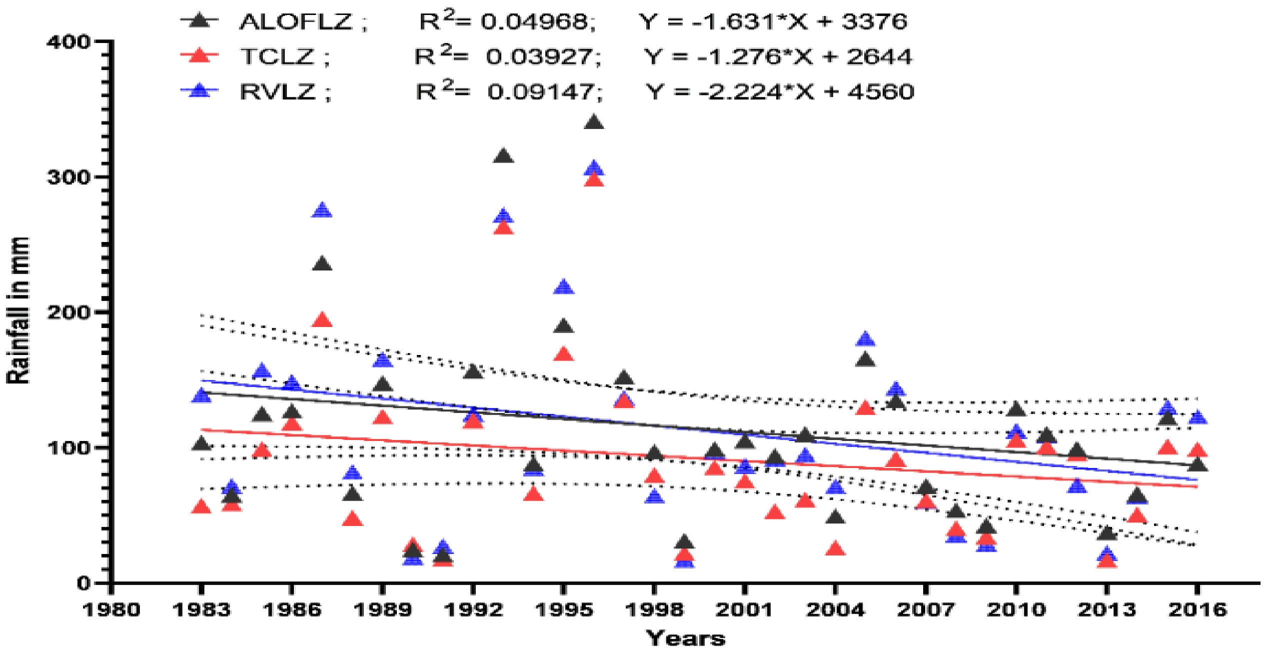
2.3.2. Seasonal (Belg and Kiremt) and Annual Rainfall Trends

The minimum, maximum, mean, and standard deviation of Seasonal (Belg and Kiremt) and annual rainfall results are presented in **(**Table 2.3 and Figure 2.2**)**. The results revealed that the Belg rainy season covers about 33%, 31.04%, and 31.61% in ALOFLZ, TCLZ, and RVLZ, respectively. Besides, the Kiremt rainy season covers 63.42%, 67.27%, and 66.42% of the annual rainfall in ALOFLZ, TCLZ, and RVLZ, respectively. Annual rainfall trends showed neither positive nor negative significant trends in ALOFLZ and TCLZ. It has shown increasing trends but statistically insignificantly in all studies LZ. However, in the Belg rainy season, the basis for cultivation and moisture sources for local ecosystems, the rainfall trends show decreasing trends but statistically insignificantly in ALOFLZ and TCLZ. The magnitude of recorded SSE for Belg rainfall negative trends was –1.133,–0.797, and –1.787) in ALOFLZ, TCLZ, and RVLZ, respectively. However, the MKT during the Kiremt rain season shows statistically significant trends with an SSE magnitude of 8.081 and 8.511 in RVLZ and TCLZ, respectively. The combined rainy seasons (Belg and Kiremt) almost cover more than 96% of annual rainfall in the study LZ. For that reason, most of the study area's agricultural activities and ecosystem precipitation sources depend on binomial rainfall (Belg and Kiremt).

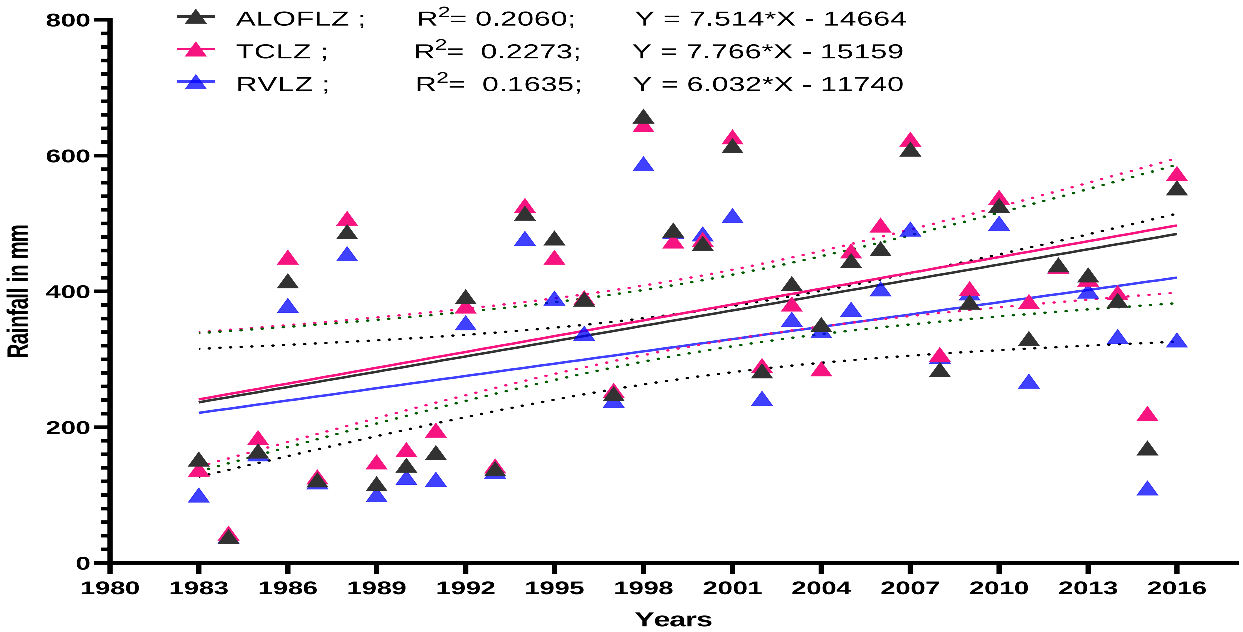
Asfaw *et al*. (2018) revealed a significant decline in annual and Kiremt rainfall, but Belg rainfall declined with a non-significant trend in north-central Ethiopia. Also, Ademe *et al*. (2020) showed annual and Kiremt rainfall decreasing trends in an agricultural region of the Ethiopia Highlands. The Ademe *et al*. (2020) analysis of rain in Ethiopia from 1961 to 2105 showed an insignificantly decreasing annual and seasonal rainfall trend. Kedir and Tekalign (2016) in central Ethiopia and Esayas *et al*. (2019) in southern Ethiopia also reported decreased annual rainfall but were statistically non-significant. The Benti and Abara (2019) study indicated significantly declined Kiremt and Annual rainfall from 1980 to 2015 in Southern Ethiopia. The Benti and Abara (2019) study also revealed that Belg rainfall decreased insignificantly from 1980 to 2015 in Southern Ethiopia. The Bayable *et al*. (2021) report showed Belg, Kiremt, and Annual rainfall insignificantly reduced from 1983 to 2019 in West Harerge Zone, Eastern Ethiopia.

However, the current finding coincides with Asfaw *et al*. (2018), Benti and Abara (2019), and Bayable *et al*. (2021) studies of the Belg rainfall trends that declined but were not significant. The current result also coincides with the Mekuyie and Mulu (2021) finding that reported a significant increasing trend of Kiremt rainfall from 1983 to 2017 in the Fentale district of Oromia Region, Ethiopia. This finding also coincides with the Obsi *et al*. (2020) study that revealed the total amount of rainfall increased while rainfall distribution and frequencies changed from long climate conditions in Jimma, Ethiopia. The Geremew *et al*. (2020) study in Northwest Ethiopia revealed annual rainfall trends were increasing but statistically insignificant. These reviewed studies have shown that different parts of Ethiopia vary in seasonal and inter-annual rainfall trends. The country has different rainfall histories regarding the seasonal and annual rainfall patterns that affect the farmers who depend on rain-fed agricultural systems.

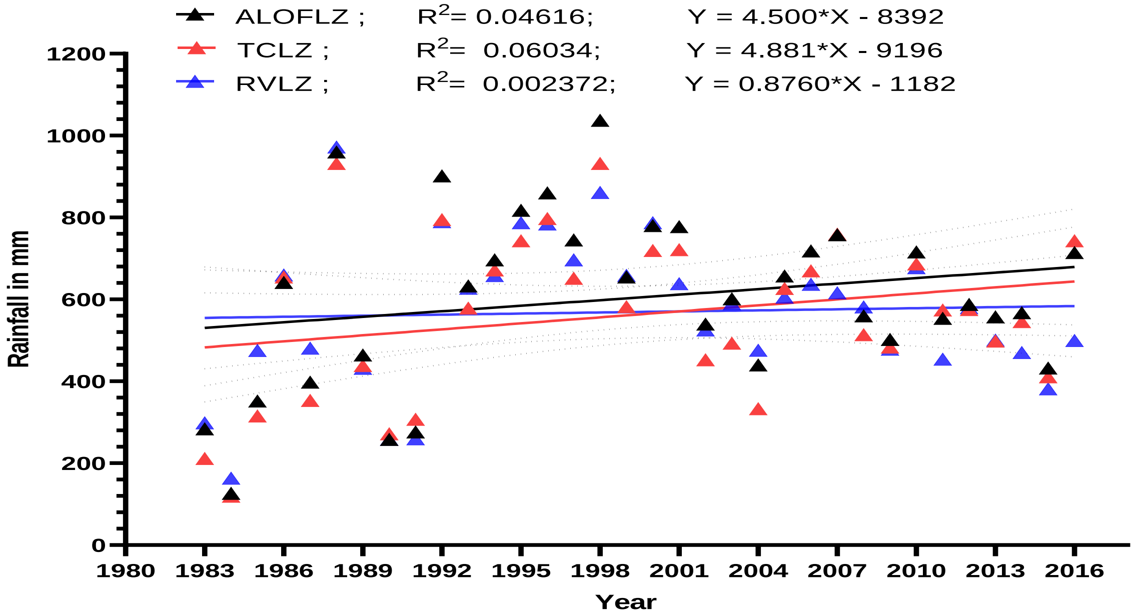
Therefore local studies have positive implications for revealing the rainfall variability situation on the grassroots level to take appropriate measures at the point sources. Studies concerning local climate variability trends at livelihood zones like the current study will indicate the gap policymakers should be concerned about, and the local communities will be resilient to the situation in the future.



Belg rainfall trends



Kiremt rainfall trends



Annual rainfall trends

Figure 2.2. Trends of Belg, Kiremt and annual rainfall from 1983–2016

Table 2.3 Rainfall trends using MKT and Sen’s slope in Belg, Kiremt, and annual from 1983–2016

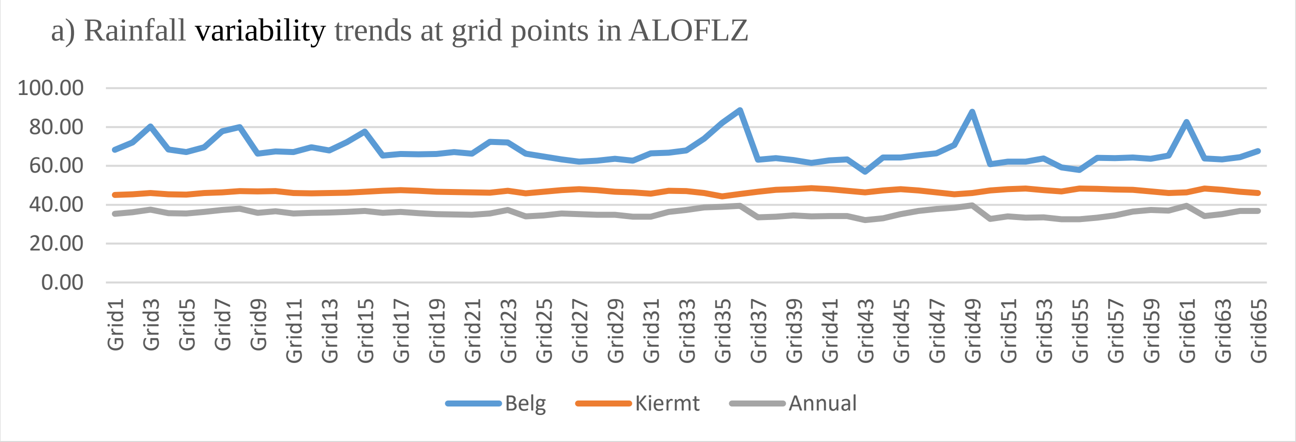
Series/ Test	**Livelihood zones**	**Min (mm)**	**Max (mm)**	**Mean (mm)**	**Std. deviation**	**Sen's slope**	**Kendall's tau**	**P value at (alpha = 0.05) (Two tailed)**	
								P-value	Trends
Rainfall Belg	ALOFLZ	21.092	341.185	113.876	72.888	–1.133	–0.116	0.396	–ve
	TCLZ	16.91	298.62	92.074	64.138	–0.797	–0.098	0.423	–ve
	RVLZ	17.037	307.296	112.913	73.227	–1.787	–0.184	0.177	–ve
Rainfall Kiremt	ALOFLZ	38.846	657.862	360.652	164.862	8.081	0.262	0.068	+ve
	TCLZ	43.776	645.621	369.090	162.212	8.511	0.312	0.010*	+ve
	RVLZ	39.685	588.000	320.743	148.540	6.169	0.251	0.038*	+ve
Rainfall Annual	ALOFLZ	126.31	1037.37	604.80	208.57	2.464	0.059	0.635	+ve
	TCLZ	119.38	932.09	563.47	197.865	4.28	0.116	0.343	+ve
	RVLZ	163.54	972.02	569.33	179.101	-2.06	-0.094	0.441	-ve

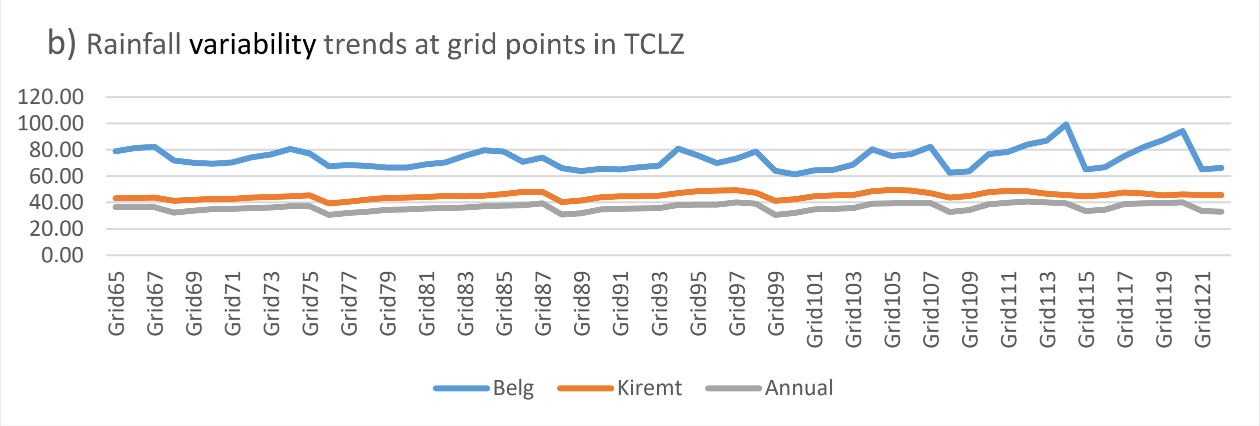
*Significant at P< 0.05, (+ve) positive trends, (–ve) negative trends

2.3.3. Seasonal (Belg and Kiremt) and Annual Rainfall Variability Trends

At LZ and grid point levels of the study area, there was very severe precipitation variation of rainfall in all study time scales. Further, the rainfall variabilities were highly varied and fluctuated within the study timescale over the study years. However, at LZ levels for the measured year or season, the trends of rainfall variability were less varied within the LZs (Figure 2.3). The precipitation variability at the LZ level in the Belg season recorded about 64.01, 69.66, and 64.85 % in ALOFLZ, TCLZ, and RVLZ, respectively. The recorded precipitation variability in Belg rainy season is relatively higher than Kiremt (45.71, 43.95, and 46.31 %) and annual (34.4, 35.12, and 31.62 %) rainfall variabilities in the study LZ (ALOFLZ, TCLZ, and RVLZ), respectively. The rainfall variability trends at LZ levels for inter-seasonal and inter-annual rainfall variabilities are present in (Figures 2.3-2.5**)** for Belg, Kiremt, and annual time scales for the study LZs.

Similarly, Grid level rainfall variability analysis across all study sites shows highly severe rainfall variabilities in all measured time scales. However, similar to findings at LZ levels, the Belg season recorded relatively higher rainfall variability than Kiremt and annual time scales **(**Figure 2.2). This study coincides with the Geremew *et al*. (2020) study that revealed Belg rainy season was highly variable than Kiremt rainy season in Northwest Ethiopia. The Grid level CV results indicated that rainfall variability in ALOFLZ ranged from 56.96–88.67% in Belg to 44.30–48.52 % in Kiremt and 32.10 – 39.67 % in annual timescales. Similarly, the results for TCLZ indicated that rainfall variability at the Grid level ranged from 61.33 -99.23, 39.34- 49.55, and 30.67 - 49.55 % in Belg, Kiremt, and annual scales, respectively. Furthermore, the CV for RVLZ at the Grid level was between 60.13 -96.67 in Belg, 46.06 – 49.81 in Kiremt, and 30.19 – 38.41 % in annual time scales. As seen in (Figure 2.6**)**, relatively Belg and annual spatial rainfall variability was more severe in TCLZ than ALOFLZ and RVLZ. However, spatially rainfall variability in the Kiremt rainy season was higher in RVLZ over 34 years **(**Figures 2.2 and 2.6).





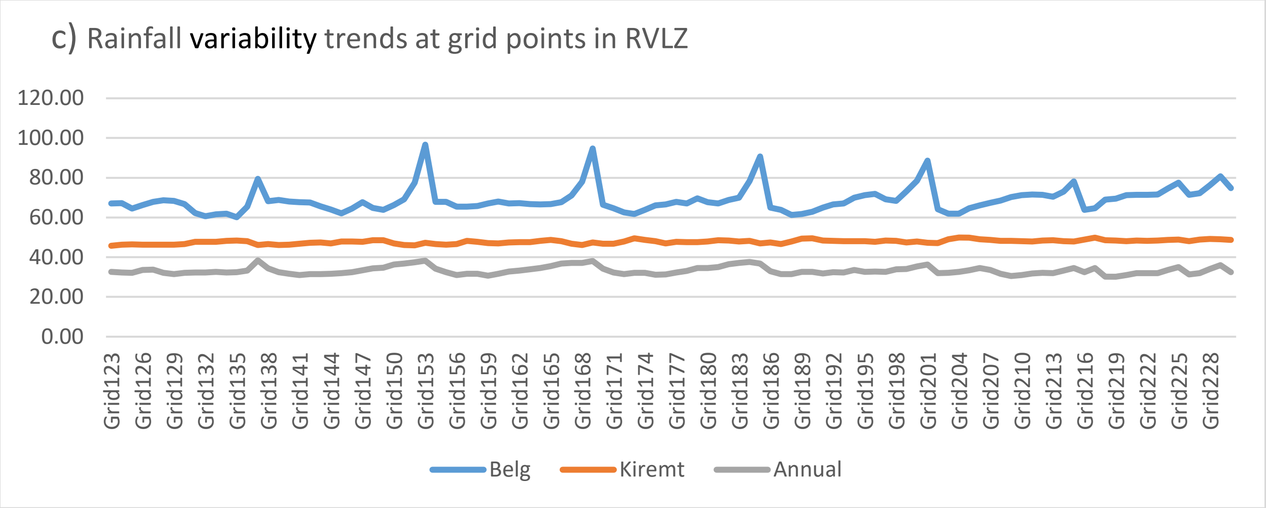


Figure 2.3. Rainfall variability during the Belg, Kiremt, and annual from 1983–2016

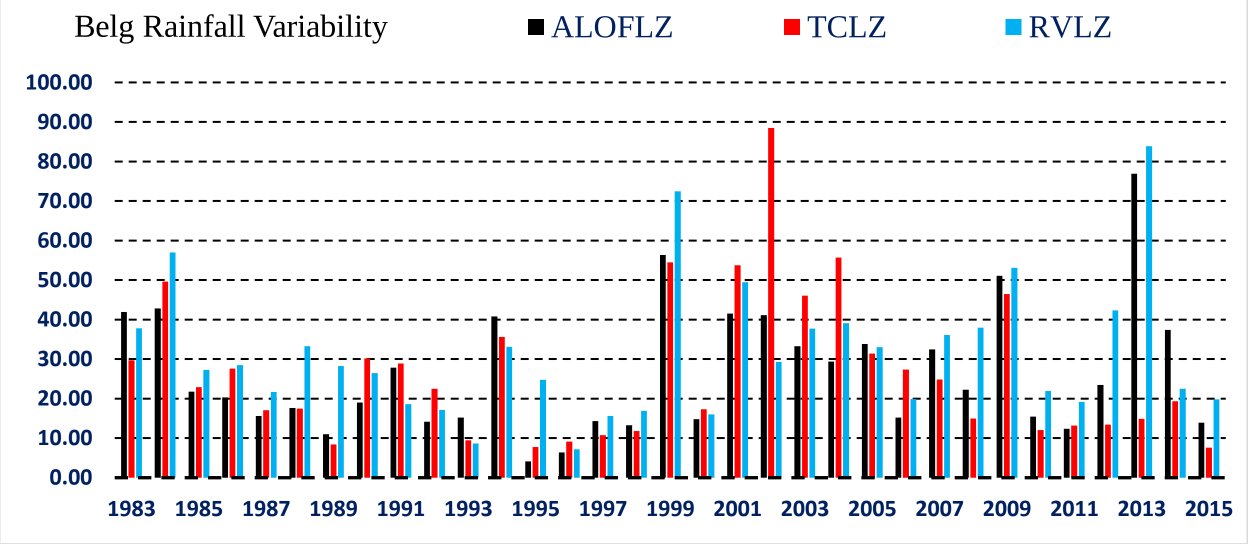


Figure 2.4. Chart of inter-seasonal rainfall variability trends in Belg seasons from1983-2016 using CVs

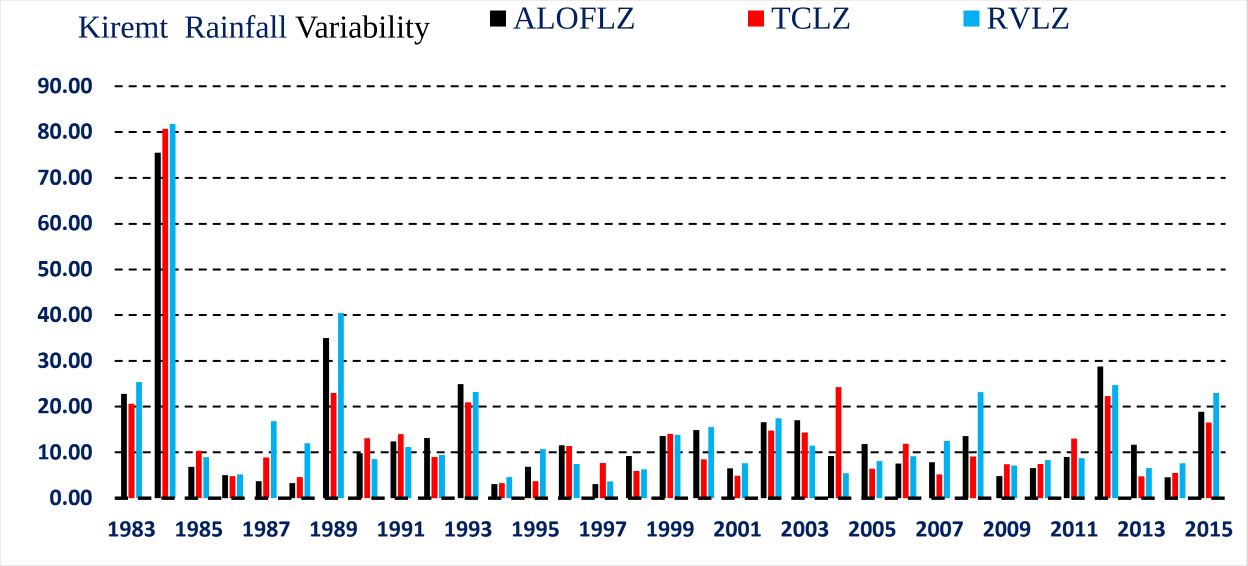


Figure 2.5. Chart of inter-seasonal rainfall variability trends in Kiremt seasons from1983-2016 using CVs

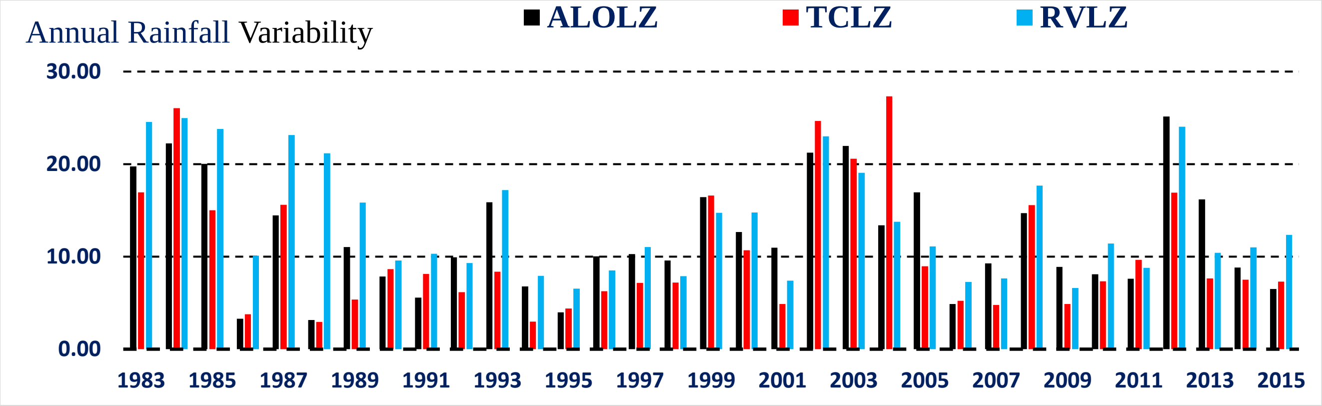


Figure 2.6. Chart of inter-annual rainfall variability trends from1983-2016 using CV

The current study's CV values imply that there were higher sessional and annual precipitation variations in the entire LZs agreed (Alemayehu *et al*., 2020; Mekonen & Berlie, 2019; Asfaw *et al*., 2018) findings. This study also coincides with the Feleke and Abera (2020) results that rainfall variability in north-eastern Ethiopia was highly variable on an annual time scale. Similarly, Fitto *et al*. (2017) study revealed annual rainfall variability was higher in the Guinea Savanna of Nigeria. The current study findings strengthened by Dechassa *et al*. (2020) report that yearly rainfall variability was extremely high in all agro-ecological zones of their study area. This study also showed the rainfall was highly irregular and varied in seasonal and annual time scales in all LZs and grid-wise levels. All study LV zones had seasonal and annual uncertainty in rainfall patterns. These inconsistent rainfall variabilities affected the agricultural productivity of smallholder farmers in all LZs of the study area and consequences frequent crop failure, shortages of forage, and water sources for households in the study livelihood zone. Higher rainfall fluctuations and variability patterns at a small scale affecting the local climate system and further influence the global climate systems.

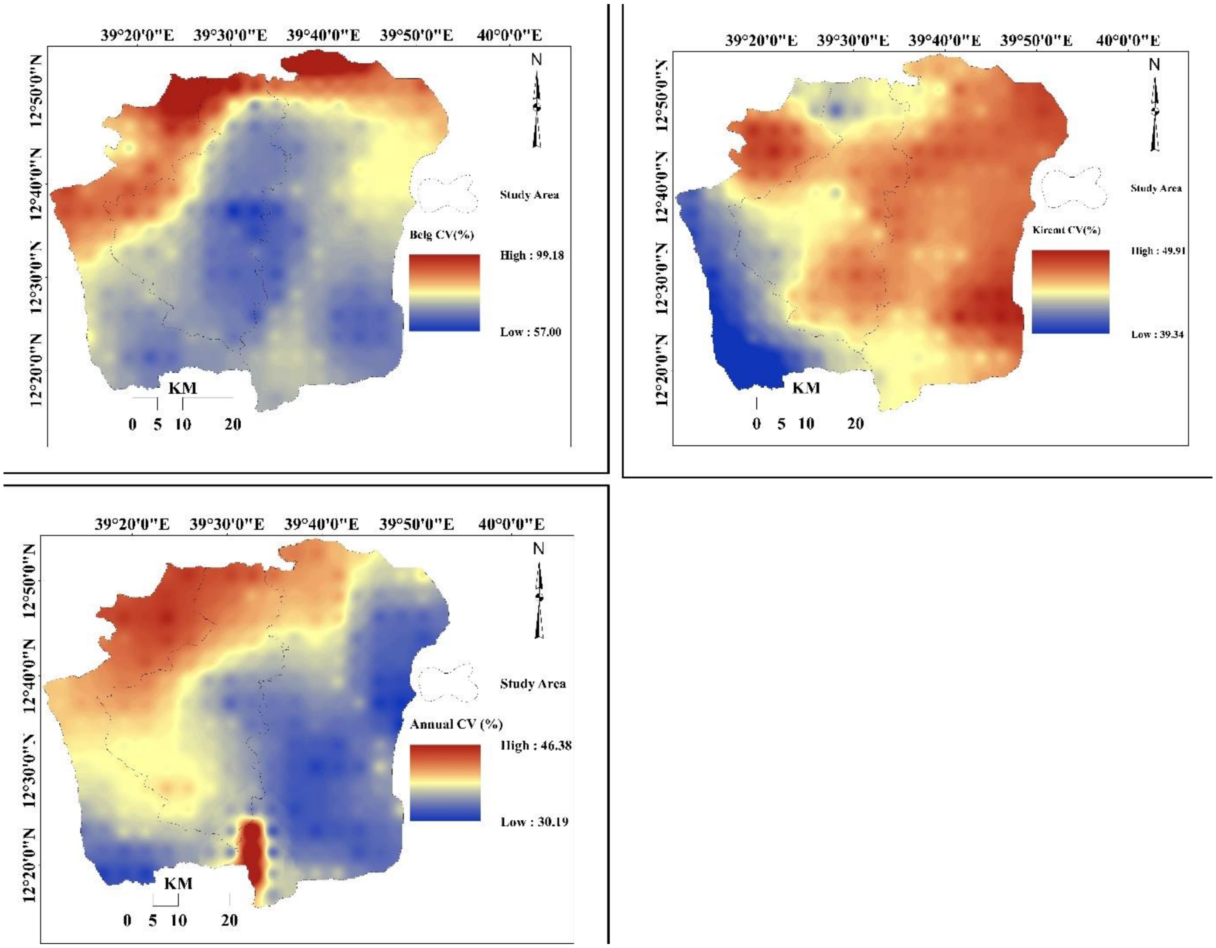


Figure 2.7. Maps of seasonal (Belg and Kiremt) and annual spatial rainfall variability trends at grid levels from 1983 to 2016 using Arc GIS version 10.5

2.4. Conclusion

Analysis of climate variability trends using MKT and SSE and long recorded data from uniformly distributed meteorological grids have high implications for revealed trends and characteristics of climate variability at LZ levels. This study analyzed the seasonal and annual climate variability trend using MKT and SSE at 5% significance levels and rainfall variability using CV from 1983 to 2016. The study revealed that the temperature is warming, and the rainfall has shown high irregularities and various seasonal and annual timescales. Besides, spatially the rainfall variability trends within inter-seasonal and inter-annual trends of CV fluctuated between and within the LZs. These inconsistencies and fluctuated variability also imply extreme events that impact agricultural productivities and forage growth through exposures to high-temperature stress, increasing evapotranspiration demands, and consequence economic loss for local communities, and disrupts the ecosystem of the study areas. Combined seasonal and annual rapidly warming temperatures with high rainfall irregularities affected the agricultural productivity of smallholder farmers in all LZs of the study area.

The agricultural sector should consider the long-cycle crop growth patterns, rainfall variability, and dry spell effects to reduce crop failures and forage problems by updating local meteorological data and technological inputs. Policies and strategies for risk management should be predicted and ongoing active responses rather than measures taken during a crisis. Further, a more in-depth study needs to see the Belg and Kiremt rainfall onsets, durations, terminations, and variabilities trends to put appropriate agricultural activities. The finding of this study will be input for agricultural research and policymakers to integrate climate variability trends into future climate adaptation measures at livelihood zone and district levels.

3. Chapter Three: Meteorological Drought in Northwestern Escarpment of Ethiopian Rift Valley: detection of seasonal and spatial trends

Abstract

The Northwestern Escarpment of the Ethiopian Rift Valley has been frequently affected by droughts for decades. The area is among the most drought-prone and chronically food-insecure areas. The study areas that include the Raya Valley livelihood Zone (RVLZ), Alagie-Offla livelihood Zone (ALOFLZ), and Tsirare Catchment Livelihood Zones (TCLZ) are amongst the most vulnerable and badly affected livelihood zones in the Northwestern Escarpment of the Ethiopian Rift Valley. Hence, this study aimed to monitor the meteorological drought conditions of the three LZs from 1983 to 2016 using the Standardized Precipitation Evapotranspiration Index (SPEI) on three months time scale. The author obtained both monthly Climate Hazards Group Infrared Precipitations with Station data (CHIRPS) and Enhancing National Climate Service (ENACTS) temperature data (1983-2016) at moderate spatial resolution (4 km-by-4km) from the National Meteorological Agency of Ethiopia. This study uncovers seasonally recurring droughts that vary in severity, frequencies, and durations within and between the livelihood zones. The results indicated that severe drought occurred in all livelihoods zone of the study area from 1983 to 1991, while ALOFLZ and TCLZ have recorded relatively higher drought severity. In addition, this study discovered that there had been Belg or Kiremt or both drought seasons in most study areas. From 1989 to 2016, the severity and frequency of droughts increased during the Belg season but decreased in Kiremt (summer). From 1983 to 1991, the severity and frequency of Kiremt droughts were higher; from 1993 to 1998, they were better; and from 2000 to 2016, they had mild to moderate drought consequences. As the frequencies and persistence of mild-drought impacts have increased, the intensity and precipitation are too small to cultivate crops and forage growth. This problem needs special consideration in the current moisture harvesting system and afforestation practices to reduce natural and human-induced drought impacts. Long-term data from many evenly spaced meteorological grids can be instrumental in determining actual drought trends. This research will help to strengthen the present drought monitoring system and increase household drought resistance. The discovery will also significantly influence early warning systems, especially district-level ones. Ended, it needs to consider solutions for short and long drought impacts. The agricultural sector should consider long-term crop growth patterns to reduce crop failures and forage problems.

Keywords: Belg, Kiremt, Livelihood Zones, Meteorological Drought, Northwestern Escarpment of the Ethiopian Rift Valley, SPEI

3.1. Background

Drought is a recurrent natural phenomenon that occurs in most parts of the globe, even in wet and humid regions (Tian, 2019; Zarei, 2019; Masih *et al*., 2014; Dai, 2011; He *et al*., 2011). It is one of the natural disasters that extensively damage the environment and the economy in several ways (e.g., agriculture, water resources, ecologies, human welfare, and animal life) (Chen *et al*., 2020; Yacoub & Tayfur, 2020; Tefera & Bello, 2019; Lu *et al*., 2015; Mavromatis, 2012). Approximately 642 drought occurrences were reported worldwide between 1900 and 2013, according to the Emergency Events Database (EM-DAT) (2014). These events claimed the lives of 12 million people and affected over 2 billion people. These events further consequence about 135 billion USD lost throughout the world. Masih *et al*. (2014) reported that about 291 drought events affected more than 362,225,799 people in Africa from 1900 to 2013.

In Ethiopia, drought is a common occurrence, and it has been, and still is, the leading driving cause behind the country's exposure to periodic famine (Andargie, 2014; Kiros, 1991; Webb & Braum, 1990). According to the EM-DAT (2017) report, Ethiopia's degree of drought varies in intensity and spatial and temporal coverage. Since 1965 the country has been revisited with drought events at regular occurrences within ten-year intervals (Andargie, 2014). However, in recent years (since 2000), drought has occurred within two to three years intervals (Gidey et al., 2018a,b; Gidey, 2012). From 1973 to 2016, about 26 mild-severe droughts occurred in northern Ethiopia (EM-DAT, 2017; Gebru & Beyene, 2012), which overlays with the territories of the current study settings.

As a land of multiple paradoxes, the rural settings in Ethiopia include pastoral, agro-pastoral, and cropping livelihood zones. These three broad livelihood zones are sub-split into 175 livelihood zones based on economic geography (The Livelihoods Integration Unit, 2010). The three livelihood zones of the study areas include the Raya Valley livelihood Zone (RVLZ), Alagie-Offla livelihood Zone (ALOFLZ), and Tsirare Catchment Livelihood Zones (TCLZ) are among these livelihood zones. These three major livelihood zones (LZs) are among the country's most droughts-prone and chronically food-insecure areas (Andargie, 2014). Agriculture and livestock, which comprise the primary livelihood system in the three LZs, are frequently affected by drought. Drought costs thousands of human lives and adversely affects the social and economic sectors because it significantly affects the smallholder farmers of the area (Tefera & Bello, 2019; Abrha & Simhadri, 2015). According to Gebru and Beyene (2012), the chronic nature of food insecurity leads to deprivation of access to immediate food demands and the depletion of assets.

Since 2000, drought has become almost a normal phenomenon, and most of the year, apart from the rainy seasons, the area is dominated by dry weather and revisited with severe droughts (Tefera & Bello, 2019; Gidey *et al.*, 2018a, 2018c, 2018b; Gidey, 2012). Ethiopia adopted the National Disaster Risk Management Policy and Strategy in 2013 to reduce disaster risks and potential damages caused by disasters (Drechsler & Soer 2016). However, the Woreda Disaster Risk Profiles (WDRPs) did not execute at the local level (Dibaba, (2018).

Some authors, including Kenawy *et al*. (2016) over Ethiopia, Mohammed (2018) in Ethiopia's North East Highland, and Gidey (2012) in Tigray Regional State, confirmed the presence of locally embedded characters dry events. They recommended it needs detailed spatial drought studies to provide evidence for policymakers to adopt appropriate policies to cope with drought risks. In the three LZs, the agro-ecosystem is very sensitive to precipitation change. The changes or variability in precipitation amount and distribution negatively impact the environment and the livelihood of marginal households. In most cases, drought recurs before the affected area recovers from the most recent drought event (Abrha & Simhadri, 2015).

Several authors used SPEI to study drought in different parts of the globe. For instance, Abbasi *et al*. (2019) studied drought impacts using SPEI and gene expiration model from 1951 to 2009 for all time scales in Urmia, Iran. They found that the prediction accuracy increased by increasing SPEI time scales, better than indicators that only use precipitation data. It also can be an indicator of hydrological drought. Bae *et al*. (2018) found the characteristics of drought occurrences based on SPEI using Thornthwaite and Penman-Monteith equations in South Korea from 1981 to 2010. They discovered that SPEI using Penman-Monteith equations slightly shows more severe drought than Thorn Thwaite equations. Diaz *et al*. (2020) studied drought tracks using gird data from SPEI in India from 1901 to 2013, and they found the severity, duration, onset, and end positions way of the drought. Beharry *et al*. (2019) studied to build baseline scenarios of meteorological droughts using the SPI Index for the southernmost Caribbean islands of Trinidad and Tobago from 1980 to 2014. Their result shows variations of drought characteristics over a small island and the possible adverse effects on surface water reservoirs.

There have been a few studies in Tigray at the regional and zonal levels, but none at the livelihood zone level. For instance, Gidey (2012) and Gidey *et al*. (2008 a,b) studied the effectiveness of food security policy in ensuring rural food security and poverty reduction in the Tigray region and assessing the various drought conditions of the area. Annys *et al*. (2016) studied the relationship between rainfall variability and land cover changes impacted by spatial-temporal rainfall variability along the Ethiopian Rift Valley escarpment. Gidey *et al*. (2018a, 2018b, 2018d, 2018c) also analyzed the meteorological and agricultural droughts' onset, cessation, duration, frequency, and spatial extent using an advanced approach of geospatial technologies. Moreover, Abrha and Simhadri (2015) conducted a study on climate change and farmers' perceptions and factors affecting the perception of climate change in Southern Tigray. Tefera and Bello (2019) also studied the correlation between SPI and SPEI index for drought measurement in Tigray. They have used 12 grids for meteorological data analysis throughout the region.

Most of these reviewed studies have limitations in showing the evolutions, spatiotemporal drought frequencies, durations, and severities in livelihood zone levels. The survey of drought conditions at zonal, regional, national, or continental levels could generalize the vulnerable areas' situations that need special focuses and local solutions based on the magnitude of their vulnerabilities. So far, little or no intensive study has attempted to capture the frequencies, severity, duration, and spatial coverage of drought at the LZ level, which will be data sources for the WDRPs. Most of the evaluated literature relied on data from a small number of stations that were not proportional to their spatiality. But, according to Sadat *et al*. (2020), drought protection and preparedness depend on long-term recorded and spatially well-distributed meteorological data. Unrepresentative data could not demonstrate a complete picture of results that vividly put the magnitude and intensities of droughts and the accurate spatial distributions and time series of these occurrences.

Kiremt (June to August or September) and Belg (March to May) are precipitate sources for the research area's rain-fed agricultural activities and productivity. Also, the Belg and Kiremt seasons are the primary moisture sources for animal forage productions and sources of moisture budget for the local ecosystems' stabilities. As a result, extensive meteorological data and detailed investigations of the Belg and Kiremt drought evolution, trends, and magnitudes at specific livelihood zones are necessary. Studying the spatiotemporal drought frequencies, durations, and severities at livelihood zones is essential to show the vulnerable area on local levels. These methods will provide clear drought trends to reduce drought impacts and sustain the local communities' livelihoods by developing appropriate strategies. This result will give more input to policymakers in drought management and preparedness development.

Hence, this study attempts to detect meteorological drought incidence using SPEI in the Northwestern Escarpment of the Ethiopian Rift Valley. Using the result as an input concerned body can develop drought management that withstands the impact, strengthen communities' resilience, and conserve and sustainably use their natural resources. Moreover, the historical context's outlook on local drought occurrences could facilitate applying low-risk and long-term plans to develop robust livelihood systems. Therefore, this study will improve the existing drought monitoring system at the household level. The finding will also contribute to early warning systems, particularly at district levels in the study area and scientific communities that will benefit from the study.

3.2. Data Sets and Methodology

3.2.1. Data Types and Sources

The National Meteorological Agency of Ethiopia provided us with monthly Climate Hazards Group Infrared Precipitation with Station data (CHIRPS) and Enhancing National Climate Service (ENACTS) Maximum (Tmax) and minimum (Tmin) temperatures data (1983-2016) at moderate spatial resolution (4km-by-4km). The collected CHIRPS and ENACTS data were free of zero missing values and used to compute drought frequency, duration, magnitude, and spatial coverage. Ghozat *et al.* (2020) used CHIRPS-based precipitation data with a high resolution to evaluate the accuracy of satellite products with ground-based meteorological stations on daily, monthly, and annual scales in Iran.

3.2.2. Data Processing, Analysis, and Interpretation

The Standardized Precipitation Evapotranspiration Index (SPEI), one of the significant meteorological drought indices, was applied to analyze the condition of drought incidence at a three-month time scale in the study area. SPEI is a commonly used tool for estimating water balances and measuring droughts worldwide (Shi *et al.*, 2017). Vicente-Serrano *et al*. (2012) reported that the index combined Palmer Drought Severity Index (PDSI) to simplify the detection of meteorological drought incidence. For the calculation of the SPEI, the first step is to find the probability density function using the gamma probability density function, which best describes the distribution of the precipitation data over different time scales using the same computing procedure of the SPI (Zhang & Shen, 2019). However, the inputs required to calculate the SPEI program are precipitation and Potential Evapotranspiration (PET).

World Meteorological Organizations (WMO) recommends using the Penman-Monteith (MP) equation to calculate PET. However, Penman-Monteith (MP) equation requires long recording data of solar radiation, temperatures, wind speed, and relative humidity, which are not readily available in meteorological stations in developing countries (Bae *et al*., 2018). However, if there is a limitation of data, Vicente-Serrano *et al*.(2014) recommended Hargreaves (Hg) equations as the first and Thornthwaite (Th) equations as the second alternatives to estimate PET to calculate SPEI using R packages. So that, to run the PET of this study, depending on the availability of the maximum and minimum temperatures, precipitations, longitude, and latitude data, the Hargreaves (Hg) equation was used.

$$SPEI = P - PET \qquad 3.1$$

Where P monthly average rainfall and PET are Potential monthly Evapotranspiration, for further information on the SPEI tool, visit http://sac.csic.es/spei/index.html.

Table 3.1 Meteorological drought classification or interpretation by SPEI (Sources: WMO, 2012)

Descriptions	SPEI values
Extremely wet	>2
Very wet	1.5 to 1.99
Moderately wet	1.00 to 1.49
Mildly wet	0 to 0.99
Mild drought	0 to -0.99
Moderate drought	-1.0 to -1.49
Severe drought	-1.5 to -1.99
Extreme drought	<-2

After analyzing the magnitude and severity of the drought within the SPEI index, their spatial and temporal trends were further analyzed and mapped in ArcGIS. The Inverse Weighting Methods (IDM) approach was applied to interpolate the spatial drought trends. The IDM is a helpful tool for interpolating rainfall distributions and drought occurrences (Mohammed, 2018). Using the Thiessen polygon, the study computed the exact areas of each gird's points because the meteorological data were obtained in a 4km by 4km region. Using the girds, the author calculated the geographic drought coverages for the study drought seasons of the research livelihood zones. The study also compared drought spatial increasing trends between the three LZs using simple linear regression with GraphPad Prism version 8.4.2 software.

3.3. Results and Discussions

3.3.1. Drought Characteristics in the Study Area

Studying the spatiotemporal trends of drought is vital to carrying out the analysis of the impacts of drought. Rain feed agricultural activities and productivities of the study area depends on two seasonal precipitations. The study area's long and short rainy seasons are Kiremt (June to August or September) and Belg (March to May). Both seasons are the primary rain sources for cultivating short and long-term growth crops. Also, the Belg and Kiremt seasons are the primary moisture sources for animal forage productions and sources of moisture budget for the local ecosystems' stabilities. Small precipitation changes in one or both seasons can have consequences of crop failure and forage problems in the study area. Shortage of precipitations for continuous months, particularly during consecutive rainy seasons, significantly impacts rain-fed agriculture systems. Suppose there is a period of months to years of prolonged dry weather conditions due to precipitation departure in a specific region. In that case, meteorological drought may impact water resources, agricultural activities, local climate, ecosystem processes, and social affairs (Sharafati *et al*., 2019). As a result, this spatiotemporal drought study focused on short-term (Belg and Kiremt) and combined-season (March-August) drought patterns.

Charts and graphs depict the outcomes of the temporal drought pattern, and for the spatial drought trends, the researcher preferred to put tables, graphs, and maps for each LZs. The spatial coverage for SPEI value for Belg and Kiremt seasons for the measured temporal scales from 1983 to 2016 were presented in Table 3.2 and Table 3.3, respectively. The author included maps for the Belg and Kiremt seasons in Figures 3.2 and 3.6. In SPEI3, the colors represented the severity of the drought or wet seasons. The red and green colors represented the drought and wet seasons, respectively. The blue color in the red and green maps presented the highest or lowest SPEI values for the drought and wet seasons, respectively. But since the colors given to show the range of SPEI3 magnitude at a gird level, the red or the green colors does not mean 100% drought or wet season; instead, they indicate the extent of spatial drought season or the wet season coverage in the livelihood zones. Since the SPEI values were stated in ranges using IDW, it influenced neighborhood grid points' SPEI3 values. See Figure.3.2 for Belg and Figure.3.6 for Kiremt for more information on each map's highest and lowest SPEI3 values. The area coverages of drought magnitude for the scales for each year’s seen below in Table 3.2 for Belg and Table 3.3 for the Kiremt seasons.

3.3.2. Drought Condition During the Belg Rain Season

From 1983 to 2016 in Belg, 18 mild, moderate, and severe seasonal temporal droughts were recorded. SPEI3 documented moderate to severe seasonal droughts in 1990, 1991, 1999, 2000, 2003, 2004, 2008, 2009, and 2013. The frequencies of seasonal drought for Belg have increased since 1998 in all livelihood zones. Figure.3.1 indicates the SPEI3 temporal drought trends. The chart shows that this season's most extended persistent drought years occurred from 1998 to 2004, followed by five drought seasons from 2012 to 2016. Within the past thirty-four years (1983-2016), 1999 was recorded as the severe temporal Belg drought in SPEI3 in all livelihood zones. The magnitude ranged from -1.71 in TCLZ to -1.88 SPEI values in RVLZ.

From 1983 to1999, there were ten moderate up to severity wet Belg seasons in all livelihood zones but with slight differences between the livelihood zones. From 2000 to 2016, there were four wet Belg seasons in all livelihood zones. SPEI3 scores for the three LZs were highest in the wettest Belg seasons of 1994 and 1997. ALOLZ and TCLZ had a documented SPEI value of 2.00 in 1996. Furthermore, in SPEI3 value, 1993 and 1987 were the second and third highest wet Belgs, respectively. SPEI3 reported the longest continuous wet seasons from 1985 to 1987 and 1995 to 1997.

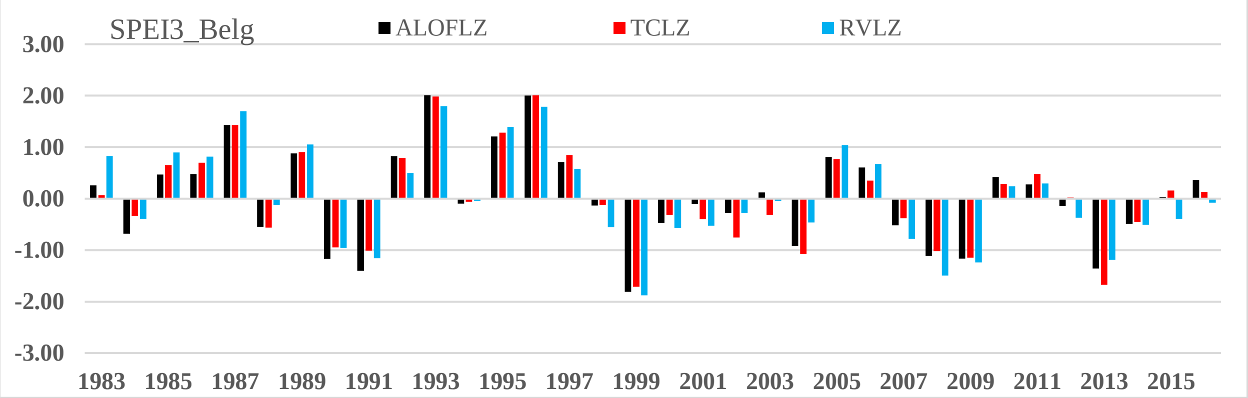
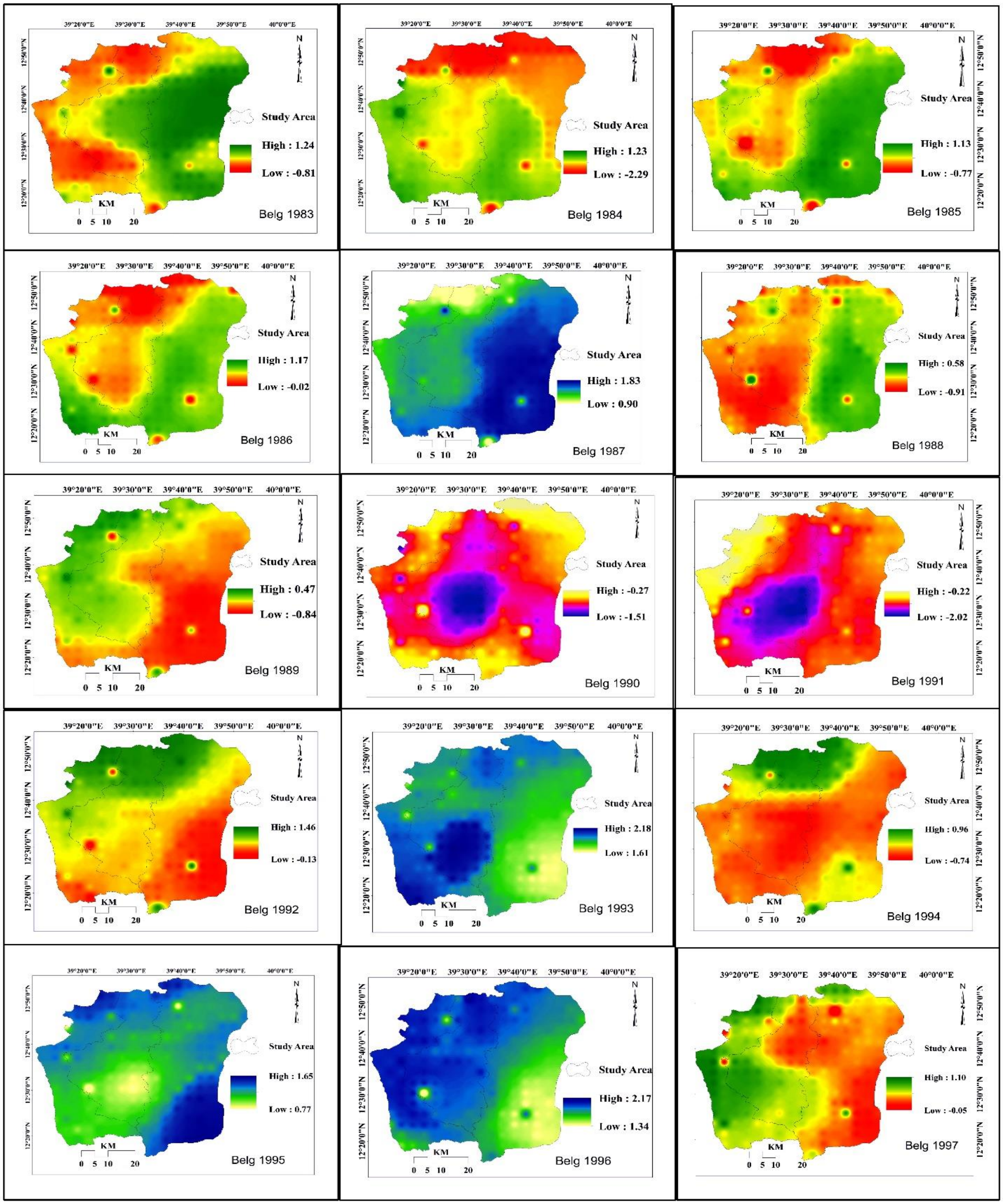


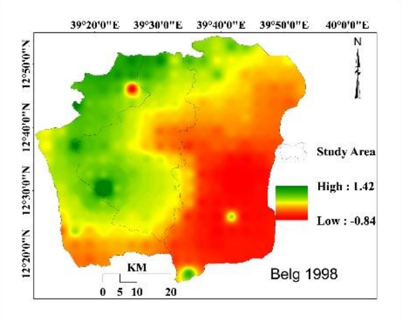
Figure 3.1. Temporal drought trends in Belg seasons from 1983 to 2016

For spatial drought coverage, from mild to extreme Belg drought occurred in partial or all study LZs. At gird point levels in ALOLZ, there was a severe to extreme spatial Belg drought. Below, the spatial drought map in Figure 3.2 indicated that in 1984, 1990,1991, 1999, 2009, and 2013, ALOLZ recorded severe to highly severe drought Belg seasons with SPEI3 magnitude of -2.24, -1.51,-2.02, and -2.33, -1.84, and -1.53 respectively. Furthermore, as indicated in Table 2, 100% of the ALOFLZ were affected by mild to extremely severe drought in 1984, 1990, 1991, 1994, 1999, 2000, 2004, 2007, 2008, 2009, and 2013. However, from 1985 to 1987 and 1995 to 1999, ALOLZ recorded better precipitation relative to the three livelihood zones.

Besides, from 1992 to 2016, the TCLZ and RVLZ recorded fluctuated dry and wet Belg seasons. In 1988, 1990, 1991, 2001, 2004, 2007, 2009, 2013, and 2014, all parts of (100%) TCLZ were affected by mild to highly seasonal Belg drought. Similarly, all areas of RVLZ were affected by drought in Belg seasons from1990-1991, 1998- 2000, 2004, 2007-2009, and 2013-2014. As seen below in Figure 3.3, relatively to the two LZs, the area coverage of Belg drought has rapidly increased in RVLZ. All LZs were partially affected by mild to highly severe drought or free from drought impacts in the Belg season for the rest of the study years. The summary of the spatial drought coverage of the study years in the Belg season for the study livelihood zone is presented below in Table 2 and Figure 3.3. The trends of area coverage are shown below in Figure 3.3.

To sum up, the drought trends in the Belg season have steadily increased temporally and spatially in all LZs. From 1989 to 2016, the drought frequencies have increased in Belg with a slight difference between the livelihood zones. The frequencies of seasonal drought for Belg have increased since 1998 in all livelihood zones. The Belg season's long and persistent drought years occurred from 1998 to 2004 and followed five drought seasons from 2012 to 2016. The current study agreed with the Haile and Tang (2019) findings that drought tends to be more frequent and severe in East Africa's boreal spring (Belg Season). The Mohammed (2018) study indicated the increasing drought tendency during the Belg season in the North East Highland of Ethiopia. This study coincided with his findings in all study LZs.


Belg 1983
High : 1.24
Low : -0.81
Belg 1984
High : 1.23
Low : -2.29
Belg 1985
High : 1.13
Low : -0.77
Belg 1986
High : 1.17
Low : -0.02
Belg 1987
High : 1.83
Low : 0.90
Belg 1988
High : 0.58
Low : -0.91
Belg 1989
High : 0.47
Low : -0.84
Belg 1990
High : -0.27
Low : -1.51
Belg 1991
High : -0.22
Low : -2.02
Belg 1992
High : 1.46
Low : -0.13
Belg 1993
High : 2.18
Low : 1.61
Belg 1994
High : 0.96
Low : -0.74
Belg 1995
High : 1.65
Low : 0.77
Belg 1996
High : 2.17
Low : 1.34
Belg 1997
High : 1.10
Low : -0.05
Study Area
N
KM
0 5 10 20
39°20'0"E
39°30'0"E
39°40'0"E
39°50'0"E
40°0'0"E
12°20'0"N
12°30'0"N
12°40'0"N
12°50'0"N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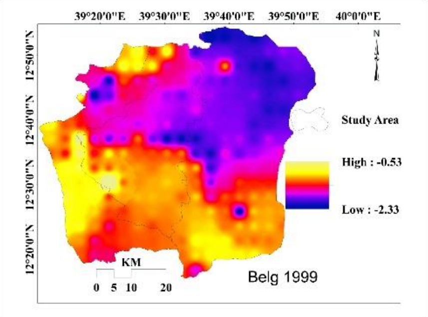
N
Study Area
High : 1.42
Low : -0.84
KM
0 5 10 20
Belg 1998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Study Area
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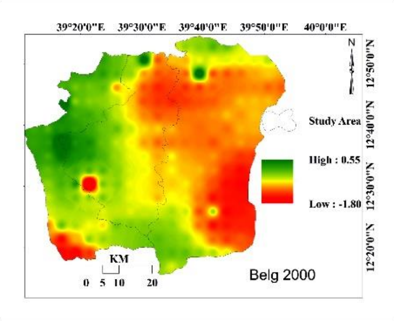
Low : -2.33
KM
0 5 10 20
Belg 1999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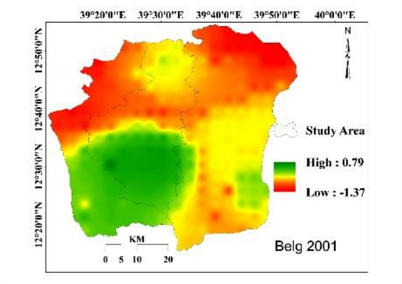
Study Area
High : 0.55
Low : -1.80
KM
0 5 10 20
Belg 2000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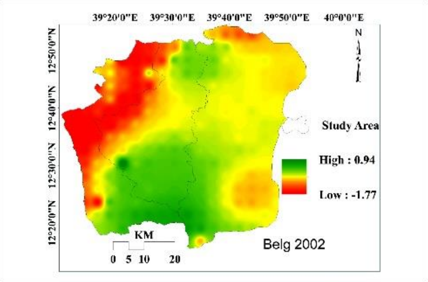
N
Study Area
High : 0.79
Low : -1.37
KM
0 5 10 20
Belg 2001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Study Area
High : 0.94
Low : -1.77
KM
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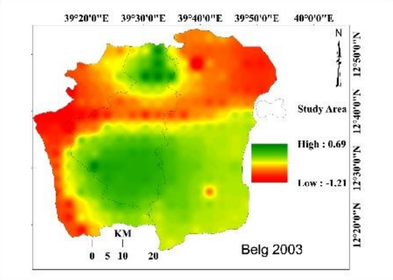
Belg 2002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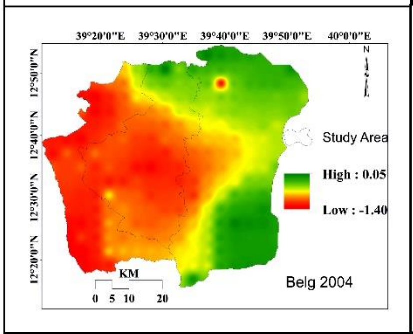
N
Study Area
High : 0.69
Low : -1.21
KM
0 5 10 20
Belg 2003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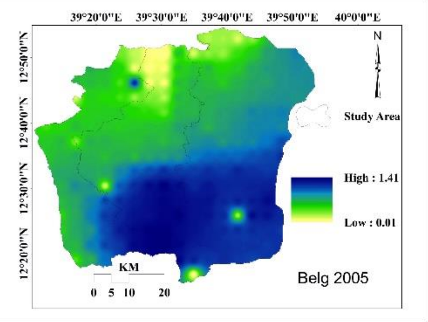
Study Area
High : 0.05
Low : -1.40
KM
0 5 10 20
Belg 2004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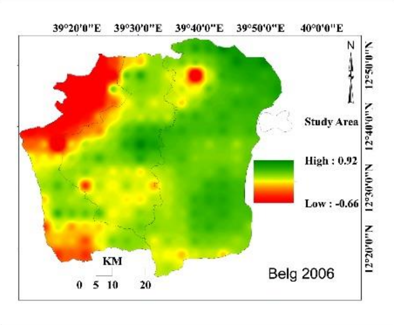
N
Study Area
High : 1.41
Low : 0.01
KM
0 5 10 20
Belg 2005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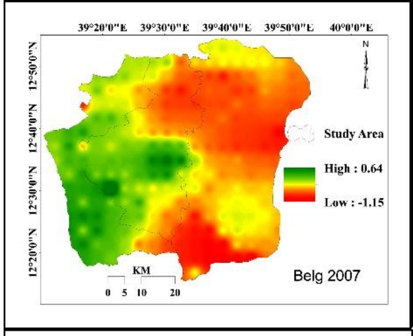
N
Study Area
High : 0.92
Low : -0.66
KM
0 5 10 20
Belg 2006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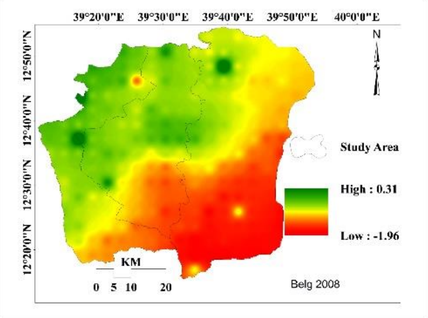
N
Study Area
High : 0.64
Low : -1.15
KM
0 5 10 20
Belg 2007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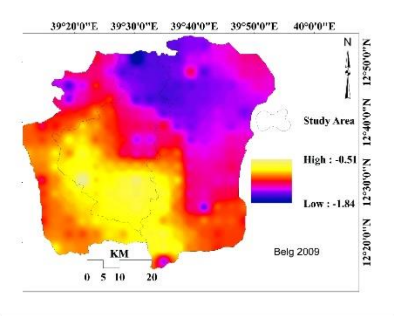
N
Study Area
High : 0.31
Low : -1.96
KM
0 5 10 20
Belg 2008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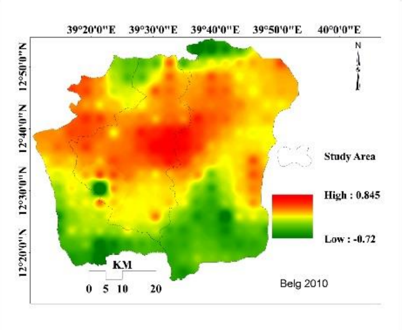
N
Study Area
High : -0.51
Low : -1.84
KM
0 5 10 20
Belg 2009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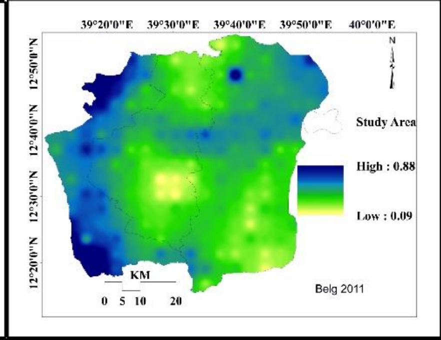
N
Study Area
High : 0.845
Low : -0.72
KM
0 5 10 20
Belg 2010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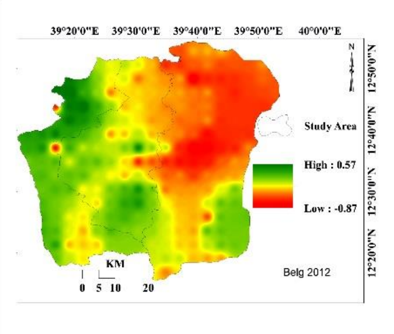
N
Study Area
High : 0.88
Low : 0.09
KM
0 5 10 20
Belg 2011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12°50'0"N 12°40'0"N 12°30'0"N 12°20'0"N
N
Study Area
High : 0.57
Low : -0.87
KM
0 5 10 20
Belg 2012

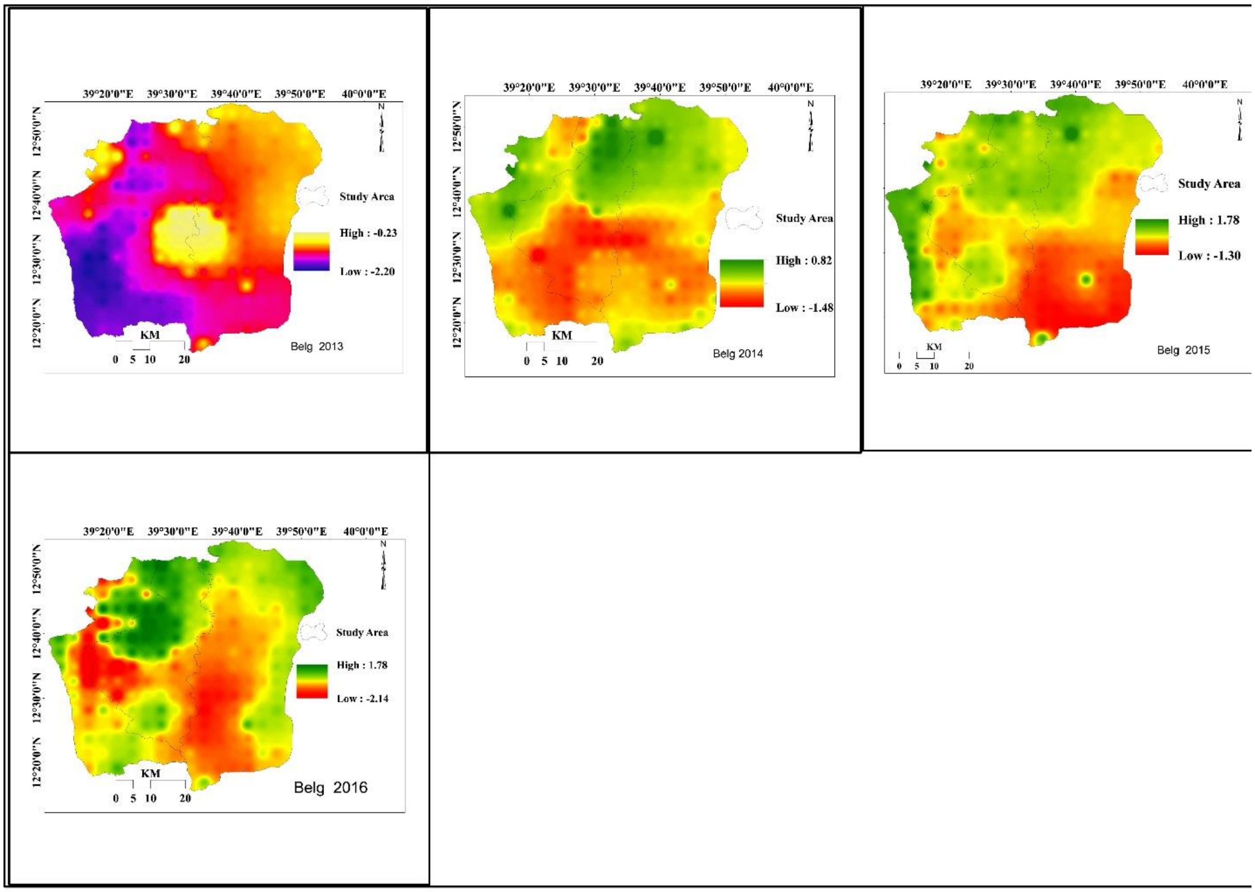


Figure 3.2. Map of spatial drought trends in Belg seasons from1983-201

Table 3.2 Spatial drought trends in % of area coverage n Belg season from 1983-2016

Years	Spatial drought area coverage in % for Belg season														
	ALOFLZ(1106.19 KM^2) in %					TCLZ(933.56 KM^2) in %					RVLZ (1850.10 KM^2) in %				
	DF	MD	MOD	SD	ESD	DF	MD	MOD	SD	ESD	DF	MD	MOD	SD	ESD
1983	72.05	27.95	-	-	-	54.26	45.74	-	-	-	98.04	1.96	-	-	-
1984	-	81.45	9.16	-	-	10.72	74.61	14.66	-	-	11.97	75.31	9.95	2.77	-
1985	93.98	6.02	-	-	-	100	-	-	-	-	100	-	-	-	-
1986	100	-	-	-	-	100	-	-	-	-	100	-	-	-	-
1987	100	-	-	-	-	100	-	-	-	-	100	-	-	-	-
1988	-	100	-	-	-	-	100	-	-	-	14.05	85.95	-	-	-
1989	100	-	-	-	-	97.38	2.62	-	-	-	99.06	0.94	-	-	-
1990	-	10.73	89.27	-	-	-	61.98	38.02	-	-	-	55.57	44.43	-	-
1991	-	6.27	54.58	1.57	17.32	-	49.92	42.66	7.42	-	-	11.44	84.82	3.75	-
1992	93.73	6.27	-	-	-	100	-	-	-	-	100	-	-	-	-
1993	100	-	-	-	-	100	-	-	-	-	100	-	-	-	-
1994	-	75.18	24.82	-	-	30.17	69.83	-	-	-	36.00	64.00	-	-	-

1995	100	-	-	-	-	100	-	-	-	-	100	-	-	-	-
1996	100	-	-	-	-	100	-	-	-	-	100	-	-	-	-
1997	100	-	-	-	-	100	-	-	-	-	100	-	-	-	-
1998	1.57	98.43	-	-	-	9.34	90.66	-	-	-	-	100	-	-	-
1999	-	1.57	28.19	-	-	100	-	-	-	-	-	-	-	42.4	57.62
2000	-	100	-	-	-	4.47	95.53	-	-	-	-	100	-	-	-
2001	46.99	53.01	-	-	-	-	45.23	14.96	39.80	-	3.17	86.80	10.02	-	-
2002	36.03	54.80	6.03	-	-	24.89	30.38	28.22	16.50	-	10.47	87.93	1.60	-	-
2003	68.92	31.08	-	-	-	26.82	70.56	2.62	-	-	48.94	51.06	-	-	-
2004	-	43.61	56.39	-	-	-	32.44	67.56	-	-	-	94.02	5.98	-	-
2005	100	-	-	-	-	100	-	-	-	-	50.25	49.75	-	-	-
2006	100	-	-	-	-	100	-	-	-	-	99.06	0.94	-	-	-
2007	-	100	-	-	-	-	100	-	-	-	-	90.45	9.55	-	-
2008	-	36.01	48.33	-	-	7.95	49.24	42.81	-	-	-	3.55	56.20	40.3	-
2009	-	37.59	46.76	-	-	-	18.09	80.07	1.84	-	-	9.17	84.18	6.65	-
2010	62.41	37.59	-	-	-	91.96	8.04	-	-	-	94.26	5.74	-	-	-
2011	100	-	-	-	-	100	-	-	-	-	100	-	-	-	-
2012	28.19	71.81	-	-	-	55.03	44.97	-	-	-	6.64	93.36	-	-	-
2013	-	20.35	21.93	3.13	34.65	-	7.91	16.27	58.65	17.2	-	31.51	61.20	7.30	-
2014	14.10	76.50	9.40	-	-	-	100	-	-	-	-	96.83	3.17	-	-
2015	56.14	43.86	-	-	-	56.93	43.07	-	-	-	38.12	54.50	7.38	-	-
2016	96.87	1.57	-	1.57	17.33	59.65	28.47	2.24	9.64	-	46.61	52.45	0.94	-	-

DF= Drought Free MD= Mild Drought, MOD= Moderate Drought, SD= Severe Drought, ESD= Extremely Severe Drought, (-) = Zero value

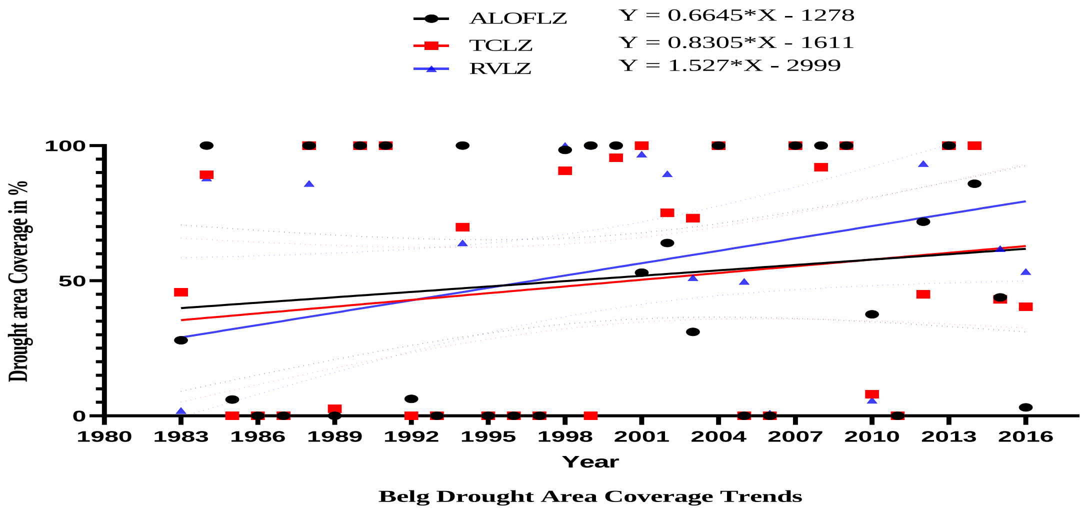


Figure 3.3. The spatial drought trends in % of area coverage from 1983-2016 using GraphPad Prism in the Belg season

3.3.3. Drought Condition During the Kiremt Rain Season

For all study years and livelihood zones, all spatial drought magnitudes from mild to extreme Kiremt drought were presented below in Table 3.3. Similarly, for the research areas and years, see Figure 3.4 for temporal charts and Figure 3.6 for spatial SPEI maps of drought and wet event trends. The study area is highly dependent on Kiremt for rain, and most agricultural activities and productivities depend on the precipitation condition of this season. However, from 1983 to 2016, 12 temporal droughts were recorded in Kiremt. Mild, moderate, and severe seasonal droughts were documented in Kiremt from 1983 to 2016, as shown in Figure 3.4. Of these seasonal drought years,7 of them were moderate up to severe seasonal droughts. However, the severity, persistence, and frequencies of the Kiremt drought events were seen from1983-1993 in all livelihood zones. In 1983, 1984, 1985, 1987, 1989, 1990, 1991, and 1993, the Kiremt drought was severe, persistent, and frequent in all livelihood zones. In 1984, the study livelihood zone experienced the worst drought. This year, SPEI3 was recorded from -1.74 in TCLZ to -1.68 in RVLZ. The 1998 Kiremt season was the wettest in all livelihood zones in the thirty-four years. In all livelihood zones, the better wet Kiremt season occurred in 1988, 1994, 1998, 2001, 2007, and 2010. Besides, 2012 for RVLZ and 2016 for ALOFLZ and TCLZ were wet Kiremts.

Table 3.3 and Figure 3.5 show that mild to extreme Kiremt drought occurred on partial or all study livelihood zones for spatial drought coverage. In ALOFLZ, about 87.47, 100, 100, 100, 100, 100, 92.17, 100, and 62.66% in the years of 1983, 1984, 1985, 1987, 1,1990,1991,1993 and 20015 were affected from moderate to extreme Kiremt drought respectively. Besides moderate to extreme Kiremt drought in TCLZ were 98.14, 100, 100, 97.38, 100, 100,43.96, 100,1.58, 9.99 and 62.66% of the area affected in the years of 1983, 1984, 1985, 1987,1989,1990,1991,1993, 2002,2004, and 20015 respectively. Moderate to extreme Kiremt drought in RVLZ were covered the area of 96.36, 99, 79.47, 97.19, 98.13, 100, 100, 97.56, 2.79, 85.16 and 62.66% in the years of 1983, 1984, 1985, 1987,1998,1990,1991,1993, 2002,2008, and 20015 respectively. As seen in Figure 3.6, the spatial drought trends in area coverage slightly decreased in all LZs.

From 1989 to 2016, the drought frequencies have increased in Belg and decreased in Kiremt. The frequencies and severity of drought slightly differed between the livelihood zones. There were yearly Kiremt, Belg, or both season droughts in local or livelihood zone levels. In the Kiremt season, extreme to severe drought decreased, but moderate to mild drought frequencies and persistence increased in all livelihood zones. Drought occurrences in this season, becoming locally fragmented even at village levels. For spatial drought coverage, mild to extreme Kiremt drought occurred in partial or all study LZs. From 1984 to 1998, in Kiremt rainy season, drought impacts have been relatively severe in ALOFLZ and TCLZ than in RVLZs. However, from 1992 to 2016, the ALOFLZ and TCLZ were recorded as moderately wettest Kiremt than RVLZs. Mild to severity short Kiremt drought frequencies frequently happened from 1997 to 2016 in TCLZ and RVLZ than ALOLZ.

Even though droughts decreased from 2001 to 2016, seven wet Kiremt seasons were recorded with SPEI values below 0.5, indicating mild wet. This precipitation value was too low for agricultural practices. These small precipitation sources and mild spatiotemporal metrological drought frequently happened in the study LZs. A plant’s demand for water is dependent on prevailing meteorological conditions and vulnerable to dry weather conditions. Besides, the Kiremt drought season is becoming locally fragmented even at village levels. There is no attention to the study area except when large-scale drought occurs at regional or nationwide scales. Furthermore, drought often elapses once it ends, and consequently, the government will again be ill-informed when the next large-scale drought event occurs. This study coincides with Gidey (2012), that stated that an isolated drought event is hazardous for the affected people.

The Mohammed (2018) study indicated that increasing tendency of drought Belg season but a reducing tendency in Kiremt and the annual timescale in the North East Highland of Ethiopia. This study partially coincided with the study of Mohammed (2018). This study also agreed with Kenawy *et al*.(2016) findings on changes in the frequencies and severity of hydrological droughts over Ethiopia, which reveal a statically significant decrease in the severity of droughts (extreme and severe drought) compared to the moderate drought over the 54 years (1960-2013). This study also coincides with the Zeleke *et al*. (2017) findings on drought trends and periodicity over Ethiopia from 1979 through 2014. The severity and frequencies of drought in this study were higher from 1983 to 1991, better 1993 to 1998, and returned mildly to moderate drought from 2000 to 2016. The current research coincides with Gidey *et al*. (2018) on the increasing frequencies and persistence of drought. Their findings stated that drought frequencies, durations, and severity are higher in the lowland area than in the mid and highlands during the last 15 years. However, since 2000 drought severity in Kiremt was reduced in the study livelihood zones except for 2015. Further, Gidey *et al*. (2018) findings show that 2001, 2003, 2003, 2006, 2007, and 2010 years were free from incidences of agricultural drought in their study area, but these years were not drought-free in the current study area, which is parts of their study area.

Table 3.3 The spatial drought trends in % of area coverage in the Kiremt season from 1983 to 2016

Years	Spatial drought area coverage in % for Kiremt season														
	ALOFLZ((total area 1106.19 KM^2)					TCLZ(total area 933.56 KM^2)					RVLZ ((total area 1850.10 KM^2)				
	DF	MD	MOD	SD	ESD	DF	MD	MOD	SD	ESD	DF	MD	MOD	SD	ESD
1983	-	12.53	79.64	7.83	-	-	1.86	72.39	25.75	-	-	3.63	88.53	7.84	-
1984	-	-	-	100	-	-	-	8.34	91.66	-	-	0.94	2.93	96.14	-
1985	-	-	100	-	-	-	-	100	-	-	-	20.53	79.47	-	-
1986	82.77	17.23	-	-	-	100	-	-	-	-	100	-	-	-	-
1987	-	-	100	-	-	-	2.62	88.36	9.02	-	-	2.81	95.18	2.01	-
1988	100	-	-	-	-	100	-	-	-	-	100	-	-	-	-
1989	-	-	65.79	32.66	1.55	-	-	93.52	6.48	-	-	1.87	79.36	18.77	-
1990	-	-	100	-	-	-	-	97.38	2.62	-	-	-	98.13	1.87	-
1991	-	7.83	92.17	-	-	-	56.04	43.96	-	-	-	-	97.19	2.81	-
1992	100	-	-	-	-	87.99	12.01	-	-	-	95.18	4.82	-	-	-
1993	-	-	100	-	-	-	-	100	-	-	-	2.44	97.56	-	-
1994	100	-	-	-	-	100	-	-	-	-	100	-	-	-	-
1995	100	-	-	-	-	100	-	-	-	-	92.51	7.49	-	-	-
1996	92.17	7.83	-	-	-	88.39	11.61	-	-	-	84.56	15.44	-	-	-
1997	-	100	-	-	-	-	100.00	-	-	-	-	100	-	-	-
1998	100	-	-	-	-	100	-	-	-	-	100	-	-	-	-
1999	100	-	-	-	-	100	-	-	-	-	100	-	-	-	-
2000	100	-	-	-	-	100	-	-	-	-	100	-	-	-	-
2001	100	-	-	-	-	100	-	-	-	-	100	-	-	-	-
2002	-	100	-	-	-	-	98.42	-	-	-	-	97.21	2.79	-	-
2003	86.14	13.86	-	-	-	63.61	36.39	-	-	-	97.25	2.75	-	-	-
2004	23.48	76.52	-	-	-	-	90.01	-	-	-	85.55	14.45	-	-	-
2005	100	-	-	-	-	100	-	-	-	-	95.26	4.74	-	-	-
2006	100	-	-	-	-	100	-	-	-	-	94.14	5.86	-	-	-
2007	100	-	-	-	-	100	-	-	-	-	100	-	-	-	-

2008	-	100	-	-	-	-	100.00	-	-	-	13.91	0.94	85.16	-	-
2009	49.88	50.12	-	-	-	57.58	42.42	-	-	-	82.04	17.96	-	-	-
2010	100	-	-	-	-	100	-	-	-	-	100	-	-	-	-
2011	21.93	78.07	-	-	-	62.27	37.73	-	-	-	5.18	94.82	-	-	-
2012	70.48	29.52	-	-	-	62.43	37.57	-	-	-	82.36	17.64	-	-	-
2013	100	-	-	-	-	97.38	2.62	-	-	-	98.13	1.87	-	-	-
2014	60.84	39.16	-	-	-	44.59	55.41	-	-	-	44.17	55.83	-	-	-
2015	-	34.21	62.66	3.13	-	1.86	33.62	64.53	-	-	-	0.94	40.38	58.69	-
2016	100	-	-	-	-	98.14	1.86	-	-	-	18.05	81.95	-	-	-

DF= Drought Free, MD= Mild Drought, MOD= Moderate Drought, SD= Severe Drought, ESD= Extremely Severe Drought, (-) = Zero value

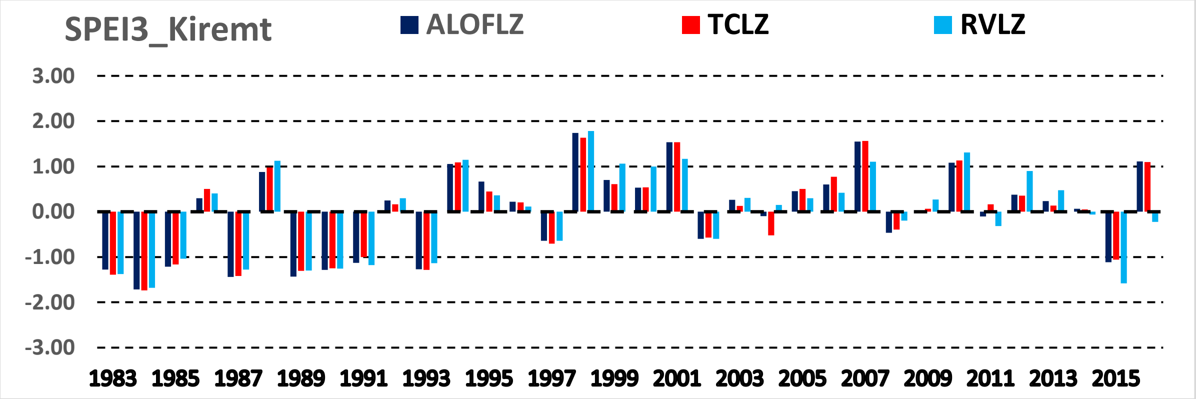


Figure 3.4. Chart of temporal drought trends in Kiremt seasons from1983-2016

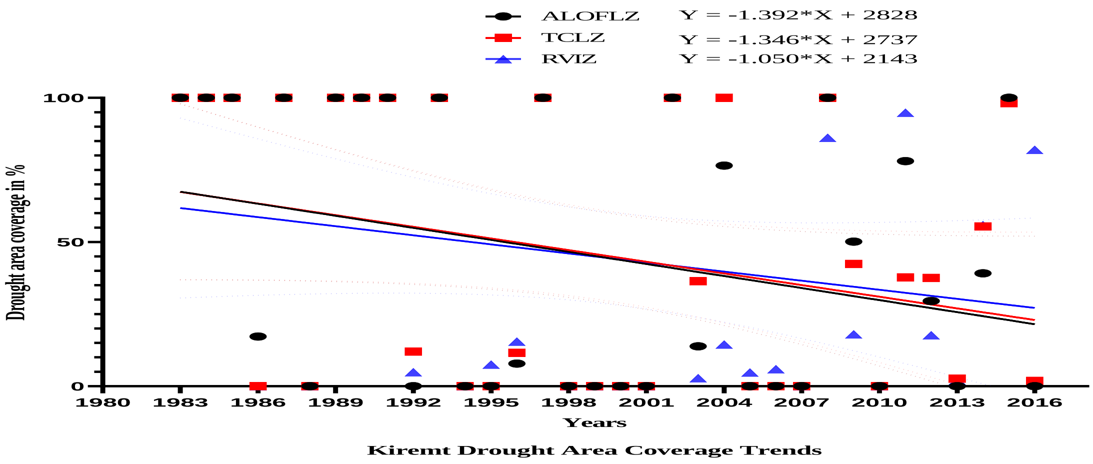
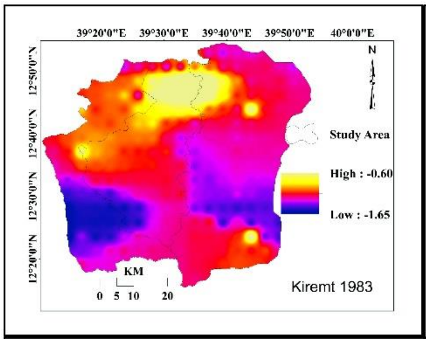


Figure 3.5. The spatial drought trends in % of area coverage from 1983-2016 using GraphPad Prism in Kiremt season.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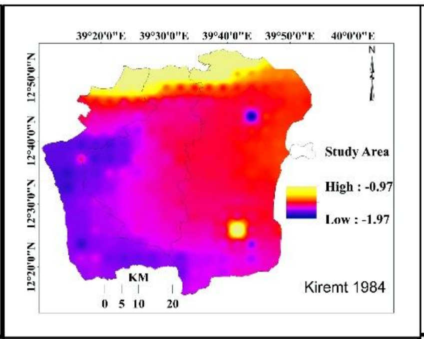
N
Study Area
High : -0.60
Low : -1.65
KM
0 5 10 20
Kiremt 1983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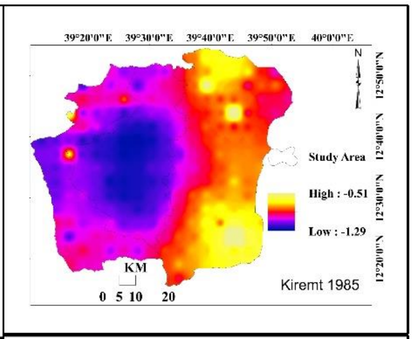
N
Study Area
High : -0.97
Low : -1.97
KM
0 5 10 20
Kiremt 1984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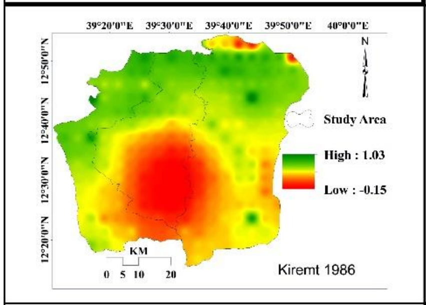
N
Study Area
High : -0.51
Low : -1.29
KM
0 5 10 20
Kiremt 1985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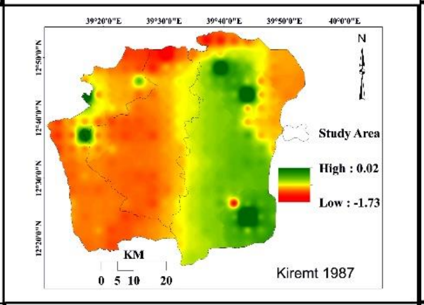
N
Study Area
High : 1.03
Low : -0.15
KM
0 5 10 20
Kiremt 1986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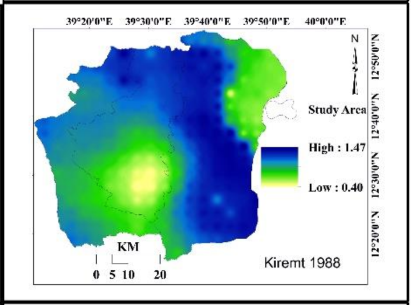
N
Study Area
High : 0.02
Low : -1.73
KM
0 5 10 20
Kiremt 1987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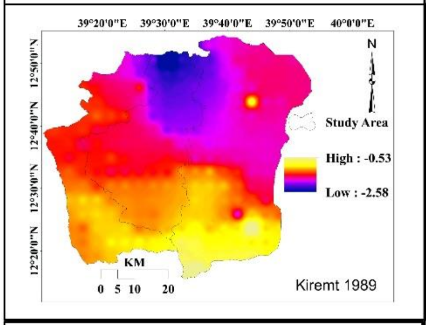
N
Study Area
High : 1.47
Low : 0.40
KM
0 5 10 20
Kiremt 1988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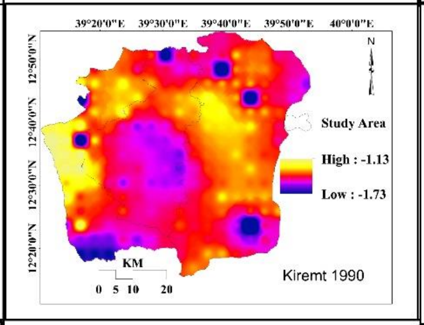
N
Study Area
High : -0.53
Low : -2.58
KM
0 5 10 20
Kiremt 1989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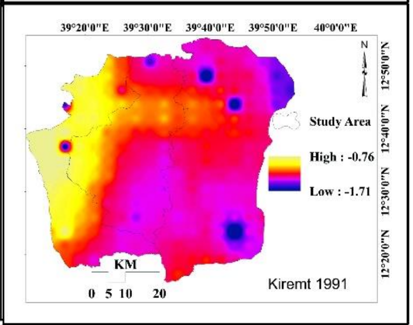
N
Study Area
High : -1.13
Low : -1.73
KM
0 5 10 20
Kiremt 1990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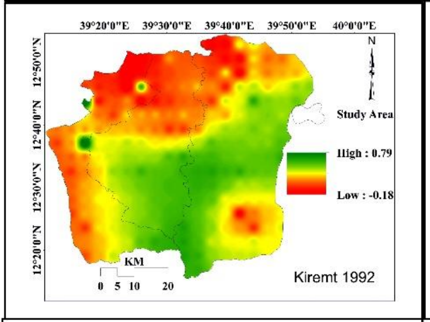
N
Study Area
High : -0.76
Low : -1.71
KM
0 5 10 20
Kiremt 1991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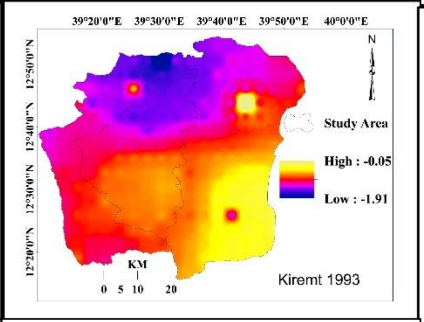
N
Study Area
High : 0.79
Low : -0.18
KM
0 5 10 20
Kiremt 1992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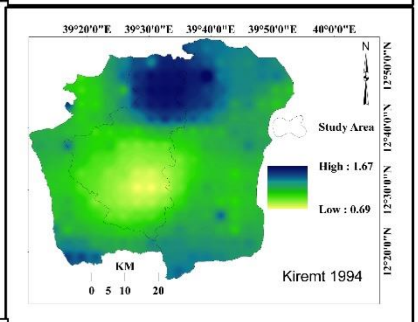
N
Study Area
High : -0.05
Low : -1.91
KM
0 5 10 20
Kiremt 1993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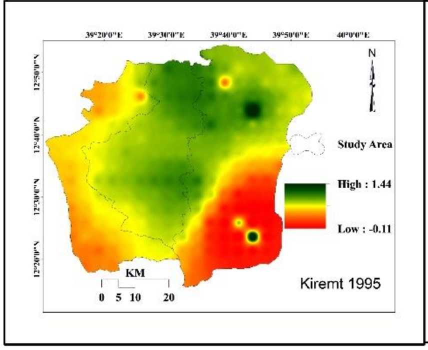
N
Study Area
High : 1.67
Low : 0.69
KM
0 5 10 20
Kiremt 1994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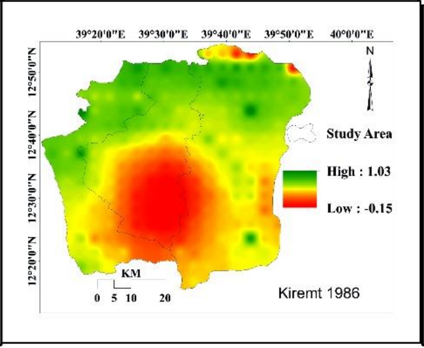
12°50'0"N 12°40'0"N 12°30'0"N 12°20'0"N
N
Study Area
High : 1.44
Low : -0.11
KM
0 5 10 20
Kiremt 1995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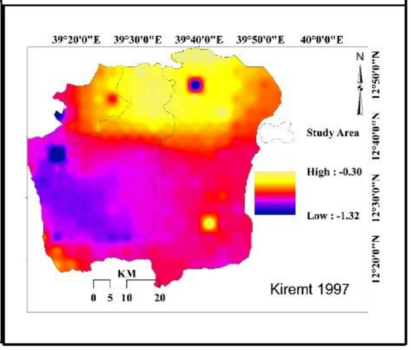
12°50'0"N 12°40'0"N 12°30'0"N 12°20'0"N
N
Study Area
High : 1.03
Low : -0.15
KM
0 5 10 20
Kiremt 1986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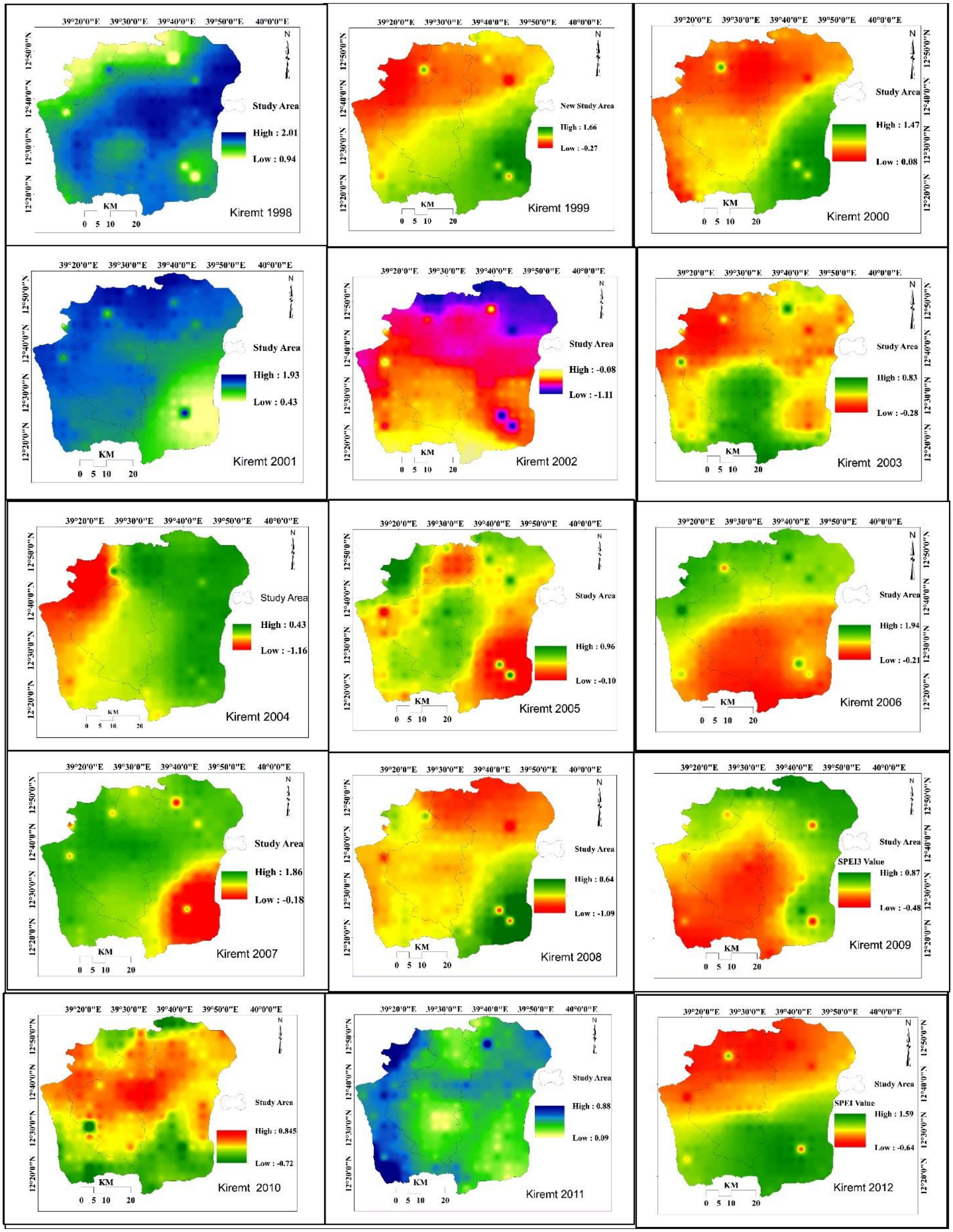
12°50'0"N 12°40'0"N 12°30'0"N 12°20'0"N
N
Study Area
High : -0.30
Low : -1.32
KM
0 5 10 20
Kiremt 1997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39°30'0"E
39°40'0"E
39°50'0"E
40°0'0"E
12°50'0"N
12°40'0"N
12°30'0"N
12°20'0"N
N
KM
0 5 10 20
Study Area
High : 2.01
Low : 0.94
Kiremt 1998
New Study Area
High : 1.66
Low : -0.27
Kiremt 1999
High : 1.47
Low : 0.08
Kiremt 2000
High : 1.93
Low : 0.43
Kiremt 2001
High : -0.08
Low : -1.11
Kiremt 2002
High : 0.83
Low : -0.28
Kiremt 2003
High : 0.43
Low : -1.16
Kiremt 2004
High : 0.96
Low : -0.10
Kiremt 2005
High : 1.94
Low : -0.21
Kiremt 2006
High : 1.86
Low : -0.18
Kiremt 2007
High : 0.64
Low : -1.09
Kiremt 2008
SPEI3 Value
High : 0.87
Low : -0.48
Kiremt 2009
High : 0.845
Low : -0.72
Kiremt 2010
High : 0.88
Low : 0.09
Kiremt 2011
SPEI Value
High : 1.59
Low : -0.64
Kiremt 2012

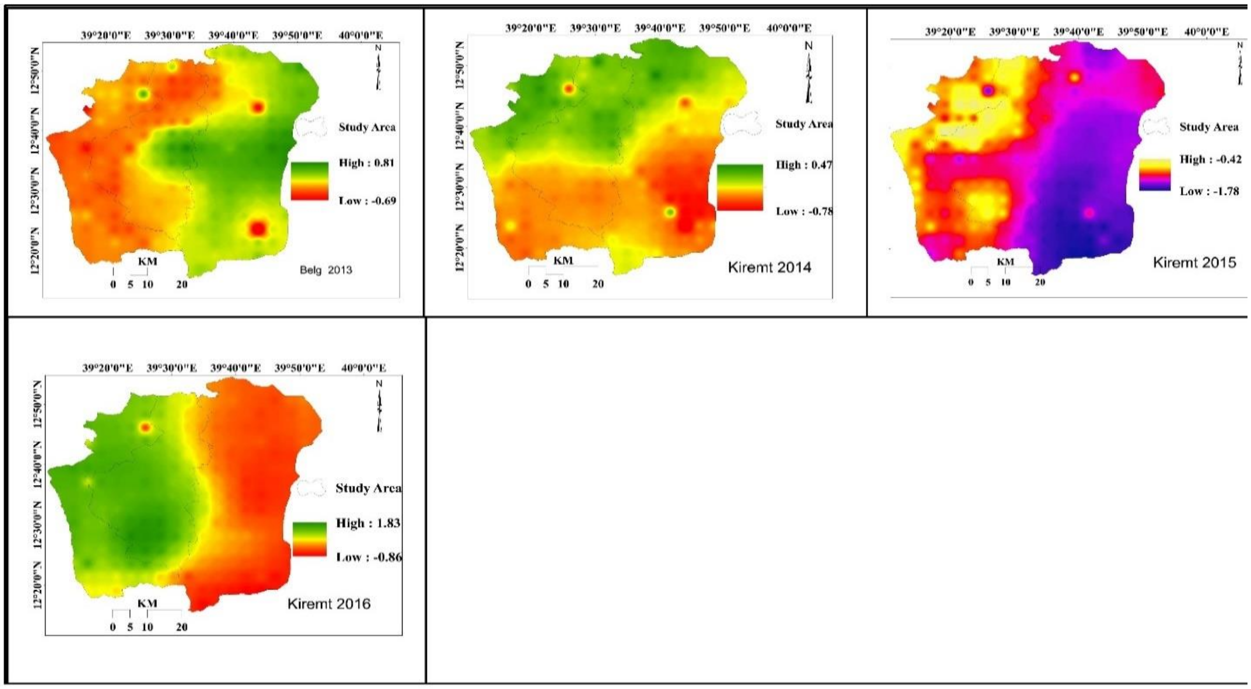


Figure 3.6. Map of spatial drought trends in Kiremt seasons from1983-2016

3.3.4. Drought Condition both During the Belg and Kiremt Rainy Seasons

This part focuses on the average combined rainy seasons of the study area. The study examined the wettest and driest years for the six months of March-August using SPEI6. From 1983 to 1991, there were two rainy and seven consecutive drought years in all livelihood zones in SPEI6 for the study months. However, from 1992 to 2007, there were two droughts and ten wet recorded years for six months. Furthermore, 2010 and 2012 were wet years for all livelihood zones and 2016 for ALOFLZ and TCLZ. Generally, from1983-2016, fifteen droughts were recorded for the combined rainy season in all livelihood zones, with two additional drought seasons for RVLZ. From 1983 to 1991, long durations and high drought severities have occurred in all livelihood zones in SPEI6 records. All livelihood zones had severe drought from SPEI6 records in 1983, 1984, 1989, 1990, and 1991, and further 2015 for RVLZ. The lowest recorded SPEI6 value in 1984 ranged from -1.90 in ALOFLZ to -1.77 in RVLZ. Further information on temporal and spatial drought trends using SPEI6 records for each year for the combined rainy season for all livelihood zones are presented below in Figures 3.7 and 3.8, respectively. As seen below in Figure 3.8, the area coverage of the combined rainy season slightly decreased in both ALOFLZ and TCLZ but increased in RVLZ.

This part focuses on the average combined rainy seasons of the study area. The moisture amount of these months implies the evapotranspiration budge and its process. There are long and short growing season crops that are sensitive to the two wet seasons of rain conditions. However, there have been Belg or Kiremt or both drought seasons in most study years in the study areas. Tefera *et al*. (2019) studied drought occurrence patterns in the Tigray region in northern Ethiopia. Their findings revealed increased drought occurrences and spatially variability in drought duration, severity, intensity, and frequency. Their result indicated that most districts in the southern (including the study LZs) and eastern zones experienced more intense droughts than the rest of their study area. This study agreed with the (Tefera *et al*. (2019) finding, except for the frequencies of drought severity occurrences. This study coincides with Ghebrezgabher *et al*. (2016) and Zeleke's (2017) findings on the severity of drought occurrences decreeing, but mild to moderate drought occurrences were escalating temporally and spatially in the study area during the study period.

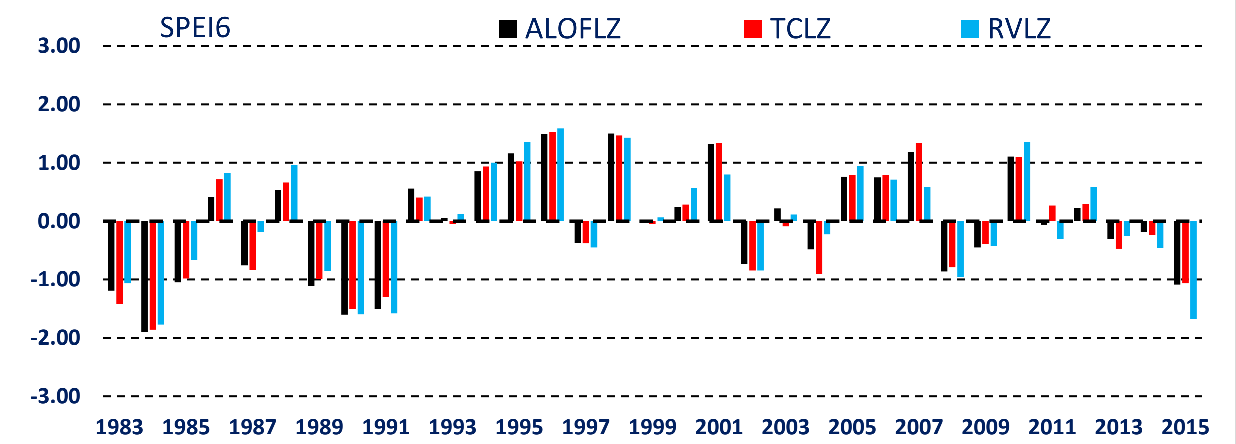


Figure 3.7. Chart of temporal drought trends in combined rainy season’s from1983-2016

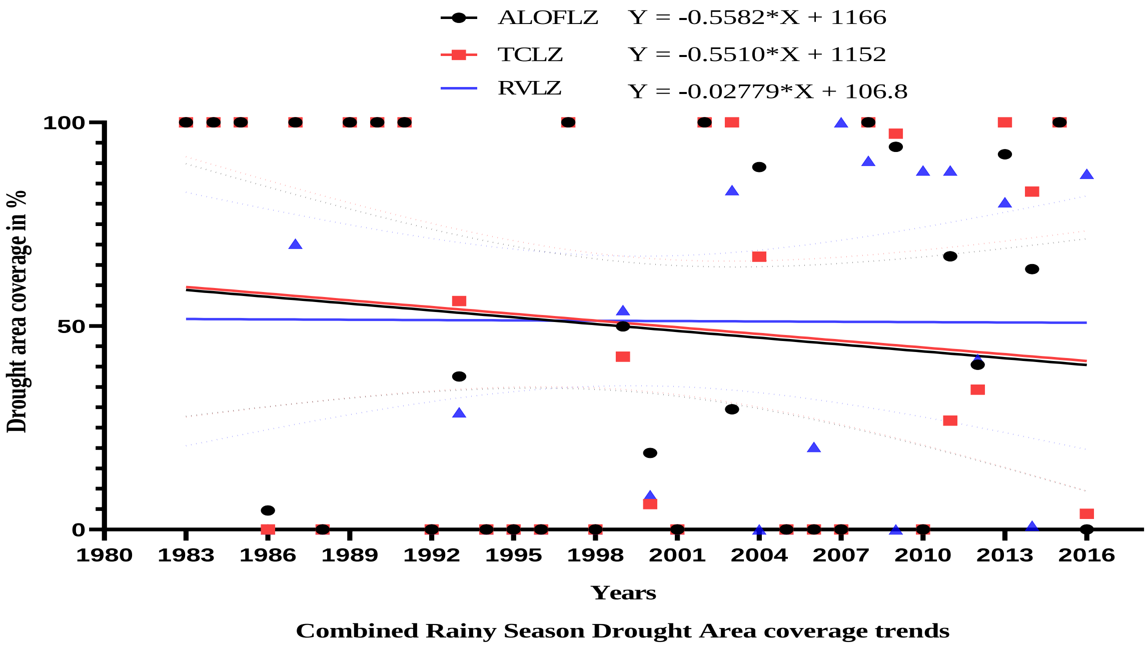


Figure 3.8. Spatial drought trends in % of area coverage from 1983-2016 using GraphPad Prism in combined rainy seasons

3.4. Conclusions

This study analyzed the trends of spatiotemporal seasonal drought frequencies, durations, and severity in LZ levels. This method enabled the researchers to investigate the drought frequencies, severity, and durations in small-scale areas. The short and medium time scales (3 and 6 months) have positive implications for seeing spatiotemporal drought frequencies, magnitudes, and severities. Studying drought in small-scale livelihood zones has advantages in finding natural and human-induced drought susceptible areas. Drought research using long-term data from many uniformly distributed meteorological grids in small-scale livelihood zones contributes to determining actual drought trends.

The Belg and Kiremt temporal drought had an inverse relationship with drought histories in the study area within-study years. If Kiremt gets good rain in some years, the Belg did not get. From 1989 to 2016, drought frequencies have increased in Belg and decreased in Kiremt within the study years. However, the frequencies and severity of drought were slight differences between the livelihood zones. Seasonal Kiremt drought incidence was becoming locally fragmented even at village levels. This problem needs special consideration in the current moisture harvesting system and afforestation practices to reduce human-induced drought impacts. As this study uncovered, long before 25 years, drought causalities were tremendous in the lives of humans and livestock in the study area. As mild drought frequencies and persistence have increased, the intensity and precipitation amount are too small to cultivate crops and forage growth. Consequently, the study area's recent drought incidents have more livestock fatalities than human suffering. Human Bing may search for alternative sources like power sales, remittance income sources, relief supports, and firewood sales to sustain the household.

The result revealed that seasonally recurring droughts vary in severity, frequencies, and durations within and between the livelihood zones. Drought frequency and persistence have been increasing in RVLZ, followed by TCLZs. In most study years, there have been seasonally or yearly human or climate-induced droughts in grid point levels or livelihood zone scales in RVLZ and TCLZ. In the last thirteen years (2003-2016), the RVLZ has suffered from persistent drought. However, in the same years, the central parts of ALOFLZ have been less vulnerable to drought than others.

This study will be used to improve the existing drought monitoring system and build resilience to drought at the household level. The finding will also significantly contribute to early warning systems, particularly at district levels. The agricultural sector should consider long-term crop growth patterns to reduce crop failures and forage problems. Ended, it needs to consider solutions for short and long drought impacts.

On the ground, further study needs to see the causes and impacts of drought at livelihood zone levels. The Belg and Kiremt rainfall onsets, durations, terminations, and variabilities trends need in-depth investigations to appropriate agricultural activities. In that case, it will help to input appropriate measurements and interventions to reduce crop failures and forage problems at local levels.

4. Chapter Four: Analyzing Trends and Drivers of Land Use and Land Cover Dynamics in Drought-prone Livelihood Zones of the Northwestern Escarpment of the Ethiopian Rift Valley

Abstract

The current study looked at the patterns and causes of land use and land cover (LULC) dynamics from 1985 to 2019 in three drought-prone areas of the Ethiopian Rift Valley's Northwestern Escarpment. Spatial data, focus group discussions, and key informant interviews were used to study the trends and causes of LULC dynamics. For Landsat image processing, ERDAS Imagine 2015 was used, and for LULC change analysis, ArcGIS 10.8 was employed. From the result, fast LULC exchange occurred in all study LZs throughout the study years. Raya Valley LZ (RVLZ) is, however, more highly shifted than Allagie Ofla LZ (ALOFLZ) and Tsirare catchment LZ (TCLZ). From the total area, only 17.7, 28.3, and 23.2 percent of RVLZ, ALOFLZ, and TCLZ persisted over the study years, respectively. The LULC change in the studied LZs was driven by population pressure and recurrent droughts. The research area's local ecosystem services have been disrupted by these changes, which have impacted the livelihood system of the local community. Consequently, the government should reform the appropriate land use policy, which benefits local farmers and their ecosystems. In addition, farm activities should be environmentally friendly to increase farmland productivity.

Keywords: Driving Forces, Landsat Images, Livelihood Zone, LULC Dynamics, Key-Informant Interviews

4.1. Background

Land use and land cover (LULC) change occur through various interacting causes from human-environment systems (Angessa *et al.*, 2019; Degife *et al.*, 2018; Gollnow *et al.*, 2018). The dynamic interaction between underlying drivers and proximal causes continually changes LULC (Deribew & Dalacho, 2019; Gidey et al., 2017a). LULC alteration by human influences is becoming a concern cause for environmental systems at all scales (Abesha et al., 2022). At the Global and continental scales, LULC change has brought biodiversity loss and influenced carbon fluxes and greenhouse gas that induce climate changes (Betru et al., 2019). At the national level, LULC change modified biogeochemical and hydrological cycles that consequence soil erosions. For example, severe soil erosion occurred in Ethiopia due to erosive rainfall, deforestation, and inappropriate land use (Frankl et al., 2014; Lesschen et al., 2005). On a local scale, LULC changes affected water bodies such as lakes (Hu & Shrestha, 2020; Meshesha et al., 2014) and forests, grasslands, and wetlands converted into farm and settlement areas (Minale, 2013.

LULC changes due to human and natural factors affected the earth's nutrients and hydrologic systems, altering landscapes, disrupting the ecosystem and ecosystem services, and soil water infiltration and holding capacity (Balabathina *et a*l., 2020; Dibaba *et al.*, 2020; Betru *et al.*, 2019). When the soil retains less water, it becomes more and more prone to drought (Sahoo *et al.*, 2017). Frequency drought also triggers the erosion and desertification of land (Agidew & Singh 2017; Vicente-serrano 2007).

LULC change has long-term consequences for communities that depend on rain-fed systems for their basics (Albert *et al.*, 2020; García-Llamas *et al*., 2019; Slegers & Stroosnijder, 2008). Environmental exploitation and soil erosion have been exacerbated by the expansion of farmlands at Ethiopia's expense of natural resources (Degife *et al.*, 2018; Selassie, 2015). Ethiopia's productivity potential has been severely affected due to these changes (Balabathina *et al.*, 2020; Kidane *et al.*, 2019). Continuously land use and mistreatment immensely reduced land productivity and the ability to resist climatic anomalies (Balabathina *et al*., 2020; Emiru *et al.*, 2018). These LULC change trends in Ethiopia imply high drought risks that will substantially influence the community's livelihood due to current suffering and future land use impacts (Maru *et al.*, 2021a; Andargie, 2014).

Based on the current population growth rate, Ethiopia will have about 118 million populations by 2025 and 170 million by 2050 (Betru *et al.*, 2019). However, currently, agriculture provides the main income source for over 80% of the population in the country ((Balabathina *et al.*, 2020). Further, the exponential population growth demands more farmlands, settlements, pasture areas, industrial areas, and the like (Deribew & Dalacho, 2019). With the growing land demand trends, the possible option in Ethiopia is to convert the remaining natural area and change land-use types (Betru *et al.*, 2019; Agidew & Singh, 2017).

Husbandry life has been experienced for centuries without rest in northern parts of Ethiopia (Andargie, 2014). These continuous land exploitation practices have caused vast environmental alterations and destructions in the current study area (northwest escarpment of the Ethiopian Rift Valley) (Gidey *et al.*, 2017a). The study area is highly vulnerable to drought in northern Ethiopia (Nasir *et al.*, 2021b). The expansion of small and large-scale farmlands in the RVLZ arose at the expense of natural areas. Due to this conversion, the local people suffered to meet their livelihoods. These changes will again impact the water sources of the LZ, particularly the groundwater. Moreover, this situation will bring extreme climate impacts such as frequent and severe droughts. Recent research has shown climate-related extreme events as the main causes of LULC change and vice versa.

Studies in Ethiopia on LULC change (Balabathina *et al.*, 2020; Betru *et al.*, 2019; Gidey *et al.*, 2017b; Selassie, 2015; Wolka *et al.*, 2015) have addressed the urgent attention needed for LULC change problems. These reviewed studies revealed that fast LULC changes aggravated food insecurity and the country's social, environmental, and economic impacts. Most of the studies done in Tigray, especially in southern Tigray (Gidey *et al.*, 2017a, 2017b; Annys *et al.*, 2016; Demissie, 2016), are concerned with regional or zonal scales. Some of the studies focused on climate change, perceptions of the local community, and some others on food security and drought. However, the current efforts of the scientific community to study LULC change at the livelihood zone level are limited and require further attention to address the underlying drivers and the proximate of LULC changes at livelihood zone levels. Studying the LULC change at the livelihood zone level is the most precise technique to understand the mechanism, types of change and forces behind the changes. Studying the trajectories and extents of LULC change is crucial for policymakers and development agents (Dibaba *et al.*, 2020).

Livelihood zones are areas grouped based on geographic similarities where households have widely comparable livelihood systems (Zone & Teshale, 2019; Pricope *et al.*, 2013). The perceptions and decisions of communities are affected by social, economic location, and technological input levels. Additionally, since the causes, trends, and extent of the LULC change are different between geographical areas and are affected by the continuous interaction among the underlying drivers and the proximal causes, studying livelihood zones is analyzing livelihood zones is critical to using these characteristics as a framework for strategic solutions. LULC change study at the LZ level is important for grouping the change and predicting vulnerability for intervening with appropriate adaptation methods. According to (Maru *et al.*, 2021b; Mekonen & Berlie, 2021), livelihood-based climate adaptation strategies are necessary to reduce agricultural susceptibility to climate extreme events. Therefore, the current study examined LULC changes in three LZs of drought-vulnerable areas in northern Ethiopia.

Studying LULC change trends and their causes with combined data is important for sustainable livelihood systems (Murthy *et al.*, 2015). Therefore, this study uses a socioeconomic survey and Landsat images to discover the real spatial patterns of LULC change at livelihood zone levels. The knowledge generated in this regard can inform development practitioners for sustainable community development. Furthermore, rather than implementing steps alone, it will provide information to include integrated drought and LULC change on livelihood management. This research will be used as input information to simplify and provide an insight for future land use management, decision-making, building the resilience of the societies, long-term planning, and capacity building in an area of LULC change management. It will also be a source of scientific data for further studies of LULC changes at the level of the livelihood zone.

4.2. Data Sets and Methodology

4.2.1. Types of Data and Sources

Analysis of LULC change trends and drivers requires a multidisciplinary methodology (Chirwa *et al.*, 2015). The current study used quantitative and auxiliary (qualitative) data to examine the trends and degree of LULC change during the last 34 years (1985-2019).

Satellite Data

Landsat images (1985, 2000, 2010, and 2019) from the USGS were used to investigate the LULC dynamics of the research region. Landsat image has high positive implications for monitoring spatiotemporal landscape changes (Alawamy *et al.*, 2020; Hailu *et al.*, 2020; Angessa *et al.*, 2019; Alemu *et al.*, 2015). The author considered Landsat images (study years), the interval of the years, and seasons with required image quality and those more likely cloud-free and less affected by moisture between December and February. Image information and the accessed dates are found in https://earthexplorer.usgs.gov/ and Table 4.1. However, Landsat 7 ETM+ Images after May 2003 had scanline errors. To avoid data gaps, the researchers used the 2010 Landsat image. Due to the lack of full satellite images for the study area on the same day, the study used different paths and rows of satellite images. The author used Wavelet resolution merge to improve spatial resolution products from 30m x 30m into 15m x 15m using band-8 panchromatic of Landsat image 8 Operational Land Imager. The author employed subsetting techniques to limit the mosaic image size in the study for classification.

Table 4.1 Summary of Satellite data used to produce LULC change maps and detections in the three LZs

Sensor	Path-Row	Date	NB	SR	SA	SE
L5 TM	168-051	01-02-1985	1,2,3,4,5,6	15m x 15m	137.42	41.40
	168-052	01-02-1985			136.35	42.31
	169-051	12-11-1985			139.37	42.70
L7 ETM	168-051	01-28-2000	1,2,3,4,5,6	15m x 15m	131.77	43.56
	168- 052	01-28-2000			130.54	44.36
	169-051	01-03-2000			138.32	42.09
L7 ETM+	168-051	12-25-2010	1,2,3,4,5,6,	15m x 15m	143.36	44.72
	168-052	12-25-2010			142.26	45.74
L8OLI/TIRS	168-051	01-16-2019	2,3,4,5,6,7,8	15m x 15m	141.21	46.63
	168-052	01-16-2019			140.00	47.61
	169-051	02-08-2019			133.86	50.15

L5 = Landsat5 Thematic Mapper, L7 ETM+ = Landsat7 Enhancement Thematic mapper plus, L8 OLI/TIRS = Landsat8 Operational Land Imager and Thermal Infrared Sensor, NB= Number of Bands; SR= Spatial Resolution, SA= Sun-Azimuth, SE= Sun-Elevation

In 2019, 900 Ground Truth Points (GTP) were obtained using Global Positioning Systems (GPS) to facilitate image classification and accuracy analysis. The study used half of the sample points for training and the other half for classification and accuracy testing. With the visual interpretation of the Landsat image from 2019, the author constructed training sites for the preset LULC classes (Table 4.2). For each mapping class with less than 4000 Km^2 and fewer than 12 kinds, a minimum of 50 samples is recommended for picture classification.

Socio-Economic Surveys

The author employed multistage sampling procedures to acquire qualitative data for the study of three LZs. A purposive sampling technique was used since the three livelihood zones were more vulnerable to LULC changes (Gidey *et al.,* 2018a, 2018b). Purposive sampling is a frequently used sampling procedure for preselected criteria related to a certain research issue which may or may not be determined before data collection, depending on resources and time constraints, and study objectives (Campbell *et al.,* 2020). As a result, based on their experience, the author employed the purposive sampling method to identify drought-prone livelihood zones. In addition, eight kebele (small administrative units) were selected randomly in each of the three livelihood zones.

Four focus group discussions with 12 individuals took place in the sampling kebele. The participants were heterogeneous in age, gender, occupation, religious leaders, specialists, and LZ. In these discussions, the majority of the data was gathered qualitatively. They inquired about sharing their experiences regarding LULC trends and their impacts. Also, crop, livestock, natural resources, and land use experts were interviewed in four research districts LZs. The experts inquired about LULC change progression, frequency, spatial coverage, intensity, ramifications, and response. Key informant interviews (KII) and focus group discussions (FGD) are required to understand local community perceptions on LULC change and related underlying reasons (Mckenna *et al.,* 2019). The livelihood system of communities is also observed in the field. Furthermore, population data were gathered from Ethiopia's Central Statistical Authority and quadrupled during the study years to see the demographic pressure on the study livelihood zones.

4.2.2. Data Processing, Analysis, and Interpretation

Image Processing, Classification, and Analysis

ERDAS Imagine 2015 was used for Landsat image processing steps, while ArcGIS 10.8 was used for LULC change analyses. A pixel-based image mosaic method was used to achieve a broader field of view. In addition, the Adinda Zone 37 of the UTM (Universal Transverse Mercator) was employed to remedy geometric faults. Supervised pixel-based classification with the maximum likelihood technique was applied to build signatures and map LULC. Supervised categorization necessitates prior experience with the research areas. Unlike an unsupervised classification system, supervised classification provides more accurate class definitions ((Meshesha *et al*., 2014).

The divided LULC into nine unique categories based on personal observation and earlier research in a similar study region (Gidey *et al.,* 2017a, 2017b), followed by (FAO, 2020; Watt & Peck, 1984). 1) Bare land (BL):- Bare land is defined as land with no more than 10% vegetative cover at any time of the year and consists of sand, bare soil, snow or rocks. 2) Built-up area (BA):- Residential, urban, commercial, and industrial districts are included in the BA. 3) Cultivation-land (CL):- Cultivation-land is a land where domesticated plants are grown, encompasses land-rotational and long fallow systems to permanent. 4) Flood Plain ((FP):- A flood plain is a flat tract of land adjacent to a river or stream that is covered by the lower course of a river, which carries a significant amount of water during the rainy season but is covered by sand, gravel, and stones for the rest of the year. 5) Forest land (FL):- Forest land is defined as land with trees taller than 5 meters covering more than 10%, or trees capable of reaching these criteria in situ, spanning more than 0.5 hectares. It excludes land that is primarily used for agriculture or urban development. 6) Grassland (GL):- Grassland is a land where natural herbaceous plants cover 10 to 100 percent of the surface. 7) Shrub and Bushland (SBL):- Shrub and Bushland is defined as land with a canopy cover of fewer than 5% trees but more than 10% shrubs, bushes, and trees. It includes areas with only shrubs and bushes and no trees. Areas with trees that will not touch a height of 5 meters in situ and a canopy cover of 10% or more are classified as shrub and bushland. 8) Waterbody (WB):- Major rivers, lakes, and water reservoirs are examples of waterbodies. 9) Wetland (WL):- Wetlands are defined as locations where the water table is above , at, or near the land surface for most of the year.

Post Classification (Accuracy Assessment)

Post-classification errors must be quantitative by assessing the classification's accuracy and producing information that describes reality. As a result, the author did an accuracy assessment for each LULC type using GPS points. Therefore, using GPS points, the study performed an accuracy assessment for each LULC class. The reliability of the categorized LULC based on pixel-to-pixel comparison was validated using Kappa coefficient statistics, user, producer and overall correctness for 1985, 2000, 2010, and 2019. The following Equation mathematically analyzes this study's producer, user, and total accuracy.

$$\text{The overall accuracy} = \frac{\text{Number of correct points(Value)}}{\text{Total number of points (Value)}} \times 100 \qquad 4.1$$

$$\text{Users accuracy} = \frac{\text{Number of correctly identified in a given map class)}}{\text{A number claimed to be in that map class)}} \times 100 \qquad 4.2$$

$$\text{Producers accuracy} = \frac{\text{Number of correctly identified in a given map class)}}{\text{The number actually in that reference class)}} \times 100 \qquad 4.3$$

In addition, for each LULC, the kappa coefficient was calculated to compare the precision of the categorized findings. The kappa coefficient data (Table 4.2) for the LULC eras (1985–2019) were evaluated and interpreted in the following way:

$$K = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_i - X_{x+i})}{N^2 - \sum_{i=1}^{r}(x_{ii} - X_{x+i})} \qquad 4.4$$

Where; $\boldsymbol{r}$ is the number of rows and columns in the error matrix, $\boldsymbol{N}$ is the total number of observations (pixels) $\boldsymbol{x_{ii}}$is observation in row $\boldsymbol{i}$ and column$\boldsymbol{i}$, $\boldsymbol{x_i} +$ is a marginal total of row$\boldsymbol{i}$, and $\boldsymbol{x} + \boldsymbol{i}$ is a marginal total of column $\boldsymbol{i}$. A Kappa coefficient equal to 1 shows perfect agreement, whereas a value near zero indicates that the bargain is no better than what would be expected by chance.

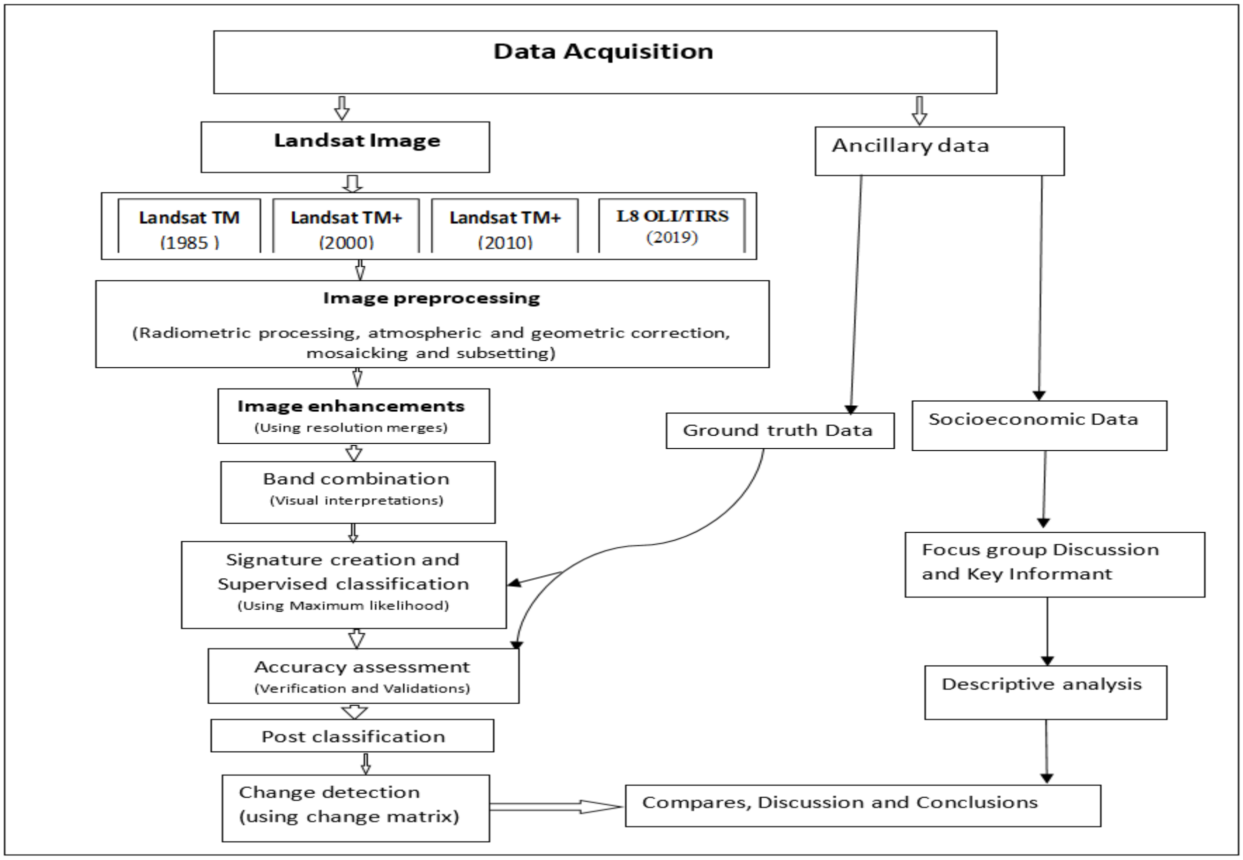


Figure 4.1. Flowcharts of data processing interpretations and discussion source

Change Detection and Analysis

LULC change based on multi-temporal and multispectral remotely sensed data has a lot of potential for understanding landscape dynamics, including detection, identification, mapping, and monitoring differences in land use/land cover change at different times irrespective of causal factors (Kleman, 2007). Cross-tabulation (from-to) was performed to identify the nature of changes, extent, and patterns of one LULC change to other types from the successive three periods (1985–2000, 2000–2010, and 2010–2019) and overstudy periods (1985-2019). Using matrix areas of simultaneous gross gain, loss, persistence, and swamping between LULC classes were computed. Equations (4.5-4.8) were used to compute the scale of change (MC), percentage of change (PC), and annual rate change (ARC) for each land-use category and each study period:

$$\text{MC} = Area\ of\ the\ \ final\ year - area\ of\ the\ intial\ year \qquad 4.5$$

$$\text{PC} = \frac{Area\ of\ the\ \ final\ year - area\ of\ the\ intial\ year}{area\ of\ the\ year\ intial} \times 100 \qquad 5.6$$

$$\text{ARC}(Km^2\ .year^{-1}) = \frac{Area\ of\ the\ \ final\ year - area\ of\ the\ intial\ year}{Number\ of\ the\ year\ of\ time\ period} \times 100 \qquad 4.7$$

$$\text{ARC}(\ \%) = \frac{Area\ of\ the\ \ final\ year - area\ of\ the\ intial\ year}{Area\ of\ the\ year\ intial\ X\ Number\ of\ the\ year\ of\ time\ period} \times 100 \qquad 4.8$$

Analysis of the Perception of Land Use and Land Cover Change Drivers

Interviews with key informants and FGD were conducted using thematic analysis. The thematic examination method is flexibly and wildly used to analyze qualitative data. It is a precise method to understand experiences, views, or behaviors across data sets (Kiger & Varpio, 2020). Furthermore, demographic statistics were gathered from the Central Statistical Authority (CSA) of Ethiopia based on the census (1984, 1994, and 2007) and Woreda offices (2017) in the study region to see the population pressure on the community's resource base in the study livelihood zones. Furthermore, the technique proposed by Kindu & Schneider (2015) and Mckenna et al. (2019) is used. The population numbers for 1985, 2000, 2010, 2019, and 2024 were projected based on the most recent census data and annual growth rates (2019).

$$P_2 = P_1 e^{rt} \qquad 4.9$$

Where P 1 and P 2 are the total populations at Time 1 and 2, e is the exponential population constant, t is the number of years between census enumerations, and r is the yearly population growth rate.

4.3. Results and Discussions

4.3.1. Extent and Trends of Land Use and Land Cover Dynamics (1985-2019)

Accuracy Assessment

Since the surveyed ground data were only available for 2019, the author assumed that the accuracy validation for the 2019 classification maps was adequate to give the required accuracy levels for

2019. Further, for 1985, 2000, and 2010 images were assessed using google earth. L8 OLI/TIRS of 2019 satellite images were used to associate with ground data and cross-tabulate for 2019. Depending on confusion (error) matrices of a study year, an overall accuracy classification was 90%, with an overall kappa value of 0.888 (Table 4.2). Besides, the producer and user assessments for LULC class were an excellent platform for subsequent analysis of LULC dynamics. Furthermore, the Kappa coefficient values for each type of LULC class revealed that the classified LULC changes and the ground survey data strongly agreed.

Table 4.2 Accuracy totals for each land cover category of the study area in the year 2019

Class Name	Area in Km^2	Reference Totals	Classified Totals	Number Correct	Producers Accuracy (%)	Users Accuracy (%)	Kappa
WL	11.04	45	50	44	97.78	88.00	0.8667
WB	86.43	53	50	50	94.34	100.00	1
SBL	2138.73	59	50	45	76.27	90.00	0.8849
GL	39.71	50	50	44	88.00	88.00	0.865
FL	161.95	53	50	46	86.79	92.00	0.9093
FP	34.88	49	50	47	95.92	94.00	0.9327
CL	1316.94	50	50	45	90.00	90.00	0.8875
BA	14.37	41	50	41	100.00	82.00	0.802
BL	5.20	50	50	43	86.00	86.00	0.8425
Totals	3809.26	450	450	405			
Overall Classification Accuracy = 90.00%,					Overall Kappa Statistics = 0.8875		

Bare land = (BL), Built-up area= (BA), Cultivation-land (CL), Flood Plain= (FP), Forest land (FL), Grassland= (GL), Shrub and Bushland= (SBL), Waterbody= (WB), Wetland= (WL)

4.3.2. Gain and Loss Trends of Land Use and Land Cover from 1985 to 2019

Overview

The current study looked at LULC dynamics at the LZ level and their determinants drivers. Nine LULC classes were analyzed using the supervised technique and the maximum likelihood classification system in the three studies LZs. Throughout the research, CL was the most common LULC type in all LZs. In the first years of the study (1985), RVLZ, ALOFLZ, and TCLZ shared 50.16 %, 42.64 %, and 46.94 % of CL, respectively. Likewise, about 60.34%, 49.92%, and 55.13% of CL were found in 2019 in RVLZ, ALOFLZ, and TCLZ, respectively. The second main LULC category in all LZ and within the study years (1985-2019) was SBL. As stated in Table 4.3, 41.78%, 46.04%, and 49.69% of SBL were available in 1985, but it reduced to 30.42%, 38.11%, and 38.79 % in 2019 in RVLZ, ALOFLZ, and TCLZ respectively.

The third dominant LULC class in RVLZ and ALOFLZ was FL throughout the study years. Forest land decreased from 5.58% in 1985 to 4.41% in 2019 in RVLZ. However, it increased from

5.24% in 1985 to 6.25% in 2019 in ALOFLZ. Except for CL and SBL LULC types, there were no persisted orders between the LULC classes in TCLZ. Similarly, for RVLZ and ALOFLZ, except for CL, SBL, and FL, there were no persistently dominant LULC types within the study years. Continuously over-exchange fluctuations trends were observed between the LULC classes in all study LZs. For example, in study interval years (1985, 2000, 2010 and 2019), GL was shared about 1.56 % (28.55 Km^2), 0.88% (16.1 Km^2), 1.06 % (19.35 Km^2) and 0.55% (10.15 Km^2) of the total area in RVLZ, respectively. In similar interval years GL was covered about 39.05 Km^2 (3.59%), 20.07(1.85%), 26.19 Km^2 (2.41%), and 14.92 Km^2 (1.37%) in ALOGLZ and about 10.24 Km^2 (1.15 %), 7.08 Km^2 (0.8%), 12.93 Km^2 (1.46 %) and 9.81 Km^2 (1.1 %) in TCLZ respectively.

Figures 4.2- 4.4 show the detailed area coverage and LULC type shares in the three LZs across study intervals. However, the trends of CL within the study LZs were not straight through the study years. Of the three LZs, RVLZ had a large CL share, followed by TCLZ in all study years. The cultivation land in RVLZ shares a large area due to the RVLZ being relatively flat and appropriate for farm development and having a higher population than the two LZs.

Table 4.3 Significant land use and land cover types in the three livelihood zones from 1985 to 2019

Years	LULC_Type	BL	BA	CL	FP	FL	GL	SBL	WB	WL	Total
1985	RVLZ(Km^2)	5.51	7.97	919.48	3.37	102.2	28.55	765.82	0.15	0.13	1833.17
	Share in %	0.3	0.43	50.16	0.18	5.58	1.56	41.78	0.01	0.01	100
	ALOFLZ(Km^2)	6.18	3	463.58	0	57.01	39.05	500.57	14.55	3.26	1087.19
	Share in %	0.57	0.28	42.64	0	5.24	3.59	46.04	1.34	0.3	100
	TCLZ(Km^2)	11.05	0.33	417	1.01	5.92	10.24	441.41	1.36	0.02	888.35
	Share in %	1.24	0.04	46.94	0.11	0.67	1.15	49.69	0.15	0	100
2000	RVLZ(Km^2)	9.42	5.9	995.36	11.25	32	16.1	762.68	0	0.48	1833.17
	Shares in %	0.51	0.32	20200	0.61	1.75	0.88	41.6	0	0.03	100
	ALOFLZ(Km^2)	0.49	4.03	489.5	1.39	50.31	20.07	504.69	13.91	2.81	1087.19
	Shares in %	0.04	0.37	45.02	0.13	4.63	1.85	46.42	1.28	0.26	100
	TCLZ(Km^2)	0.79	0.54	399.63	6.62	7.98	7.08	465.45	0.04	0.23	888.35
	Shares in %	0.9	0.06	44.99	0.75	0.9	0.8	52.4	0	0.03	100
2010	RVLZ(Km^2)	12.32	20.02	917.4	29.06	74.32	19.35	759.75	0	0.96	1833.17
	Shares in %	0.67	1.09	50.04	1.59	4.05	1.06	41.44	0	0.05	100
	ALOFLZ(Km^2)	0.66	9.39	548.05	2.95	80.84	26.19	403.53	14.04	1.52	1087.19
	Shares in %	0.06	0.86	50.41	0.27	7.44	2.41	37.12	1.29	0.14	100
	TCLZ(Km2)	3.36	4.15	489.29	4.14	20.01	12.93	354.45	0	0.02	888.35
	Share in %	0.38	0.47	55.08	0.47	2.25	1.46	39.9	0	0	100
2019	RVLZ(Km^2)	4.70	44.74	1106.13	27.64	80.79	10.15	557.70	0.00	1.31	1833.17
	Shares in %	0.26	2.44	60.34	1.51	4.41	0.55	30.42	0.00	0.07	100.00
	ALOFLZ(Km^2)	2.74	24.16	542.71	2.08	67.98	14.92	414.35	14.37	3.89	1087.19
	Shares in %	0.25	2.22	49.92	0.19	6.25	1.37	38.11	1.32	0.36	100
	TCLZ(Km^2)	3.6	17.5	489.73	9.98	13.16	9.81	344.58	0	0	888.35
	Shares in %	0.41	1.97	55.13	1.12	1.48	1.1	38.79	0	0	100

Bare land = (BL), Built-up area= (BA), Cultivation-land (CL), Flood Plain= (FP), Forest land (FL), Grassland= (GL), Shrub and Bushland= (SBL), Waterbody= (WB), Wetland= (WL)

Raya Valley Livelihood Zone

As stated in Figure 4.2 and Table 4.4 (RVLZ), CL in RVLZ had increased from 919.48 Km^2 (50.16%) in 1985 to 1106.13 Km^2 (60.34%) in 2019. Within the study years (1985-2019), about 186.65 Km^2 (20.30 %) of CL was gained in RVLZ. In the first study period (1985-2000), CL in RVLZ increased by 75.88 Km^2 (8.25%), but it lost about 77.96 Km^2 (7.83%) in the second study period (2000– 2010). The reduction of 77.96 Km^2 (7.83%) CL in the second study period in RVLZ was due to extra farmland delineated into free grazing and area closures. However, in the third study period (2010-2019), RVLZ gained about 188.73 Km^2 (20.57 %) CL. In the third study period, the reason for increasing CL in RVLZ was agricultural land demand for internal population growth, immigrants, and investors. According to key informants, from 2000 to 2019, about 95 investors were involved in farming investments and converted thousands of hectares in the northern parts of RVLZ. From different parts of the country, about 4,350 household immigrants fled into northern RVLZ only in 2018/9. Similarly, built-up area (BA) has shown rapid expansion trends in RVLZ over the study years. It grew from 7.97 Km^2 in 1985 to 44.74 Km^2 in 2019 in RVLZ. The rapidly increased BA expansion occurred between 2010 and 2019 by 24.72 Km^2 in RVLZ. CL and BA grew quickly at the cost of the natural areas.

Conversion of natural areas (forest, shrubs, woodland, and grasslands) causes soil degradation and disrupts the local climate systems of the area (RVLZ). Alemu *et al.* (2015) found that farmland fell by about 5% in a section of the Ethiopian Rift Valley escarpment from 2000 to 2014. The current result further coincided with the Annys *et al.* (2016) finding on declined CL between 2000 and 2010. The findings of Hermans-Neumann *et al.* (2017), which found that the Ethiopian Great Rift Valley was one of the hotspots of socio-ecological stressors due to the high population density of immigrants, backed up the current study. This study also agrees with the Meshesha *et al.* (2014) study, which reveals marsh, cultivation land, and residential areas increased, while grassland, plantations, and shrublands were deceased in the highlands of eastern Ethiopia.

The floodplain has shown increasing trends in RVLZ during the study period (1983-2019). It shows increased trends from 3.37 Km^2 in 1985 to 27.64 Km^2 in 2019 in RVLZ. FP gained from 1985 to 2019 was 24.27 Km^2 in RVLZ. However, the trends of FP in RVLZ were not straightforward but slightly declined to 27.64 Km^2 in 2019 from 29.06 Km^2 in 2010. Similarly, wetland increased from 0.13 Km^2 (0.09%) in 1985 to 1.31 Km^2 (0.1%) in the year 2019 in RVLZ.

This result agrees with the Meshesha *et al*. (2014) results. Meshesha *et al.* (2014) revealed increased marsh areas in eastern Ethiopia's highland. However, there was no significant perennial water body in RVLZ except for seasonal floods during the rainy seasons (Kiremt and Belg). Gidey *et al*. (2017b) found GL, WB, and FP decreased in the same study years in Raya, northern Ethiopia. However, this study revealed different results on FP land cover than the Gidey *et al.* (2017b) results. Floodplain has shown increasing trends in RVLZ over the study period (1983-2019). The expansion of FP in RVLZ is rooted in the deforesting of SBL and FL for cultivation land and settlement expansions. The FP expansions indicated that immigration of desertification increased into RVLZ. About 27.64 Km^2 is out of use at the current time due to the FP expansions.

Table 4.4 Gain and loss trends of land use and land cover in Raya Valley Livelihood Zones (1985-2019)

Years (From-To)	Gain and loss Trends		Land Use Land Cover Classes in RVLZ								
			BL	BA	CL	FP	FL	GL	SBL	WB	WL
1985-2000	MC	Km^2	3.9	-2.07	75.88	7.88	-70.21	-12.44	--3.12	-0.14	0.35
		%	70.78	-26.02	8.25	233.89	-68.7	-43.59	-0.41	-98.31	266.94
	ACR	Km^2	0.26	-0.14	5.06	0.53	-4.68	-0.83	-0.22	-0.01	0.02
		%	4.72	-1.74	0.55	15.59	-4.58	-2.91	-0.03	-6.55	17.8
2000-2010	MC	Km^2	2.91	14.12	-77.96	17.81	42.33	3.25	-2.93	-0.003	0.48
		%	30.87	239.47	-7.83	158.35	132.31	20.15	-0.38	-100	101.24
	ACR	Km^2	0.29	1.41	-7.8	1.78	4.23	0.32	-0.29	0	0.06
		%	3.09	23.95	-0.78	15.84	13.23	2.05	-0.04	-10	10.12
2010-2019	MC	Km^2	-7.62	24.72	188.73	-1.42	6.47	-9.19	-202.05	0	0.36
		%	-61.86	123.55	20.57	-4.88	8.71	-47.52	-26.6	0	37.33
	ACR	Km^2	-0.85	2.75	20.97	-0.16	0.72	-1.02	-22.45	0	0.04
		%	-6.87	13.73	2.29	-0.54	0.97	-5.28	-2.96	0	4.15
1985-2019	MC	Km^2	-0.81	36.77	186.65	24.27	-21.40	-18.39	-208.12	-0.15	1.19
		%	-14.75	461.40	20.30	720.51	-20.95	-64.43	-27.18	-100	914.09
	ACR	Km^2	-0.02	1.08	5.49	0.71	-0.63	-0.54	-6.12	00	0.05
		%	-0.43	13.57	0.60	21.20	-0.62	-1.90	-0.80	-2.94	26.89

Bare land = (BL), Built-up area= (BA), Cultivation-land (CL), Flood Plain= (FP), Forest land (FL), Grassland= (GL), Shrub and Bushland= (SBL), Waterbody= (WB), Wetland= (WL); (-) loss

On the other side, as seen in Figure 4.2, SBL showed declining trends over the study period (1985-2019) in RVLZ. Over 34 years, SBL decreased by 208.12 Km^2 (27.18%) in RVLZ. The fast SBL conversion happened from the year 2010 to 2019. Within the study period, approximately 202.05 Km^2 (26.6%) of SBL transitioned into other LULC types in RVLZ. The change rate was high, with 22.45 Km^2 of SBL shifted to another LULC type per year. From 1985 to 2019, similarly, GL was reduced by 18.39 Km^2 (64.43%) in RVLZ due to conversion to other LULC types. In

RVLZ, forest land declined from 102.2 Km^2 in 1985 to 32 Km^2 in 2000. However, it recovered from 32 Km^2 in 2000 to 80.79 Km^2 in 2019. As presented in Table 4, BL change fluctuated in RVLZ. BL gained approximately 3.9 Km^2 (70.78 %) and 2.91 Km^2 (30.87 %) in the first and second study intervals but lost 7.62 Km^2 (61.86%) in the third study interval years in RVLZ. Gidey *et al.* (2017b) found SBL increased trends from 1984 to 2015 in Raya, northern Ethiopia. Furthermore, Meire et al. (2013) study in the Northern Ethiopian mountains revealed that wood vegetation strongly increased between 1868 and 2008. The Annys *et al.* (2016) study stated that areas of woody vegetation remained relatively stable in the parts of the Ethiopian Rift Valley escarpment (including RVLZ) from 2000 to 2014. However, the current study uncovered that SBL and BL dramatically decreased from 1983 to 2019 in RVLZ due to human and natural factors. Due to the SBL and FL conversions, the extent of FP expanded through soil erosion from upstream disposed of downstream (Figure 4.2).

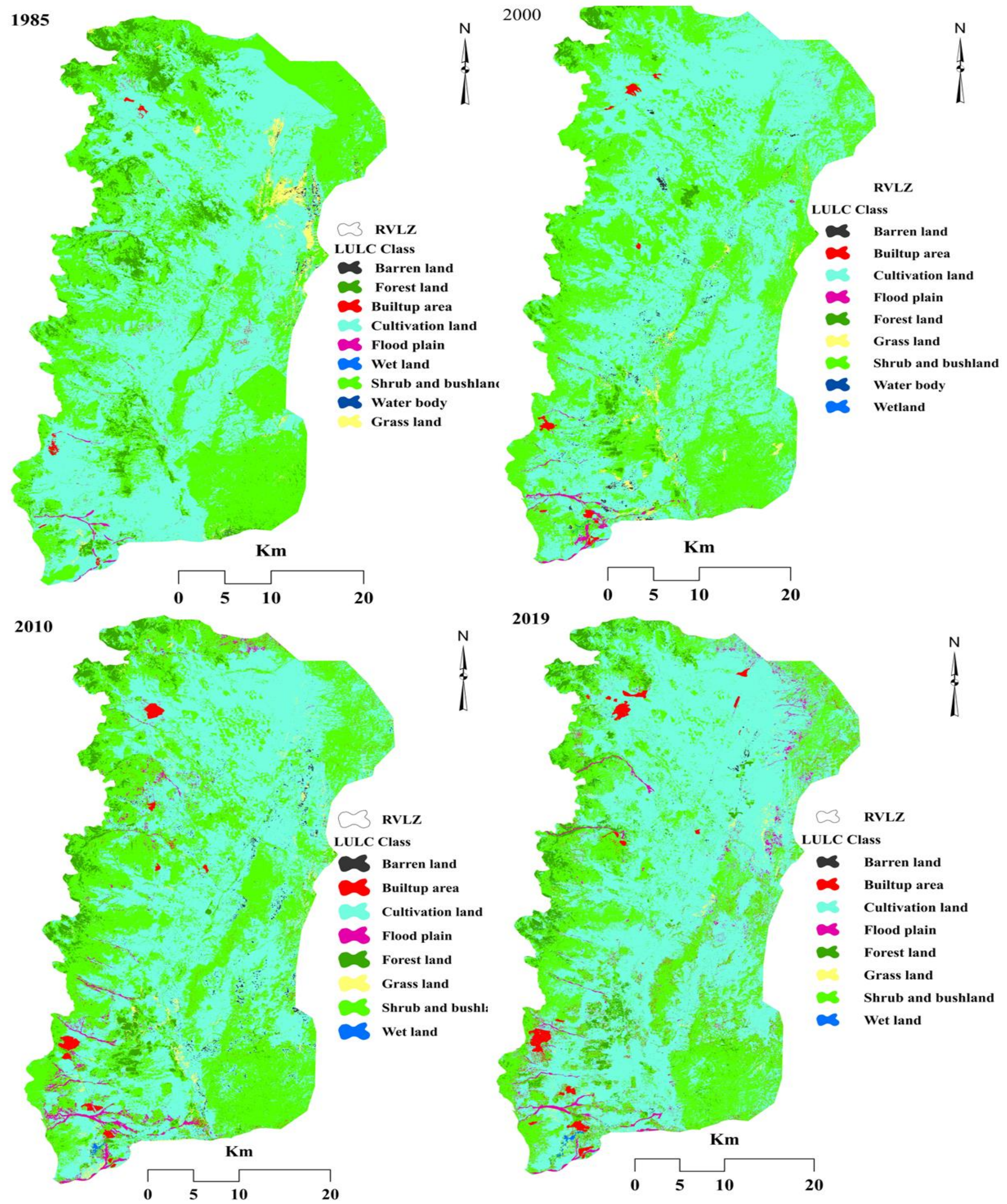


Figure 4.2. LULC change maps in RVLZ livelihood zones for the study years (1985, 2000, 2010, and 2019)

Alagie Ofla Livelihood Zone

As stated in Figure 4.3 and Table 4.5 for ALOFLZ, the cultivation land increased from 463.58 Km^2 (42.64%) in 1985 to 542.71 Km^2 (49.92 %) in 2019. Within the study years (1985-2019), about 79.13 Km^2 (17.07 %) of CL was gained in ALOFLZ. However, due to environmental alteration in ALOFLZ, CL lost 5.35 Km^2 (0.98 %) in the third study period. The WB in ALOFLZ does not show substantial change over the study years. However, BL has shown fluctuated trends over the study years in ALOFLZ. It decreased by 5.69 Km^2 (92.12%), 0.18 Km^2 (36.34%), and 2.07 Km^2 (312.43 %) in the first, second and third interval study years, respectively. Over 34 years, ALOFLZ lost about 3.44 Km^2 (55.67%) of its BL and was left with 2.74 Km^2 (0.25 %) in 2019.

Similarly, BA increased from 3 Km^2 in 1985 to 24.16 Km^2 in 2019 in ALOFLZ. The rapid BA expansion trends occurred between 2010 and 2019 by 14.77 Km^2 in ALOFLZ. Additionally, FL in ALOFLZ showed increasing trends from 57.01 Km^2 (5.24 %) in 1985 to 67.98 Km^2 (6.25 %) in 2019 (Figure 4.3). However, SBL declined over the study period (1985-2019) in ALOFLZ. SBL was shrinkage by 86.22 Km^2 (17.22 %) in ALOFLZ. From 1985 to 2019, similar to SBL trends, an area of GL declined by 24.13 Km^2 (61.80%) in ALOFLZ. Similarly, WL has shown fluctuated trends in ALOFLZ (Figure 4.3). It was shrinkage by 0.46 Km^2 (14.02%) and 1.28 Km^2 (45.73%) in the first and second study interval years but gained about 2.37 Km^2 (155.54%) in the third study years. However, WB did not significantly change within the study period in ALOFLZ (Table 4.5). Similarly, the extent of FP trends in ALOFLZ was insignificant throughout the study years.

The finding of CL and BA in ALOFLZ agreed with the Wubie *et al*. (2016) finding. Wubie *et al.* (2016) revealed an expansion of CL and BA in the Gumara basin, Northern Ethiopia. The current result also agreed with the Wubie *et al.* (2016) study, which revealed that SBL, GL, and WL declined over their analysis period in the Gumara-watershed, Northern Ethiopia. The finding of this study also coincided with the Angessa *et al.* (2019) reports on the expansion trends of CL, BL, and BA in the last 44 years in the central Ethiopian highlands. Angessa *et al*. (2019) found that the WL, FL, and shrub cover declined over the past 44 years. However, in the Meire *et al.* (2013) study in the Northern Ethiopian Highlands, wood vegetation increased from 1868 to 2008. Also, Annys *et al*. (2016) stated that the areas of woody vegetation remained relatively stable from 2000 to 2014 along the Ethiopian Rift Valley escarpment. The study understands that different locations have different causes and problems regarding LULC change from the reviewed studies. Therefore, studying LULC change at the LZ level is fundamental to uncover local LULC change problems which need local solutions than general study and responses.

Table 4.5 Gain and loss trends of land use and land cover in Allagie Ofla Livelihood Zones (1985-2019)

Years (From-To)	Gain and loss Trends		Land Use Land Cover Classes in ALOFLZ								
			BL	BA	CL	FP	FL	GL	SBL	WB	WL
1985-2000	MC	Km^2	-5.69	1.03	25.93	1.39	-6.70	-18.98	4.12	-0.64	-0.46
		%	-92.12	34.31	5.59		-11.76	-1.39	0.82	-4.41	-14.02
	ACR	Km^2	-0.38	0.07	1.73	0.09	-0.45	-1.27	0.27	-0.04	-0.03
		%	-6.14	2.29	0.37	0.00	-0.78	0.09	0.05	-0.29	-0.93
2000-2010	MC	Km^2	0.18	5.37	58.55	1.56	30.53	6.12	-101.16	0.13	-1.28
		%	36.34	133.29	11.96		60.69	1.39	-20.04	0.96	-45.73
	ACR	Km^2	0.02	0.54	5.85	0.16	3.05	0.61	-10.12	0.01	-0.13
		%	3.63	13.33	1.20	0.00	6.07	0.14	-2.00	0.10	-4.57
2010-2019	MC	Km^2	2.07	14.77	-5.35	-0.87	-12.86	-11.28	10.82	0.33	2.37
		%	312.43	157.23	-0.98	-29.55	-15.91	-43.06	2.68	2.34	155.54
	ACR	Km^2	0.23	1.64	-0.59	-0.10	-1.43	-1.25	1.20	0.04	0.26
		%	34.71	17.47	-0.11	-3.28	-1.77	-4.78	0.30	0.26	17.28
1985-2019	MC	Km^2	-3.44	21.16	79.13	2.08	10.97	-24.13	-86.22	-0.18	0.63
		%	-55.67	706.01	17.07	0.00	19.25	-61.80	-17.22	-1.23	19.25
	ACR	Km^2	-0.10	0.62	2.33	0.06	0.32	-0.71	-2.54	-0.01	0.02
		%	-1.64	20.77	0.50	0.00	0.57	-1.82	-0.51	-0.04	0.57

Bare land = (BL), Built-up area= (BA), Cultivation-land (CL), Flood Plain= (FP), Forest land (FL), Grassland= (GL), Shrub and Bushland= (SBL), Waterbody= (WB), Wetland= (WL); (-) loss

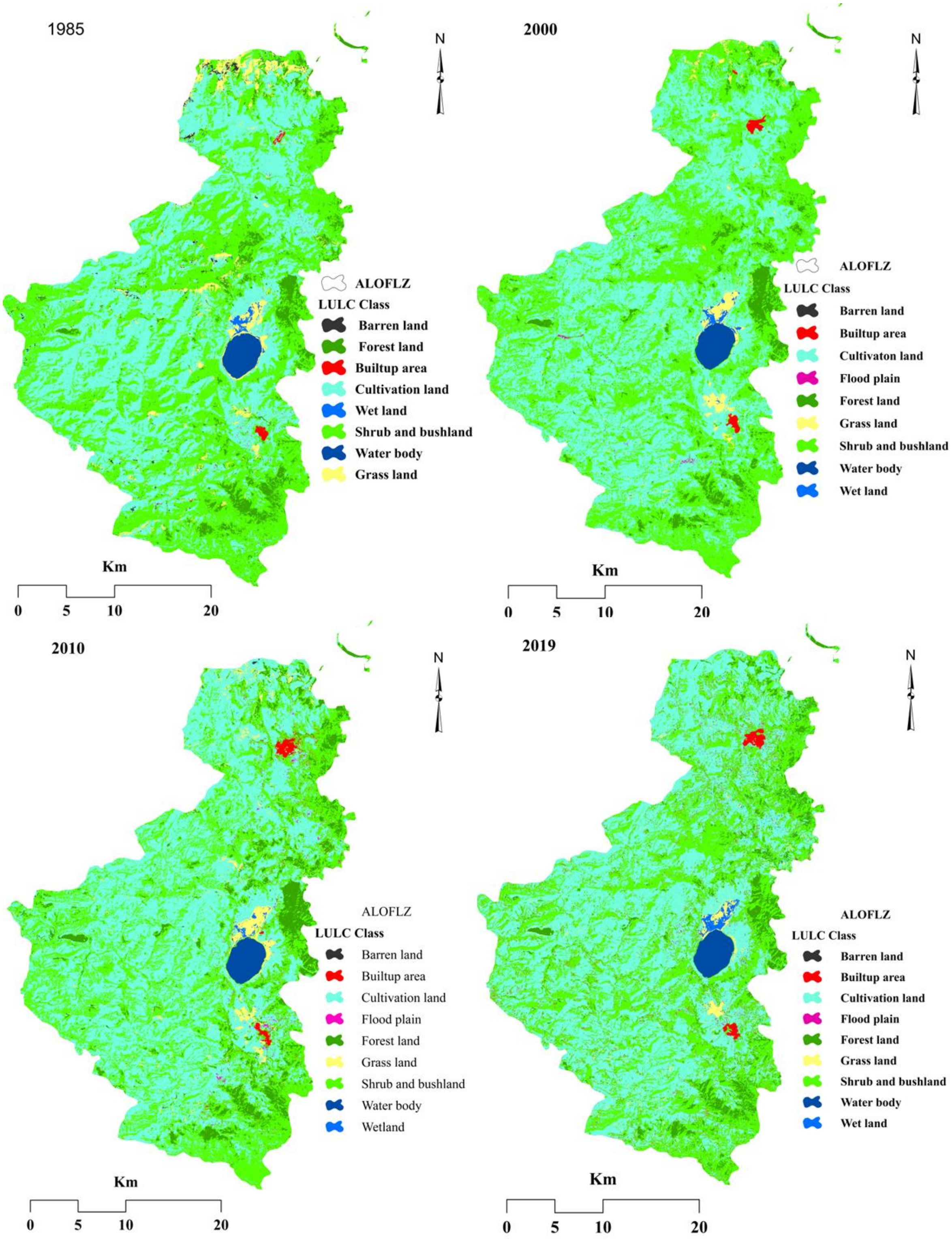


Figure 4.3. LULC change maps in Alagie-Ofla livelihood zones for the study years (1985, 2000, 2010, and 2019)

Tsirare Catchment Livelihood Zone

As presented in Figure 4.4 and Table 4.6, the CL had increased from 417 Km^2 (46.94 %) in 1985 to 489.73 Km^2 (55.13 %) in 2019 in TCLZ. Within the study years (1985-2019), about 72.73 Km^2 (17.44 %) of CL was gained in TCLZ. However, CL trends in the study LZ were not immediately apparent. In the first study period (1985-2000), CL lost approximately 17.38 km^2 (4.17%), but in the second study period (2000– 2010), CL gained 89.66 km^2 (22.44%) in TCLZ. Similarly, in the third study period (2010-2019), CL gained about 0.44 Km^2 (0.09 %) in TCLZ. Like RVLZ and ALOFLZ, BA showed fast-increasing trends in TCLZ throughout the study years. BA in TCLZ increased from 0.33 Km^2 in 1985 to 17.5 Km^2 in 2019. The rapidly increased trends of BA occurred between the years 2010 and 2019, by 13.34 Km^2 in TCLZ. In the same way, FP was shown increased trends during the study years in TCLZ. It was extended from 1.01 Km^2 in 1985 to 9.98 Km^2 in 2019 in TCLZ. Flood plain gained 8.96 Km^2 from the year 1985 to 2019 in TCLZ.

Similarly, FL increased from 5.92 Km^2 (0.67 %) in 1985 to 13.16 Km^2 (1.48%) in 2019 in TCLZ. However, in 34 years, SBL declined by 96.84 Km^2 (21.94 %) in TCLZ. However, the SBL trend shows contrasting trends during the study years in TCLZ. The SBL in TCLZ initially increased from 441.41 Km^2 (49.69%) in 1985 to 465.45 Km^2 (52.4 %) in 2000. However, it moved timidly away into 354.45 Km^2 (39.9 %) in 2010 and 344.58 Km^2 (38.79%) in 2019. Similarly, GL in TCLZ declined and fluctuated throughout the study years. Furthermore, the BL in TCLZ lost about 7.45 km^2 (67.39%) over the 34 study years and left with areas of 2.74 km^2 in the year 2019. Likewise, due to human and natural factors, WL disappeared over time in TCLZ. The water body in TCLZ was 1.36 km^2 (136 ha) in 1985, but it disappeared over time from the LZ.

The current result agreed with the Wubie *et al.* (2016) findings, which showed CL and BA expanded in their study years. Further, the discovery of this study coincided with the Angessa *et al.* (2019) study in the Lake Wanchi watershed. Angessa *et al.* (2019) uncovered that wetland, forest, shrub cover, and water bodies declined over the past 44 years. Further, they reported that CL, BL, and BA expanded in the same study years. The current result is supported by the Alemu *et al.* (2015) findings that uncovered forest land reduced from 1985 to 2010 in the northern lowlands of Ethiopia. The finding of this study also coincided with the Liyew *et al.* (2019) results, which revealed forest land, bushland, and grassland declined from 1982 to 2017. Similarly, the results found by Wubie *et al*. (2016) reported shrublands, grassland, and wetland declined during their analysis period in the Gumara basin of the Lake Tana basin, Northern Ethiopia.

Table 4.6 Gain and loss trends of land use and land cover in Tsirare Catchment Livelihood Zones (1985-2019)

Years (From-To)	Gain and loss Trends		Land Use Land Cover Classes in TCLZ								
			BL	BA	CL	FP	FL	GL	SBL	WB	WL
1985-2000	MC	Km^2	-10.25	0.21	-17.38	5.61	2.05	-3.16	24.04	-1.32	0.21
		%	-92.81	62.80	-4.17	554.27	34.66	-30.88	5.45	-97.43	1037.83
	ARC	Km^2	-0.68	0.01	-1.16	0.37	0.14	-0.21	1.60	-0.09	0.01
		%	-6.19	4.19	-0.28	36.95	2.31	-2.06	0.36	-6.50	69.19
2000-2010	MC	Km^2	2.56	3.62	89.66	-2.48	12.04	5.85	-111.00	-0.03	-0.20
		%	322.99	671.00	22.44	-37.47	150.87	82.66	-23.85	-100.00	-89.71
	ARC	Km^2	0.26	0.36	8.97	-0.25	1.20	0.58	-11.10	0.00	-0.02
		%	32.30	67.10	2.24	-3.75	15.09	8.27	-2.38	-10.00	-8.97
2010-2019	MC	Km^2	0.24	13.34	0.44	5.84	-6.85	-3.12	-9.87	0.00	-0.02
		%	7.25	321.25	0.09	140.90	-34.22	-24.14	-2.79	0.00	-100.00
	ARC	Km^2	0.03	1.48	0.05	0.65	-0.76	-0.35	-1.10	0.00	0.00
		%	0.81	35.69	0.01	15.66	-3.80	-2.68	-0.31	0.00	-11.11
1985-2019	MC	Km^2	-7.45	17.17	72.73	8.96	7.24	-0.43	-96.84	-1.36	-0.02
		%	-67.39	5187.42	17.44	885.58	122.22	-4.22	-21.94	-100.00	-100.00
	ARC	Km^2	-0.22	0.50	2.14	0.26	0.21	-0.01	-2.85	-0.04	0.00
		%	-1.98	152.57	0.51	26.05	3.59	-0.12	-0.65	-2.94	-2.94

Bare land = (BL), Built-up area= (BA), Cultivation-land (CL), Flood Plain= (FP), Forest land (FL), Grassland= (GL), Shrub and Bushland= (SBL), Waterbody= (WB), Wetland= (WL); (-) loss

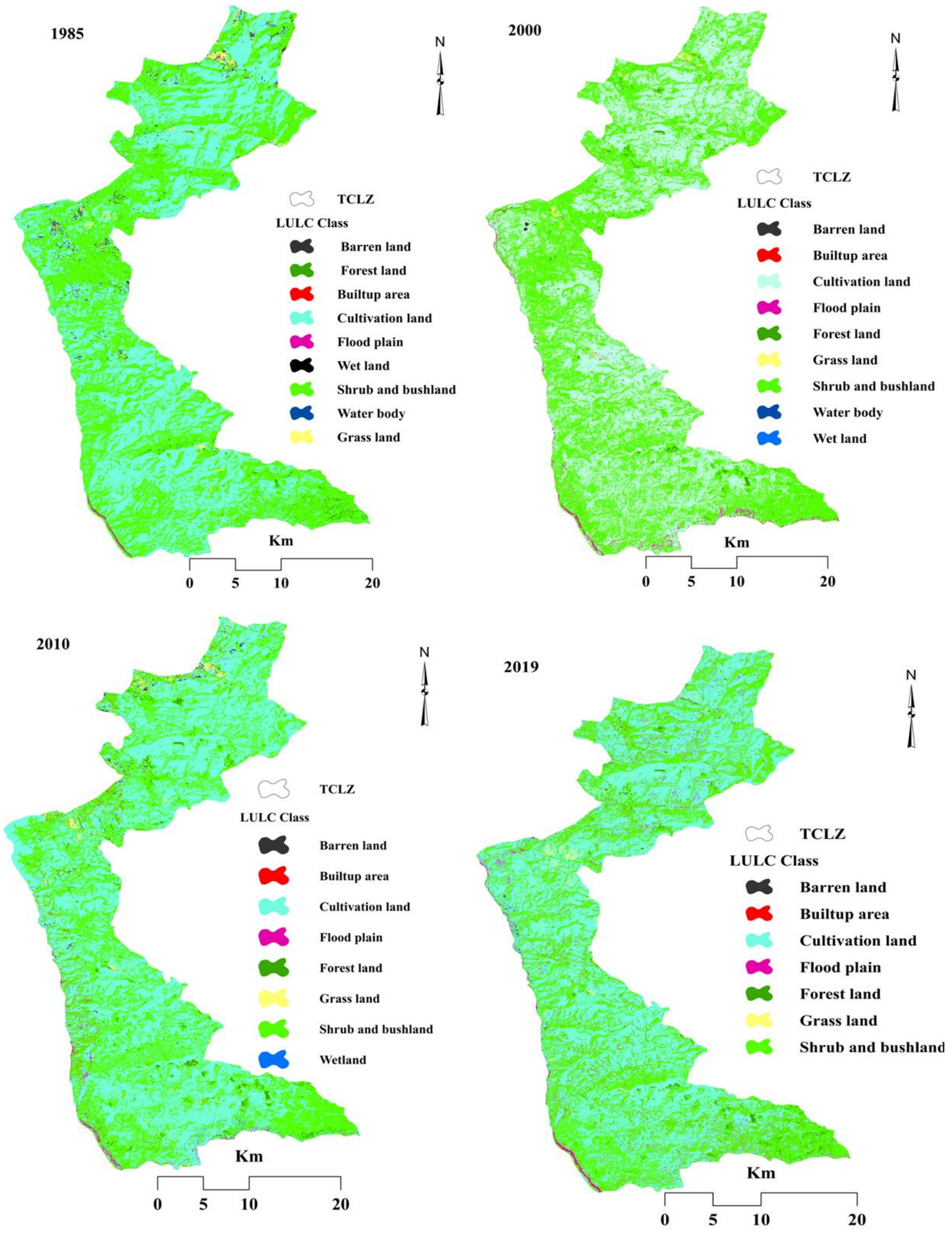


Figure 4.4. LULC change maps in Tsirare Catchment livelihood zones for the study years (1985, 2000, 2010, and 2019)

4.3.3. Land Use and Land Cover Detections Analysis for the Periods 1985-2019

Raya Valley Livelihood Zone

Over the study period, CL gained about 372.34 Km^2 and lost about 185.67 Km^2 in RVLZ. SBL contributed 316.70 Km^2 (85.06%) to CL and gained about 122.26 Km^2 (65.85%) from CL in RVLZ. Further, Cl received 14.91 Km^2 (6.95 %) from GL, and 14.28 Km^2 (5.85 %) from FL, and lost 8.03% (14.91 Km^2) into FP and 7.69% (14.28 Km^2) into FL in RVLZ. Over 34 years, about 733.77 Km^2 of CL persisted in RVLZ (Figure 4.5). Similarly, SBL gained about 174.66 Km^2 and lost 382.81 Km^2 in the study years in RVLZ. Beyond CL, about 9.65 % (36.94 Km^2), 4.33 %(16.59 Km^2), and 2.50 % (9.58 Km^2) SBL shifted into FL, BA, and FP, respectively. Following CL, FL contributed 48.30 Km^2 (27.65%) for SBL. About 382.93 Km^2 of SBL persisted as SBL types over the study period in RVLZ. During the study periods, FL gained 80.79 Km^2 and shifted by 73.09 Km^2. Besides, 29.10 Km^2 of FL kept its originality in RVLZ. About 36.94 Km^2 (71.48 %) and 14.28 Km^2 (27.63 %) of the gain were from SBL and CL. FL was converted by 48.30 Km^2 (66.08 %) into SBL and by about 21.77 Km^2 (29.78 %) into CL (Table 4.7) in RVLZ.

Dramatically shifts of GL were seen in RVLZ over the study periods (Figure 4.5). From the 28.54 Km^2 loss of the GL, about 25.89 Km^2 (93.53%) changed into CL. Similarly, from the total (9.30 Km^2) gained grasslands, approximately 6.57 Km^2 derived from CL, 2.03 Km^2 from SBL, and 0.59 Km^2 from other types of LULC. Over the study years, BA gained about 42.49 Km^2 (94.98%) in RVLZ from other LULC classes. BA shared high values with SBL and CL. FP also gates 25.60 Km^2 in RVLZ over the study years. FP gained from CL (58.25%) and SBL (37.40%) in RVLZ. From 1985 to 2019, BL lost about 5.38 Km^2 and gained a 4.57 Km^2 area in RVLZ. Most of the lost and gained BL occurred within CL. During the study years, there was no significant water body in RVLZ except seasonal rivers during the rainy seasons (Kiremt and Belg). However, the wetland gained approximately 1.31 Km^2 (133 ha) and lost 0.13 Km^2 (13 ha) from and into other types of LULC in RVLZ (Table 4.7).

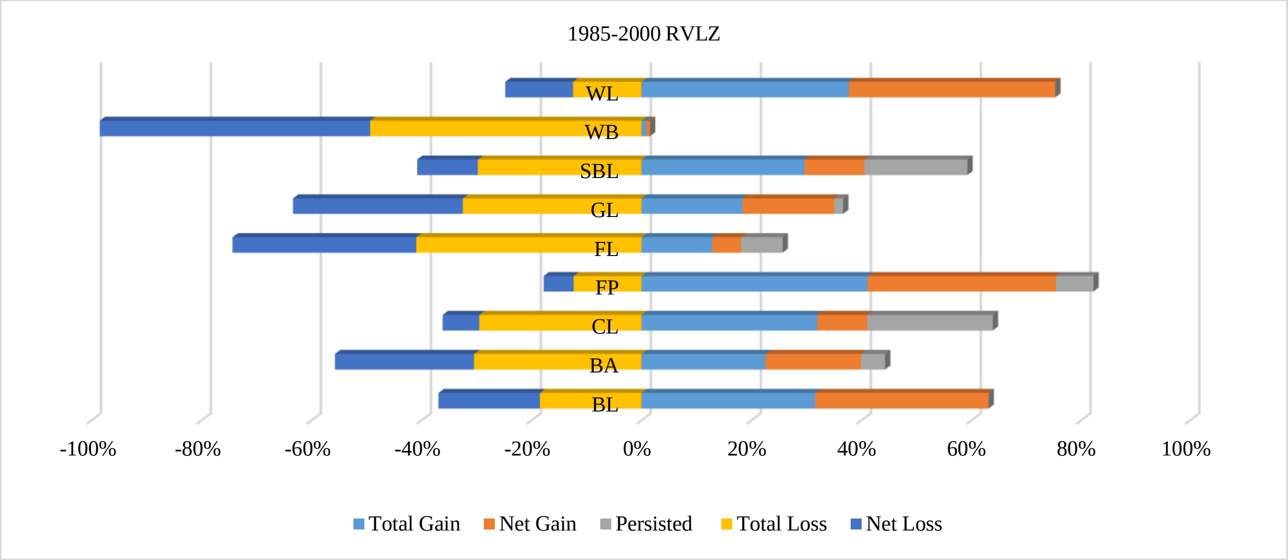
The current result coincided with the Yesuph and Dagnew (2019) findings. They discovered LULC detection in the Beshillo catchment's Afro/sub-Afro-alpine vegetation area's steady increase of farmland and settlement. Similarly, Alemu *et al.* (2015) found that woodland transformation between 1985 and 2010 was due to agricultural expansion in the northwestern lowlands of

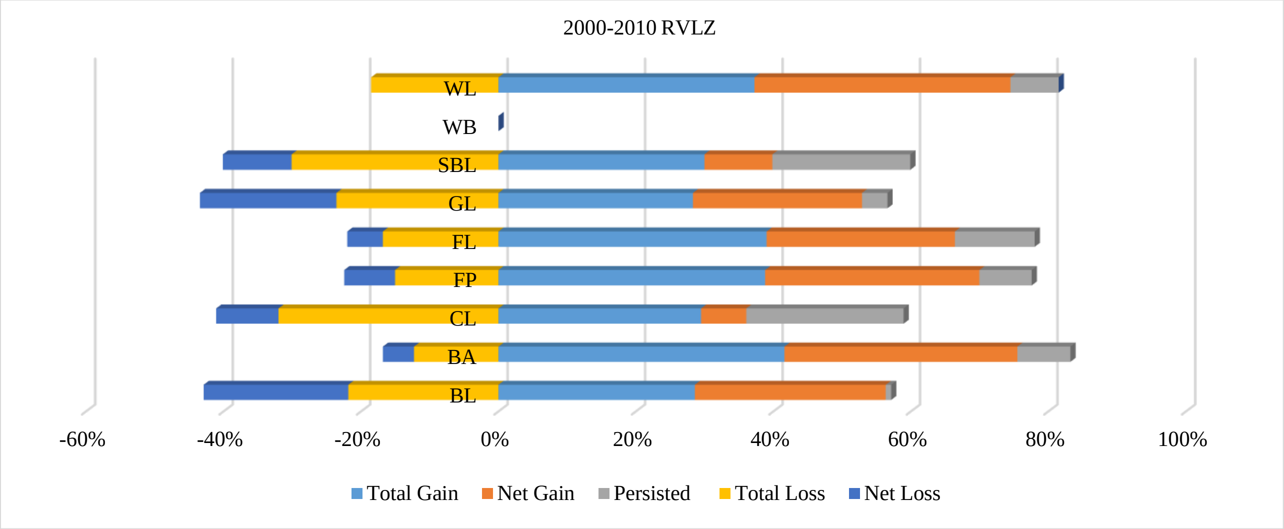
Ethiopia. The Annys et al. (2016) study in the Ethiopian Rift Valley escarpment showed that GL cover increased between 2000 and 2014. However, between 1985 and 2019, about 64.43% of GL was converted in the RVLZ. Rapid transitions in cultivation land and bush and shrublands fluctuated over the research years in the RVLZ. In RVLZ, SBL reduction started in 2010. Due to demands from the internal and immigrant population and large and medium agricultural investors in RVLZ, there are correlations between SBL reduction and CL increases. In the LZ, major LULC exchanges occurred between CL and SBL over the study years.

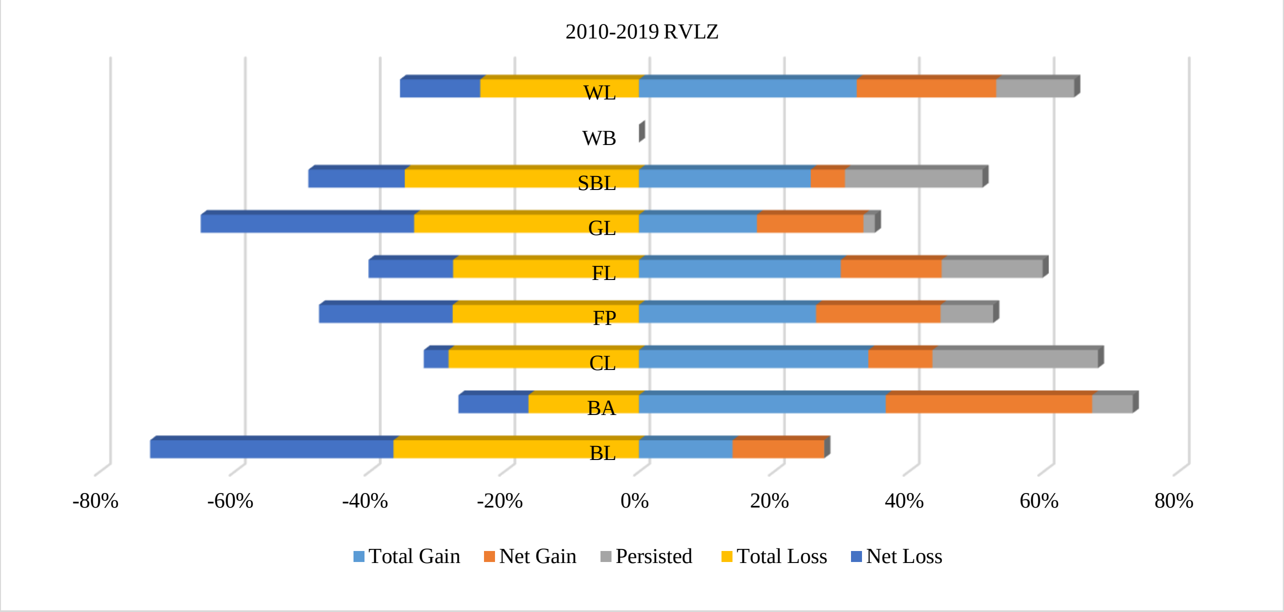
Table 4.7 LULC detections in Raya Valley Livelihood Zones for the periods of 1985-2019

RVLZ		To 2019				Land use land cover (Km^2)						
		BL	BA	CL	FP	FL	GL	SBL	WL	GT	Loss (Km^2)	Loss (%)
From 1985	BL	0.13	0.10	3.67	0.05	0.01	0.58	0.97	0.00	5.51	5.38	97.66
	BA	0.01	2.24	3.70	0.54	0.06	0.01	1.41		7.97	5.73	71.84
	CL	3.65	23.71	733.77	14.91	14.28	6.57	122.26	0.29	919.44	185.67	20.19
	FP	0.00	0.21	0.56	2.04	0.09	0.01	0.45		3.37	1.33	39.42
	FL	0.04	1.78	21.77	0.51	29.10	0.09	48.30	0.59	102.19	73.09	71.52
	GL	0.30	0.09	25.89	0.01	0.30	0.86	1.04	0.04	28.54	27.69	96.99
	SBL	0.57	16.59	316.70	9.58	36.94	2.03	382.93	0.39	765.74	382.81	49.99
	WB			0.00				0.15	-	0.15	0.15	100.00
	WL	0.00	0.00	0.04		0.01	0.00	0.08	0.00	0.13	0.13	97.43
	GT	4.70	44.74	1106.11	27.64	80.79	10.15	557.59	1.31	1833.04		
	Gain(Km^2)	4.57	42.49	372.34	25.60	51.69	9.30	174.66	1.31			
	Gain (%)	97.25	94.98	33.66	92.62	63.98	91.55	31.32	99.75			

Bare land = (BL), Built-up area= (BA), Cultivation-land (CL), Flood Plain= (FP), Forest land (FL), Grassland= (GL), Shrub and Bushland= (SBL), Waterbody= (WB), Wetland= (WL)




2000-2010 RVLZ
WL
WB
SBL
GL
FL
FP
CL
BA
BL
-60%
-40%
-20%
0%
20%
40%
60%
80%
100%
Total Gain
Net Gain
Persisted
Total Loss
Net Loss


2010-2019 RVLZ
WL
WB
SBL
GL
FL
FP
CL
BA
BL
-80%
-60%
-40%
-20%
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20%
40%
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80%
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Net Gain
Persisted
Total Loss
Net Loss

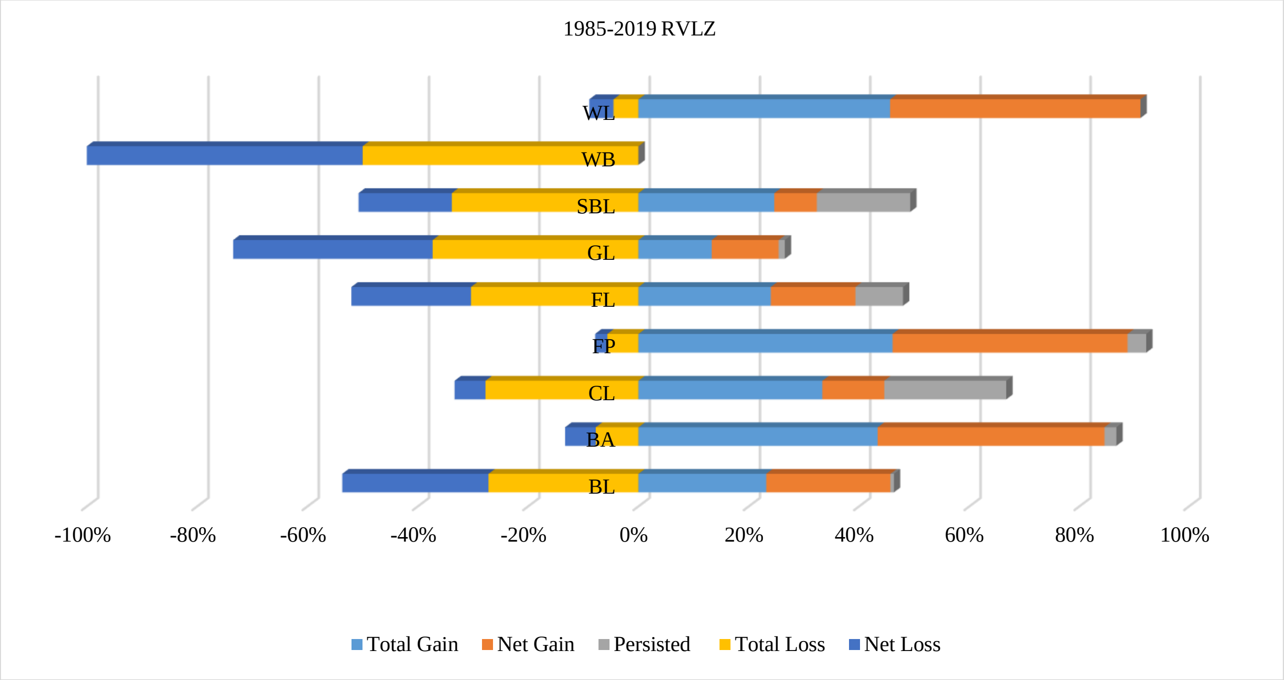


Figure 4.5. Histogram showing LULC shifts in Raya Valley livelihood zones in the study interval year

BL= Bare land, BA= Built-up area, CL= Cultivation-land, FP=Flood Plain, FL= Forest land, GL = Grassland, SBL= Shrub, and Bushland, WB = Waterbody, WL= Wetland

Alagie Ofla Livelihood Zone

During the study period, CL gained approximately 177.10 Km^2 from other classes in ALOFLZ. Simultaneously, 97.98Km^2 of CL shifted in ALOFLZ. Most of the CL exchange occurred with SBL. From the exchanges, about 72.63Km^2 (74.13 %) of CL was converted into SBL, but it gained 143.45 Km^2 (81 %) from SBL in ALOFLZ (Table 4.8). In ALOFLZ, CL also gained about 25.20 Km^2 from GL and 8.45 Km^2 from others (Table 4.8). Over the study period, about 1430.57 Km^2, CL persisted. During the study years, SBL lost 192.78 Km^2 and gained about 106.56 Km^2 in LOFLZ. In similar study years, 74.41 % and 16.78 % of SBL changed to CL and BA. However, the gain (106.56 Km^2) for SBL was 72.63 Km^2 (68.16 %) from CL and 27.81 Km^2 (26.10 %) from FL in ALOFLZ (Figure 4.6). About 307.78 Km^2 of SBL persisted as SBL types over the study period in ALOFLZ.

Furthermore, across the study periods, FL in ALOLZZ gained 41.08 Km^2, lost 30.11 Km^2, and maintained its originality with 26.89 Km^2. However, the gain and loss trends were not prominent (Table 4.8). FL similarly acquired 32.34 Km^2 (78.72%) from SBL and 6.58 Km^2 (16.02%) from CL. Further, FL's 27.81 Km^2 (92.35 %) was gone into SBL (Table 4.8). Again, 34.64 Km^2 of GL shifted to CL (25.20 Km^2), SBL (4.16 Km^2), and WL (2.15 Km^2) in ALOFLZ. However, GL only gained 10.51 Km^2 in total, which gained 6.53 Km^2 from CL, 2.20 Km^2 from SBL, and other LULC types (1.81 Km^2). Only about 4.41 Km^2 of the grassland persisted within the study periods. Over the study years (1985-2019), BA gained 22.81 Km^2 (94.40%) from other LULC classes in ALOFLZ (Figure 4.6). From the gain, SBL and CL shared high values. In the same study years, FP gained only 2.08 Km^2 from SBL and Cl in ALOFLZ. Compared to other LULC types, BL lost 6.13 Km^2 and gained 2.69 Km^2 in the past 34 years (1985-2019) in ALOFLZ. The loss of 4.76 Km^2 (77.62%) and gained 2.40 Km^2 (84.44%) of BL in ALOFLZ occurred within CL. WB in ALOFLZ lost 0.99 Km^2 and only gained 0.81 Km^2 from other LULC classes. Similarly, wetland gained about 2.37 Km^2 and lost 1.74 Km^2 in ALOFLZ. About 2.15 Km^2 wetland gained was from GL.

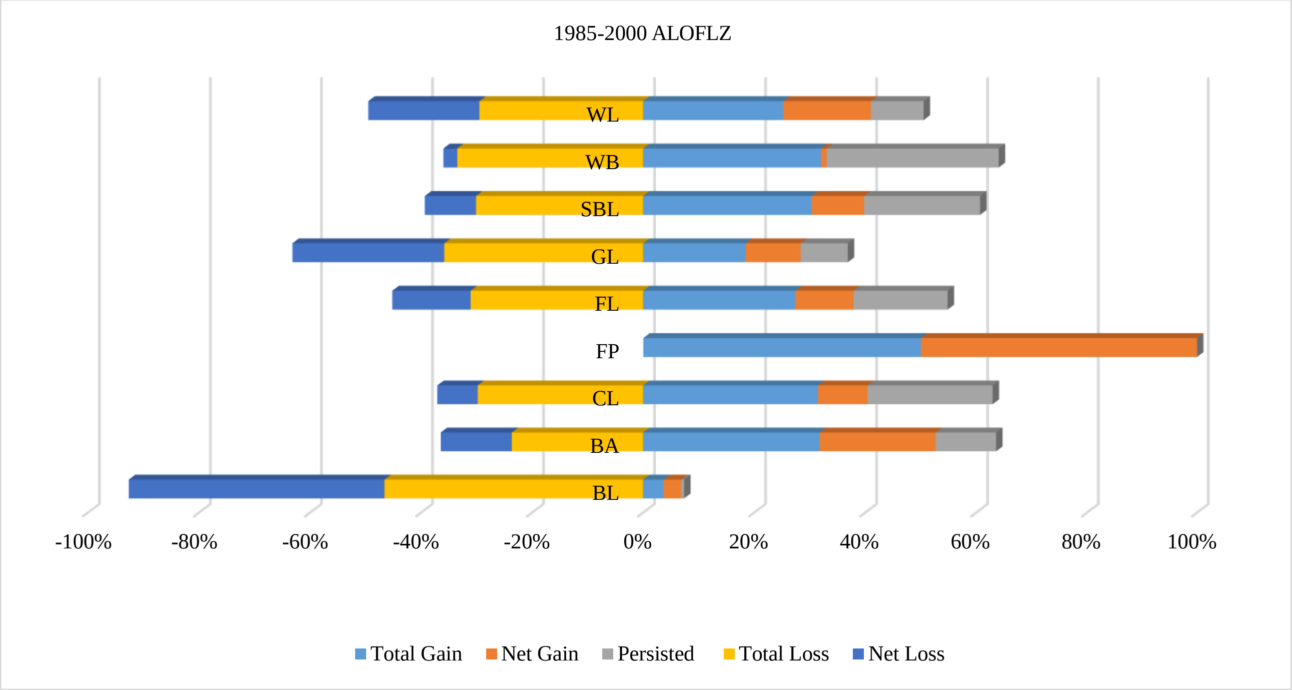
The current result coincided with the Xu *et al.* (2020) report in Bangladesh, which showed that changes in LULC occur between agricultural land and forests and shrublands. The Yesuph and Dagnew (2019) findings also supported the current study. The LULC detecting a constant increase of farmland/settlements area was discovered by Yesuph & Dagnew (2019) in the Beshillo catchment, primarily at the expanse of Afro/sub-Afro-alpine vegetation. Similar results from Li *et al*. (2016) in Wuhan City of China uncovered newly developed areas that come mostly from the alteration of pasture and cultivation lands. GL and FL were a source of additional land for CL and SBL in ALOVZ. Continually LULC shifting and disturbances have advantages and disadvantages for production and productivity in the study LZ. Changing land-use types offers the benefit of ending centuries of land exploitation. However, the growth of cultivated land has come at the cost of natural areas, which has exacerbated soil erosion concerns by destroying soil water infiltration and holding capacity through land degradation.

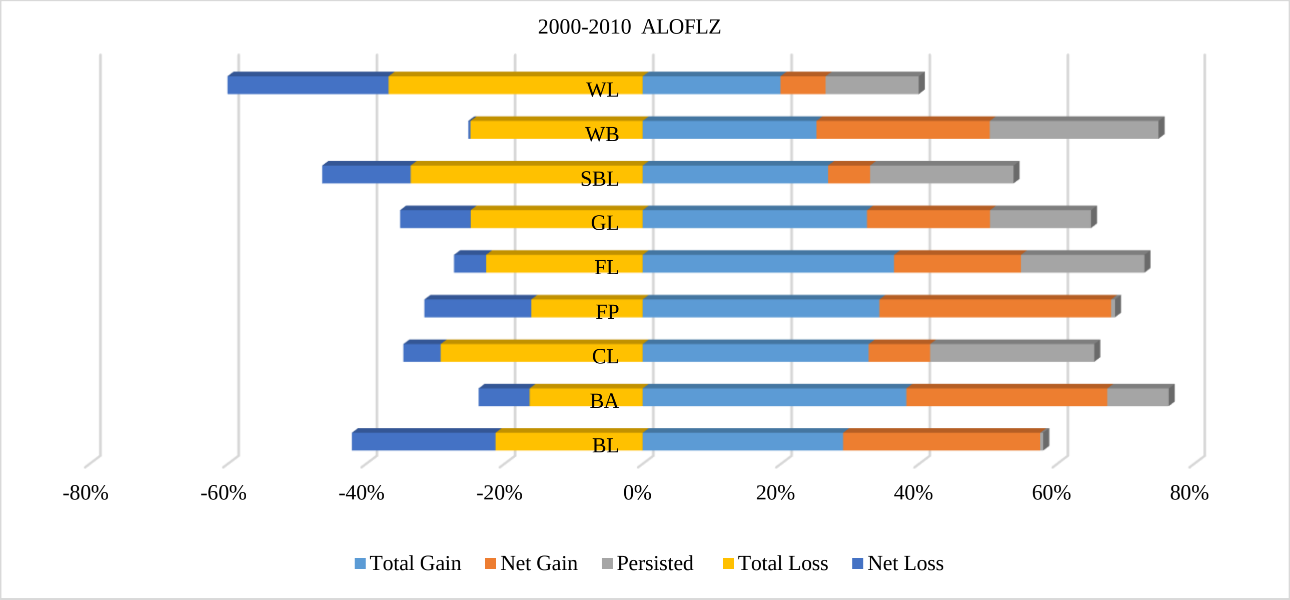
Table 4.8 LULC detections in Allagie Ofla Livelihood Zones for the periods of 1985-2019

		To 2019				Land use land cover (Km^2)							
ALOFLZ		BL	BA	CL	FP	FL	GL	SBL	WB	WL	GT	Loss (Km^2)	Loss (%)
From 1985	BL	0.05	0.06	4.76	0.00	0.01	0.77	0.53		0.00	6.18	6.13	99.25
	BA	0.01	1.35	1.12	0.08	0.04	0.02	0.37	0.00	0.00	3.00	1.65	54.89
	CL	2.40	8.43	365.60	1.20	6.58	6.53	72.63	0.00	0.19	463.57	97.98	21.13
	FL	0.00	0.23	2.01	0.02	26.89	0.04	27.81	0.00	0.01	57.00	30.11	52.82
	GL	0.13	0.19	25.20	0.04	2.03	4.41	4.16	0.74	2.15	39.04	34.64	88.71
	SBL	0.14	13.90	143.45	0.73	32.34	2.20	307.78	0.00	0.02	500.56	192.78	38.51
	WB		0.00	0.01	0.00	0.00	0.01	0.97	13.56		14.55	0.99	6.81
	WL	0.00	0.00	0.56	0.00	0.08	0.94	0.10	0.06	1.52	3.26	1.74	53.44
	GT	2.74	24.16	542.70	2.08	67.97	14.92	414.34	14.37	3.89	1087.16		

Gain(Km^2)	2.69	22.81	177.10	2.08	41.08	10.51	106.56	0.81	2.37
Gain (%)	98.32	94.40	32.63	100.00	60.44	70.44	25.72	5.65	60.96

Bare land = (BL), Built-up area= (BA), Cultivation-land (CL), Flood Plain= (FP), Forest land (FL), Grassland= (GL), Shrub and Bushland= (SBL), Waterbody= (WB), Wetland= (WL)





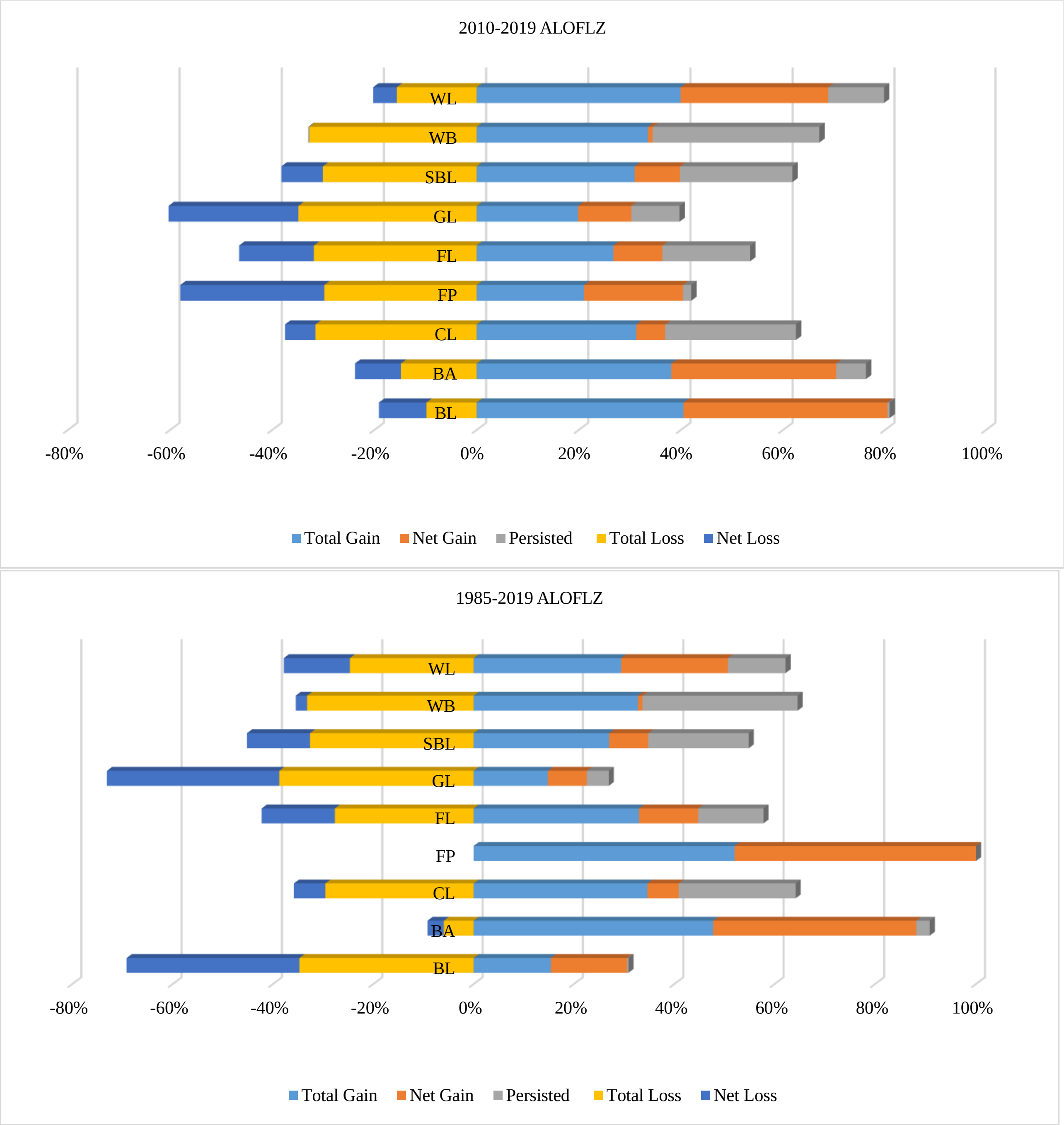


Figure 4.6. Histogram showing LULC shifts in Alagie Ofla livelihood zones in the study interval years

BL= Bare land, BA= Built-up area, CL= Cultivation-land, FP=Flood Plain, FL= Forest land, GL = Grassland, SBL= Shrub, and Bushland, WB = Waterbody, WL= Wetland

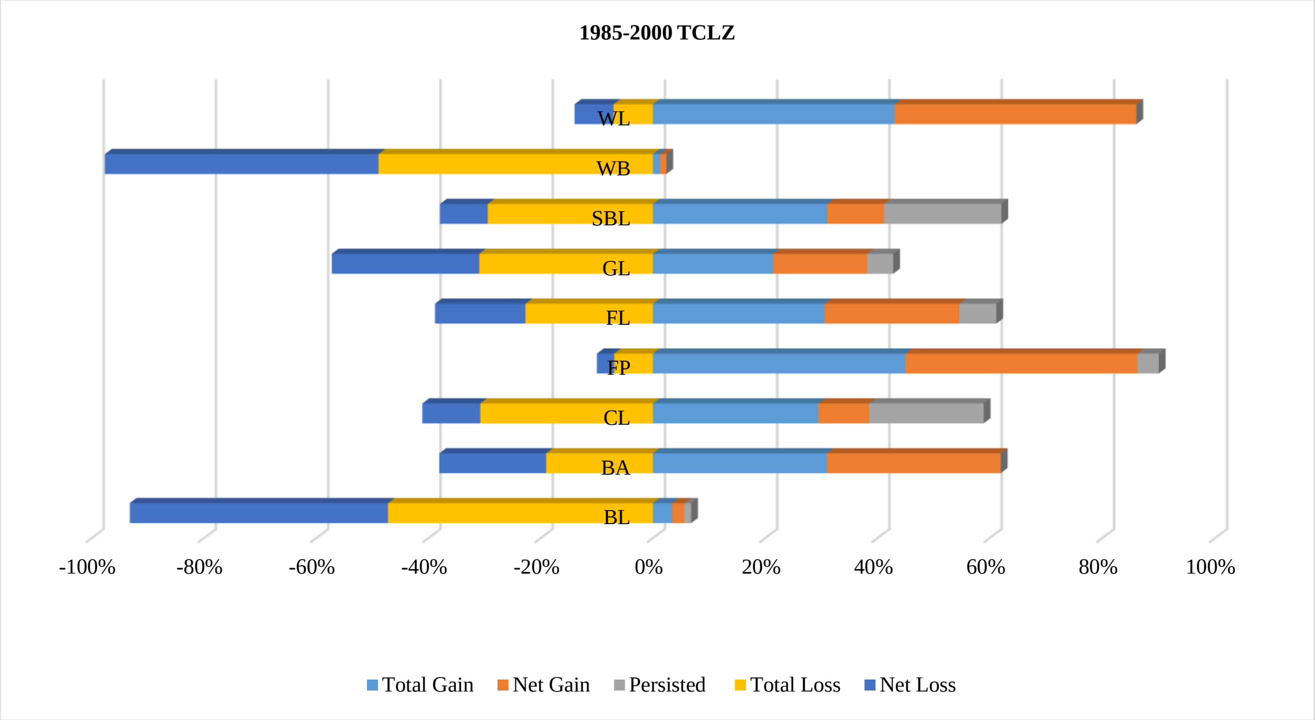
Tsirare Catchment Livelihood Zone

CL in TCLZ lost 86.47Km^2 and gained 159.19 Km^2 from other LULC types (Table 4.9). From the change, about 66.10 Km^2 (76.44%) of CL shifted to SBL, but at the same time, it gained 141.95 Km^2 (89.17%) from SBL (Figure 4. 7). Following SBL, GL contributed approximately 8.05 Km^2

(5.06%) to CL in TCLZ. Around 330.48 Km^2 of CL remained in TCLZ for the study's 34 years. SBL dropped 169.22 Km^2 in TCLZ throughout the same research years. About 83.89 % of SBL were transferred into CL and 7.32% into BA due to the loss.

However, SBL gained about 72.38 Km^2 over other LULC types with the highest share of CL (91.32%). On the other hand, only 272.12 Km^2 of SBL persisted as SBL types over the study period in TCLZ. Similarly, FL gained about 10.88 Km^2 and lost 3.64 Km^2 in TCLZ from 1985 to 2019. About 3.11 Km^2 (85.40 %) of the loss and 8.36 Km^2 (76.83 %) gained for FL occurred within SBL (Figure 4.7). Besides, only 2.29 Km^2 of FL remained original over the study years. On the other hand, from the total (9.29 Km^2) loss of GL, about 8.40 Km^2 (90.37%) was shifted into CL. Grassland only gained 8.86 Km^2 (5.76%) from CL, 1.55 Km^2 (17.53%) from SBL, and 1.54 Km^2 (17.37%) from BL, and only 0.94 Km^2 of GL was unchanged in the study years. From 1985 to 2019, BA gained about 17.47 Km^2 (99.87 %) from other LULC classes. Like RVZ and ALOFLZ, BL gained a high share from SBL and CL. Similarly, FP in TCLZ gained 9.23 Km^2 from SBL (50.57%) and CL (48.93%) (Figure 4.7). As presented in (Table 4.9), in the past 34 years, 10.83 Km^2 of BL shifted to other types of LULC in TCLZ. Besides WB and WL in TCLZ, there was no gain and lost trends within the study periods since there were no significant trends for WB and WL in TCLZ.

The current study agreed with Yesuph & Dagnew's (2019) findings in the Beshillo catchment of the Blue Nile Basin. The present study also coincided with Li *et al*. (2016) findings in Wuhan City, China, which found that development areas derived from the change in agricultural fields. Significant water difficulties, faster runoffs, increased land degradations, altered rainfall patterns, a scarcity of firewood sources and raw materials, and decreased free space and grazing areas in the study LZs result from the impacts of LULC dynamics.


1985-2000 TCLZ
WL
WB
SBL
GL
FL
FP
CL
BA
BL
-100%
-80%
-60%
-40%
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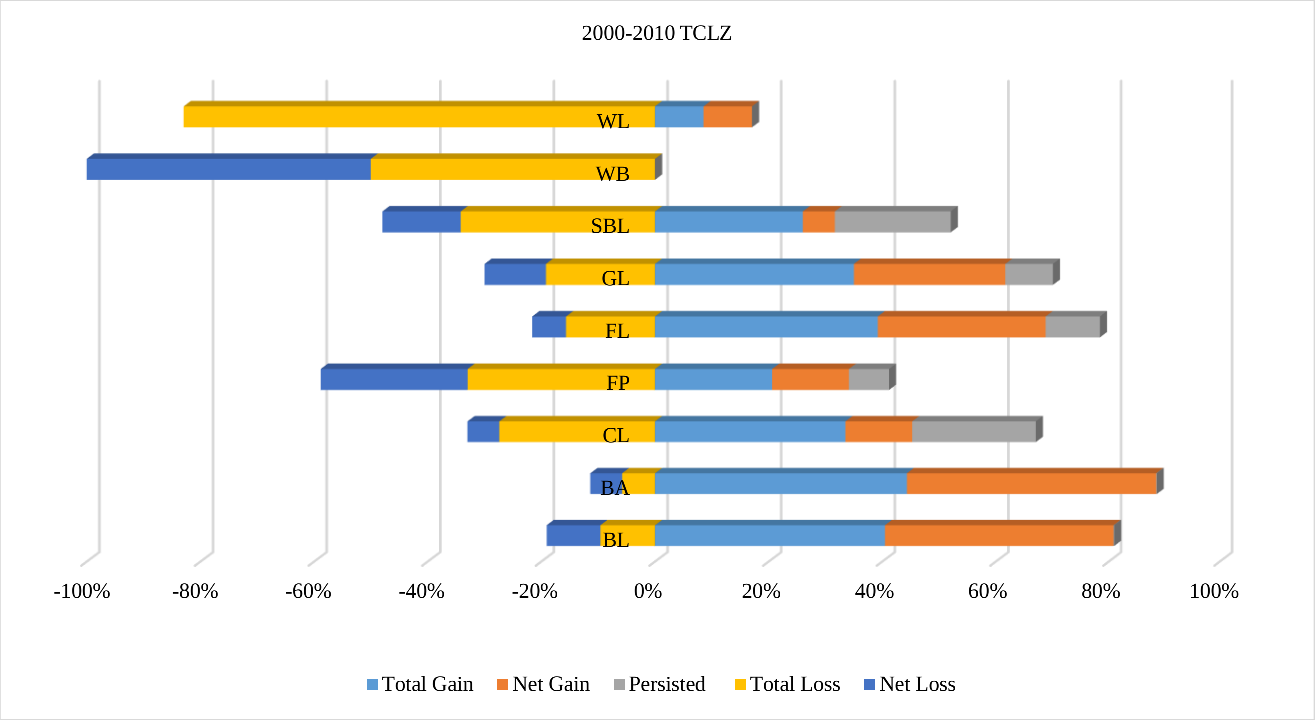
2000-2010 TCLZ
WL
WB
SBL
GL
FL
FP
CL
BA
BL
-100%
-80%
-60%
-40%
-20%
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Persisted
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Net Loss

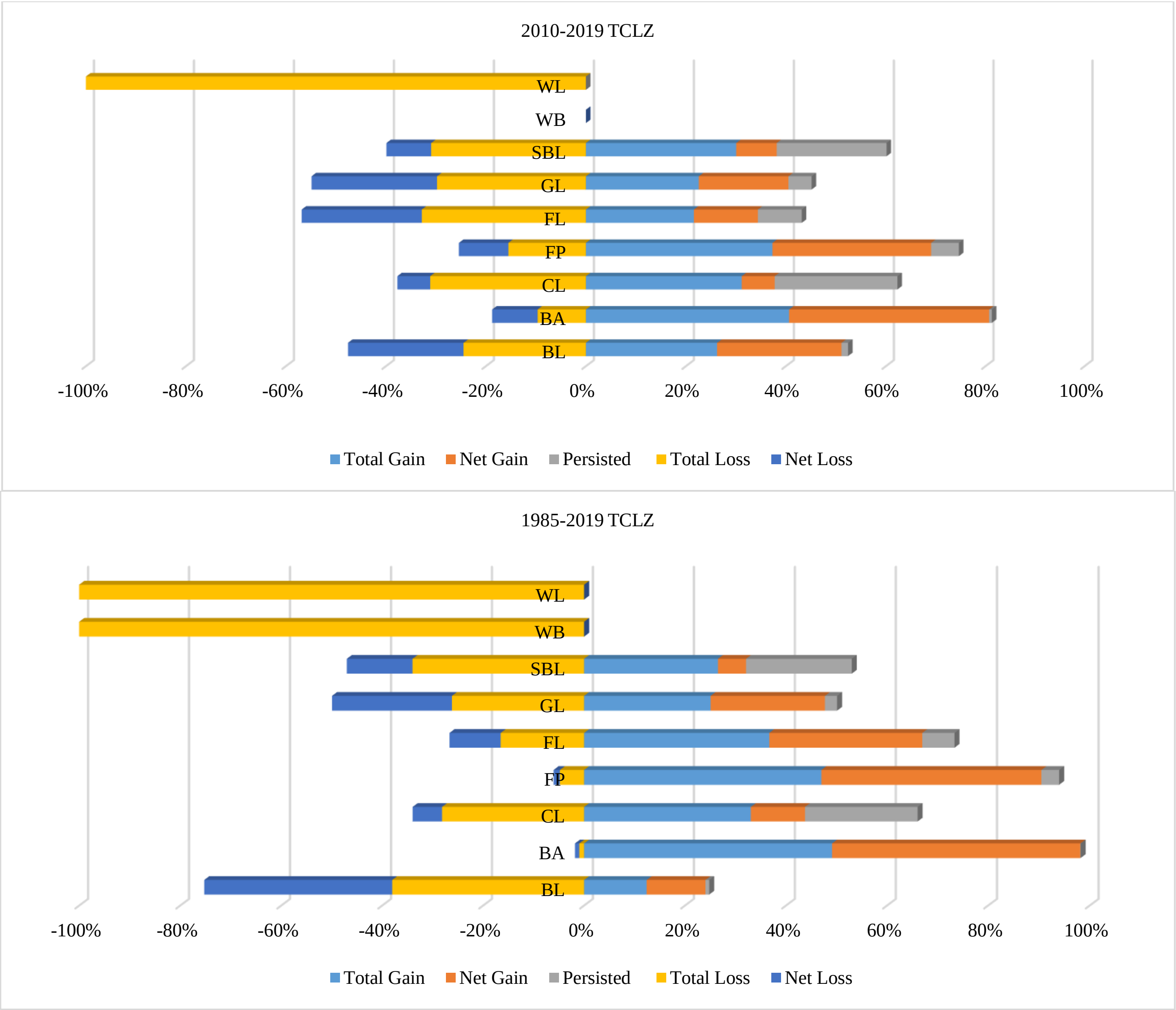

Figure 4.7. Histogram showing LULC shifts in Tsirare Catchment livelihood zones in the study interval years

BL= Bare land, BA= Built-up area, CL= Cultivation-land, FP=Flood Plain, FL= Forest land, GL = Grassland, SBL=Shrub, and Bushland, WB = Waterbody, WL= Wetland

Table 4.9 LULC Detections in Tsirare Catchment Livelihood Zones for the periods 1985-2019

TCLZ		2019			Land use land cover in (Km^2)						
		BL	BA	CL	FP	FL	GL	SBL	GT	Loss(Km^2)	Loss (%)
1985	BL	0.22	0.11	8.05	0.02	0.05	1.54	1.06	11.05	10.83	98.04
	BA	0.00	0.02	0.21	0.00	0.00	0.00	0.10	0.33	0.31	93.18
	CL	2.94	4.89	330.48	4.52	2.27	5.76	66.10	416.94	86.47	20.74
	FP	0.00	0.03	0.10	0.74		0.00	0.14	1.01	0.27	26.41
	FL	0.00	0.04	0.46	0.03	2.29	0.01	3.11	5.92	3.64	61.40
	GL	0.15	0.01	8.40		0.20	0.94	0.53	10.23	9.29	90.79
	SBL	0.29	12.39	141.95	4.67	8.36	1.55	272.12	441.33	169.22	38.34
	WB		0.00	0.01	0.00	0.00		1.35	1.36		0.00
	WL			0.01		0.00	0.00	0.00	0.02		0.00
	GT	3.60	17.49	489.67	9.98	13.16	9.81	344.49	888.21		
	Gain (Km^2)	3.39	17.47	159.19	9.23	10.88	8.86	72.38			
	Gain (%)	93.99	99.87	32.51	92.53	82.63	90.38	21.01			

Bare land = (BL), Built-up area= (BA), Cultivation-land (CL), Flood Plain= (FP), Forest land (FL), Grassland= (GL), Shrub and Bushland= (SBL), Waterbody= (WB), Wetland= (WL)

Summary of Land Use and Land Cover Detections over the Study Livelihood Zones for the Periods 1985-2019

The RVLZ shifted faster than the ALOFLZ and TCLZs, according to the land use and land cover detection analyses. Only roughly 17.7 %, 28.3 %, and 23.2 % of RVLZ, ALOFLZ, and TCLZ remained as initial LULC types across the research years, as shown in Table 10. According to the findings, 82.3 %, 71.7 %, and 76.8% of RVLZ, ALOFLZ, and TCLZ LULC types changed across classifications. Within the research years, no LULC types reached a climax or stabilized in any study LZs. In comparison to ALOFLZ and TCLZ, RVLZ has more environmental disruptions. This result was consistent with Othow et al. (2017), who found that the conversion of natural vegetation decreased agricultural productivity per plot of land in the Gog District from 1990 to 2017. Conferring to the Congreso et al. (2014) study, declining the biological regulator can flow pest densities that affect pollinator services and roots ecofriendly reductions.

As a result, without a peak and a stable ecosystem, the ecosystem service will be unable to support natural ecosystem cycles and human requirements. Drought hazards are more likely in a continuously disrupted ecosystem, resulting in local climate system disturbances and affecting the agricultural productivity of LZs in the study.

According to Nasir et al. (2021a), *“from 1983 to 2016, Belg or Kiremt or combined drought seasons were in the study livelihood zones. From 1983 to 2016, there were 18 drought episodes in*

Belg, 12 in Kiremt, and 15 in the combined rainy season (Belg and Kiremt), with two additional drought seasons for RVLZ”. Furthermore, the study LZs were affected by 15 annual drought years. Additional, Nasir et al. (2021a), stated that “over the study years, drought in the Kiremt season was frequently revisited with 2.8, 2.5, and 2 intervals in RVZL, ALOFLZ, and TCLZ. Similarly, drought incidents in the annual timescale repeated with an interval of 2.14, 1.86, and 2.1 in RVZL, ALOFLZ, and TCLZ, respectively”.

The study by Nasir et al. (2021b) showed that in the current study LZs, *“annual Tmin was rising (0.31, 0.30, and 0.27 ^{0}C) combined with higher rainfall variability (34%, 35%, and 32%) in ALOFLZ, TCLZ, and RVZL, respectively. Similarly, annual Tmax increases by 0.32 and 0.42 ^{0}C, respectively, in TCLZ and RVLZ. Further, their result indicates Belg Tmax rising by 0.30, 0.40, and 0.43 ^{0}C with extreme higher rainfall variability (64%, 70%, and 65%) in ALOFLZ, TCLZ, and RVLZ, respectively. Similarly, there was high variability in rainfall in the Kiremt season, which records 46%, 43%, and 46 % CV in ALOFLZ, TCLZ, and RVLZ, respectively”.*

This study revealed that FGD and key informant interviews supported the results of Nasir et al. (2021 a&b). Drought is chronic and severe in their LZs, according to early warning experts from RVLZ and TCLZ. These climate variations, joined with the study LZs' fast and disrupting environments, point to future drought hazards and uncertainty in land-use systems (Table 4.10).

Table 4.10 Summary of LULC detections in the three study livelihood zones for the periods 1985-2019

LULC types	Livelihood Zones RVLZ Gain (%)	Lost (%)	Persist (%)	ALOFLZ Gain (%)	Lost (%)	Persist (%)	TCLZ Gain (%)	Lost (%)	Persist (%)
BA	97.25	97.66	18.15	98.32	99.25	0.81	93.99	98.04	0.02
BL	94.98	71.84	28.10	94.40	54.89	45	99.87	93.18	6.06
CL	33.66	20.19	80	32.63	21.13	79	32.51	20.74	79.25
FP	92.62	39.42	61	100.00	0	0	92.53	26.41	73.27
FL	63.98	71.52	29	60.44	52.82	47	82.63	61.40	38.68
GL	91.55	96.99	3.01	70.44	88.71	7.74	90.38	90.79	9.18
SBL	31.32	49.99	50	25.72	38.51	62	21.01	38.34	78.04
WB	0	100.00	0	5.65	6.81	93.19	-	-	-
WL	99.75	97.43	0	60.96	53.44	46.63	-	-	-
CC	67.23	71.67	29.92	60.95	46.17	42.37	73.27	61.27	40.64
PC	39.83	42.45	17.72	40.77	30.89	28.34	41.83	34.97	23.20

Bare land = (BL), Built-up area= (BA), Cultivation-land (CL), Flood Plain= (FP), Forest land (FL), Grassland= (GL), Shrub and Bushland= (SBL), Waterbody= (WB), Wetland= (WL), CC= Cumulative changes, PC= Proportional change

4.3.4. Drivers of Land Use and Land Cover Change and Implications on Communal Resources

Population Pressures

FGD and key informant interview results showed that the population number rapidly increased during the study years in all LZs. This reality corroborated the findings of the demographic model utilized in the study livelihood zones, which predicted a population rise over the study period (1985 to 2019). Population numbers increased from 59,310 to 270,388 in ALOFLZ, from 15539 to 70843 in TCLZ, and from 61728 to 281416 in RVLZ, respectively (Table 4.11). The census tract level of population change showed increased trends by 130.50%, from 1985-2000, by 50.43%, in 2000-2010, by 31.48% in 2010-2019, and will increase by 13.84% in 2019-2024 in all study livelihood zones. This fast population growth brings population pressure on the natural resources of the study livelihood zone. As stated by the focus group discussion participants and the key informant interview results, population pressure in ALOFLZ and TCLZ came from the growth of the internal population. However, in the RVLZ, population pressure came from population growth and neighboring immigrants. For example, from 2018 to 2019, more than 4350 household immigrants fled to the northern parts of RVLZ.

Reports from the key informants' interviews in RVLZ revealed 95 investors involved in agricultural investments in the past 20 years (2000-2019) in the northern parts of the LZ. Investors converted thousands of hectares in the northern parts of RVLZ. They changed shrub and Bushland, grazing land, woodlands, and forests into farmlands in RVLZ. For example, from 2016 to 2019, about 2393.5 hectares of the natural area were cleared for farmlands only in7 kebeles (small administration area) of northern RVLZ. According to the FGD view, there is no scientific land management in all study LZs. In ALOFLZ and TCLZ, there were problems regarding land redistributions in the sloppy area. Further, the participants of FGD in all LZs discussed land distribution for youth has consequences of deforestation, grazing land shrinkage, land degradation, and affects local climate patterns. They fear it may have long impacts on an agro-climatic zone of their area, and their fertile soil washed out.

The studies of Onuoha *et al.* (2018) in the USA, Kindu and Schneider (2015) and *Damtew et al.* (2021) in Ethiopia, and Munthali *et al.* (2019) in Malawi reported that population growth was the main LULC driver across their study areas. The current result coincided with the Munthali *et* *al.* (2019) findings. Munthali *et al.* (2019) showed that the need for fuelwood and charcoal, the growth of the population, and poverty were identified as drivers of the change in LULC during their study years in Dedza District central Malawi Region. Further, this study agreed with the findings of Hermans-Neumann et al. (2017). The Hermans-Neumann *et al.* (2017) study revealed that the Ethiopian Great Rift Valley was among the hotspots of socio-ecological pressures due to the high population density of immigrants. Population pressure, fuelwood, demand for construction materials, agricultural development, and land use regulation were key LULC change drivers in the Gumara-watershed, Northern Ethiopia, according to Wubie *et al.* (2016). They also find that immigrants place additional stress on local natural resources. Furthermore, the current investigation supports the findings of Xu *et al.* (2020) in Bangladesh. They identified climate change dynamics, extreme occurrences, and changes in urban and rural households as drivers of forest conversions in Bangladesh.

Table 4.11 Population growth trends in the study livelihood zones for the periods 1985-2024

Year	Growth rate	Alagie Ofla Livelihood Zone		Tsirare catchment zone		Raya Valley Livelihood Zone	
		Population Data	Population density (Population number /Area (Km^2)	Population Data	Population density (Population number /Area (Km^2)	Population Data	Population density (Population number /Area (Km^2)
1985	0.03	59310	54.56	15539	16.65	61728	33.68
2000	0.029	136708	125.77	35818	38.37	142284	77.62
2010	0.026	205652	189.19	53882	57.72	214040	116.77
2019	0.026	270388	248.75	70843	75.88	281416	153.53
2024	0.026	307803	283.17	80646	86.39	320358	174.77

Source: Central Statistical Authority (CSA) census (1984, 1994, and 2007) and Woreda offices (2017) of the study LZs

Build up Area Expansion

According to the key-informant interviews perspective of the study of three LZs, another cause of LULC changes was rapid settlement expansion and infrastructure developments in recent years. In the focus group discussions, participants in all LZs recalled that settlement expansion due to high population growth or immigrants was insignificant before two decades. The FGD participants perceived that the settlement expansion was widespread from 2000 to 2019. Spatial data results support the perspective of FGD participants and key informant interviews on settlement expansion. In the study years, spatial data results showed rapid BA development in all study LZs. BA has increased from 7.97 Km^2 in 1985 to 44.74 Km^2 in the year 2019 in RVLZ. The rapidly increased BA expansion occurred between 2010 and 2019 by 24.72 Km^2 in RVLZ. These rapid expansions of BA happened at the expense of natural resources.

Similarly, BA increased from 3 Km^2 and 0.33 Km^2 in 1985 to 24.16 Km^2 and 17.5 Km^2 in 2019 in ALOFLZ and TCLZ, respectively. The fast BA expansion trends occurred between 2010 and 2019, increasing by 14.77 Km^2 in ALOFLZ and 13.34 Km^2 in TCLZ. This study coincides with the Hailemariam *et al.* (2016) results. They indicated that CL and BA expansions were the main LULC drivers from 1985 to 2015 in the Bale Mountain Ecoregion of Ethiopia. The current study coincided with the Meire et al. (2013) findings in the Northern Ethiopian Highlands. According to the Meire *et al.* (2013) study, the built-up area increased from 1868 to 2008 due to population density in the Northern Ethiopian Highlands. Furthermore, the current result on BA expansion is consistent with the Li *et al*. (2016) findings in Wuhan City, China. Li *et al.* (2016) found that the built-up land came mainly from cultivation land for economic development purposes.

Cultivation Land Expansion

As information shared from key informant interviews and all (four) FGDs, similar to settlement trends, the expansion of farmland is increasing in all study LZs. FGD results indicated that deforestation for farmland expansion occurred at an alarming rate in all study LZs. The results from the satellite survey supported the perceptions of FGD and key informant interviews on the LULC change trends of the study LZs. CL in RVLZ had increased from 919.48 Km^2 (50.16%) in 1985 to 1106.13 Km^2 (60.34%) in 2019. Within the study years (1985-2019), about 186.65 Km^2 (20.30 %) of CL was gained in RVLZ. However, in the third study period (2010-2019), RVLZ gained about 188.73 Km^2 (20.57 %) CL. CL in ALOFLZ had increased from 463.58 Km^2 in 1985 to 542.71 Km^2 in 2019.

Similarly, CL had increased from 417 Km^2 in 1985 to 489.73 Km^2 (55.13 %) in 2019 in TCLZ. As FGD participants in RVLZ explained, since 2015, community forests have been lost due to farmland expansion, except for state forests and area closures. Participants in all FGD and key informant interviews elaborated that the size of farmland for individuals decreased with time. The participants of FGD in all LZs discussed land distribution for youth has consequences of deforestation, grazing land shrinkage, land degradation, and affects local climate patterns. Participants fear that they may face more frequent and severe droughts than ever in the future. The anchored soil with forest roots was exposed and degraded into the lower streams. The current study agreed on the drivers of LULC change with the Hailemariam *et al.* (2016) study, which revealed farmland and urban settlement expansion were the drivers of LULC changes in the Bale Mountain Eco-Region of Ethiopia from 1985 to 2015. The study by Betru *et al.* (2019) in Western Ethiopia revealed that small- and large-scale agriculture was the proximate driver of deforestation in their study years.

Investors involved in RVLZ are converting thousands of hectares of natural vegetation. They displaced and dispossessed farmers from their farmland and settlements without appropriate compensation and alternative farmland. Land distribution to investors consequences severe problems of grazing lands, displacing farmers, affecting livestock sectors, aggravated climate change, disrupting rainfall patterns, bringing conflict interests, and affecting fuelwood resources and forest ecosystems. The Dibaba *et al.* (2020) study found Similar results that reported intensive agriculture commercial famed affected Fincha Catchment in Northwestern Ethiopia. Further, the Dibaba *et al.* (2020) study showed an expansion of large-scale commercial agriculture became the main driver for forest cover change out of all drivers in Gog District, Gambella Regional State, from 1990 to 2017.

4.4. Conclusion

The current study revealed substantial LULC dynamics over the past 34 years using remote sensing and geographical information systems (GIS), key informant interviews, and focus discussion analysis. The study uncovered that CL was the dominant LULC type in all livelihood zones throughout the study years. Except for CL and SBL LULC types in TCLZ and CL, SBL, and FL in RVLZ and ALOFLZ, there were no persistently dominant LULC types within the study years. Cultivation land and Built-up area in all LZs and FP in RVLZ and TCLZ showed remarkable trends, mainly at the expense of other LULC types in all LZs. In contrast, SBL, GL, and BL reduced markedly over the study years. The wetland area increased in RVLZ but decreased in ALOFLZ.

The results of the LULC change detection showed a rapid change in land use and land cover in all LZs. There were no climaxes and stabilization of LULC types within the study years in all LZs. The overall land use and land cover detection analysis shows RVLZ is highly (largely) LULC shifted than the ALOFLZ and TCLZs. Relatively, ecosystem disturbances are higher in RVLZ than in ALOFLZ and TCLZ. CL and SBL change was fast and fluctuated within and between studies LZs. In the RVLZ, SBL shrinkages started in the year 2010. There are links between SBL reduction and CL expansions due to pressures from the growth of the internal and immigrant population and large and medium agricultural investors in RVLZ. In all LZs, major LULC exchanges occurred between CL and SBL over study years. GL and FL were a source of additional land for CL and BA in all LZs.

Continually LULC shifting and disturbances have two implications for production and productivity in the study LZs. Shifting from one land-use type to another has the advantage of resting the centuries of relentless land exploitation. However, the expansion of the cultivated lands was at the expense of natural vegetation covers that has intensified the soil erosion problems through land degradation and destructing soil water infiltration and holding capacity. Therefore, if there is no climax and stabilized ecosystem, the ecosystem service cannot support natural ecosystem cycles and human needs. A continuously disrupted ecosystem is more exposed to drought hazards that result in local climate system disturbances and affect the agricultural productivity of LZs in the study. These combined climate variabilities with rapid and disrupting the ecosystems of the study LZs imply possible future drought risks and instability of land-use systems that can impact agricultural productivities and forage growth and climate systems of the study areas.

The demand for land is increasing each year due to population pressures. Population pressures from lack of alternative income sources and fuelwood demands for household consumption, lack of appropriate land use mechanisms, land demands for agriculture and settlement, disruption of local climate patterns, and frequent droughts were among the LULC change driving factors in all LZs. Internal population pressure is the main driving force of land change in ALOFLZ and TCLZ. Population pressures from the residents and immigrants from neighboring were the main driving LULC change in RVLZ. In RVLZ, large and medium agricultural investors were also the main driving force behind the change in LULC. Communities in RVLZ are left without contingency land for their youths and coming generations.

Due to grazing land conversions, livestock number was decreasing in RVLZ. Livestock was a means for a household's livelihood during the drought period in RVLZ. Before 20 years, there was no trend to harvest agricultural residues for animal feed in all LZ. However, recently everything has been gathered during the production season for the dry season. This trend will affect the soil fertility and productivity of their farmland. Integrating, updating, and projected land use plans will reduce the vulnerability and risks of LULC change and associated climate impacts in the future. Further, farm activities should be eco-friendly instead of depending on intensive chemical inputs to increase the productivity of the land. More research on the nexus between LULC dynamics and drought consequences on livelihoods is needed.

5. Chapter Five: Modeling the Vulnerability of Livelihood Systems to Drought Along Livelihood Zones in the Northwestern Escarpment of Ethiopian Rift Valley

Abstract

Drought is becoming a common problem for farmers in the Northwestern Escarpment Ethiopian Rift Valley's three studied livelihood zones (LZs). Droughts wreaked havoc on the community's livelihood systems regularly. It lefts the community food insure and repeatedly disturbs their ecosystems. As a result, the current study used meteorological, spatial, and socioeconomic data from the area to assess the community's drought susceptibility. Each variable of drought vulnerability was normalized as proxy indicators to calculate exposure, sensitivity, and adaptive capacity indexes. From the results, the Raya valley livelihood zone (RVLZ) is relatively more drought vulnerable (0.65) than the Tsirare catchment livelihood zone (TCLZ) (0.63) and Alagie-Ofla livelihood zones (ALOFLZ) (0.60). The RVLZ has a less adaptive capacity than ALOFLZ but more susceptibility and higher exposures to drought risks than the two LZs. Besides, the TCLZ has less adaptive capacity than the two livelihood zones, with more vulnerability and exposure to drought risks than ALOFLZ. The highest levels of exposition and susceptibility synergy with low resilience have aggravated the vulnerability to drought in all study LZs. Livelihood zone-based interventions and climate-smart farming are thus necessary for all LZs to reduce possible drought risks and transfer vulnerable communities into high adaptive capacities.

Keywords: Adaptive capacity, Drought Vulnerability, Exposure, Livelihood system, Livelihood zone, Sensitivity

5.1. Background

Since 1950th, extreme climate variabilities are becoming the main environmental challenges (IPCC, 2013), and they will also continue affecting the globe (Mekonen & Berlie, 2021). Climate change causes rising temperature and erratic rainfall, which leads to extreme events and disturbs human livelihood and the environment in general (Filho *et al.,* 2017; IPCC, 2014). If climate variability continues at this rate, devastating consequences will happen to human beings in the future, too (Gujree *et al.*, 2017; Olayide & Tetteh, 2017). Due to climate variability and anthropogenic effects, drought has frequently occurred in the last two decades in Africa (Maru *et al.,* 2021a; Ashraf *et al.*, 2020; Sadat *et al.,* 2020; Guha-Sapir & Mami, 2019; Sharafati *et al.*, 2019; Filho *et al.*, 2017; IPCC, 2013). East Africa is the most vulnerable region to drought events that are the main risks to agricultural production and productivity (Gebrechorkos et al., 2019; IPCC, 2007b; Haile, 2005) and chronic crisis roots in socioeconomic issues (Gebrechorkos et al., 2019; Haile & Tang, 2019). Since 2005 the occurrence of drought has doubled from once every six years to once every three years, and it has been causing socioeconomic instability in the region (Birara *et al.*, 2020; Haile & Tang, 2019).

In Ethiopia, drought is a common occurrence, and it has been, and still is, the driving cause behind the country's exposure to periodic pandemics (Andargie, 2014; Kiros, 1991; Webb & Braum, 1990). Farmers in Ethiopia are vulnerable to drought as most of their livelihood relies on rain-fed agriculture (Esayas *et al.*, 2018, 2019; Asrat & Simane, 2017) and is associated with low-level adaptation and mitigation systems (Maru *et al.*, 2021b; Filho *et al.*, 2017). The country is more likely to be drought due to frequent climate variabilities (Dechassa *et al.,* 2020), anthropogenic effects, and an inadequate response to climate variations (Esayas *et al.,* 2019).

Raya Valley livelihood Zone (RVLZ), Alagie–Ofla livelihood Zone (ALOFLZ), and Tsirare Catchment Livelihood Zones (TCLZ) are among the most droughts-prone and chronically food-insecure areas of the country in the Northwestern Escarpment of Ethiopian Rift Valley (Nasir *et al.,* 2021a; Andargie, 2014). From 1983 to 2016, there have been Belg, Kiremt, or combined drought seasons in the study livelihood zones. From 1989 to 2016, the severity and frequency of droughts increased during the Belg season. Seasonal drought incidents in Kiremt are becoming locally fragmented, even at village levels. Still, the temperature is going warm, and the rainfall has shown high irregularities and various seasonal and annual timescales in the study LZs (Nasir *et* *al.*, 2021b). These inconsistencies and fluctuated variability also imply possible extreme drought events (Gidey *et al.*, 2018a,b) that impact agricultural productivities and forage growth and disrupt the ecosystem of the study areas (Nasir *et al.*, 2021a). However, not all the damage to agricultural products and the environment is necessarily a consequence of the prevalence of drought alone in the study LZs. The Northwestern Escarpment of the Ethiopian Rift Valley is among the centuries of relentless exploitation of the land that has resulted in severe environmental alterations and destructions (Gidey *et al.*, 2017). Consequently, the change affected the livelihood system and disrupted the local ecosystems of the study area.

Since prehistory, humans have been altering land cover by clearing patches of land for agriculture and pastures (Angessa *et al.*, 2019; Degife *et al.*, 2018; Gollnow *et al.*, 2018; Awoke *et al.*, 2014; Awange & Kyalo, 2013; Richards & Remot, 2012). However, during the last three centuries, the global human population has increased dramatically, and people's activities have become essential in global change processes (Dibaba *et al.*, 2020; Das & Sarkar, 2019; Frankl *et al.*, 2014). Human activities on land have grown enormously, altering entire landscapes, nutrients, hydrological cycles, and the climate system (Balabathina *et al.*, 2020; Betru *et al.*, 2019; Degife *et al.*, 2018). The change in land use profoundly impacts food security and increases human vulnerability worldwide (Chirwa *et al.*, 2015). LULC change consequences long-lasting effects on the livelihood systems of the community that depend on rain-fed systems and their essentials (Albert *et al.*, 2020; Deribew & Dalacho, 2019; García-Llamas *et al.*, 2019; Slegers & Stroosnijder, 2008). Land use and land cover changes are local and location-specific, occurring in ways that often escape our attention (Balabathina *et al.*, 2020; Betru *et al.*, 2019; Degife *et al.*, 2018; Selassie, 2015; Minale, 2013).

Due to LULC change in Ethiopia, the long-term biological productivity of the country was seriously affected (Balabathina *et al*., 2020; Kidane *et al*., 2019; Alemu *et al*., 2015; Masih *et al*., 2014). Centuries of land exploitation vastly reduced the productive capacity and diminished the ability of the land to withstand climatic anomalies (Balabathina *et al.*, 2020; Emiru *et al.*, 2018; Meshesha *et al.*, 2014). The northern provinces of Ethiopia are areas where sedentary agriculture has been practiced for thousands of years (Andargie, 2014). Notably, the northwestern escarpment of the Ethiopian Rift Valley is among the most drought-vulnerable (Nasir *et al*., 2021a), and centuries of relentless exploitation of the land have resulted in severe environmental alterations and destructions (Gidey *et al.*, 2017a). The expansion of croplands (both large and small-scale farms) in parts of the northwestern escarpment of the Ethiopian Rift Valley (RVLZ) comes at the expense of natural vegetation and grasslands. Due to this conversion of natural areas to farmland, the communities suffer from a shortage of grazing land, access to raw materials, fuelwood, and a lack of free space. This conversion will again have an impact on groundwater. Furthermore, it can induce and aggravate climate extreme events such as droughts.

Therefore, if drought and LULC change have a significant impact independently, their combined effect is greater on the livelihoods system (Chirwa *et al.*, 2015) in the hotspot areas for drought and LULC changes. Frequent drought occurrences lead to an increased LULC change incidence with a reverse feedback system (Slegers & Stroosnijder, 2008). Frequent drought events can trigger land degradation and desertification (Agidew & Singh, 2017; Chirwa *et al.*, 2015; Tsue *et al.*, 2014; Vicente-serrano, 2007) and, in addition, land degradation exacerbates vulnerability to drought (Reichhuber *et al.*, 2019; Sahoo *et al.*, 2017). Combined impacts of climate change and LULC changes, according to Dosdogru *et al.* (2020), will result in more frequent and severe drought occurrences for hostages. These stresses and exogenous factors can further double exposure and impact livelihood systems and ecosystem services of the local communities (Bunce et al., 2010). The effects resulting from the interaction of LULC change and drought are not a simple sum of each impact, but it has potent effects when both are considered (Dosdogru *et al.*, 2020; Soini, 2006).

The results of the drought effect accompanied by the change in LULC have historically been the main challenge to food security in Ethiopia (Berhe, 2011). The drought that caused the 1984-1985 famine in Ethiopia was rooted in human abuse of the environment (Andargie, 2014). The LULC change and drought trends in Ethiopia imply other hazards that are likely to have much more significant influences on the livelihood system of the community (Betru *et al.*, 2019; Agidew & Singh, 2017). The nature of drought and LULC change impacts are long-lasting or irreversible, although we can mitigate them by implementing climate mitigation strategies and adequate adaptation options (Djalante, 2019; IPCC, 2007a). The scientific evidence of vulnerability level of drought and LULC change in livelihood system is important for effective and proactive drought management and sustainable land use system in Ethiopia (Reichhuber *et al.*, 2019), particularly for the study of livelihood zones (Nasir et al., 2021b).

Vulnerability is conceptualized differently by scholars (Khan *et al.*, 2020). Vulnerability includes biophysical and socioeconomic factors coupled with human-environment interaction systems (Balaganesh *et al*., 2020; Frazier *et al.*, 2014). According to IPCC (2007a), vulnerability is the degree to which these systems are susceptible to and unable to cope with adverse impacts. It is a function of exposure, sensitivity, and adaptive capacity (Xu *et al*., 2020; Tsue *et al.*, 2014), though exposure[1], sensitivity[2], and adaptive capacity[3] are not mutually exclusive (Omerkhil *et al.*, 2020; Shah *et al.*, 2013). The term vulnerability for the current study is referring the characteristics of a livelihood zone system that makes it susceptible to suffering the consequences of climate variability, drought, and LULC changes. If the people's capacity to adapt to change remains unchanged, increased exposure will lead to increased vulnerability (Simane *et al.*, 2016; Turner *et al*., 2003).

The risks and adverse consequences of extreme events like drought and precipitation deficits depend on the locations of the area, level of vulnerability, adaptation, and mitigation measures taken by the local communities (Djalante, 2019). Updated climate variability information for exposure, the local community's socioeconomic conditions, and their vulnerability level is needed to predict the drought risks (Elum *et al.*, 2017; Enenkel *et al.*, 2020). Beyond the climate variability, drought, and LULC change challenges, and small-scale farmers are affected by internal and external factors (Budhathoki & Zander, 2019). Farmers' adaptation decisions may be affected by religious and cultural practices, policies, social networks, the severity of the impacts they perceived, natural and social assets, their wealth, and their geographical locations.

This research has reviewed studies on drought or climate change in developing nations (e.g., Maru et al., 2021b; Adnan & Ullah, 2020; Gupta *et al.*, 2020a; Sharafi *et al.*, 2020; Peng *et al.*, 2018; Zhao *et al.*, 2018; Shah *et al.*, 2013). However, most studies (Dechassa *et al.*, 2020; Abeje *et al.*, 2019; Hill & Porter, 2017; Simane *et al.*, 2016; Shiferaw *et al.*, 2014) applied in Ethiopia used either secondary data or socioeconomic surveys. Since drought vulnerability varies with space and time, it is challenging to study using only secondary data or socioeconomic surveys. Livelihood zones are not demarcated based on administration divisions, but they are an area

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[1] Exposure is the nature and degree to which a system is exposed to hazards (Omerkhil et al. 2020; Shah et al. 2013).

[2] Sensitivity is the ability of systems to be adversely affected by hazard incidences (Balaganesh et al. 2020; Peng et al., 2018; IPCC 2007)

[3] Adaptive capacity is the ability of societal assets to adjust to and cope with the effects of the hazard (Khan et al. 2020; Opiyo et al., 2014; Peng et al. 2018).

that is combined based on their geographic similarity and demography patterns (Zone & Teshale, 2019). Therefore, livelihood zones are areas within which households share broadly similar livelihood patterns, including options for income sources and market opportunities (Pricope *et al.*, 2013). Since the perception levels, the decision of individuals, and the communities are affected by socioeconomic, geographical locations, and technological inputs, livelihood zones are fundamental to including these parameters as an umbrella. Studying livelihood system drought vulnerability at the livelihood zone level is essential to cluster the exposure and susceptibility inductors to intervene with appropriative adaptation strategies to all community's livelihood systems. Mekonen & Berlie (2021) stated that livelihood-based adaption interventions are essential to reduce agricultural vulnerability to climate changes. Therefore, the current study uses socioeconomic survey, meteorological data, and LULC change trends using Landsat images to find the actual level of spatial and temporal drought vulnerability patterns to use as an input for policymakers and adaptation measures in livelihood zone levels.

Niehof and Price (2001) described livelihood as "systems (livelihood systems) that are wholly dependent on agriculture, linked agriculture, or non-linked agriculture." Livelihoods encompass different kinds of livelihood systems (Niehof, 2004). For example, in drylands, agroecosystems are composed of a complex mix of pastoral, agro-pastoral, rain-fed, and irrigated farming methods (Ginkel *et al.*, 2013). Therefore, since this study used the concept of a sustainable livelihood development framework, the author used the three main components of livelihoods (assets, activities, and access to these assets) to analyze the vulnerability to the drought of the livelihood zones of the study.

The livelihoods of the study communities are mainly dependent on mixed crop-livestock systems. As a result, based on the mixed crop-livestock methods of the livelihood zones, the author established the components of drought vulnerability to livelihood systems (Table 5.2). Studying drought vulnerability using integrated data is not questionable in applying low-risk and long-term plans to build sustainable livelihood systems that can withstand the negative consequences (Murthy *et al., 2015*). It can strengthen the resilience of communities and conserve and sustainably use their natural resources. It will help for interventions in climate resiliencies agriculture systems; and sustainable ecosystem services. Further, it will provide insights to incorporate integrated management for drought and LULC change on livelihood rather than taking measures independently. It can also be an input for scientific information and a baseline for further synergetic studies of the drought and LULC changes on livelihoods.

5.2. Data Sets and Methodology

5.2.1. Data Types and Sources

This study uses three categories of data to explore drought vulnerability at livelihood zone levels. These are meteorological data, Landsat images and ground truth points, and socioeconomic data (generated from survey questionnaires, focus group discussions, and key-informant interviews).

Meteorological Data

Both the monthly Climate Hazards Group InfraRed Rainfall with Station data (CHIRPS) and Enhancing National Climate Service (ENACTS) maximum (Tmax) and minimum (Tmin) temperatures data (1983–2016) were used at moderate spatial resolution (4km–by–4km) to analyze the vulnerability to drought frequency, drought intensity, temperature trends, rainfall trends, and rainfall variability. Before 1983, there was no grid data; after 2016, it is under process in the National Meteorological Agency of Ethiopia. As a result, the author employed gridded meteorological data from 1983 to 2016. The obtained data sets were free of missing values to compute the meteorological variables (temperature and rainfall).

Satellite Data

Multi-disciplinary analyses are required to analyze LULC change-induced ecosystem disturbance (Chirwa et al., 2015). Therefore, this study surveyed the extent and trend of land use changes over the last four decades through quantitative (Landsat images) and ancillary (qualitative) data. For studying the LULC dynamics of the study area, satellite images were downloaded (1985 and 2019) from the United States Geological Survey (USGS) (https://earthexplorer.usgs.gov/). The detailed descriptions of the two satellite images are present in Table 5.1. For supporting image classification and accuracy analysis, 900 Ground Truth Points (GTP) were acquired through fields using Global Positioning Systems (GPS) in 2019.

Table 5.1 Summary of Satellite data used to produce LULC change maps and detections in the three LZs

Sensor	Path-Row	Date	NB	SR	SA	SE
L5 TM	168-051	01-02-1985	1,2,3,4,5,6	15m x 15m	137.42	41.40
	168-052	01-02-1985			136.35	42.31
	169-051	12-11-1985			139.37	42.70
L8OLI/TIRS	168-051	01-16-2019	2,3,4,5,6,7,8	15m x 15m	141.21	46.63
	168-052	01-16-2019			140.00	47.61
	169-051	02-08-2019			133.86	50.15

L5 = Landsat5 Thematic Mapper, L8 OLI/TIRS = Landsat8 Operational Land Imager and Thermal Infrared Sensor, NB= Number of Bands; SR= Spatial Resolution, SA= Sun-Azimuth, SE= Sun-Elevation

Data from Household Survey, Focus Group Discussion, and Key Informant interview

For qualitative data collection, the author used multistage sampling methods. Household data was collected from April to July 2020 in the three study livelihood zones. Since three livelihood zones were drought-prone areas, a purposive sampling method was applied to select the study LZs. In addition, among the three livelihood zones, eight kebele (small administrative units) were chosen randomly. Depending on the 2020 population number of the sampled kebeles, 387 household heads for ALOFLZ (n=109), TCLZ (n=121), and RVLZ (n=157) were selected using simple random sampling methods for semi-structured interviews. Depending on the household number proportions, two kebele from ALOFLZ and three for each TCLZ and RVLZ were selected. The author calculated the sampling households using the (Cochran, 1977) formula with maximum variability of 50% (p=0.5) and a 95% confidence level with ±5% precision. The following is the formula for calculating the required sample size:

$$\mathrm{n_0} = \frac{\mathrm{Z^2pq}}{e^2} \qquad 5.1$$

Where $\mathrm{n_0}$ is the sample size, Z is the selected critical value of desired confidence level, p is the estimated proportion of an attribute present in the population, $\mathrm{q} = 1 - \mathrm{q}$ =1-p, and e is the desired level of precision.

The following proportional formal is used to determine the sample size distribution to the total household size for each kebele:

$$\mathrm{n_i} = \mathrm{n} * \frac{\mathrm{N_i}}{\sum \mathrm{N_i}} \qquad 5.2$$

Where $\mathrm{n_i}$ is the sample size of surveyed $\mathrm{i^{th}}$ kebele, n is the sample size of $\mathrm{i^{th}}$ kebele, and N is the total household number of $\mathrm{i^{th}}$ kebele.

The author holds FGD in four groups of 12 participants for each of the eight sample kebeles. Data collection in these discussions was mainly qualitative. The participants were diverse in age, gender, occupation, religious leaders, experts, and livelihood zones heterogeneities. Twenty-four extension workers participated in key informant interviews on thematic topics of the crop, livestock, natural resources, land use, early warning, and food security. The study conducted field observations to assess the characteristics of the LZs and examine the people's livelihood systems.

The questionnaire for household, key-informant interview, and FGD were prepared and pretested to verify their responses on drought vulnerability. The study checked and deleted the repeated questionnaires after the pilot tests. Eight trained enumerators administrated the survey from each sampled kebeles. During the survey, households, FGD, and key informants asked about drought occurrence, frequencies, and severity based on rainfall duration and productivity contexts. They also asked about rainfall patterns (frequencies, intensity, spatial coverage, onset, and termination) and temperature trends. Households, focus groups, and key informants were also requested to share their perspectives on LULC change patterns, drivers, severity, and impacts in their communities during the last four decades. They also asked about livelihood strategies and agricultural package accessibility in their respective LZs (Table 5.2).

5.2.2. Data Processing, Analysis, and Interpretation

Mann Kendall Trend (MKT) for Seasonal and Annual Precipitation and Temperatures

Mann Kendall trend statistical test was applied to analyze the seasonal (Belg and Kiremt) and annual climate variability trends of the study LZs over the study years (1983-2016). Mann Kendall trend is low sensitivity to abrupt breaks due to inhomogeneous time series (Mohammad & Goswami, 2019; Vu *et al.*, 2018; Tabari *et al.*, 2011). It is applied to perceive statistically significant decreasing or increasing daily, monthly, seasonal, and annual climate variability trends (minimum temperature, maximum temperature, and precipitation) (Shawul, 2020; Lakshmi & Vani, 2019; Asfaw *et al.,* 2018; Hamed, 2009). There is a direct relationship between seasonal and annual Tmin and Tmax trends and drought exposures. But increasing precipitation trends have inverse relationships with exposures to drought vulnerabilities (Zhao *et al*., 2018).

Coefficient of Variations for Seasonal and Annual Precipitations

Coefficient of variation (CV) is countenance acquired through converting the standard deviation (SD) to a % of the mean (Koech *et al.,* 2019; Fitto *et al.*, 2017). Coefficient variation is applied to calculate temporal and spatial rainfall variability trends at seasonal or annual time scales. High rainfall variation has a positive functional relationship with drought exposures (Murthy *et al*. 2015) that aggravates drought vulnerabilities at LZ levels. So, in this study, I used CV to reveal seasonal (Belg and Kiremt) and annual rainfall variability at LZ and Grid levels of the study areas.

The Standardized Precipitation Evapotranspiration Index (SPEI)

The Standardized Precipitation Evapotranspiration Index (SPEI), one of the leading meteorological drought indices, was applied to analyze the condition of drought incidence at three months (seasonal) and annual time scale in the study area. Inputs required to calculate the SPEI program are precipitation and Potential Evapotranspiration (PET). So that, to run the PET of this study, depending on the availability of the maximum and minimum temperatures, precipitations, longitude, and latitude data, the Hargreaves (Hg) equation was used in R packages.

$$\mathrm{SPEI} = \mathrm{P} - \mathrm{PET} \tag{5.3}$$

P is monthly average rainfall, and PET is monthly- Potential Evapotranspiration.

As the frequencies and severity of drought increase, the vulnerability of the local community increases for coming drought events. Therefore, the longer the frequency of occurrence, the less exposure to drought vulnerability. But as the drought severity increases, the exposure to drought vulnerability is also higher.

Change Detection and Analysis

All image processing, classification, and change detection were applied using ERDAS Imagine 2015, while the LULC change was analyzed using ArcGIS 10.8. A pixel-based image mosaic algorithm was applied to have a wider field of view. Besides, the Universal Transverse Mercator (UTM) Adindan Zone 37 was used to correct geometric errors. A supervised pixel-based classification with the maximum likelihood technique was used to create signatures and map LULC classes using ground truths data (training areas). To ascertain whether there have been changes in LULC in the study area, the author classified images between 1985 and 2019. Bare land (BL), Built-up area (BA), Cultivation-land (CL), Flood Plain (FP), Forest land (FL), Grassland (GL), Shrub and Bushland (SBL), Waterbody (WB), and Wetland (WL) LULC types were analyses to discover ecosystem disturbance of the study LZs. The computed magnitude of Change (MC), percentage of change (PC), and annual rate change (ARC) for each land-use type and each successive study period were implemented using change detection analysis (Equation 5.4-5.7).

$$\mathrm{MC} = \text{Area of the final year} - \text{area of the initial year} \tag{5.4}$$

$$\text{PC} = \frac{\text{Area of the final year} - \text{area of the initial year}}{\text{Area of the initial year}} \times 100 \qquad 5.5$$

$$\text{ARC}(\text{Km}^2\,.\,\text{year}^{-1}) = \frac{\text{Area of the final year} - \text{area of the initial year}}{\text{Number of the year of a period}} \times 100 \qquad 5.6$$

$$\text{ARC}(\,\%) = \frac{\text{Area of the final year} - \text{area of the initial year}}{\text{Area of the year initial X Number of the year of the period}} \times 100 \qquad 5.7$$

Analysis of socioeconomic data

Using SPSS version 26, perception of the local community was analyzed using frequency analysis giving proportion and chi-square tests giving associations. Thematic analysis was used for key-informant interviews and focus group discussion analysis.

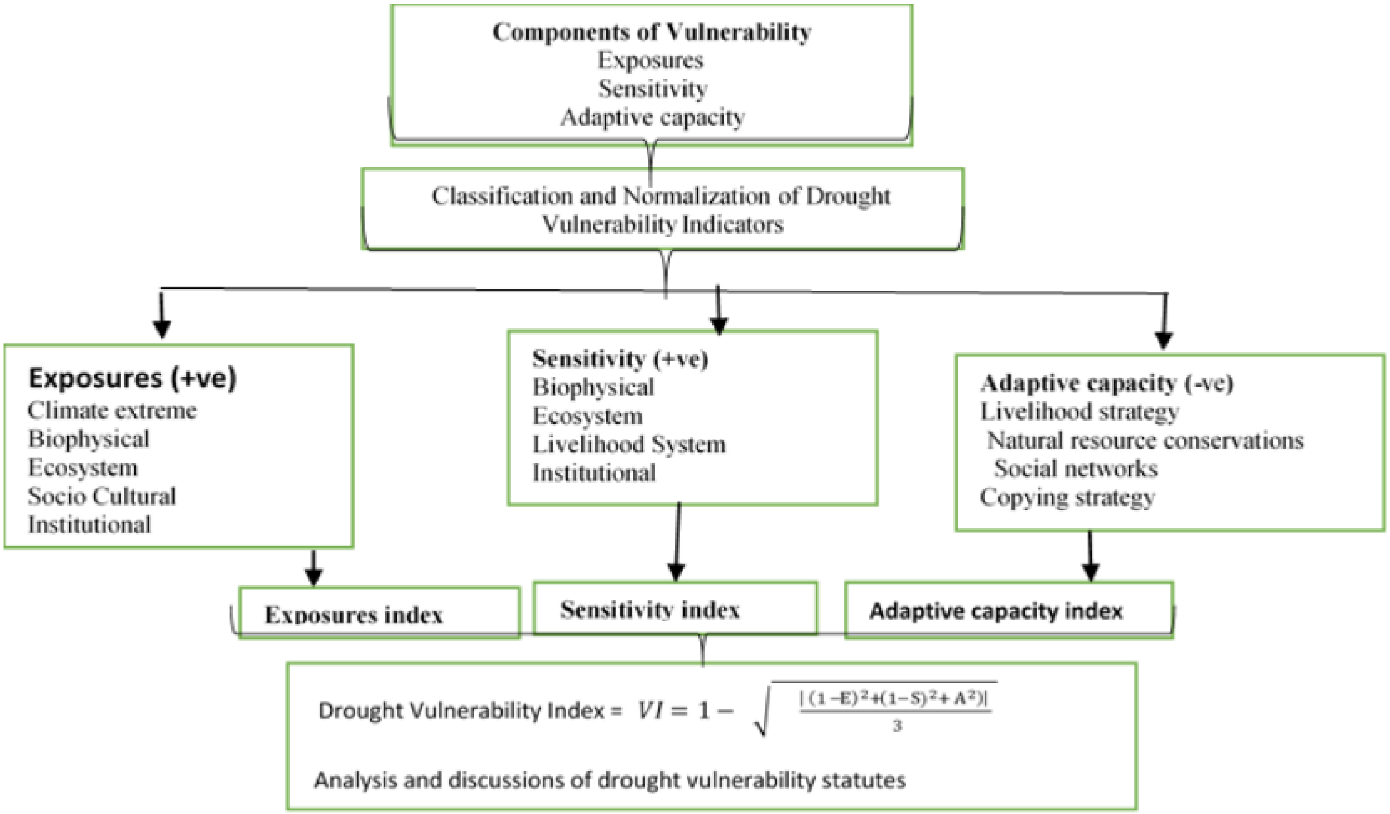


Figure 5.1. The methodological framework of drought vulnerability assessment across the study of livelihood

Table 5.2 Descriptions of drought vulnerability indicators, sub-indicators, and variables

Indicators	Sub indicators	Variable	VRD VI	Variable Descriptions /Units
Exposures	Climate extreme exposure	Rainfall trends	-	Belg, Kiremt, and annual rainfall trends(mm) using Mann-Kendall trend tests
		Coefficient of Rainfall variations (CV)	+	Belg, Kiremt, and annual rainfall variations (%) using Coefficient of Rainfall variations (CV) tests
		Temperature trends	+	Belg, Kiremt, and annual temperature (maximum and minimum) trends(⁰C) using Mann-Kendall trend
	Biophysical exposure	Drought frequencies	-	Belg, Kiremt, and annual drought frequencies using SPEI values (the extended frequencies have less vulnerability)
		Drought severity	+	Belg, Kiremt, and annual increasing drought severity using SPEI values
		Increasing disease emergences (for humans, livestock, and crops)	+	Households who perceived increasing disease emergences (%)
		Increasing emergences herbs	+	Households who perceived increasing emergences herbs (%)
	Ecosystem exposures	Shifting the LULC classes	+	Shifting the LULC classes (%) from 1985 to 2019 Using GIS and Landsat images, and Ground surveys
	Socio-Cultural Exposures	Poor saving habits	+	Households who perceived poor saving habits (%)
		Expenses for a cultural ceremony	+	Households who perceived there are high expenses for the cultural ceremony (%)
		Expenses for a religious ceremony	+	Households who perceived there are high expenses for a religious ceremony (%)
	Institutional exposures	Lack of early warning system	+	Households who perceived there is a Lack of enough access to agricultural technologies (%)
		Lack of enough access to agricultural technologies	+	Households who perceived there is a Lack of enough access to agricultural technologies (%)
		Does not involved in development activities	+	Lack of enough access to agricultural technologies
Sensitivity	Climate Variability Sensitivity	Erratic rainfall trends	+	Households who were perceived not involved in development activities (%)
		Increasing temperature trends	+	Households who perceived there are increasing temperature trends (%)
		Declining rainfall coverage in the rainy season	-	Households who perceived declining rainfall coverage in the rainy season (%)
		Late-onset and early termination of rainfall in rainy seasons	+	Households who perceived late-onset and early termination of rainfall in rainy seasons (%)
		Rain feed farm	+	Households who demand rain feed farm (%)
	Ecosystem sensitivity	Fast natural vegetation conversions	+	Households who perceived there are fast natural vegetation conversions (%)
		Fast land degradation	+	Households who perceived there is fast land degradation (%)
		Water stress	+	Households who perceived there is fast land degradation (%)
		High reduction in crop productivity	+	Households who perceived there is high Water stress (%)
	Livelihood System	Frequencies of erratic rainfall	+	Households who perceived there are high frequencies of erratic rainfall (%)
		Food insecurity situations	+	Households who perceived they are in food insecurity situations (%)

		Have not modernized fuel sources	+	Households who perceived they have not modernized fuel sources (%)
	Institutional sensitivity	Lack of training to improve production efficiencies	+	Households who perceived there is a lack of training to improve production efficiencies (%)
		Lack of appropriate market network and information	+	Households who perceived they have a lack of appropriate market network and information (%)
		Lack of sufficient services in livestock sectors	+	Households who perceived they have a lack of sufficient services in livestock sectors (%)
Adaptive capacity	Livelihood strategy	Practicing diversifications and coping strategies	-	Households practicing diversifications and coping strategies (%)
		Intensive cropping management	-	Households practicing intensive cropping management (%)
		Applying fertilizer and compost or manure	-	Households applying fertilizer and compost or manure (%)
		Planting moisture stress or early maturing crop	-	Households planting moisture stress or early maturing crops (%)
		Applying chemicals for pests and Herbs	-	Households applying chemicals for pests and Herbs (%)
		Using of tractor for plow	-	Households using tractors for plowing (%)
		Shifting to high-value crops or value additions	-	Households shifting to high-value crops or value additions (%)
		Using improved livestock bread and technology	-	Households using improved livestock bread and technology (%)
		Practicing fattening (sheep, goat, ox)	-	Households practicing fattening (sheep, goat, ox) (%)
		Livestock forage management	-	Households practicing forage management (%)
	Natural resource conservations	Physical soil and water conservation practices	-	Households applying physical soil and water conservation practices (%)
		Practicing to increase soil fertility	-	Households practicing increasing soil fertility (%)
	Social networks	Participating in community organization	-	Households participating in community organization (%)
		Community's financial saving system "Ekub."	-	Households participating in "Equb" (%)
		Christian community's monthly gathering events ("Mahber."	-	Households participating in "Mahber" (%)
		Community administration system "Eddir."	-	Households participating in "Eddir" (%)
		Islamic finance system that obligated individuals ("Zakat")	-	Households participating in "Zeka" (%)
		Labor-sharing on-farm activities	-	Households participating in labor-sharing on-farm activities (%)
	Coping strategy	Destocking during drought years	-	Households destocking during drought years (%)
		Migration to the nearby area	-	Households migrating to nearby areas during drought time (%)
		Consuming fewer cost foods	-	Households consuming fewer cost foods during drought time (%)
		Borrowing from each other and money lenders	-	Households borrowing from each other and money lenders during drought (%)
		Selling utensils and natural resources	-	Households selling utensils and natural resources during drought time (%)

VRDVI= Variables Relationship with Drought Vulnerability Indexes

Indicator Selection

To measure drought sensitivity, biophysical and socioeconomic indicators were gathered from Scopus-indexed journal papers and personal experiences for each drought vulnerability dimension (exposure, susceptibility, and adaptive capacity) (Gupta *et al.,* 2020b; Omerkhil *et al.*, 2020; Murthy *et al.*, 2015; Shah *et al.*, 2013). A total of 128 indicators were selected (39 exposure, 34 for sensitivity, and 54 for adaptive capacity) depending on the dimensions of drought vulnerability. Besides, these indicators comprised 52(14 for exposure, 15 for sensitivity, and 23 for adaptive capacity) sub-major components depending on their association with exposure, sensitivity, and adaptive capacity. In addition, those 52 sub-component indicators aggregated into 13 major sub-components representing the three dimensions of drought vulnerability (5 for exposure, 4 for sensitivity, and 4 for adaptive capacity) (Table 5.2). Each indictor was normalized as proxy indicators to calculate an exposure index, sensitivity index, and adaptive capacity index for computing the drought vulnerability index (DVI). Each selected notice is normalized with the following formula (Balaganesh *et al*., 2020; Singh, 2020; Xu *et al*., 2020; Zhao *et al*., 2018 Simane *et al*., 2016;):

$$\text{Normalization } = \frac{\text{Actual value} - \text{Minimum value}}{\text{Maximum value} - \text{Minimum value}} \qquad 5.8$$

The drought Vulnerability dimensions have a positive functional relationship with their associated variables. On the other hand, if a negative functional relationship occurs, the following equation has been used for normalization.

$$\text{Normalization } = \frac{\text{Maximum value} - \text{ Actual value}}{\text{Maximum value} - \text{Minimum value}} \qquad 5.9$$

After normalizing the indictors, allocating index weight is the next step for vulnerability assessments (Xu *et al.*, 2020). There are many methods to determine the index weight that can divide into three major parts: subjective (e.g., Expert grading method), objective (e.g., Principal component weighting method), and other combined (e.g., Pareto ranking method) weighting methods (Xu *et al.*, 2020; Zhao *et al.,* 2018). However, each method has limitations in determining the indicator weights. The subjective weighting method is vulnerable to overestimation or underestimation (Zhao *et al.*, 2018). The objective evaluation method is performed based on the original data to evaluate the weights of the indicators. However, it does not deliberate the subjective intention of the experts (Xu *et al.*, 2020). For example, the principal component weighting method removed parts of the information during electing components that may affect the weighted indicators ((Zhao *et al.*, 2018).

Despite these constraints, several researchers have recently used an indicator-based strategy to develop a livelihood vulnerability index in various contexts. As a result, the author used an indicator-based method (weighting methods) in this study. The study's indicators are essential in generating the drought vulnerability index for the studied livelihood zones. The objective weighting (index-based methods) approach calculates the index's weight based on the data provided by the observation value of each indicator used by researchers (Omerkhil *et al.*, 2020; Zhao *et al.*, 2018; Shah *et al.*, 2013). The weighted sum of all the evaluated indications for each measurement forms the index for the three dimensions of vulnerability (exposure, sensitivity, and adaptive capacity). After normalization of each indicator, Exposure, Sensitive, and Adaptive Capacity are computed separately from their receptive variables along with their corresponding calculated weights using the following formula (Balaganesh *et al.*, 2020; Reis *et al.*, 2020; Gupta *et al.*, 2019; Murthy *et al.*, 2015):

$$\text{Exposure index (E)} = \frac{\text{CE} + \text{BE} + \text{EE} + \text{SCE} + \text{IE}}{5} \qquad 5.10$$

$$\text{Sensitivity index (S)} = \frac{\text{CVS} + \text{ES} + \text{LSS} + \text{IS}}{4} \qquad 5.11$$

$$\text{Adaptive capacity index (A} = \frac{\text{LSAC} + \text{NRCAC} + \text{SNAC} + \text{CSAC}}{4} \qquad 5.12$$

CE=Climate extreme exposure, BE= Biophysical exposure, EE=Ecosystem exposures, SCE= Socio-Cultural Exposures, IE= Institutional exposures, CVS=Climate Variability Sensitivity, ES=Ecosystem sensitivity, LSS=Livelihood System, IS=Institutional sensitivity, LSAC=Livelihood strategy adaptive capacity, NRCAC =Natural resource conservations adaptive capacity, SNAC =Social networks' adaptive capacity, CSAC =Coping strategy adaptive capacity

The drought vulnerability of the current study was derived based on the displaced ideal methods. Drought vulnerability estimation considered the dispersion of exposure, sensitivity, and adaptive capacity index that focused on the dispersion property of the indictors and stated that a better system should have less distance from the ideal (Singh, 2020). Following (Gupta *et al.*, 2020a; Singh, 2020), the study measured the distance between the displaced-ideal methods through the Euclidean distances. The Euclidean distance between the ideal and the study system for exposure (E) and sensitivity (S) were $(1\text{-E})^2$ and $(1\text{-S})^2$, respectively. However the distance between the ideal and study system for adaptive capacity(A) was $(A)^2$ (Gupta *et al.*, 2020a), as the adaptive capacity of the most vulnerable system would be zero (Peng *et al.*, 2018). The DVI of this study is estimated by considering the departure of the study system from the most vulnerable state (i.e., the ideal state) flowing (Gupta *et al.*, 2020a; Xu *et al.*, 2020; Zhao *et al.*, 2018):

$$\mathrm{VI} = 1 - \sqrt{\frac{|(1-\mathrm{E})^2 + (1-\mathrm{S})^2 + \mathrm{A}^2)|}{3}} \qquad 5.13$$

Where E, S, and A are the weights of the dimensions, i.e., exposure, sensitivity, and adaptive capacity.

5.3. Results and Discussions

5.3.1. Exposures

The results of the exposure index of the current study uncovered higher values of 0.70 in RVLZ, 0.61 in ALOFLZ, and 0.62 in TCLZ, which shows that the community's livelihood systems in all study LZs are exposed to drought and its linked impacts. This finding coincides with Peng *et al.* (2018)). They reveal that rural households in China's Gorges Reservoir area are highly vulnerable to high exposure. The finding further revealed that the exposure index in RVLZ has relatively higher exposure to drought risks than ALOFLZ and TCLZ (Figure 5.2). The exposure indicators, divided into five sub-indicators, refer to climate, biophysical, ecosystem, socio-cultural, and institutional exposures. The index values of these sub-indicators in RVLZ show that the community has higher exposure to institutional limitation (0.99), followed by biophysical risks (0.77), ecosystem disruption (0.72), and socio-cultural effects (0.55), and climate variability trends (0.45). However, ALOFLZ has higher exposure to biophysical (0.83), followed by socio-cultural (0.78), ecosystem disrupts (0.53), climate variability events (0.52), and institutional limitations (0.41). Similarly, TCLZ has higher exposure to biophysical (0.83), followed by socio-cultural (0.79), climate (0.50), institutional limitations (0.50), and ecosystem (0.48).

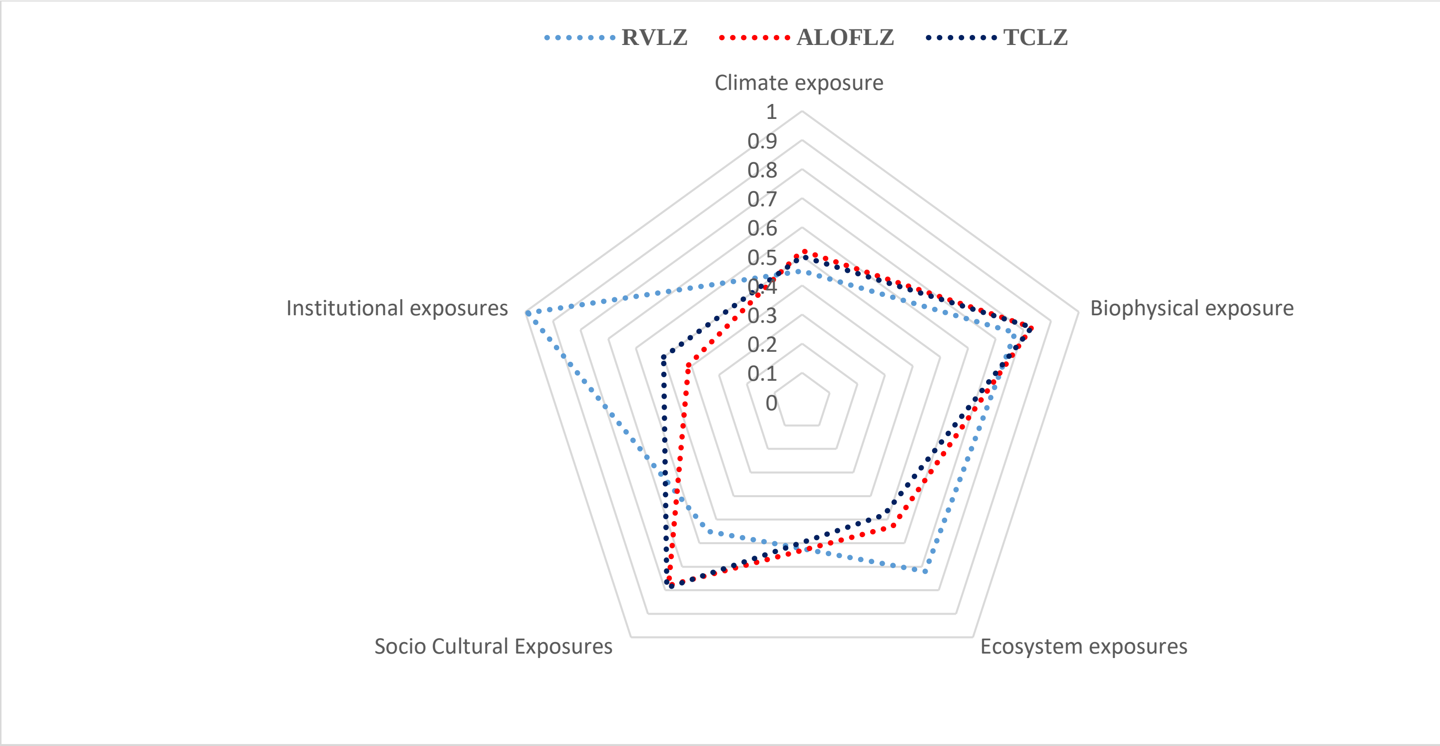


Figure 5.2. Radar diagram showing exposure sub-indicators across the study livelihood zones

Climate exposure

The composed sub-indicator results of the climate exposure index for RVLZ, ALFOLZ, and TCLZ were 0.45, 0.52, and 0.50, respectively. This finding coincided with the Mekonen & Berlie (2021)findings. They reported that the highest exposures to livelihood zones to vulnerability were found during the Belg and Meher seasons. The ALOFLZ was more exposed to seasonal and annual climate variability trends, followed by TCLZ and RVLZ (Table 5.3). The current results also coincide with (Gupta *et al.*, 2020a; Singh, 2020) findings that reported rapid climate variability trends observed in their study area that can consequence drought risks for local farmers and their environments. The MKT test result shows that annual Tmin was rising (0.31, 0.30, and 0.27 ºC) combined with higher rainfall variability (34, 35, and 32%) in ALOFLZ, TCLZ, and RVZL, respectively. Similarly, receptively, annual Tmax increases by 0.32 and 0.42 ºC in TCLZ and RVLZ. Further, the MKT test result indicates Belg Tmax rising by 0.30, 0.40, and 0.43 ºC with extreme higher rainfall variability (64, 70, and 65%) in ALOFLZ, TCLZ, and RVLZ, respectively. Similarly, there was more significant variability in rainfall in the Kiremt season, which records 46, 43, and 46 % CV in ALOFLZ, TCLZ, and RVLZ, respectively. These combined climate variabilities imply possible drought risks in the future that can affect humans and the environments in all study LZs.

Biophysical exposure

Climate variability and drought frequencies have implications that create a favorable environment for pathogenic growth, pests, insects, and weeds that affects crop, livestock, and human health. The composed sub-indicator of the biophysical exposure index shows higher values of 0.77, 0.83, and 0.83 in RVLZ, ALOFLZ, and TCLZ, respectively. These values indicated that all LZs are higher exposures to biophysical events over the study years. Over the study years, the author detected recurrent Kiremt drought with 2.8, 2.5, and 2 intervals in RVZL, ALOFLZ, and TCLZ. These results show higher drought frequencies in ALOFLZ and TCLZ, but the severity is extreme in RVLZ. Similarly, drought in the annual timescale revisits with an interval of 2.14, 1.86, and 2.1 in RVZL, ALOFLZ, and TCLZ, respectively. This result is sported by finding the household survey, FGD, and KII of the study LZ. According to early warning experts from RVLZ and TCLZ, drought is chronic and severe in their LZs. It is defined interims of rain coverage, internist's, frequencies, onset and offset of the normal is devoid and affects the crop production and forage sources. According to the early warning expert, every year, from 60% to 70% total population of RVLZ is affected by drought. Human and animal disease exposure was higher in ALOFLZ (1.00) and TCLZ (0.98) than in RVLZ (0.72) (Table 5.3).

Omerkhil *et al.* (2020) reported a high frequency of pests and disease outbreaks, and more erratic rainfall and higher temperature were the main risks in their study area. The current finding coincided with Khan et al. (2020) and Singh's (2020) studies. They reported that farmers' livelihood systems are highly exposed to biological hazards in their study areas. Incidences of new herbs are observed in all LZs each year. According to crop experts, in all study LZs, crop production is more affected by herbs and diseases than before. Communities use insect and herb sides, but the crop is affected by new pathogens, insects, and herpes every year. The nature, types, and emergence time of pathogens, insects, and herpes continually changed. The new herbs did not affect only crop production but also affected animal forages. Congreso *et al.* (2014) evidenced that loss of biological control can affect pest densities and pollinator services. The fertilizers and compose used for productivity have implications on herbs emergencies. There are some herbs and insects which resist herb sides and insect sides. Some of the crop diseases were selectively attacking a few cereal types. Besides, the herb and insect sides have been affecting cereals, bees, and the quality of honey products. Animals do not consume some herbs, and some affect milk production and the tests.

Ecosystem exposures

Ecosystem exposures of the study LZs were studied using GIS and remote sensing. Consequently, the study classified nine land use and land cover types in study LZ from (1985 to 2019). The overall ecosystem exposures sub-indicator index value shows that RVLZ has higher exposure than the ALOFLZ and TCLZs with 0.72, 0.53, and 0.48 ecosystem exposures indexes, respectively (Table 5.3). As presented in (Figure 5.3), only about 17.72, 28.34, and 23.20% of RVLZ, ALOFLZ, and TCLZ persisted as the initial LULC types over the study years. The study shows that 82.3, 71.7, and 76.8% of RVLZ, ALOFLZ, and TCLZ LULC types changed between classified LULC types. There were no climaxes and stabilization of LULC types within the study years in all LZs. Relatively, ecosystem disturbances are higher in RVLZ than in ALOFLZ and TCLZ. This result coincided with the study of Othow *et al.* (2017). They reported that the conversion of natural vegetation has led to a decline in agricultural yield per plot of land in the Gog District from 1990 to 2017. According to Congreso *et al.* (2014), the loss of biological control impacts pest densities, pollinator services, and environmental deterioration.

Therefore, if there is no climax and stabilized ecosystem, the ecosystem service cannot support natural ecosystem cycles and human needs. Zhang *et al.* (2014) revealed similar reports that the cause of ecological environment problems is rooted in anthropogenic and poor weather conditions in the western regions of Jilin province. A continuously disrupted ecosystem is more exposed to drought hazards that result in local climate system disturbances and affect the agricultural productivity of LZs in the study.

Figure 5.3. Histogram showing ecosystem exposure across the study livelihood zones from 1985 to 2019,

BL= Bare land, BA= Built-up area, CL= Cultivation-land, FP=Flood Plain, FL= Forest land, GL = Grassland, SBL= Shrub, and Bushland, WB = Waterbody, WL= Wetland, CC= Cumulative change, PC= proportional change

Socio-cultural exposures

Culture plays a fundamental role in mitigating and adapting to climate change (Adger *et al*., 2013). Every community has sociocultural practices during events and daily activities to continue their lives and the community's well-being. However, some cultural practices may affect the economy and healthiest of the community. For example, there is an over expense for weddings, funerals, and other cultural events and ceremonies. During production surplus, communities do not save extra resources for contingency time. According to key informants and FGD participants in RVLZ, the community harvested high surplus productions during the good rain seasons that can be enough to meet three years' food needs of the households if they have good saving habits. However, they expend resources on cultural practices like wedding and funeral ceremonies. The socio-cultural exposures index value of the study livelihood zones indicated higher in TCLZ (0.79) and ALOFLZ (0.78) than RVLZ (0.55) (Table 5.3). Therefore**,** further efforts need to build skills and awareness to save surplus production and resources into assets.

Institutional exposures

Strong institutions for early warning systems and relief support during emergencies, such as agricultural technologies, financing availability, and community development engagement, are among the fundamental interventions to help community vulnerability against drought impacts (Omerkhil *et al.,* 2020). This study revealed weak institutional capacity in RVLZ than ALOFLZ and TCLZ, with an index value of 0.99, 0.41, and 0.50, respectively. The sub-index for early warning systems from a household survey of the study livelihood zones indicated high value (0.98) in RVLZ than in ALOFLZ (0.57) and TCLZ (0.45) (Table 5.3). Therefore, RVLZ is higher exposure for lack of early warning to prepare and cop up for drought risks than ALOFZ and TCLZ.

However, according to early warning experts of the study LZs they have seminars and workshops to build their capacity and skills for early warning systems from the regional government. They have an emergency program to respond to natural and human-induced hazards. For instance, during drought 2015/6, molasses, straw, water, and reused from industry were provided by the government, humanitarians, and community care collaging for livestock in RVLZ and TCLZ. However, it needs sustainable works to reduce and eradicate poverties levels in the communities beyond this. There is a limitation on emergency responses to the transitory food gap because it takes time until the kebeles report gets reactions from the federal government. In addition, there was a lack of access to agricultural technologies and credit access in RVLZ than in the two LZs

(Table 5.3). According to the FGD participants, to get the herb and insect sides from the agricultural offices, they requested to make a group with a minimum of 10 individual members. However, this takes time and bureaucracy.

Further, the credit system does not allow all community members to diversify their income sources. For example, the credit system does not include the Muslim community's access due to religious obligations. According to the FGD view, the credit institutions' credit systems differ between cities and villages depending on the saving proportions. The villages can credit 40% by 60 %, but it is 20% by 80% in cities. So, it needs consideration for village habitants. According to the participants, the interest rate of the credit does not consider the capacity of the communities. Also, there is a limitation on amounts of financial credit. The Relief Society of Tigray (REST) allows only 35000 birr per household, which is very small to accommodate the financial requirements of the market inflation rates. Sertse *et al.* (2021) study in the Raya Azebo district that is part of the current study (RVLZ) showed that "*households face financial constraints (72%), a lack of credit facility (59%), and a lack of information and awareness (46%) as constraints for adaptations*".

However, according to the interview results with food security experts in TCLZ and ALOFLZ, they have three sources for credit accessibility. They have rural society credit associations, credit access from Disc (Dedebit) for poor people, and banks for better-off communities. Through these three credit institutions, communities can credit to fulfill their livelihood needs. According to the key informants, those institutions developed their solutions during drought. They mentioned that there is credit access in-kind and cash, but the return from the community is low. However, according to FGD participants,' there is a system for credits full of bureaucracy. The market network is a big problem in practices, particularly for individuals. There is a problem regarding value chains with agro-processing technology and markets.

On the other hand, there is a safety net payment to subside the farmer to change the livelihood system at 5-year intervals. The safety net program depends on the food gaps and assets of the communities. The program's main objective is to develop the community and conserve the environment. The program is vital to help the ultra-poor and transitory food gap from the shocks. However, there is a lack of performance to achieve the set goals, and there are no safety net experts on the ground. There is a complex process to allot safety net beneficiaries.

During nomination, each safety net beneficiary community has its criteria to nominate. However, during the nomination, there were technical problems. It does not consider households that have above five family numbers. In general, there are four supply and procedural limitations. One challenge is an inclusive error for those who have not targeted groups in the program and an exclusive error for those needed or targeted groups from the program. Second, the beneficiaries are nominated based on the quota system. However, the appropriate procedure for the program is that the beneficiary should be pointed out by the community and then ratified by the kebele community council. The third is that beneficiaries are not committed to work. In addition, the beneficiaries did not save extra capital using the safety net as an opportunity. The fourth problem is a shortage of service providers like transport, computer, and stationery materials.

Further, there is no cooperation among governmental sectors regarding community development. Credit organizations did not work with the program to facilitate on and off-farm activities to sustain the communities. The safety net program does nothing alone to alleviate poverty rather than appreciating dependency. Some FGD participants believed the safety net has disadvantages for communities. They said it increased the dependence syndrome and partiality during nominating beneficiaries. However, they perceived that the safety net program has advantages of conserving nature and building infrastructure, constructing roads, schools, flood diversion, and small dams built with almost free labor.

Nevertheless, when communities reach their graduation schedule, they are not voluntarily leaving the program. Further, there are wage rate problems in the safety net program. One household paid 41 birrs per day (205 per person per month), comparable to other wage rates. In addition, the safety net program payment does not perform in time. Communities paid late after 3 or 4 months. So there should be a system to measure the achievement of the program. Rather than evaluating the work, there should be day-to-day follow-up and monitoring procedures from the beginning (nominating stage) to the end (paying stage). The first issue is that the stakeholder should create community awareness.

Table 5.3 Exposure sub-indicators across their study livelihood zones

Indicators	Sub indicators	Variables for Exposures Measurements	RVLZ		ALOFLZ		TCLZ	
			Variable Indexes	Sub indicator Index	Variable Indexes	Sub indicator Indexes	Variable Index	Sub indicator Indexes
Exposures	Climate exposure	Rainfall trends	0.55	0.45	0.56	0.52	0.55	0.50
		Coefficient of Rainfall variations (CV)	0.37		0.46		0.48	
		Temperature trends	0.44		0.53		0.47	
	Biophysical exposure	Drought frequencies	0.77	0.77	0.72	0.83	0.75	0.83
		Drought severity	0.60		0.58		0.58	
		Increasing disease emergences (for humans, livestock, and crops)	0.72		1.00		0.98	
		Increasing herbs emergences	1.00		1.00		1.00	
	Ecosystem exposures	Shifting the LULC classes	0.72	0.72	0.53	0.53	0.48	0.48
	Socio-Cultural Exposures	Poor saving habits	0.75	0.55	0.95	0.78	0.90	0.79
		Expenses for the cultural ceremony	0.68		0.72		0.66	
		Expenses for a religious ceremony	0.22		0.68		0.79	
	Institutional exposures	Lack of early warning system	0.98	0.99	0.57	0.41	0.45	0.50
		Lack of enough access to agricultural technologies	1		0.33		0.43	
		Does not involved in development activities	1		0.33		0.61	
	Exposures Index at Livelihood Zone Levels			**0.70**		**0.61**	**0.62**	

Note: The author did not use population pressure as a subfactor to examine the exposure of livelihood systems to drought

5.3.2. Sensitivity

The surveyed households were asked about their climate variability sensitivity (decreasing rainfall trends, increasing temperature trends, declining rainfall coverage in the rainy season, disrupting rainfall time, frequencies of erratic rainfall) in their LZs. This study further composed these variables into four sub-indicators under sensitivity components. These under-sensitivity sub-indicators are climate variability, ecosystem, livelihood system, and institutional sensitivity. The computed index record of the sensitivity indicators (0.87 in RVLZ, 0.75 in ALOFLZ, and 0.81 in TCLZ) indicated critical values while considering the higher susceptibility for drought risks in the study livelihood zones. This finding coincides with the study of Peng *et al.* (2018). They revealed that rural households in China's Gorges Reservoir area are highly vulnerable due to high sensitivity. However, communities in ALOFLZ are susceptible in terms of institutional (0.84), followed by livelihood system (0.80), ecosystem sensitivity (0.74), and climate variability (0.63) (Table 5.4). The calculated index value of sub-indicators shows that communities in RVLZ are susceptible in terms of climate variability (0.98), followed by livelihood system (0.85), institutional (0.83), and ecosystem sensitivity (0.82) (Figure 5.4). Similarly, communities in TCLZ are highly susceptible in terms of climate variability (0.87), followed by ecosystem (0.86), livelihood system (0.76), and institutional (0.75).

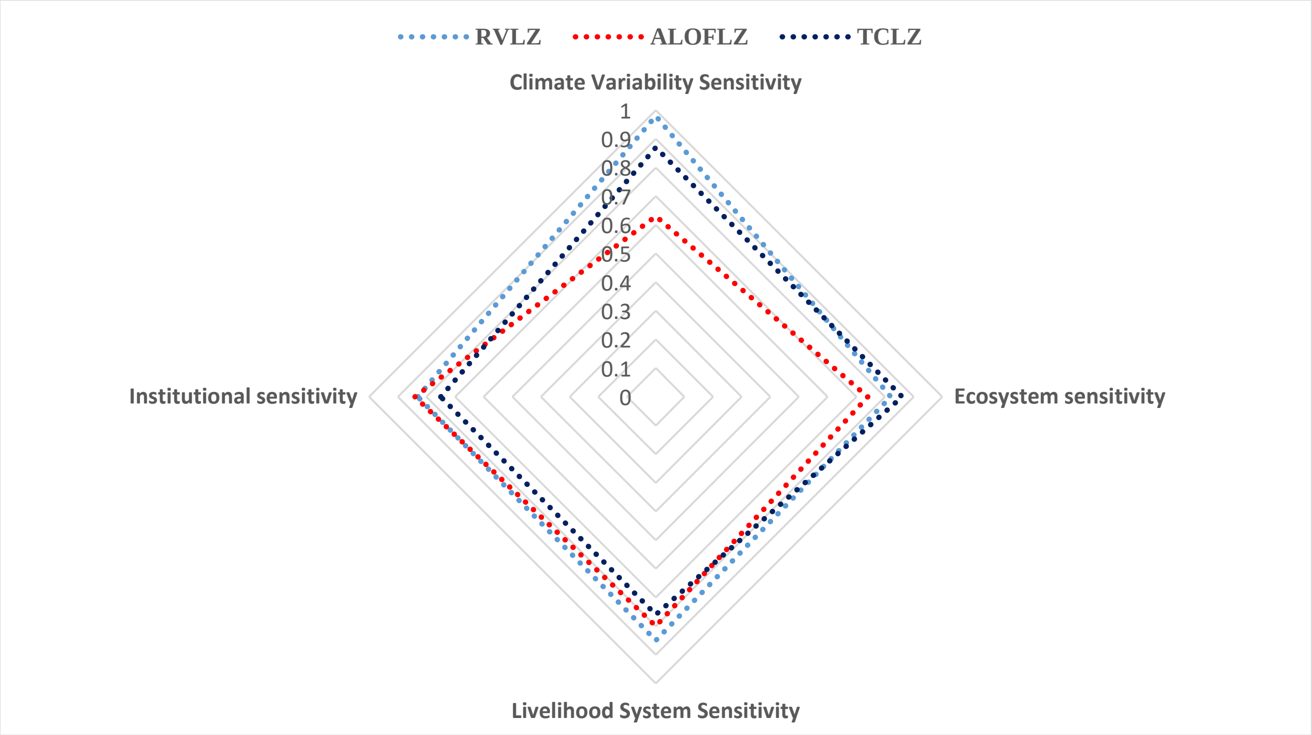


Figure 5.4. Radar diagram showing sensitivity sub-indicators across the study livelihood

Climate Variability Sensitivity

Gupta *et al*. (2020b) and Singh (2020) supported the current findings of rapid climate variability trends observed in their study area that can consequence drought risks for local farmers and their environments. The climate variability sensitivity index indicated that all study LZs are highly susceptible to ecosystem disturbances. RVLZ relatively recorded a high index value (0.98), followed by the TCLZ (0.87) and ALOFLZ (0.63) (Table 5.4). Respondents in the RVLZ, AOLZ, and TLCZ (99.3%, 80.4%, and 82.6%, respectively) thought the temperature in their area was rising. Similarly, Gupta *et al*. (2019) reported that all farmers perceived increasing temperature across their study area. They also argued that distribution, intensity, onset, and the termination of the rainy season are changed. According to the respondents, Belg (spring) rain season started in mid-February and terminated in late May in the past decades. They also explained that the Kiremt rain started in mid-Jun and ended in early September.

However, the rainfall coverage has recently become fragmented, late-onset, early termination, and partially distributed within small-scale areas. Within the past ten years, the Belg rain has come at the end of April, and the Kiremt (summer) rain started at the end of July, particularly in RVLZ and TCLZ. Respondents of the study livelihood zones cognizant that drought increased over time due to erratic rainfall. The results of key informant interviews and focus group discussions from RVLZ indicated that the area is chronic drought occurrences and more vulnerable to its impacts. Since 2001, the drought frequency happened within two or one-year intervals and persisted for two or three years. In the past five years, communities suffered from continuously persistent droughts. The situation was becoming inverses. In the past, drought happened within three years or above intervals, but now, the drought-free years come within three or more years. The food security data of the area indicated that 60% and 70% of people are more vulnerable to drought every year. Before fifteen years, drought was a severe hazard for humans and livestock. But the recent drought occurrences were more severe for livestock than humans. The respondents elaborate that the drought causes are climate change, expansions of desertification from the Afar area, and deforestation.

According to the experts of early warning and food security of ALOFLZ, the severity and the spatial coverage of the drought in the area were higher before twenty years, and it happened within ten-year intervals. For example, the drought years in the area were 1973/4, 1983/4, and 1993/4 years. According to the FGD participants, the drought of 1984 was the most severe in their LZ in the past 35 years. However, since 1995 the spatial intensity coverage of drought has reduced in ALOFLZ. The central parts of this livelihood zone were less vulnerable to drought than all three livelihood zones. The central ALOFLZ had drought occurrences by severe colds “wurch,” marshes, excessive rains, and frosts. In past decades, the crop was hardly affected by “wurch.” However, the rain intensity has decreased, and the temperature is warming over time, and these trends have positive implications for reducing “wurch” effects on productivity. These warming situations favored crop growth and productivity of the livelihood zone.

The FGD participants indicated community has more droughts for livestock than before. Droughts are also a common occurrence in the TCLZ. Frequency, spatial coverage, duration, and rain intensity decrease over time in TCLZ, similar to RVLZ. According to the participants, the range and magnitude of drought in the catchment differed from place to place. The northern parts of the catchment are better than the rest. However, the central and southern parts of the catchment have been affected by mild to severe droughts each year. The years 1965, 1975, 1977, 1980, 2015, and 2016 were severe droughts in the catchments. In 1984, 1989 to 1991, and 2015/6, drought years were severe problems for livestock and humans.

Ecosystem sensitivity

The ecosystem sensitivity index indicated that all study LZs are higher-level sensitive to ecosystem disturbances. TCLZ relatively recorded a high index value (0.86), followed by RVLZ (0.82) and ALOFLZ (0.74) (Table 5.4). The results from key informant interviews and FGD participants of the three LZ shows that they had communal grazing lands, forest area, and area closures in their respective LZs. However, in recent years, their communal area has converted into other LULC types due to anthropogenic and natural factors. The LULC change detection showed rapped land use and land cover shifts in all LZs. CL and SBL changes were fast and fluctuated within and between studies LZs. There are links between SBL reduction and CL expansions due to pressures from the growth of the internal and immigrant population and large and medium agricultural investors in RVLZ. Continually shifting land use and land cover of the study LZs consequence serious water problems, accelerated runoffs, disrupted rainfall patterns, a flow shortage of fuelwood sources and raw materials, shrinkage free space, and grazing lands in all study LZs. This result coincided with the Othow *et al.* (2017) study, which reported that the conversion of natural vegetation has led to a decline in agricultural yield per plot of land.

Livelihood system sensitivity

Communities' livelihood system attributes, in particular, that depend on rain-fed farm activity, food security situations, and fuel sources for household uses are essential in determining the level of susceptibility against drought impacts and related risks. Murthy *et al.* (2015) and Omerkhil *et al*. (2020) revealed that agricultural drought vulnerability, sustainable agriculture challenges, and food security problems are closely related. The livelihood system sensitivity attributes revealed higher score values of 0.85 in RVLZ, 0.80 in ALOFLZ, and 0.76 in TCLZ, showing the communities of the selected livelihood zones are at a high level of drought vulnerability. The livelihood system of all respondents of the study LZs depends on farming and mixed agriculture system, which is highly vulnerable to climate variability events due to their livelihood system depends on rain-fed agricultural systems. Food insecurity index values of livelihood system sensitivity of the study livelihood zone score higher value in RVLZ (0.81), ALOFLZ (0.64), and TCLZ (0.55) (Table 5.4). Therefore, the food security process in study LZs is to secure the lives of most study area communities.

According to the food security experts, the emergency food needs for disaster risk communities and under the poverty line peoples are the main target for food security in the study LZs. The food security program is run based on household economic analysis (community wealth status). According to the experts, there are four community levels based on their wealth status in the three LZs: under the poverty line, on the poverty line, medium riches people, and better wealthy people. So the food security program runs based on the wealth status of the community and the federal government development plans (GDP1 and GDP2). The direct benefits of the safety net are these people who live below the poverty line, especially aged people and disabled people who cannot live without this support.

According to Choden *et a*l. (2020), rural households that depend on agriculture are vulnerable to climate change due to the farming system's sensitivity to climate variability and extremes. Participants of FGD in RVLZ stated that Sorghum and Maize production decreased from 80 quintals to less than 30 per hectare due to erratic rainfalls and declining soil fertility. As said by the participants in RVLZ, their communities did not use inorganic fertilizers to maximize production due to the moisture scarcity of their LZ. FGD participants in TCLZ had different perspectives on the production trends in all study intervals. The reasons for their different perceptions are that some parts of the LZ are more vulnerable to a dry spell, drought, and deforestation that aggravates soil fertility decline and degradation.

Besides the respondents of ALOFLZ, they have different experiences from RVLZ and TCLZ in productivity and production trends. The respondents' perceived production was better from the year 2000 to 2019. According to the Key informants and FGD results, before two decades (2000), crop production in ALOFLZ was affected by frost, marsh, and soil degradations. The participants stated that the same plot's productivity is better than in the past due to using agricultural inputs, intensive management in small farmlands, and forbore weather conditions due to climate change. However, they threatened for side effects of chemical inputs. Farmland in ALOFLZ is already addicted to chemicals and inorganic fertilizers. Chemicals and inorganic fertilizers impact the ecosystem services the land provides and its future value.

Since the recent time, the local community has used residue and post-harvesting crops for firewood and forage sources. This trend affects the farmlands' natural soil fertility, mineral contents, and moisture conservation. The litter is reduced and affects the soil fertility and productivity of the lands. There are new invaded herbs and insects that affect land fertility and productivity.

Institutional sensitivity

Institutional services, such as training to improve production efficiencies, appropriate market networks, updated information, and good livestock services, are among the institutional interventions which can reduce the community's vulnerability to drought risks and impacts (Omerkhil *et al*., 2020).

This study demonstrated low institutional competency with an index score of 0.84 in ALOFLZ, 0.83 in RVLZ, and 0.75 in TCLZ. With the current levels of institutional interventions, these findings suggest that the study LZs are more sensitive to drought impacts. This is in line with the findings of Choden *et al*. (2020) and Omerkhil *et al*. (2020). They highlight the susceptibility of households impacted by exposure to and adaptation capacity to climate change due to insufficient institutional services. Household survey results for lack of training to improve production efficiencies indicated higher index values of 0.68 in RVLZ, 0.60 in ALOFLZ, and 0.42 in TCLZ (Table 5.4). About 71, 81, and 46% of households in RVLZ, ALOFLZ, and TCLZ revealed they never get training on improved crop input use, respectively. About 62, 82, and 49% of the respondents in RVLZ, ALOFLZ, and TCLZ confirmed they never get extension advice on improved crop input use, respectively. In addition, about 71, 17, and 31% of respondents in RVLZ, ALOFLZ, and TCLZ, reported they never get training services on improved production practices, respectively. This result coincided with the Omerkhil *et al.* (2020) study that stated only 1% of farmers had access to agricultural technical support. There was a lack of appropriate market network and information (lack of market linkage advice, extension advice on market network, lack of market for stock and their products, lack of updated market information) in all study LZ. Similarly, there was a lack of veterinary services and access to better stock breeds in all study LZs.

Table 5.4 Sensitivity sub-indicators across the study livelihood zones

Indicator	Sub indicators	Variables for Sensitivity Measurements	RVLZ		ALOFLZ		TCLZ	
			Variable Indexes	Sub indicator Indexes	Variable Indexes	Sub indicator Indexes	Variable Index	Sub indicator Indexes
Sensitivity	Climate Variability Sensitivity	Decreasing rainfall trends	0.99	0.98	0.84	0.63	0.79	0.87
		Increasing temperature trends	0.96		0.29		0.77	
		Declining rainfall coverage in the rainy season	0.96		0.98		0.95	
		Disrupting rainfall time	0.99		0.57		0.97	
		Frequencies of erratic rainfall	1		0.45		0,85	
	Ecosystem sensitivity	Fast natural vegetation conversions	0.93	0.82	0.75	0.74	0.91	0.86
		Fast land degradation	0.66		0.86		0.96	
		Water stress	0.70		0.85		0.84	
		High reduction of crop productivity	1.00		0.49		0.74	
	Livelihood System Sensitivity	Dependents on rain-fed farm activity	1.00	0.85	1	0.80	1	0.76
		Food insecurity situations	0.81		0.64		0.55	
		Fuel sources for household consumptions	0.75		0.75		0.73	
	Institutional sensitivity	Lack of training to improved production efficiencies	0.68	0.83	0.60	0.84	0.42	0.75
		Lack of appropriate market network and information	0.87		0.98		0.90	
		Lack of sufficient services in livestock sectors	0.94		0.94		0.93	
	Sensitivity Index at Livelihood Zone Levels			**0.87**		**0.75**		**0.81**

5.3.3. Adaptive Capacity

Adaptive capacity is the ability of society to be resilient or cope with the current or future potential drought hazards. The study developed sub-indicators such as livelihood strategy, nature conservation, social network, and coping strategy to measure the adaptive capacity index for drought vulnerability. The index value of the adaptive capacity indicator in the three study livelihood zone showed low records (0.51 in RVLZ, 0.55 in ALOFLZ, and 0.49 TCLZ) relatively to the exposure and sensitivity drought occurrences and their linked risks (Figure 5.5). The Gupta *et al.* (2020b) study similarly revealed high climate vulnerability in the Indian Himalayas due to high exposures and less adaptive capacities. Moreover, sub-components of adaptive capacity indicated that the RVLZ has the least resilience in terms of coping strategy (0.40), followed by nature conservations (0.51), social networks (0.54), and livelihood strategy (0.58). However, sub-components of adaptive capacity in ALOFLZ indicated that the least resilience was the score in nature conservations (0.48), followed by coping strategy (0.50), social networks (0.59), and livelihood strategy (0.62) (Figure 5.5). Similarly, TCLZ scores the least resilience in nature conservations (0.48), followed by coping strategy and social networks (0.49 for each) and livelihood strategy (0.55). TCLZ is less resilient to drought-induced hazards than RVLZ and ALOFLZ (Table 5.5).

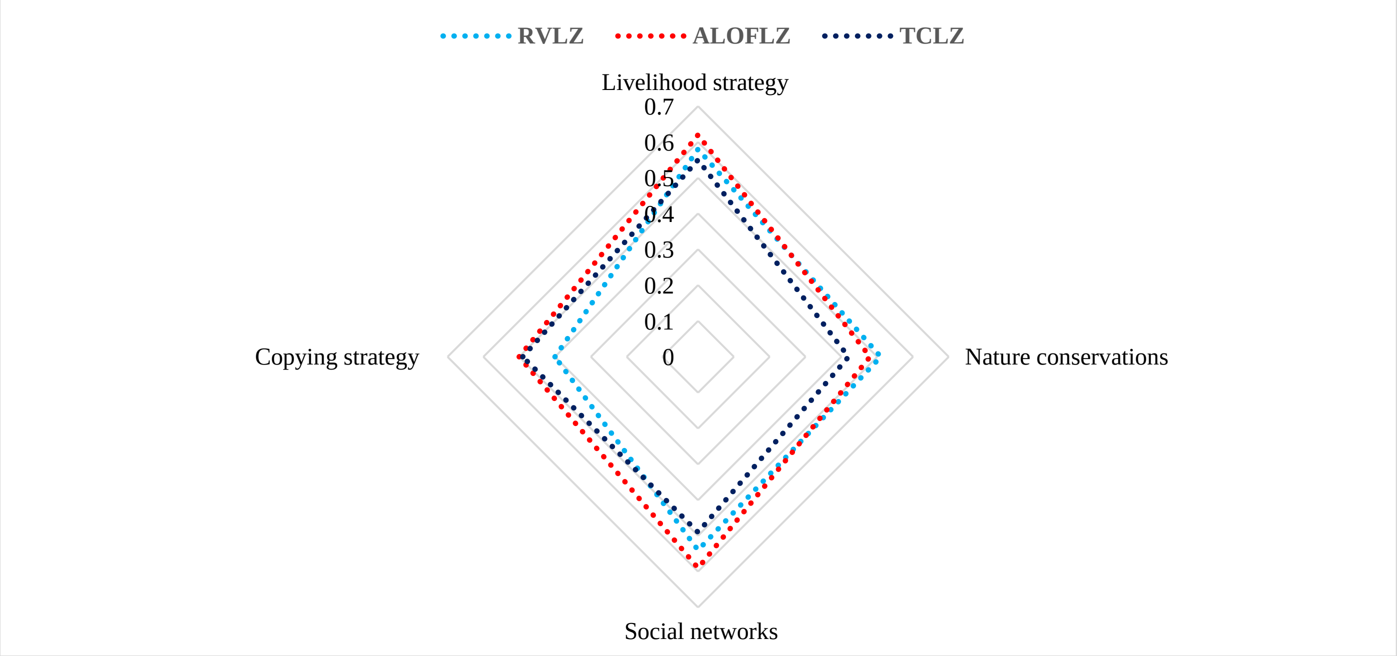


Figure 5.5. Radar diagram showing adaptive capacity sub-indicators across the study livelihood zones

Livelihood strategy

Considering the importance of integrated agricultural packages for livelihood strategy attributes revealed critically low values of adaptive capacity (0.58, 0.62, and 0.55) in RVLZ, ALOFLZ, and TCLZ, respectively. Adaptive capacity in terms of livelihood strategy refers to practicing and integrating agricultural packages. Crop diversifications, intensive cropping management, applying fertilizer and compost or manure, planting moisture stress or early maturing crop, applying chemicals for pests and herbs, using of tractor for the plow, shifting to high-value crops or value additions, using improved livestock bread and technology, practicing fattening, and livestock forage management practices are among the agricultural packages. Intensive crop management includes intercropping, row planting, proper crop density, and repeated weeding. Similarly, fertilizer and compost or manure have advantages for increasing productivity during the good rainy season. Planting early maturing crops and moisture stress-resistant improved seeds is curial, reducing crop failure and forage problems in drought-prone areas. Practicing these integrating agricultural packages shapes the capability and resilience of communities against drought impacts and their associated consequences. However, as seen in (Table 5.5), the livelihood strategy adaptive capacity of the three LZs is insignificant to resist drought-induced impacts and recover from the drought impacts before the following drought hazards occur.

Similarly, Omerkhil *et al*. (2020) revealed that farmers were experiencing a severe cycle of food insecurity due to low production. The Murthy *et al.* (2015) study showed that the level of agricultural drought vulnerability is closely related to the challenges of sustainable agriculture. According to the Choden *et al.* (2020) study, the rural communities that depend on agricultural livelihood systems are vulnerable to climate change due to the sensitivity of farming to climate variability and extremes.

Natural resource conservations

Adaptive capacity regarding natural resource conservations refers to physical soil and water conservation practices to improve soil fertility of both arable and non-arable land. Practices like fallowing, crop rotation, maintaining crop residue, and cultivating leguminous crops and forages are necessary for soil fertility enhancement on farmland. On farmlands, soil and water conservation use deep tillage to enhance water storage. Constructing flood diverting detach, using traditional flood diversion or pump, rainwater harvesting, applying water-efficient practices, and improving irrigation are the main physical soil and water conservation practices in the study LZs. The results of the index value of soil and water conservation for the natural resource conservations adaptive capacity indicator better score in RVLZ (0.70) than ALOFLZ (0.48) and TCLZ (0.42) (Table 5.5). This study sported with the Sertse *et al.* (2021) findings in the Raya Azebo district (parts of RVLZ). They revealed that "*farmers adopted climate change, including mulching (88%), soil and water conservation (78%), and the use of alternative tillage practices (74%)*". However, the index value for strategies to enhance soil fertility on farmlands for natural resource conservation adaptation capability in RVLZ, ALOFLZ, and TCLZ, respectively, is dangerously low (0.33, 0.35, and 0.23). The result revealed that all study LZ have low soil fertility conservation in their farmlands, implying a high reduction in productivity. According to the results, the index value of natural resource conservations adaptive capacity has shown a lower record value (0.51 in RVLZ, 0.48 in ALOFLZ, and 0.42 in TCLZ), which implies higher exposures and sensitivities for drought occurrences and their impacts.

According to RVLZ natural resources management experts, there are various strategies to conserve moisture on-farm and structures to conserve soil and waters on both watersheds and farmland levels. The expert verifies there are positive outcomes on water conservation and crop and forage productivity in some areas. However, according to ALOFLZ natural resource experts, moisture conservation practices on farmland is not satisfactory. According to them, the community has no full awareness of the role of moisture conservation in reducing drought impacts. Therefore, efforts must incorporate moisture, water, and soil conservation practices at livelihood zone and on-farm levels. The most priority intervention in the area should focus on moisture and soil conservation practices.

Practice in social networks

The Adger *et al.* (2013) study shows there are essential cultural dimensions that communities respond to and adapt to climate induce risks. Social networks such as the availability of the community's financial saving system ("Ekub") and Zakat are fundamentals to reduce the financial limitation of the community. Zakat is the Islamic finance system that obligates individuals to donate a fixed portion of wealth each year to charitable causes. Further participation in community organization for the community development and community administration system during mirage, funeral, and other social issues and events ("Eddir") have advantages to communities to administrate themselves with endogenous knowledge. Christian communities have monthly gathering events as group members ("Mahber") for ceremonies or to help each other during economic difficulty. On-farm labor-sharing ("Lifent") and free services ("Ofera") for a plow, weeding, and harvesting, as well as other social issues such as housing constructions, are considered among the primary social networks that can help the community's vulnerability against drought hazards and its impacts. The findings of this study on social networks' adaptive capacity revealed a low index value of 0.54, 0.59, and 0.49 in RVLZ, ALOFLZ, and TCLZ, respectively (Table 5. 5).

Similarly, Pandey and Jha (2012) found weak institutional innovation through traditional knowledge for disaster adaptation capacity. Even if the social networks' adaptive capacity of the study LZs are scored lower value, food security experts of all study areas argue the above community association and practices have high contributions to mitigating droughts. For example, communities can conserve moisture with “Ofera” on their farmland. These practices can increase crop productivity. “Edire” is one of the community practices to help each other, and it is holistic for all communities. Any community member can participate in “Edire” without considering their wealthy status and age. “Ekub” is a mechanism to save their resources and to use as a contingency during drought times. Community care collage and village saving associations were also local associations created by the community for credit and saving purposes without interest rates and to help each other during harsh conditions. It is incomparable with governmental emergency support. It is early support for the victims than the government. Religious institutions like mosques and churches also contribute to helping people during drought. Therefore the above local community association can reach the victims and the vulnerable peoples. So, the government should consider strengthing and assisting these communities in social networks to reduce drought and other natural and social impacts.

Coping strategy during drought time

This study further unrecovered the communities coping strategies for adaptive capacity during the drought. Coping up strategies during drought were assessed for destocking, migration to the nearby area, consuming fewer-cost foods, borrowing grain from others, borrowing cash from a moneylender, firewood and charcoal selling, and leasing out the land. However, the coping strategy sub-inductors recorded a lower value of 0.40, 0.50, and 0.49 in the RVLZ, ALOFLZ, and TCLZ, respectively (Table 5.5). Considering the drought frequencies and severity threats in terms of the communities are high exposure and susceptibility, the current level of cop-up strategy is not diverse, strong, and sustainable to challenge the drought-induced impacts of the study LZs. Omerkhil *et al.* (2020) stated that these adaptive systems help moderate impacts on community livelihoods, but they are not strong enough for farmers to cope with severe food insecurity. According to the key informant and FGD participants in RVLZ, the coping mechanisms during drought depends on remittance, relief support, sales of livestock, and labor forces, changing their food habits on quality and quantities.

The FGD participants in ALOFLZ mentioned one of the cops-up methods for livestock is sale/ destocking and migration to the drought-free area. The market equilibrium is upset when there is a drought. During drought time, the quality of the livestock is highly affected, and the supply is high, but demand is low. If crop failures happen, there is a reduction in total crop production, which will affect the per capita income. In the market system, demand will be high, but the crop supply is low. Therefore there will be resource shortages, and prices will be inversely high. Drought brings multi-hazards and needs multi-sectoral responses like health, food, water, education, crop, livestock, securities, transport, markets, information services, early warning services, etc. It needs awareness creation and holistic and cooperative responses from whole relevant stakeholders.

Table 5.5 Adaptive capacity sub-indicators across the three study livelihood zones

Indicators	Sub indicators	Variables for Adaptive capacity Measurements	RVLZ		ALOFLZ		TCLZ	
			Variable Indexes	Sub indicator Indexes	Variable Indexes	Sub indicator Indexes	Variable Index	Sub indicator Indexes
Adaptive capacity	Livelihood strategy	Practicing diversifications	0.72	0.58	0.72	0.62	0.62	0.55
		Intensive cropping management	0.50		0.53		0.60	
		Applying fertilizer and compost or manure	0.10		0.89		0.61	
		Planting moisture stress or early maturing crop	0.99		0.88		0.71	
		Applying chemicals for pests and Herbs	1.00		0.97		0.88	
		Using of tractor for plow	0.64		0.00		0.00	
		Shifting to high value crops or value additions	0.88		0.34		0.42	
		Using improved livestock bread and technology	0.15		0.25		0.24	
		Practicing fattening (sheep, goat, ox)	0.28		0.43		0.48	
		Livestock forage management	0.49		0.72		0.63	
	Nature conservations	Physical soil and water conservation practices	0.70	0.51	0.61	0.48	0.60	0.42
		Practicing to increase soil fertility	0.33		0.35		0.23	
	Social networks	“Ekub”	0.28	0.54	0.91	0.59	0.69	0.49
		“Zeka”	0.99		0.25		0.06	
		Participate in community organization	0.00		0.67		0.39	
		Eddir”	0.90		0.36		0.47	
		“Mahber”	0.06		0.55		0.39	
		Labor sharing on-farm activities	0.99		0.78		0.99	
	Coping strategy	Destocking	0.38	0.40	0.93	0.50	0.75	0.49
		Migration to a nearby area	0.33		0.56		0.61	
		Consuming less cost foods	0.63		0.65		0.66	
		Borrowing grain from others	0.34		0.32		0.29	
		Borrowing cash from a money lender	0.23		0.37		0.38	
		Firewood and charcoal selling	0.33		0.25		0.27	

Lease out land	0.54	0.39	0.49
Adaptive capacity Index at Livelihood Zone Levels	0.51	0.55	0.49

5.3.4. Drought Vulnerability Across the Three Livelihood Zones

The components and sub-components of drought vulnerability inductors were compared across the three livelihood zones to explore the community's drought vulnerability levels. The composite drought vulnerability indexes (Table 5.6 and Figure 5.6) of all study LZs show highly vulnerable to drought impacts. However, the Raya valley livelihood zone is relatively more susceptible to drought (0.65) than the Tsirare catchment (0.63) and Alagie-Ofla (0.60) livelihood zones. Xu *et al.* (2020) and Balaganesh *et al.* (2020) reported that there was less divergence in exposure but with high deviations in sensitivity and adaptive capacity among their study sites (districts). However, this study revealed that all drought vulnerability components diverge across all study livelihood zones. The drought vulnerability index was detected because the livelihood zones evaluated differed in exposures, sensitivities, and adaptive capacity.

The Raya valley livelihood zone has a less adaptive capacity (0.51) with more susceptibility (0.87) and exposure (0.70) to drought risks compared to the Allagie-Ofla livelihood zones (Table 5.6). The Gupta *et al.* (2020b) study similarly revealed high climate vulnerability in the Indian Himalayas due to high exposures and less adaptive capacities. In particular, the exposure index (Figure 5.6) shows that the Raya valley livelihood zone has higher exposure (0.70) to drought impacts and linked risks than the two livelihood zones. The index values of the sub-indicators in the Raya valley livelihood zone show that the community is more exposed to institutional limitations (0.99), followed by biophysical risks (0.77), and ecosystem disruptions (0.72), sociocultural effects (0.55), and trends in climate variability (0.45). However, the calculated index value of the sub-indicators shows that communities in the Raya Valley livelihood zone are susceptible in terms of climate variability (0.98), followed by the livelihood system (0.85) and institutional (0.83), and ecosystem sensitivity (0.82). Furthermore, the subcomponents of adaptive capacity indicated that the Raya valley livelihood zone has the least resilience in terms of the coping strategy (0.40), followed by the conservation of nature (0.51), social networks (0.54), and the livelihood strategy (0.58). This finding coincides with that of Peng *et al*. (2018). They revealed that rural households in the Gorges reservoir area in China are highly vulnerable due to high exposure and sensitivity dimensions.

Besides, the Tsirare Catchment livelihood zone possessed less adaptive capacity (0.49) than the two livelihood zones with more susceptibility (0.81) and exposure (0.62) to the drought risks compared to the Alagie-Ofla livelihood zone (Table 5.6). Tsirare catchment livelihood zone has higher exposure to biophysical (0.83), followed by socio-cultural (0.79), climate (0.50), and institutional limitations (0.50) and ecosystem disrupts (0.48). However, communities in the Tsirare Catchment livelihood zone are highly susceptible in terms of climate variability (0.87), followed by ecosystem (0.86), livelihood system (0.76), and institutional (0.75) sensitivities. The result coincided with Choden et al. (2020) findings, which stated that both degrees of exposure and adaptive capacity to climate change are determinants of households' and communities' impact levels. The TCLZ is critically less resilient to drought-induced hazards than the Raya valley and Allagie-Ofla livelihood zones from the study livelihood zone. TCLZ scores the least resilience in natural conservations (0.48), followed by the coping strategy and social networks (0.49 for each) and the livelihood strategy (0.55).

Even if the ALOFLZ is relatively less for drought vulnerability than RVLZ and TCLZ, the area has a less adaptive capacity (0.55) with more susceptibility (0.75) and high exposure (0.61) to drought risks. The index values of sub-indicators in the Alagie-Ofla livelihood zone show that the area is higher exposure to biophysical (0.83), followed by socio-cultural (0.78), ecosystem disrupts (0.53), climate variability events (0.52), and institutional limitations (0.41). According to the Congreso *et al.* (2014) study, loss of biological control can consequences pest densities, affects pollinator services, and causes environmental degradation. However, communities in the Alagie-Ofla livelihood zone are susceptible in terms of institutional (0.84), followed by livelihood system (0.80), ecosystem sensitivity (0.74), and climate variability (0.63). Moreover, sub-components of adaptive capacity in the Alagie-Ofla livelihood zone indicated the least resilience in nature conservations (0.48), followed by coping strategy (0.50), social networks (0.59), and livelihood strategy (0.62).

Table 5.6 Drought vulnerability across the three study livelihood zones

Vulnerability Components	Livelihood Zones		
	Raya Valley	Allagie-Ofla	Tsirare Catchment
Exposures Index	0.70	0.61	0.62
Sensitivity Index	0.87	0.75	0.81
Adaptive Capacity Index	0.51	0.55	0.49
Drought Vulnerability Index= $VI = 1 - \sqrt{\frac{\lvert(1-E)^2+(1-S)^2+A^2)\rvert}{3}}$	0.65	0.60	0.63

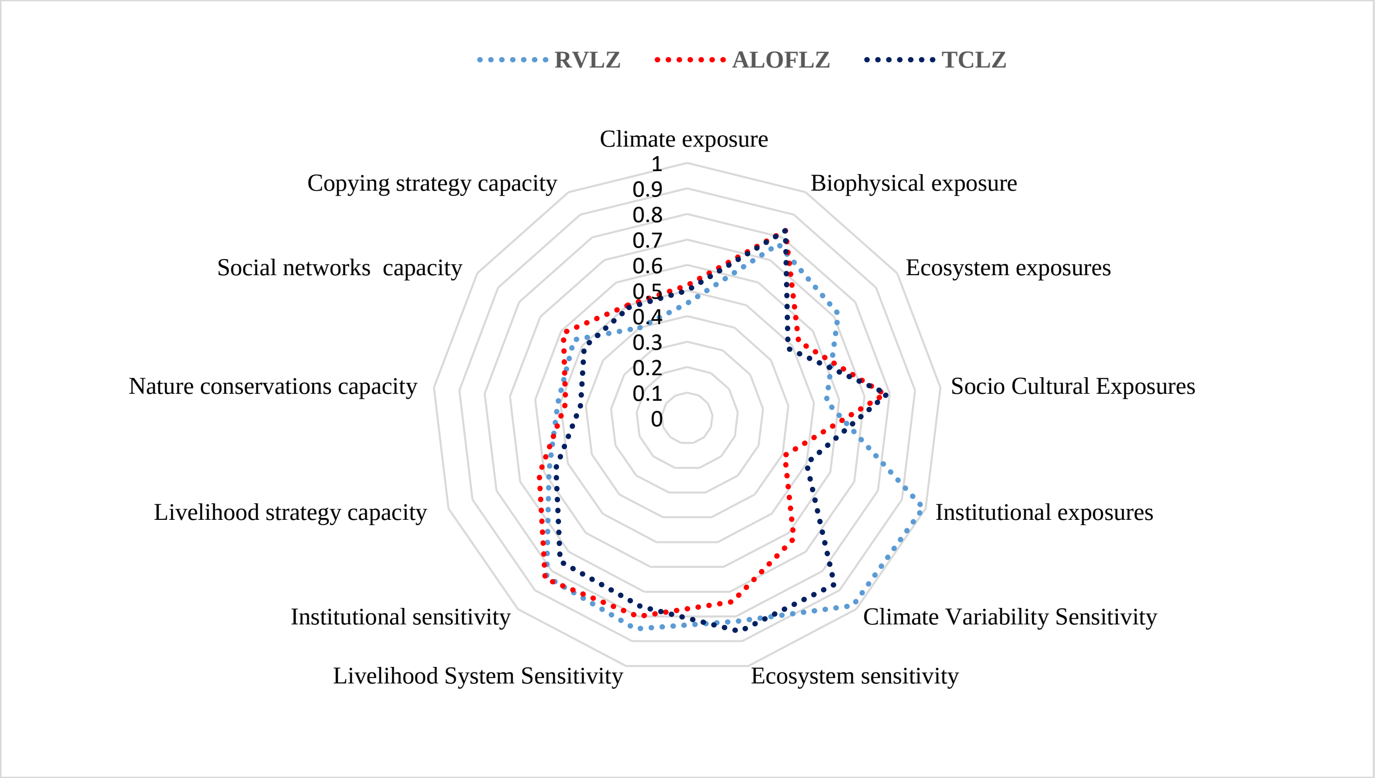


Figure 5.6. Radar diagram of drought vulnerability sub-indicators across the study livelihood zones

5.4. Conclusion

This study aimed to explore the drought vulnerability in three livelihood zone (LZ) of Northwestern Ethiopian Rift Valley. The author gathered meteorological, spatial, and socioeconomic data to develop a drought vulnerability index at livelihood zone levels. Drought intensity, temperature and rainfall trends, and rainfall variability were studied using meteorological data. LULC change detections were analyzed using Landsat images and ground truth points to investigate the ecosystem disturbance. This study used socioeconomic data from households, focus group discussions, and key informants to model the study's LZs' susceptibility to drought. This new approach can be used as input for strategies and policymakers to combine critical sectors to reduce drought-prone livelihood systems.

The composite drought vulnerability indexes of all study LZs show high vulnerability to drought impacts. However, the Raya Valley livelihood zone is relatively more vulnerable to drought than the Tsirare catchment and Allagie Ofla livelihood zones. There is a difference in drought vulnerability indexes between the livelihood zones of the study because the livelihood zones varied in exposure, sensitivities, and adaptive capacities. RVLZ has less adaptive capacity than ALOFLZ and more susceptibility and exposure to drought risks than the two LZs. In particular, the exposure index shows that the Raya valley livelihood zone has higher exposure to drought impacts and linked risks than the two livelihood zones. The index values of the Raya valley livelihood zone sub-indicators show that the community has higher exposure to institutional limitations followed by biophysical risks, ecosystem disruptions, socio-cultural effects, and climate variability trends. Similarly, RVLZ is highly sensitive to climate variability, followed by livelihood system, institutional, and ecosystem sensitivity. Regarding adaptive capacity, RVLA has the least resilience in coping strategy, followed by weak natural conservations, weak social networks, and fragile livelihood strategy.

Besides, the TCLZ has less adaptive capacity than the Raya Valley and Alagie Ofla livelihood zones. The LZ is more susceptible to drought risks than the livelihood zones of Alagie Ofla. The TCLZ has higher exposure to biophysical risks, followed by sensitive socio-cultural practices, climate-induced risks, institutional limitations, and ecosystem disruption. However, communities in the LZ are highly susceptible to climate variability trends, followed by ecosystem disturbances, weak livelihood systems, and institutional sensitivities. TCLZ scores less resilience in natural conservations, followed by coping strategies, social networks, and livelihood strategies.

Furthermore, even if the Allagie-Ofla livelihood zone is relatively better to drought vulnerable than RVLZ and TCLZ, the area has the less adaptive capacity with more susceptibility and exposure to drought occurrences and related risks. The ALOFLA faced higher exposure to biophysical risks, followed by sensitive socio-cultural practices, ecosystem disruption, climate variability events, and institutional limitations. However, communities in the ALOFLZ are higher sensitive to weak institutional services, followed by a fragile livelihood system, ecosystem sensitivity, and climate variability. Moreover, the LZ was less resilient in nature conservations, followed by a coping strategy, weak social networks, and a vulnerable livelihood strategy.

This study provides insight into how drought vulnerability differs between livelihood zones. The study LZs needs vertical and horizontal solutions depending on the vulnerability's causes. Drought brings multi-hazards that demand multisector responses. It required integrated responses through health sectors, food securities, water sectors, education, crop sectors, livestock sectors, transport sectors, markets, information services, and early warning services under one umbrella rather than individual responses. Due to a lack of early warning and institutional capacity to prepare for and respond to drought hazards, RVLZ is more vulnerable. As a result, well-developed and anticipated information systems and holistic and cooperative responses from all relevant sectors are essential.

Furthermore, TCLZ and ALOFLZ have higher socio-cultural exposures. As a result, they need more efforts to develop skills and raise knowledge about turning surplus production and resources into assets. The coping approach in all study livelihood zones was not diverse, robust, or long-term to combat drought-induced consequences. As a result, initiatives at the livelihood zone and on-farm levels should enhance the existing moisture conservation and water and soil conservation methods in all LZs. There most priority intervention in the area should be focused on afforestation with indigenous species, moisture, and soil conservation practices. For immediate intervention, moisture conservation techniques are essential, and irrigation sectors are needed for long-term sustainability to promote the production of drought-tolerant and market-oriented crops. As a result, livelihood-based interventions and climate-smart farming techniques are urgently required for all study LZs to transfer vulnerable communities and reduce possible drought risks. To reduce drought vulnerability, and to achieve sustainable development, rainwater harvesting with reservoirs in all livelihood zones is required. Also, the concerned body in RVLZ needs to focus on efficiently using the existing and proposed groundwater projects.

6. Chapter 6: Analyzing Synergetic Impact of Drought and Land Use and Land Cover Changes on Livelihood Systems Across Three Livelihood Zones in the Northwestern Escarpment of Ethiopian Rift Valley

Abstract

Drought and centuries of persistent land exploitation have resulted in food insecure communities and significant environmental changes in Northwestern Escarpment Ethiopian Rift Valley. The study evaluated the climate variability, drought trends, LULC change, and drought vulnerability in three livelihood zones (LZ) from 1983 to 2019. Socioeconomic surveys, meteorological data, and Landsat images were employed in the study. The study discovered significantly increased seasonal and annual temperature trends in all studied LZ. Significant annual (31–50%) and seasonal (39–99%) rainfall variability were recorded in the study LZs. Drought was revisited every 2.13, 2.2, and 2.13 years and persisted for 1.5, 1.9, and 1.7 years in Alagie-Ofla livelihood zones (ALOFLZ), Tsirare catchment livelihood zone (TCLZ), and Raya valley livelihood zone (RVLZ), respectively. Of the total areas, 82%, 72%, and 77% of RVLZ, ALOFLZ, and TCLZ changed between identified LULC categories. There were no climaxes LULC types within the study years in all LZs. These cumulative effects have impacted agricultural productivities and local ecosystems in the areas, particularly the RVLZ. This study enabled the researchers to investigate how synergetic drought and LULC change affect livelihood systems. The study hints at improving the current drought impact and LULC changes monitoring system of the country.

Keywords: Climate Variability, Drought, Land Use and Land Cover Change, Livelihood System, Synergetic Impacts

6.1. Background

Every year, new risk drivers emerge due to climate change and fluctuation around the globe (Sadat *et al.,* 2020; IPCC, 2013). Drought is one of the climatic variability and anthropogenic-induced hazards that have significantly impacted the livelihood systems of the local population in East Africa (Tefera & Bello, 2019). For example, precipitation deficiencies and rising temperatures have significantly impacted smallholder farmers, particularly in developing countries where most livelihoods depend on rain-fed agricultural systems (Yacoub & Tayfur, 2020). East Africa is the most vulnerable region to climate variability and extreme weather events that are the main risks for farming activities and productivity (IPCC, 2007; Haile, 2005) and chronic crises rooted in socioeconomic issues (Gebrechorkos *et al.,* 2019; Haile & Tang, 2019).

Ethiopia is one of the most drought-prone nations globally (Birara *et al.,* 2020). The country is ranked 22nd in terms of vulnerability to the effects of climate change on agriculture (Teshome & Zhang, 2019). A growing dry spell (Maru *et al.,* 2021), high rainfall variability (Eze *et al.,* 2020), a significant increase in mean temperature, and frequent drought (Eshetu *et al.*, 2014) all pose substantial challenges to agricultural production and productivity. Farmers in Ethiopia are susceptible to the threat caused by climate variability since most of their livelihood systems rely on weather-dependent rain-fed agricultural systems (Esayas *et al.* 2018, 2019). In different parts of the country, extreme climate fluctuation and drought impacts are usual, resulting in crop failure, animal loss, and human deaths (Eze *et al.*, 2020; Esayas *et al.*, 2018).

Drought is becoming more of a risk for farmers in Northern Ethiopia such to frequent crop failures (Eze *et al.*, 2020). It remains the leading cause of exposure to periodic famine in Northern Ethiopia (Andargie 2014; Kiros 199; Webb & Braum, 1990). From 1973 to 2016, the region has experienced nearly 26 mild-to-severe droughts (EM-DAT, 2017; Gebru & Beyene, 2012), which overlays with the territories of the current study settings. Droughts have returned to the area at ten-year intervals since 1965 (Andargie, 2014). However, in recent years (since 2000), droughts have occurred at two to three-year intervals (Gidey *et al.,* 2018a,b; Gidey, 2012). Consequently, it is one of the strategic adversaries in Northern Ethiopia that requires serious mitigation measures at the local level. The Raya Valley livelihood Zone (RVLZ), Alagie–Ofla livelihood Zone (ALOFLZ), and Tsirare Catchment Livelihood Zones (TCLZ) are among Northern Ethiopia's most vulnerable to climate variability events, periodic drought impacts, and uncertainty (Tefera & Bello, 2019; Gidey *et al.*, 2018a,b,c).

On the other hand, over the previous three centuries, the worldwide human population has grown substantially, becoming a significant driver in changing land cover and global change processes (Dibaba *et al.*, 2020; Das & Sarkar, 2019). Human activities negatively influence smallholders by reducing land productivity, changing weather systems, and intensifying environmental degradation, desertification, and biodiversity loss in East Africa (Dibaba *et al.*, 2020; Gidey *et al*., 2017b). The changes will have long-term consequences for community livelihood systems that rely on rain-fed systems and their basics in the region. Similarly, Ethiopia's long-term biological production has been severely affected due to the LULC changes (Balabathina *et al.*, 2020; Kidane *et al.*, 2019). Remarkably, the northern regions of Ethiopia are where decades of land exploitation have severely lowered the soil's productive capacity and weakened its ability to endure climatic extremes (Andargie, 2014).

Remarkably, the northern regions of Ethiopia are where decades of land exploitation have severely lowered soil productive capacity and weakened its ability to endure climatic extremes (Andargie, 2014). Furthermore the northwestern escarpment of the Ethiopian Rift Valley (including the current study area) is centuries of unrelenting land exploitation that has resulted in severe environmental alterations and degradations (Gidey *et al*., 2017a). The expansion of croplands in parts of the northwestern escarpment of the Ethiopian Rift Valley (RVLZ) comes at the cost of natural vegetation and grasslands. Due to this conversion of natural areas to farmland, the communities suffer from a shortage of grazing land, access to raw materials, fuelwood, and a lack of free space. This conversion will again impact groundwater and can induce and aggravate climate extreme events such as droughts. Recent studies have shown climate-related extreme events as the primary drivers of LULC change and vice versa (Reef *et al.*, 2015)

Therefore, while drought and LULC change have a substantial impact, their combination on the livelihood system in the drought and LULC change hotspot area is much more significant (Bunce *et al.*, 2010). Drought, combined with a change in LULC, has long been seen as Ethiopia's most serious food security threat (Berhe, 2011). The LULC change and drought frequencies in Ethiopia imply other hazards that are likely to have much more significant influences on the livelihood system of the community (Betru *et al.*, 2019).

The synergetic impact of LULC and drought is not a simple sum of each impact, but it has a more significant synergetic effect on the livelihood systems of the community due to their feedback effect (Dosdogru *et al*., 2020). Despite area differences in the factors triggering droughts in a specific region, El Niño–Southern Oscillation (ENSO) and sea surface temperatures (SSTs) are major influencing factors across the continents (Slegers & Stroosnijder, 2008). However, the drivers of drought events can be more complex than rainfall deficit alone (Alahacoon & Edirisinghe, 2022). It depends not only on such biophysical factors as climate conditions and soil properties but also on such management factors as land use and the management practices of local land user and their strategies to cope with drought (Masih *et al*., 2014).

Land-atmosphere feedback through natural vegetation and land cover change are essential factors for drought induces (Achugbu *et al.*, 2021). This change influences carbon fluxes and greenhouse gas (GHG) emissions which directly alter atmospheric composition and cause current warming and drying trends (Dai, 2011). Changes in vegetation type and cover can modify the characteristics of the regional atmospheric circulation and the large-scale external moisture fluxes(Kumar *et al.*, 2018). Reduced vegetation cover and surface evaporation may have provided positive feedback that enhances and prolongs the droughts (Dai, 2011). Such changes may involve "biogeophysical" feedback mechanisms, i.e., once they start, they give feedback on themselves and extend the drought conditions (Laguë *et al.*, 2019).

On the other hand, drought significantly affects critical ecological functions, and the crucial issue of global environmental change and its changes are cumulatively significant drivers of global climate change (Dai, 2011). Drought is a vital issue due to its considerable influence on landscape patterns, land degradation, biodiversity loss, water quality, eco-hydrological effects, and human life (Zhong *et al.*, 2018). The proximate cause of a rainfall shortage may be one or more of these factors (Dai 2013). Such factors involve weather systems on many spatial scales ranging from local to regional to global (Laguë *et al.*, 2019).

Several synergy studies on climate policy around the world are concerned with the performance of single systems (mitigation or adaptations) aimed at reducing climate impact with multiple regulatory levels at the same time (Bergh *et al.*, 2021; Golfam & Ashofteh, 2021; Adolph *et al.*, 2020; Drews *et al.*, 2020; Wang et al. 2020; Makate *et al.*, 2019). The author appreciated the research the study looked at for their scholarly contributions in their priority areas. However, the reviewed studies did not analyze the synergetic impacts of drought and LULC modification on livelihood systems. They did not cover all the parameter combinations the author discussed synergistic impacts. This study is also different because it used a wide range of data, including meteorological, Landsat images, ground surveys, socioeconomic data, reports, and reviews from scientific papers (Figure 6.1). In addition, unlike most scholars, this research concentrated on livelihood systems at the livelihood zone level rather than agroecological zones. Therefore, the author believes policymakers need this research to design synergetic solutions at the livelihood system level. Further, the author believes this empirical proof of the synergistic effects of drought and LULC change on livelihood systems will contribute to the existing scientific knowledge.

There are no standard ways to define the interactions between drought, LULC change, and livelihood systems. Knowing the magnitude or direction of synergetic implications of drought and the LULC change on the livelihood system is necessary (Wanga et al., 2019). But, knowing the exact interaction and synergistic impacts of drought and LULC change on the livelihood system of the local community is difficult to synthesize measurable outcomes using an empirical formula. Drought, LULC change, and the livelihood system have various dimensions, interconnections (synergy), and biophysical and social circumstances that aren't always similar. However, understanding synergy is essential for lowering operating costs and producing effective results (Vinca *et al*., 2021).

This study investigates the synergistic influence of drought and LULC changes on livelihood systems in three livelihood zones of the Ethiopian rift valley's northwestern escarpment. Livelihood zones are areas that have been grouped based on geographic similarities where households broadly share similar livelihood patterns, such as income sources and market opportunities, as well as demographic patterns rather than administrative boundaries (Zone & Teshale, 2019). Because social, geographical, and technological inputs influence individual and group perceptions and decisions, livelihood zones are essential in encompassing these aspects as one umbrella. Therefore, this study hypothesized that the synergistic impacts of drought and the change in LULC on the livelihood system have more significant consequences than independently or the sum of their results.

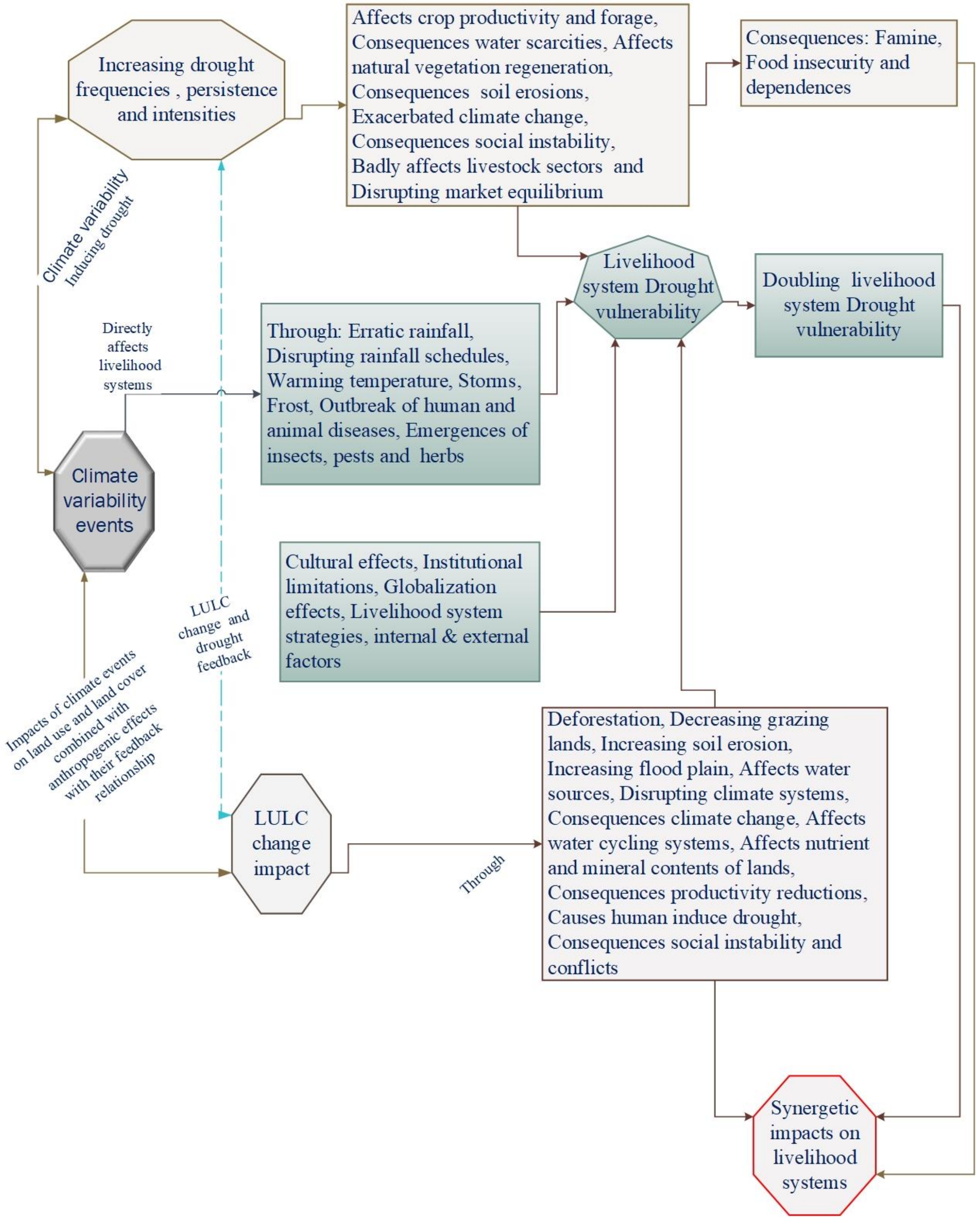


Figure 6.1. Conceptual framework of the synergistic impacts of drought and land use and land cover change on livelihood systems: Source Own developed.

6.2. Data Sets and Methods

6.2.1. Data Types and Sources

The author applied four data sources in the three livelihood zones of the study area to analyze the synergistic impacts of drought and LULC change on livelihood systems (Figure 6.2). The key factors are seasonal metrological drought and LULC change, with climate variability trends and their characteristics and the drought vulnerability index as sub-factors. More up-to-date, scientific information on the synergetic effects of drought and LULC change helps communities adapt to low-risk agricultural operations and crop productivity through agricultural inputs (Budhathoki & Zander 2019).

Climate variability and metrological drought analysis are the first and second parts of the study, respectively. Climate variability and meteorological drought are studied using meteorological data. CHIRPS and ENACTS were used to deal with climate variability trends and their characteristics based on the magnitude and intensities of temperature and rainfall trends for Belg, Kiremt, and combined rainy season (Belg and Kiremt), and annual time scale. The Kiremt and Belg rainy seasons are the rainfall seasons to cultivate the short and long-cycle growing crops. Rain feed farming activities and productivities of the study area depend on the two seasonal precipitations. Seasonal and annual rainfall variabilities temperature patterns during the consecutive rainy seasons have higher impacts on the rain-fed agriculture systems (Endale *et al.*, 2020).

The study's third data type investigated the changes in LULC in three livelihood zones of drought-prone areas. This section used Landsat images and a socioeconomic survey to determine the actual LULC change at the livelihood zone level. Studying the change in LULC at the livelihood zone level was the most precise technique to understand the mechanism, types of change, and forces and processes behind the changes (Dibaba *et al.*, 2020). Furthermore, because the causes, trends, and extent of the LULC change vary by geography and the dynamic interaction between the underlying drivers and proximal causes, analyzing livelihood zones is critical to using these characteristics as input for strategic solutions. A livelihood zone-level LULC change analysis was essential for clustering the changes and forecasting vulnerability to intervene with appropriate adaptation measures. However, the current efforts of the scientific community to study LULC change at the livelihood zone level are limited and require further attention to address the underlying drivers and the proximate of LULC changes at livelihood zone levels.

The study's fourth data source is devoted to determining drought vulnerability. This section examined drought vulnerability at the livelihood zone level using three data types. The data types are meteorological, LULC change, and socioeconomic (generated from survey questionnaires, focus group discussions, and key-informant interviews). The drought vulnerability estimation considered the dispersion of exposure, sensitivity, and adaptive capacity index that focused on the dispersion property of the indictors and stated that a better system should have less distance from the ideal (Singh, 2020). Flowing the (Gupta *et al.*, 2020a; Xu *et al.*, 2020; Zhao *et al.*, 2018), the author computed the divergence of the study DVI system from the most vulnerable state (i.e., the ideal state). The distance between the displaced-ideal methods was determined using Euclidean distance methods (Gupta *et al.,* 2020a; Singh, 2020).

The study applied four data sources in the three livelihood zones of the study area to analyze the synergistic impacts of drought and LULC change on livelihood systems (Figure 6.2). The key factors are seasonal metrological drought and LULC change, with climate variability trends and their characteristics and the drought vulnerability index as sub-factors. More up-to-date, scientific information on the synergetic effects of drought and LULC change helps communities adapt to low-risk agricultural operations and crop productivity through agricultural inputs (Budhathoki & Zander, 2019).

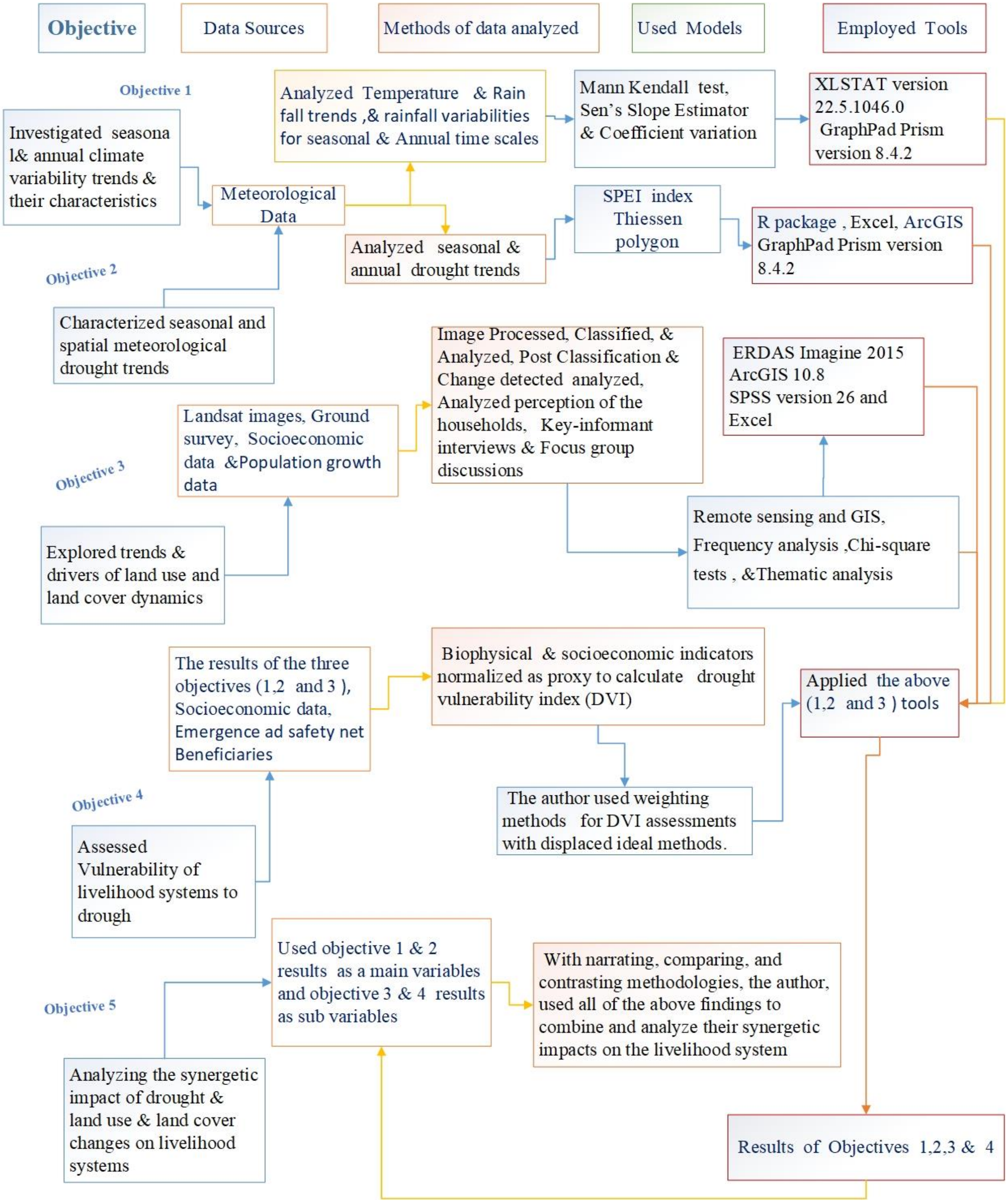


Figure 6.2. Methods and data sets to examine the synergetic impact of drought and land use and land cover changes on livelihood systems

6.2.2. Data Processing, Analysis, and Interpretations

Meteorological Data Analysis

Mann Kendall trend statistical test is used to detect statistically significant daily, monthly, seasonal, and annual climatic variability trends (minimum temperature, maximum temperature, and precipitation) that show decreasing or increasing trends) (Shawul, 2020; Lakshmi & Vani, 2019). Due to the inhomogeneous time series, the Mann-Kendall trend has a low sensitivity to inconsistencies (Mohammad & Goswami, 2019; Vu *et al.,* 2018). Therefore, the author used the Mann Kendall trend statistical test to examine the seasonal (Belg and Kiremt) and annual climate variability trends of the studied LZs from 1983 to 2016. The author applied Sen's slope to see the linear trends of seasonal rainfall and temperature of the study livelihood zones using nonparametric techniques in XLSTAT version 22.5.1046.0 from 1983 to 2016. Further, the study used GraphPad Prism version 8.4.2 software to compare Tmax, Tmin, and rainfall trends across livelihood zones. The author also converted the standard deviation (SD) to a percentage of the mean yields to see coefficient variation (CV) (Koech *et al.,* 2019; Fitto *et al.,* 2017). Further, this study employed Arc GIS with inverse distance weighting for the measured time scales to map the spatial rainfall variability trends during the study year (Belg, Kiremt, and annual).

The Standardized Precipitation Evapotranspiration Index (SPEI), one of the most widely used meteorological drought indices, was used to assess the state of drought incidence in the research area during three months, six months, and annual time scales. SPEI has been widely used to estimate water balances and measure droughts worldwide (Zhang & Shen, 2019). Using the Hargreaves (Hg) equation with the R program, the study runs the PET of this study based on the availability of maximum and minimum temperatures, precipitations, longitude, and latitude data. The spatial and temporal tendencies of the drought were further studied and mapped in ArcGIS. The study interpolated spatial drought patterns using the Inverse Weighting Methods (IDM) technique. Furthermore, this study employed the Thiessen polygon to calculate the exact areas of each meteorological data gird's points. Further, this study used GraphPad Prism version 8.4.2 software to compare drought spatial expansion trends between the three LZs.

Land Use and Land Cover Change Analysis

To analyze Landsat images and perform LULC change analysis, researchers used ERDAS Imagine 2015 and ArcGIS 10.8, respectively. The author corrected geometric errors using the Adindan

Zone 37 of the Universal Transverse Mercator (UTM). Further, a pixel-based image mosaic method is employed to obtain a broader field of view. Supervised pixel-based classification with the maximum likelihood technique created signatures and mapped LULC classes based on ground truths (training areas). Unlike an unsupervised classification system, supervised classification provides more accurate class definitions (Meshesha *et al.*, 2014). In the study area, based on personal observation and earlier research (Gidey *et al.*, 2017a, 2017b) and (FAO, 2020; Watt & Peck,1984), the study classified the land use land cover into 9 with distinct definitions.

The accuracy of the user, the producer, and the total accuracy are measured quantitatively. The study assessed the accuracy of each land use and land cover type using GPS points to quantify post-classification errors. The reliability of the classified LULC based on pixel-to-pixel comparison was validated using Kappa coefficient statistics, producer, user, and overall accuracies for 1985, 2000, 2010, and 2019. The nature of changes, extent, and patterns of one LULC transition to other types was identified using change detection "from-to" cross-tabulation from the succeeding three eras (1985–2000, 2000–2010, and 2010–2019) and overstudy periods (1985-2019). Consequently, an accurate assessment based on error (confusion matrices) of a study year showed the overall accuracy classification of 90.00% with an overall kappa coefficient of 0.888 for each LULC, which is an excellent platform for subsequent analysis of LULC changes.

Analysis of socioeconomic data

The author examined the households' perceptions using frequency analysis to determine proportions and chi-square tests to assess associations using SPSS version 26. Thematic analysis was used for key informant interviews and focus group discussions. Thematic analysis is a technique for analyzing qualitative data that is both flexible and widely utilized. It is a method for understanding experiences, perspectives, or behaviors across data sets in a systematic way (Kiger & Varpio, 2020). The study also gathered population data from the Central Statistical Authority (CSA) of Ethiopia based on the census (1984, 1994, and 2007) and Woreda offices (2017) in the study region to see the population pressure on the community's resource base in the study livelihood zones. Using the formula following Kindu and Schneider (2015) and Mckenna et al. (2019), the population numbers for 1985, 2000, 2010, 2019, and 2024 were extrapolated using the nearest census data and annual growth rates. Available emergence and safety net beneficiaries were collected further from Tigray agricultural office to see the synergetic impacts of drought and LULC change on community food security.

Indicator selection and drought vulnerability analysis

This study compared the three livelihood zones in terms of drought vulnerability components (exposure, sensitivity, and adaptive capacity) and sub-components of drought vulnerability inductors. To measure drought sensitivity, biophysical and socioeconomic indicators were gathered from Scopus indexed journal papers and personal experiences for each drought vulnerability dimension (exposure, susceptibility, and adaptive capacity) (Gupta *et al.,* 2020b; Omerkhil *et al.,* 2020; Shah *et al*., 2013). A total of 128 indicators were chosen based on the essential characteristics of drought vulnerability (39 for exposure, 34 for sensitivity, and 54 for adaptive capability). Besides, these indicators comprised 52(14 for exposure, 15 for sensitivity, and 23 for adaptive capacity) sub-major components depending on their association with exposure, sensitivity, and adaptive capacity. Furthermore, the 52 sub-component indicators were combined into 13 major sub-components, representing the three aspects of drought vulnerability (5 for exposure, 4 for sensitivity, and 4 for adaptive capacity). Five sub-indicators, which refer to climate variability, biophysical, ecosystem, socio-cultural, and Institutional exposures, were composed to measure the exposure index for drought vulnerability. This study further organized four sub-indicators (climate variability, ecosystem, livelihood system, and institutional sensitivity) under sensitivity components. Additionally, the author used livelihood strategy, natural conservation, social network, and coping strategy sub-indicators to quantify the adaptive capacity index for drought vulnerability measurement.

Each indicator was standardized as a proxy indicator for the drought vulnerability index to create an exposure, sensitivity, and adaptive capacity index. After normalizing the variables, the next step in vulnerability assessments is to assign index weight (Xu *et al.,* 2020). For DVI assessments, the study employs weighting techniques (index-based methodologies). The objective weighting approach (index-based methods) establishes the index’s weight based on the data provided by each indicator’s observation value (Zhao *et al*., 2018; Shah *et al*., 2013). The weighted sum of all the relevant indicators for each dimension of each variable makes up the index for the three dimensions of vulnerability (exposure, sensitivity, and adaptive capacity). Drought vulnerability estimation considered the dispersion of exposure, sensitivity, and an adaptive capacity index that emphasized the dispersion property of the indicators and a better system that has less distance from the ideal (Singh, 2020). The distance between the displaced-ideal techniques was determined using Euclidean distance methods (Gupta *et al.*, 2020a; Singh, 2020).

For exposure (E) and sensitivity (S), the Euclidean distance between the ideal and the study system was $(1\text{-}E)^{2}$ and $(1\text{-}S)^{2}$, respectively. However, the difference in adaptive capacity(A) between the ideal and study systems was $(A)^2$ because the adaptive capacity of the most vulnerable system would be zero (Gupta *et al.*, 2020a). The study calculated the system's DVI by considering the study system's departure from the most susceptible state.

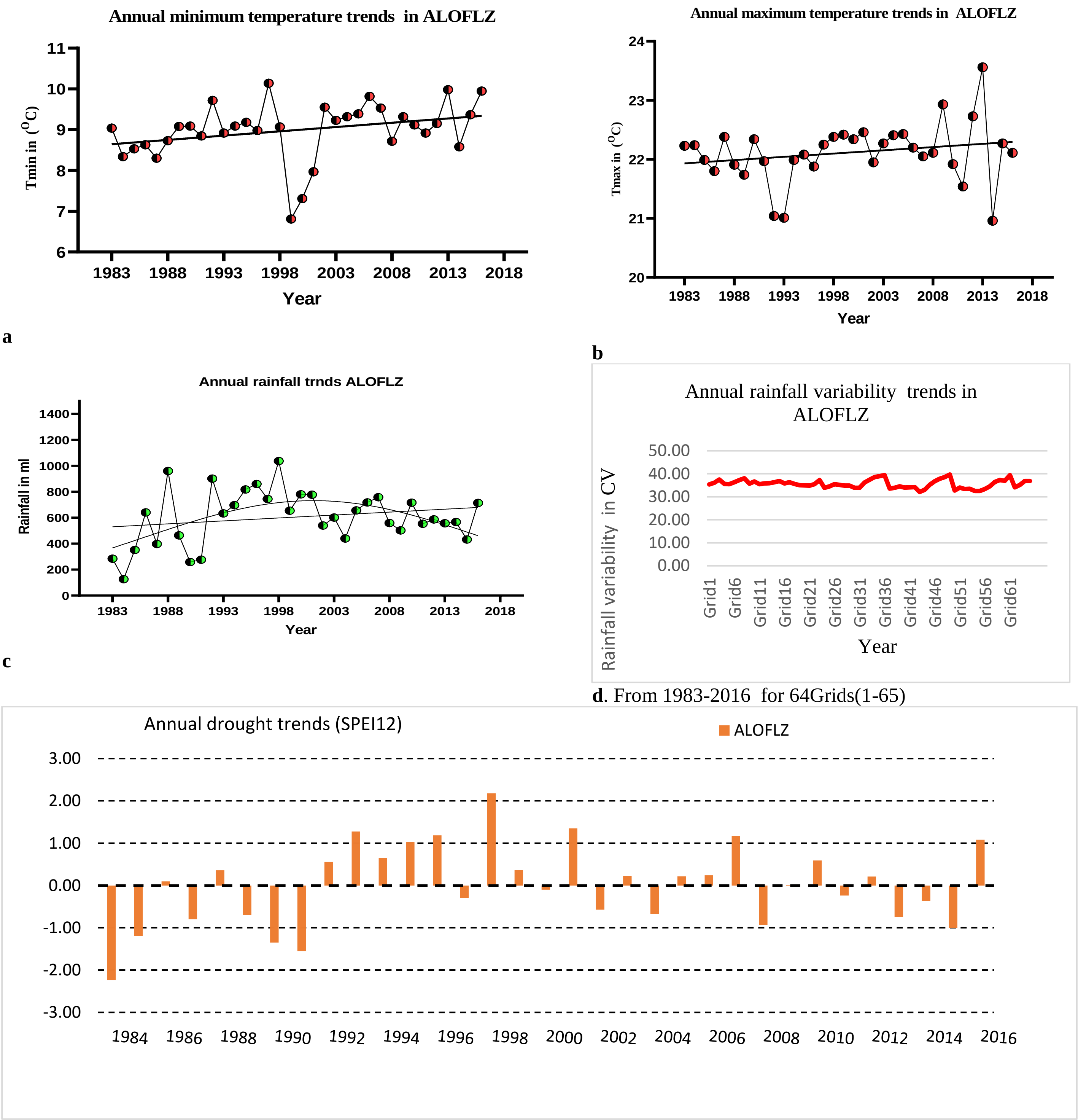
The author used all the above results to integrate and analyze their synergetic impacts on the livelihood system with narration, comparing, and contrasting methods; results are presented in texts, graphs, charts, and maps formats in comparison and integrated ways.

6.3. Results and Discussions

6.3.1. Climate variability and drought trends

As seen in Figure 6.3 -6.5 (**a**), annual Tmin showed a statistically significant trend in all study LZ (from 0.32 °C in ALOFLZ to 0.27 °C in RVLZ). Furthermore, the TCLZ (Figure 6.4b) and RVLZ (Figure 6.5b) recorded the statistical significance of annual Tmax (0.32°C and 0.42°C), respectively. Also, this study discovered significant and highly severe yearly rainfall variability, ranging from 32-35 % and 31–50 % at the livelihood zone and grid levels, respectively (Figure 6.3- 6.5(**c**)). This finding revealed that rainfall variability trends were positively related to temperature trends in the study areas. At grid and livelihood zone levels, TCLZ had more yearly spatial rainfall followed by ALOFLZ than RVLZ. However, the annual rainfall of the study livelihood zones did not indicate any significant positive or negative changes trends during the study periods (Figure 6.3- 6.5 (**d**)).

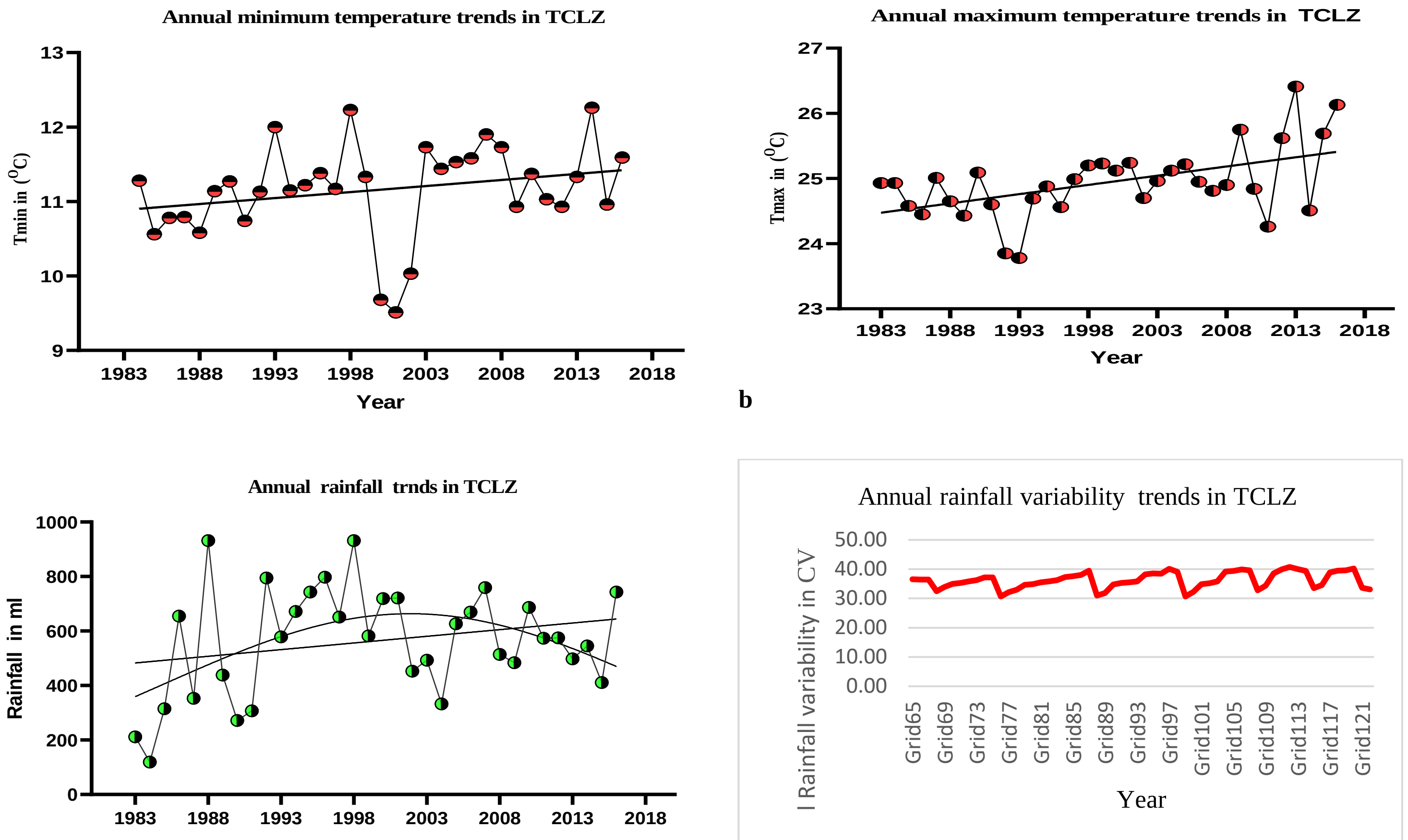
As a result, from 1984 to 2016, the increasing temperature trends combined with declining rainfall trends, high rainfall variability, and anthropogenic factors (e.g., LULC change) were consequences of fourteen mild to extreme severity drought years in all the study LZs (Figure 6.3- 6.5(**e**)). Drought was revisited annually with 2.13, 2.2, and 2.13 interval years in ALOFLZ, TCLZ, and RVLZ, respectively. Once drought occurred, it lasted 1.5, 1.9, and 1.7 years in ALOFLZ, TCLZ, and RVLZ. From 1984 to 1998, ALOFLZ and TCLZ experienced more severe yearly droughts than RVLZ (Figure 6.10a).



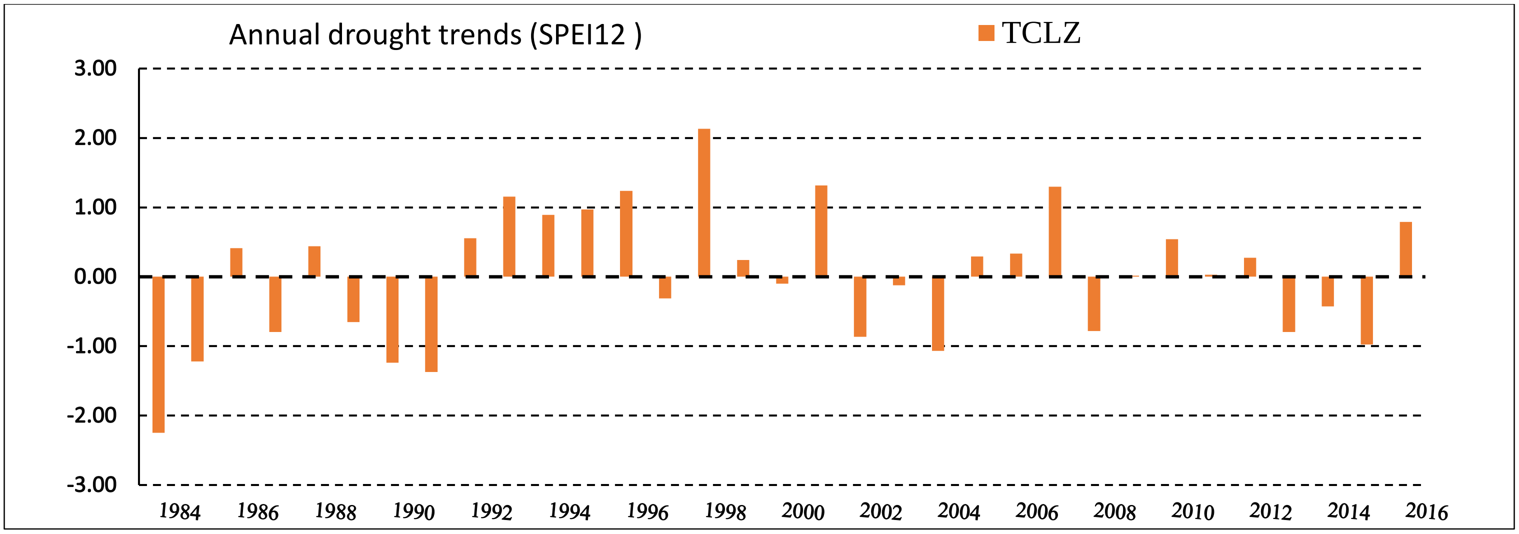
d. From 1983-2016 for 64Grids(1-65)

e

Figure 6.3. Trends of annual Tmin, Tmax, rainfall, and rainfall variability in ALOFLZ from 1983 to 2016

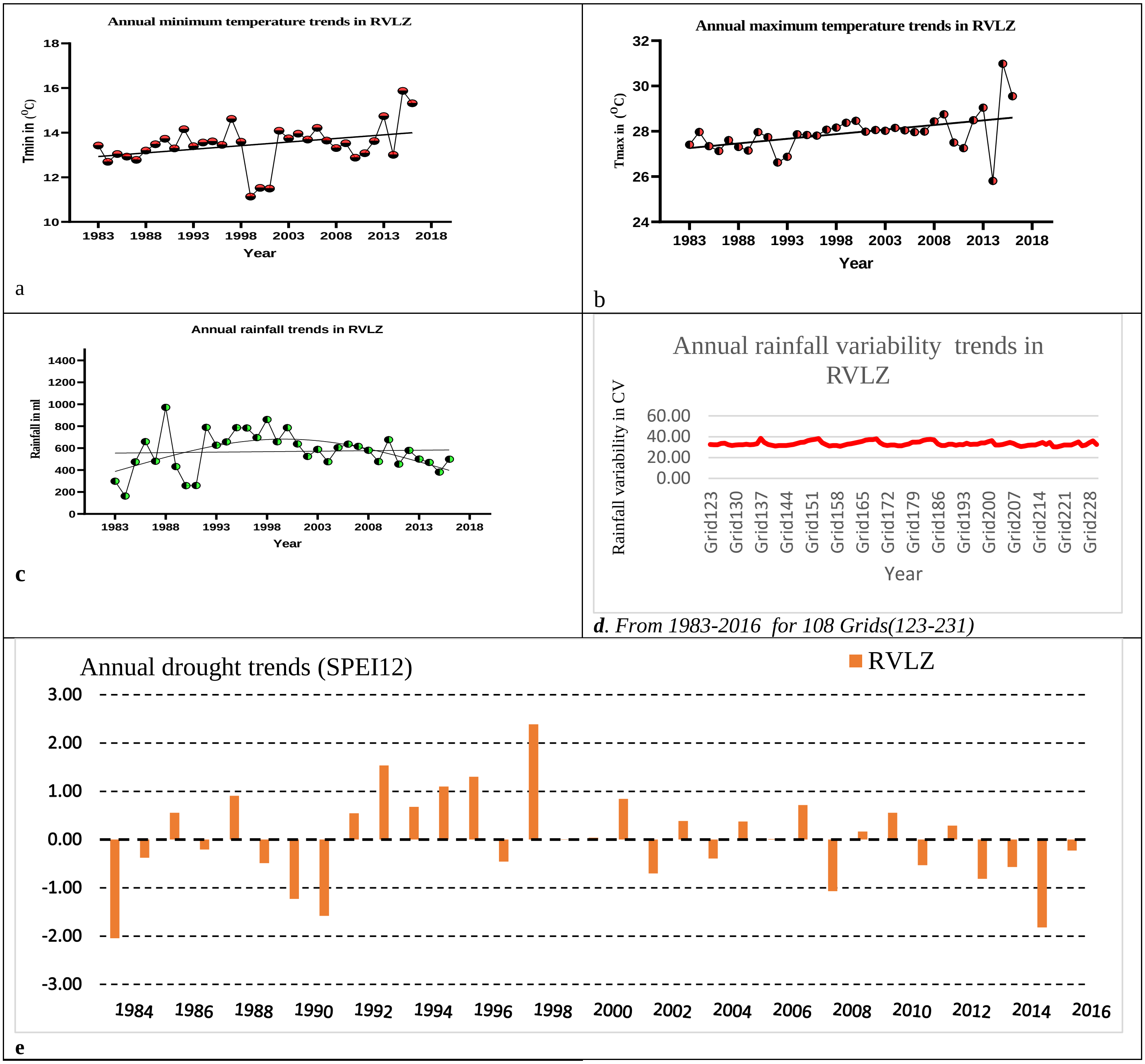


d. From 1983-2016 for 57 Grids (65-122)



e

Figure 6.4. Trends of Annual Tmin, Tmax, rainfall, and rainfall variability in TCLZ from 1983 to 2016



***d**. From 1983-2016 for 108 Grids(123-231)*

Figure 6.5. Trends of annual Tmin, Tmax, rainfall, and rainfall variability in RVLZ from 1983 to 2016

Belg climate variability and drought trends

Seasonally, the Belg Tmax increased significantly (from 0.30 to 0.43 °C) in all study LZs (Nasir *et al.*, 2021b). Tmin, on the other hand, showed a non-significant however and positive trend in all study LZs during this season. Rainfall in the Belg season showed declining trends, which is the foundation for farming and a source of moisture for local ecosystems. Subsequently, the significantly increased temperature in Belg associated with decreasing rainfall trends consequences extreme rainfall variabilities recorded from 64% to 70 % at livelihood zones and from 57% to 99% at grid levels coefficient versions across all LZs (Figure 6.6a). The rainfall variability in the Belg is more severe than in Kirem (Figure 6.6b) and annual time scales (Figure 6.4c). The TCLZ had relatively higher Belg rainfall variability, followed by RVLZ and ALOFLZ (Nasir *et al.,* 2021b).

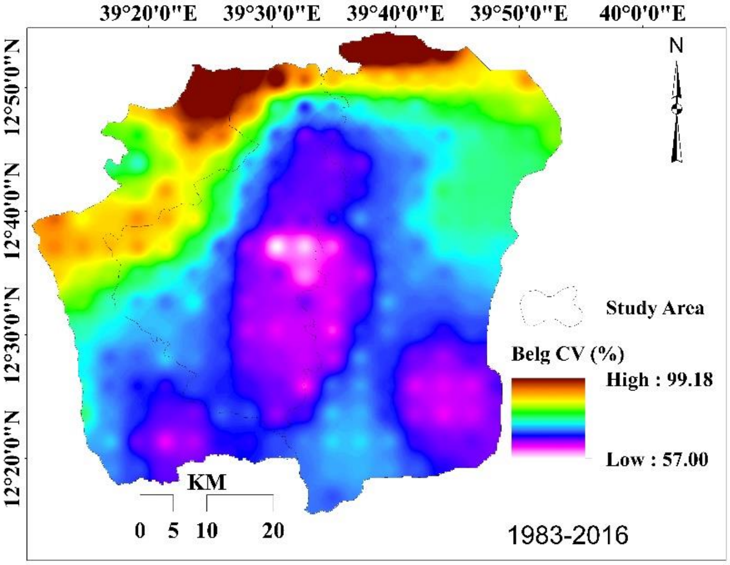
Drought is prevalent in all livelihood zones due to rising temperature trends, falling rainfall in spatial and temporal patterns, extreme rainfall variability, and human-caused consequences. Over the study years, drought trends in the Belg have consistently increased in all LZs, both temporally and spatially, with a slight difference between livelihood zones. From 1998 to 2004 and 2012 to 2016, the Belg drought persisted for seven and five years. There have been 18 mild to severe Belg droughts during the study years in the three LZs. Since 1998, drought occurrences have become more common in this season across the study LZs. The frequencies of periodic drought for Belg had increased with 1.82, 1.77, and 1.6 interval years in ALOFLZ, TCLZ, and RVLZ, respectively. The drought in ALOFLZ, TCLZ, and RVLZ lasted 1.4, 2, and 1.8 years during the Belg season.

Kiremt Climate variability and drought trends

Furthermore, the Tmax demonstrated non-significant positive trends in TCLZ and RVLZ in Kiremt rainy season. However, the Tmax in ALOFLZ displays negative but not statistically significant trends during the season. On the other hand, the study discovered statistically significant positive rainfall changes in RVLZ and TCLZ during the Kiremt rainy season (Figure 6.6b). Despite increasing rainfall trends in RVLZ and TCLZ, the author found extreme rainfall variability in all livelihood zones studied (44.3 % to 49.81 % at livelihood zones and 39.34 % to 49.81 %at grid levels) (Nasir *et al.* 2021b). From these contradicting trends (increasing temperature, increasing rainfall, and increasing rainfall variability), the author argued that the rainfall was concentrated for months or weeks rather than properly distributed temporally and spatially within this rainy season. As a result, while the total amount of rain does not guarantee drought occurrence, rainfall consistent with temporal and spatial distribution is critical for drought incidences.

Over the study years (1983–2016), the combined effects of maximum temperature, unevenly temporal and spatial rainfall distribution trends, extreme rainfall variability, and other anthropogenic factors were consequences of twelve mild to highly severe droughts in kiremt season across all study LZs (Nasir et al. 2021a). Between 1983 and 1993, high drought severity, persistence, and frequent events happened in all LZs. Over the study years, drought in the Kiremt season was revisited with 2.36, 2.27, and 2.54 intervals in ALOFLZ, TCLZ, and RVLZ, respectively. The drought lasted 1.3, 1.4, and 1.5 years in ALOFLZ, TCLZ, and RVLZ, respectively, once it started in the Kiremt season throughout the research years.

There were yearly Kiremt, Belg, or both season droughts in grids or livelihood zone levels. Extreme drought frequency and persistence decreased in the Kiremt season, whereas moderate to mild drought frequency increased in all livelihood zones. Even though droughts decreased from 2001 to 2016, seven wet Kiremt seasons were recorded with SPEI values below 0.5, indicating mild wet (Nasir et al. 2021a). For agricultural purposes, this precipitation value was too low. Drought incidences in this season, becoming locally fragmented even at village levels.



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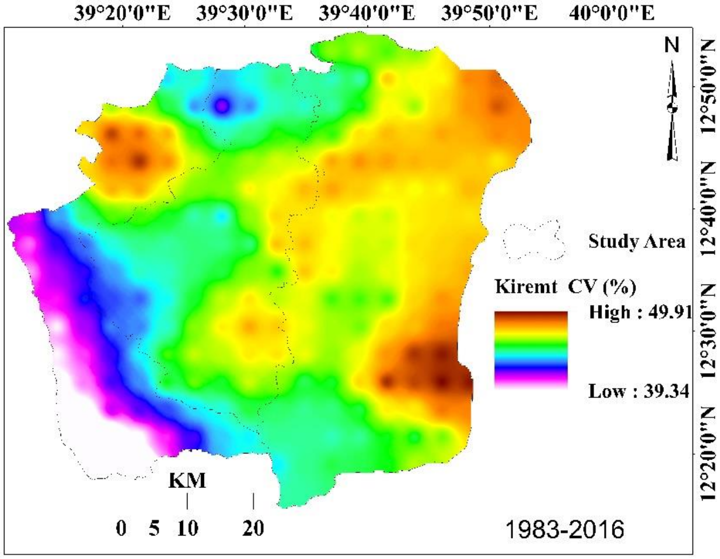

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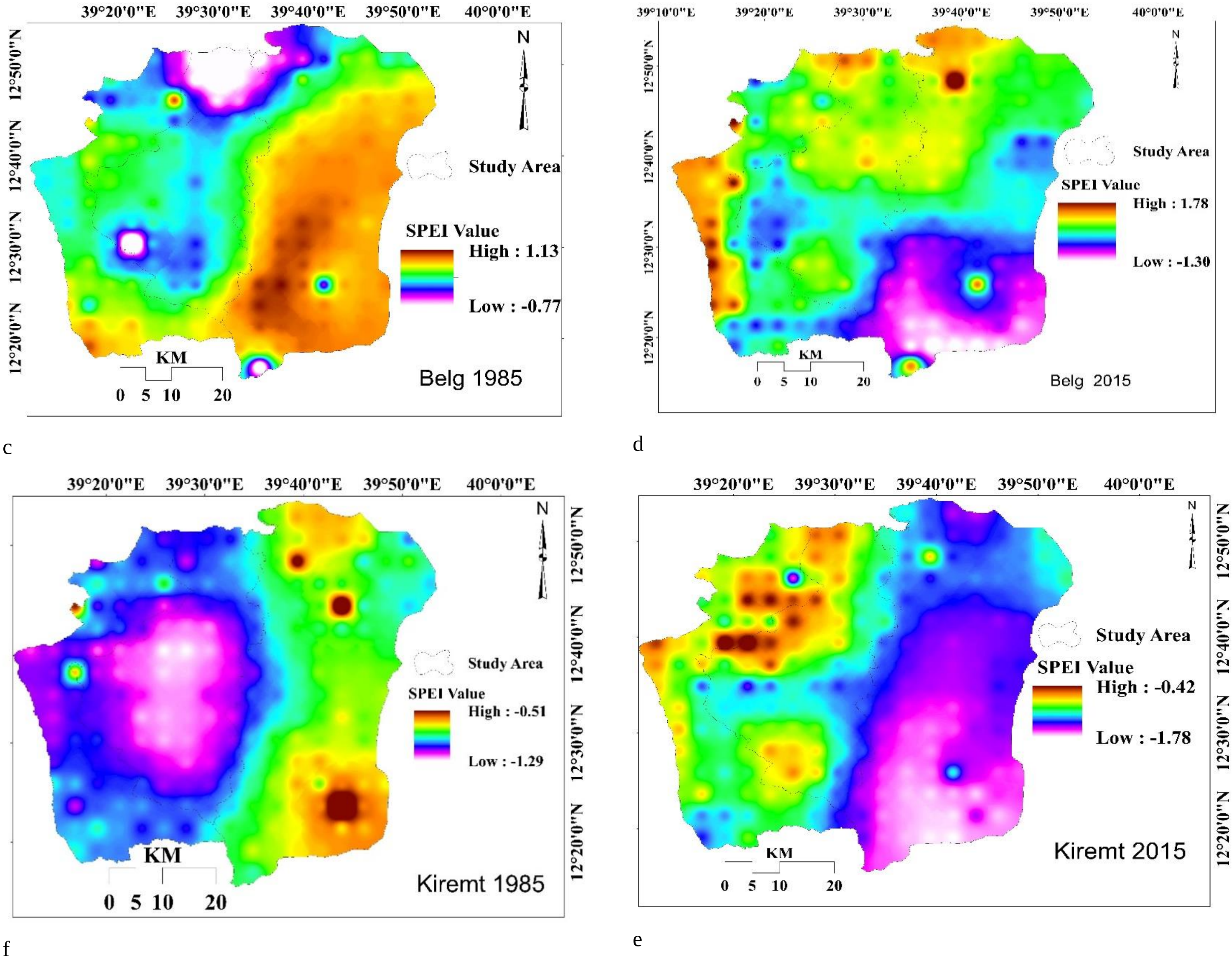


Figure 6.6. Trends rainfall variability from 1983–2016 and spatial drought comparison between 1985 and 206 for Belg and Kiremt rainy season

6.3.2. Land use and land cover change trends

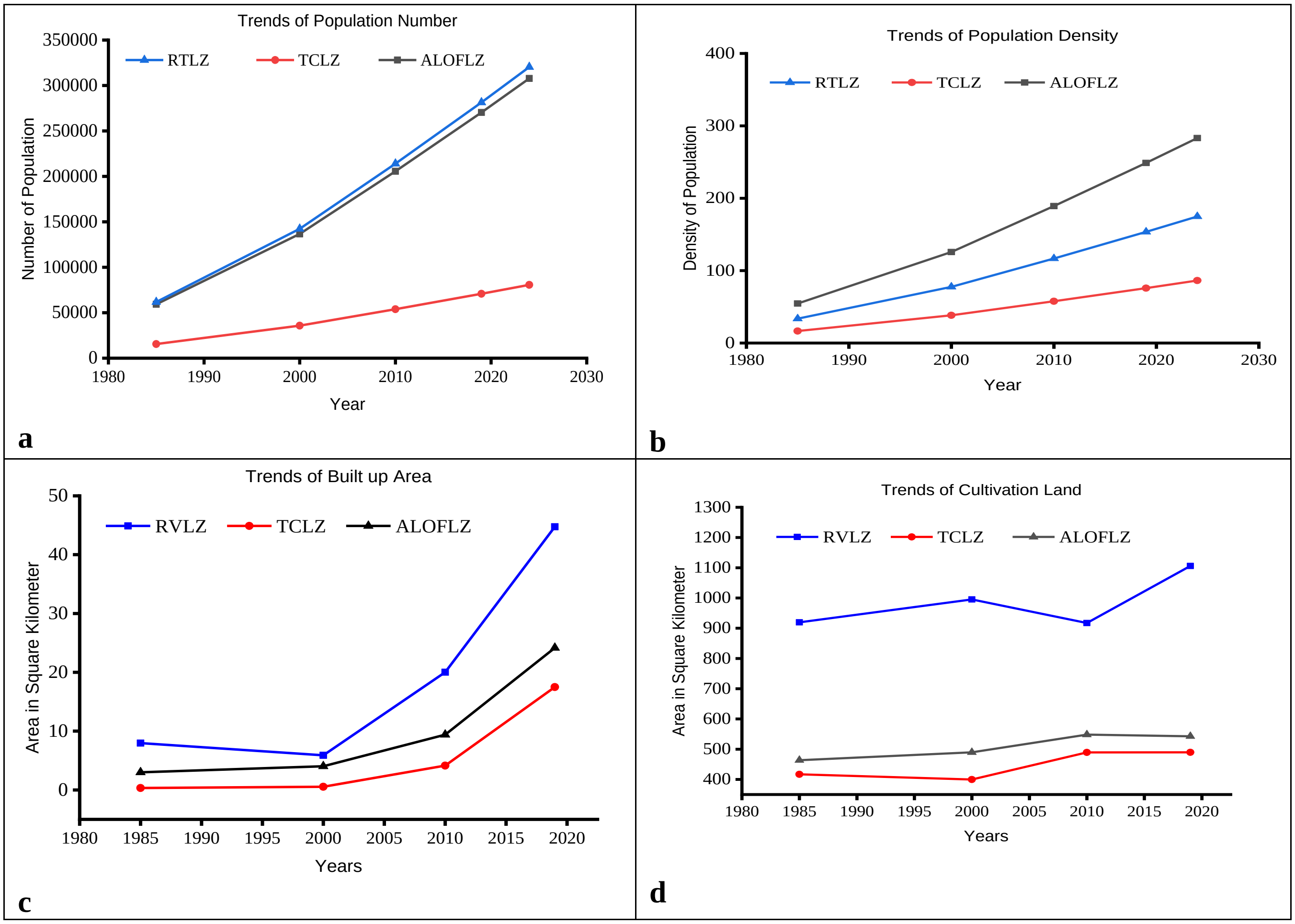
Nine LULC classes were analyzed using the supervised technique and the maximum likelihood classification system in the three studies LZs. In all study LZs, CL was the dominant LULC type throughout the study years. However, the trends of CL within the study LZs were not straight through the study years. The second dominant LULC type in all LZ and over the study years was SBL. The third dominant LULC class in RVLZ and ALOFLZ was FL throughout the study years for a detailed visit (Nasir *et al.* 2022b). This study further analyzed LULC change in the three drought-prone livelihood zones. The author revealed rapid LULC change trends throughout the research years in all studied LZs. Cultivation land (Figure 6.**d**) and the built-up area (Figure 6.7**c**) in all LZs and flood plains (Figure 6.7**g**) in RVLZ and TCLZ showed rapid increasing trends. From the total gained 177.10, 159.19, and 372.34 Km^2 of cultivation land, about 171.21 Km^2 (97%), 150.83 Km^2 (95%), and 364.36 Km^2 (98%) of the area were derived from natural source areas (SBL, FL, and GL) conversions in ALOFLZ, TCLZ, and RVLZ respectively. Similarly, from the net gain of 22.81, 17.47, and 42.49 Km^2 of built-up area, about 14.12 Km^2 (62%), 12.44 Km^2 (71%), and 18.38 Km^2 (43%) Km^2 of it were derived from the conversion of the above natural areas in ALOFLZ, TCLZ and RVLZ respectively. Flood plain also derived about 4.77, 12.62, and 30.17 Km^2 from 1985 to 2019 in ALOFLZ, TCLZ, and RVLZ, respectively. TCLZ gained 5.14 and 7.46 Km^2 FP, while RVLZ gained 19.31 and 18.56 Km^2 FP from the natural areas and CL, respectively.

Similarly, all LZs significantly reduced shrub and bushland covers (Figure 6.7**e**). In addition, grassland (Figure 6.7**f**) in RVLZ and ALOFLZ has decreased dramatically. Over the study 34 years (1985-2019), 257.51 Km^2 in ALOFLZ, 182.15 Km^2 in TCLZ, and 483.59 Km^2 in RVLZ of natural area (SBL, FL, and GL) were changed into other LULC types, respectively (Figure 6.7**e,f & g**). The study results show that 82%, 72%, and 77% of RVLZ, ALOFLZ, and TCLZ LULC types changed between classified LULC types. Except for wetland and water bodies, all LULC change trends with the population trends presented in Figure 6.7. These trends indicated no climaxes or stabilization of LULC types within the study years in all LZs.

The focus groups and key informant interviews revealed that the population of all studied LZs expanded considerably over the study years. Natural resources in the study livelihood zone are under stress due to rapid population growth. Population pressure in ALOFLZ and TCLZ was coming from the expansion of the internal population, according to the FGD participants and KII findings. The RVLZ, on the other hand, was being squeezed by both population growth and surrounding immigrants (Figure 6.7**a & b)**. According to the KII perspective of the study of three LZs, another cause of LULC changes was rapid settlement expansion and infrastructure developments in recent years. The findings of the spatial data (Figure 6.7**c &d)** back up the viewpoints of FGD participants and key informant interviews on settlement expansion. The spatial data findings corroborate the perspectives of FGD participants and KII on settlement expansion. The settlement expansion's rapid growth came at the expense of natural resources.

According to data from KII and all (four) focus groups, farmland is expanding in all study LZs, similar to settlement patterns. According to KII reports, thousands of hectares in the RVLZ's northern parts have been cultivated. Investors in RVLZ displaced and dispossessed farmers from their farmland and settlements without appropriate compensation and alternative farmland. Further, severe problems with grazing lands affected livestock sectors, aggravated climate change, disrupted rainfall patterns, brought conflict interests, affecting fuelwood resources and forest ecosystems. There were issues with land redistribution in the sloppy area in ALOFLZ and TCLZ. In all study LZs, according to the FGD, there is no appropriate land management.

Moreover, FGD participants in all LZs examined how land distribution for youth influences local climatic patterns and has implications such as deforestation, grazing land shrinkage, and land degradation. Participants are concerned that future droughts will be more frequent and severe. They are worried that it will have long-term effects on their area's agro-climatic zone and the soil fertility of their farmlands.



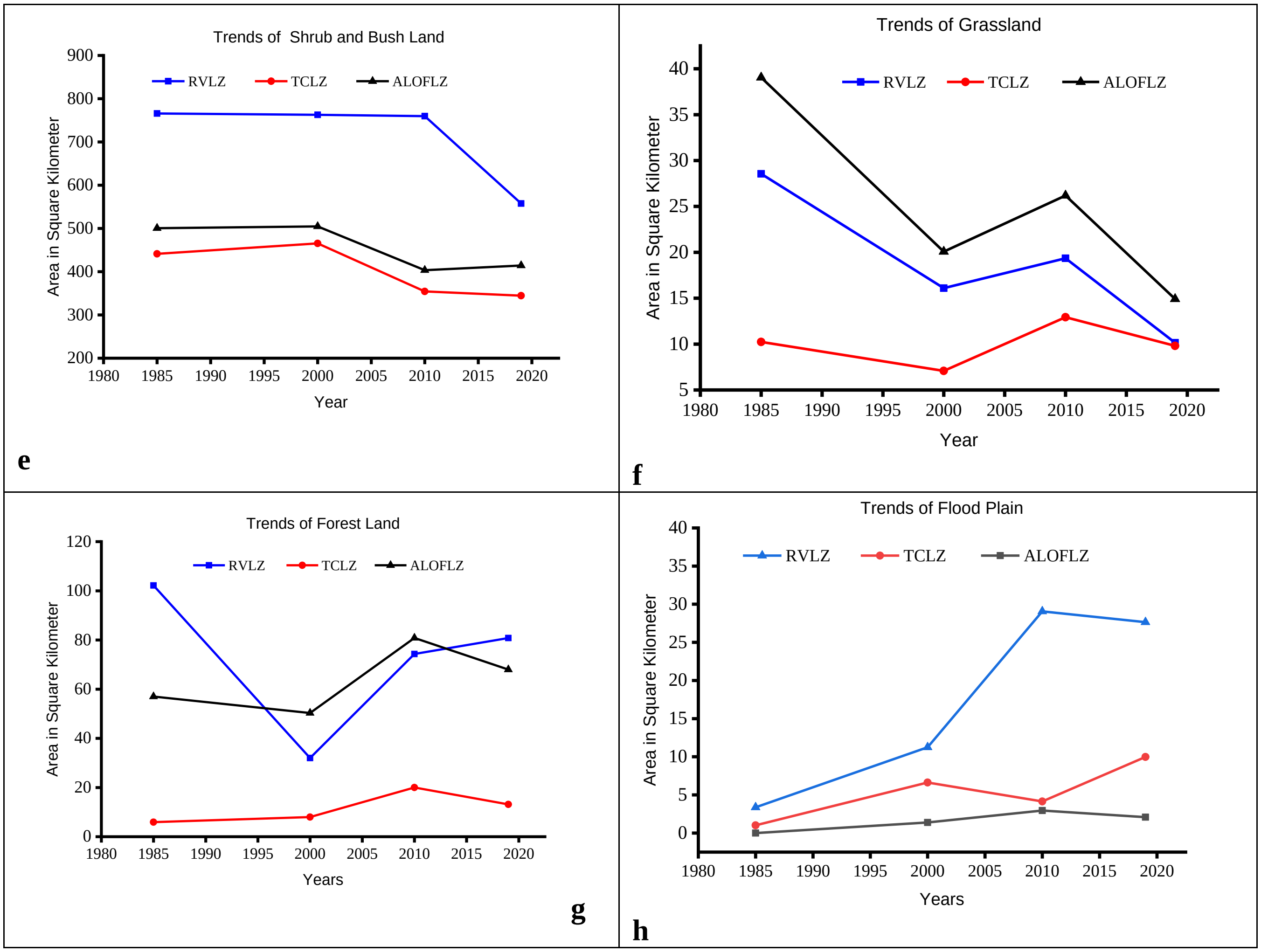


Figure 6.7. Land use and land cover change trends from 1985 to 2019, and population growth and density trends from 1985 to 2024

6.3.3. Drought vulnerability patterns

This study discovered that all drought vulnerability components differ across study livelihood zones. All of the study LZs' composite drought vulnerability indexes suggest that all the study LZs are highly vulnerable to drought impacts (Nasir *et al.*, 2022a). The RVLZ is relatively more susceptible to drought (0.65) than the TCLZ (0.63) and ALOFLZ (0.60) (Figure 6.8). The study observed drought vulnerability differences between the studied livelihood zones because the livelihood zones varied in exposures, sensitivities, and adaptive capacities. According to the exposure index, the RVLZ has more significant exposure to drought impacts and associated hazards than the other two (Figure 6.10**a**).

The RVLZ has a lower adaptive ability than the ALOFLZ and is more vulnerable to drought threats than the other two LZs. As an outcome, drought poses a more significant threat to the RVLZ than TCLZ and ALOFLZ. Per the RVLZ index values, the community is most vulnerable to institutional constraints, followed by biophysical hazards, ecosystem disturbances, socio-cultural consequences, and climate variability trends. However, the sub-indicator index values sensitivity show that communities in the RVLZ are the most vulnerable to climatic variability, followed by livelihood system, institutional, and environmental sensitivity.

TCLZ has the lowest resilience in natural conservations, followed by the coping approach, social networks, and livelihood strategy. Furthermore, the TCLZ has a lower adaptation potential than the livelihood zones of Raya Valley and Alagie Ofla (Figures 6.8 & 6.10a). The LZ is more vulnerable and subject to drought threats than Alagie Ofla's livelihood zones. Biophysical risks are the most prevalent in the TCLZ, followed by sensitive socio-cultural practices, climate-related risks, institutional constraints, and ecological disruption. On the other hand, communities in the LZ are particularly vulnerable to climate change, environmental alterations, inadequate livelihood systems, and institutional sensitivities.

Furthermore, while the Allagie-Ofla livelihood zone is less drought vulnerable than the RVLZ and TCLZ, it has a lower adaptation capacity and is more susceptible to drought events and associated dangers. The LZ has higher biophysical exposure (Figure 6.8), followed by socio-cultural, ecosystem disturbances, climate variability events, and institutional restrictions, according to the index values of sub-indicators in the ALOFLZ. Communities in the ALOFLZ, on the other hand, are more vulnerable to poor institutional services, a frail livelihood system, environmental sensitivity, and climate variability. Furthermore, the LZ was the least robust in nature conservation, trailed by the coping method, weak social networks, and a susceptible livelihood strategy.

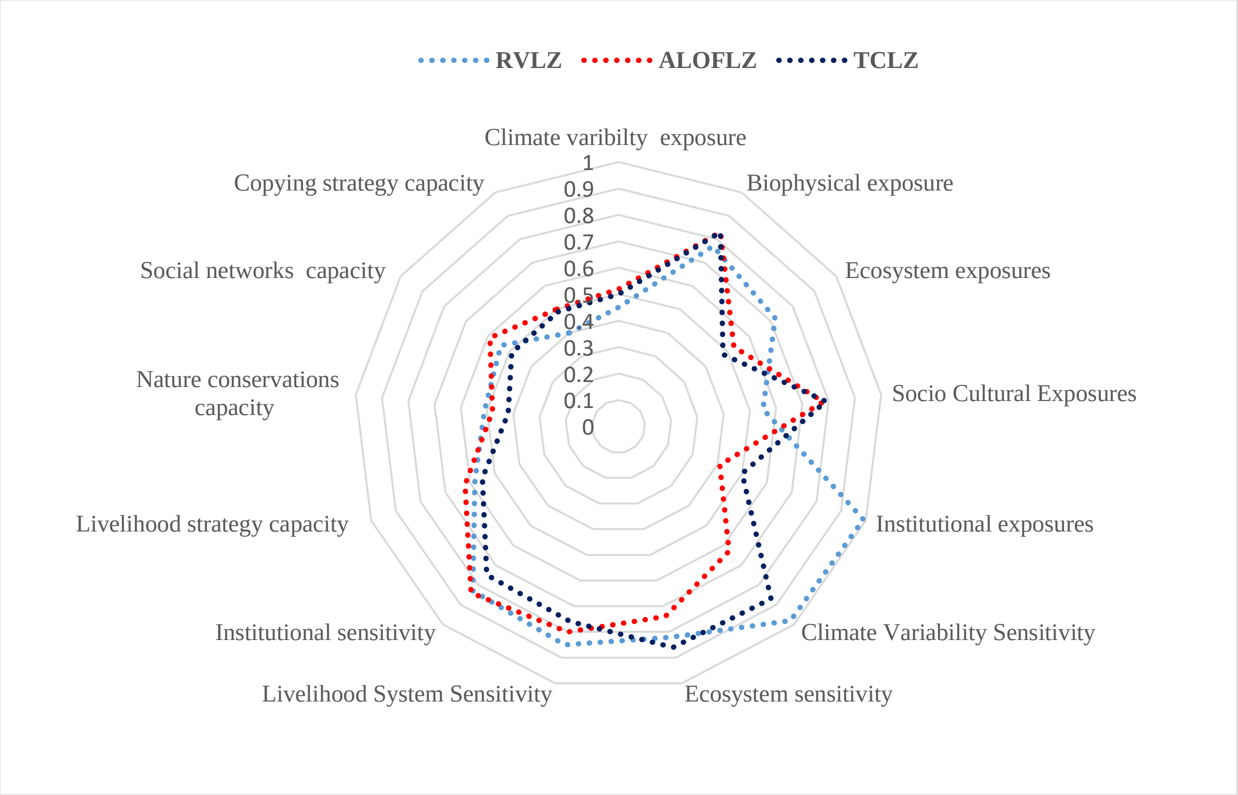


Figure 6.8. Radar diagram of drought vulnerability sub-indicators across the study livelihood zones. Adopted from *Nasir et al. (2022a)*

6.3.4. The summary of the synergic results

The results show consistency between temperature trends, rainfall variability, drought occurrences, LULC change trends, and drought vulnerabilities patterns of the study LZs. However, the study LZs did not have the same exposure, trends, or magnitude of temperature changes (Nasir *et al.* 2021b). The study found that temperatures rose, and rainfall was erratic, varying seasonal and annual timescales. All study LZs showed significant and non-significant Tmin and Tmax trends at measured time scales. However, yearly rainfall trends did not indicate substantial positive or negative changes. This research also revealed that rainfall in all study LZs and grid-wise levels were erratic and varied in seasonal and annual time frames (Figure 6.9**e**). All LZs experienced significant and severe seasonal and yearly rainfall fluctuation.

From this contradicting trend (increasing temperature, increasing Kiremt rainfall (RVLZ), and increasing rainfall variability) results, the author argued that the intensive rainfall was concentrated for months or weeks rather than properly distributed temporally and spatially through the study LZs. The surveyed households were asked about their climate variability sensitivity (decreasing rainfall trends, increasing temperature trends, declining rainfall coverage in the rainy season, disrupting rainfall time, frequencies of erratic rainfall) in their LZs. The household respondents of the RVLZ, AOLZ and TLCZ (99.3 %, 80.4%, and 82.6%) considered temperature warming within their area, respectively. The respondents also argued that distribution, intensity, onset, and the termination of the rainy season are changed. According to the respondents, key informants, and FGD participants, in the past decades, Belg (spring) rain season started in mid-February and terminated in late May. They also explained that the Kiremt rain started mid-Jun and ended in early September. However, they claimed that recent rainfall coverage has become fragmented, late-onset, early-termination, and partially distributed across small-scale areas. The Belg rain has arrived at the end of April in the last ten years, while the Kiremt (summer) rain has begun at the end of July, especially in RVLZ and TCLZ. Furthermore, rainfall variability trends within inter-seasonal and inter-annual CV varied spatially between and within LZs. Seasonal and yearly increasing temperatures and high rainfall fluctuations (Figure 6.9) resulted in frequent seasonal and annual droughts.

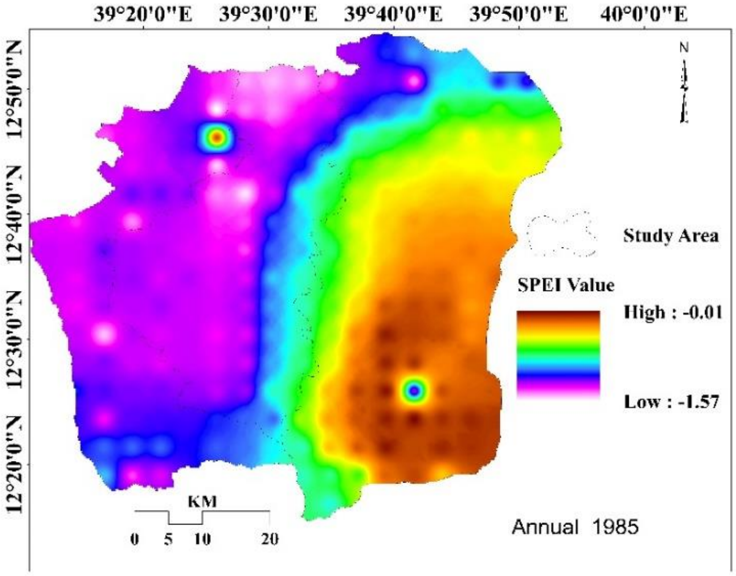
The author observed the effects of climate variability on drought inducement within and along the study livelihood zones. These rapidly increasing temperatures accompany erratic and fragmented rainfall in spatial and temporal patterns, extreme rainfall variability, and human-induced impacts of frequent drought in all livelihood zones. Drought exposures have a positive functional association with high rainfall variation (Murthy *et al.* 2015), exacerbating drought vulnerabilities at the LZ level. This study uncovers seasonal and annual recurrent droughts that vary in intensity, frequency, and duration within and between livelihood zones. This result coincides with the Zhao et al. (2018) findings that revealed an increased precipitation pattern had an inverse relationship with drought vulnerability in their study area.

The demand for land is increasing each year due to population pressures. This study examined the changes in LULC in three livelihood zones of drought-prone areas. Population pressures from lack of alternative income sources and fuelwood demands for household consumption, lack of appropriate land use mechanisms, land demands for agriculture and settlement, disruption of local climate patterns, and frequent droughts were among the LULC change driving factors in all LZs.

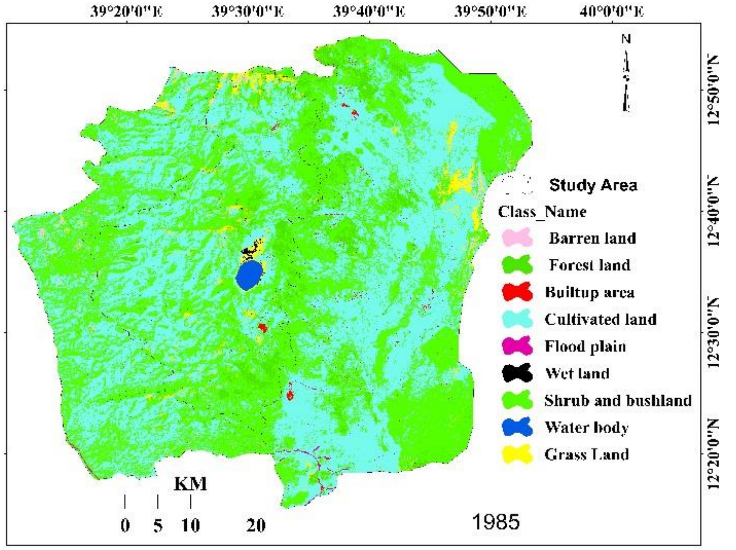
The study observed how human activities affect productivity, change weather systems, and exacerbate environmental degradation, desertification, and biodiversity loss. The changes will have long-term consequences for community livelihood systems that rely on rain-fed systems and their fundamentals in studying livelihood systems. These combined climate variabilities with rapid and disrupting the ecosystems of the study LZs imply possible drought risks and instability of land-use systems that can impact agricultural productivities and forage growth and climate systems of the study areas. However, the overall land use and land cover detection analysis revealed that RVLZs shifted more quickly than ALOFLZs and TCLZs. Because of this, RVLZ has more significant ecosystem disruptions than ALOFLZ and TCLZ.

The author compared rainfall variability and drought occurrences with LULC change trends using two reference years (1985 and 2019) (Figure 6.9). In 1985, the natural vegetation cover in RVLZ was healthier, and drought intensities and geographical distribution were better (Figure 6.9**a** & **b**). However, the author discovered significantly diminished natural vegetation trends when comparing the 2019 maps (Figure 6.9**d**) to the 1985 maps in RVLZ (Figure 6.9**b**). As the maps indicate, drought effects (Figure 6.9c) and LULC change (Figure 6.9d) had feedback loops. No LULC types reached a climax within the research years or stabilized LZs. Therefore, if there is no climax and stabilized ecosystem, the ecosystem service cannot support natural ecosystem cycles and human needs. A continuously disrupted ecosystem is more exposed to drought hazards that result in local climate system disturbances and affect the agricultural productivity of LZs in the study.

The results show that the study's LZs are highly vulnerable to drought impacts due to the incredible exposition levels, susceptibility, and inadequate adaptive capacity. The RVLZ is relatively more susceptible to drought than the TCLZ and ALOFLZ. As presented in (Figure 6.10b), annually (2000 to 2018), about 31% (56764) in RVLZ, 9 % (15322) in ALOFLZ, and 56% (24705) in TCLZ were recorded as emergence beneficiaries since they were more vulnerable to drought. Similarly, from 2005 to 2019, annually, about 43 %(92299) in RVLZ, 24 %(50676) in ALOFLZ, and 39% (21311) in TCLZ of the total population were safety net program beneficiaries because of less resilience (Figure 6.9**c**). This result coincides with climate variability trends, drought frequencies, LULC change trends, and the drought vulnerability of the study livelihood zones. TCLZ has less adaptive capacity than RVLZ and ALOFLZ; similarly, the study area emergency beneficiaries are more (in %) in TCLZ followed by RVLZ. On the other hand, RVLZ is affected by high climate variability that consequences more drought occurrences, combined with high disturbance of LULC change and more drought vulnerability areas (Figure 6.10a). The synergy impacts followed about 62% of the RVLZ population food insured and waiting for relief support from emergency and safety net programs every year in the past twenty years.



a



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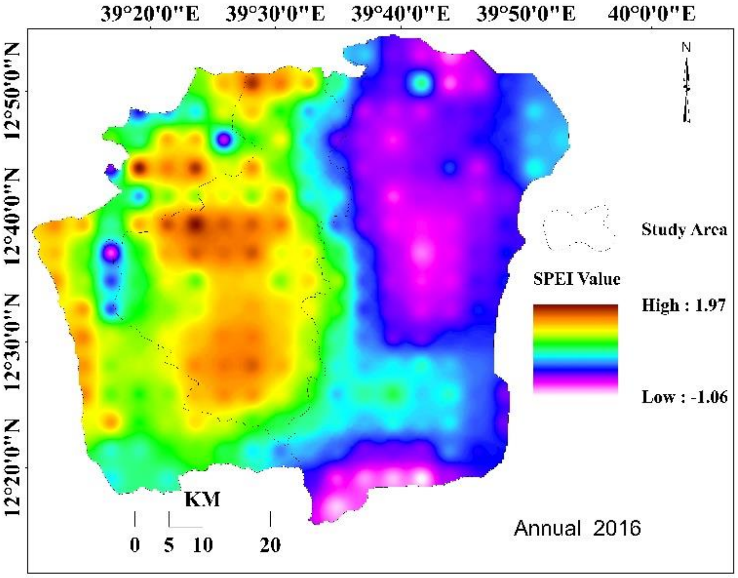

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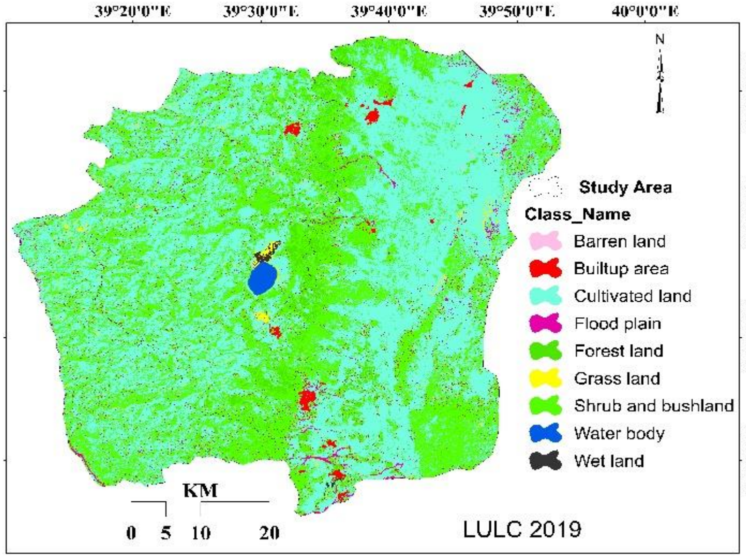

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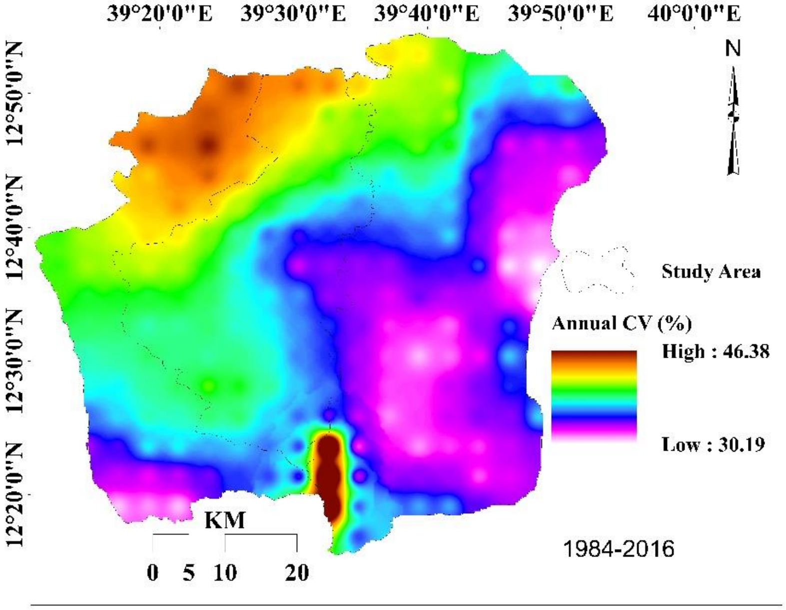
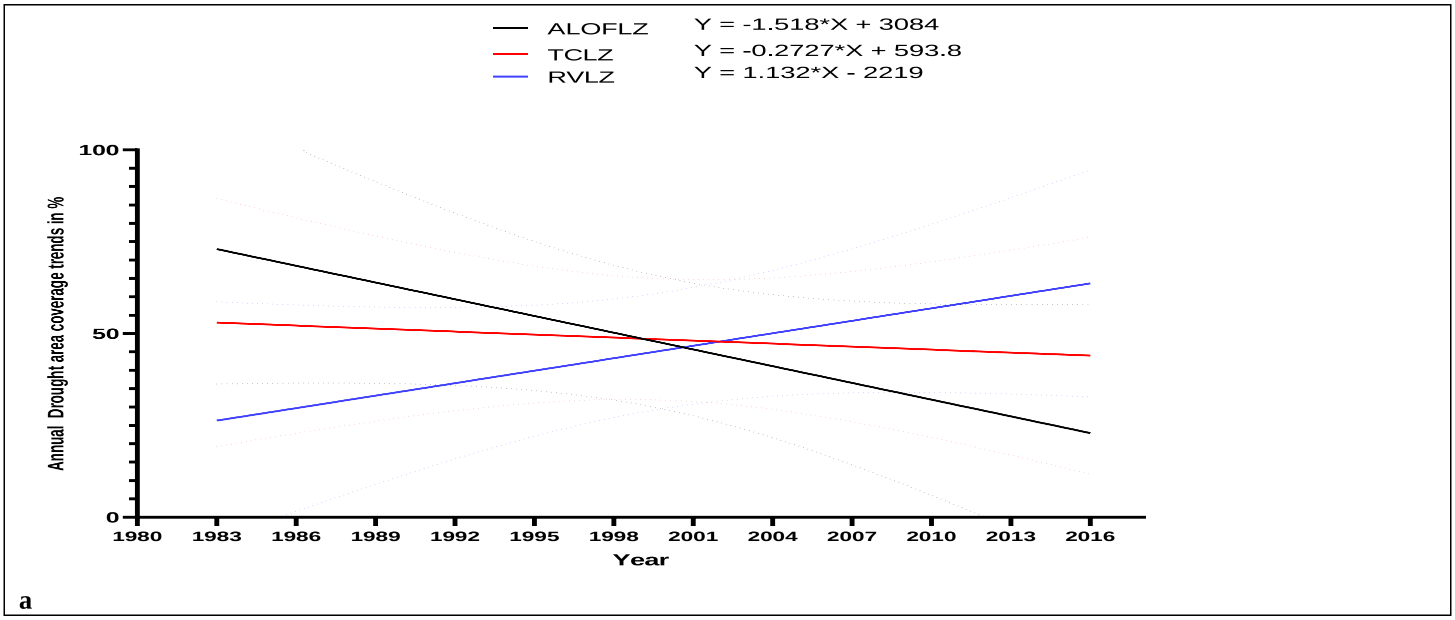


e

Figure 6.9. Drought (a &c) and land use and land cover changes (b & d) for 1985 and 2018 and trends of rainfall variability from 1983–2016(e)



a

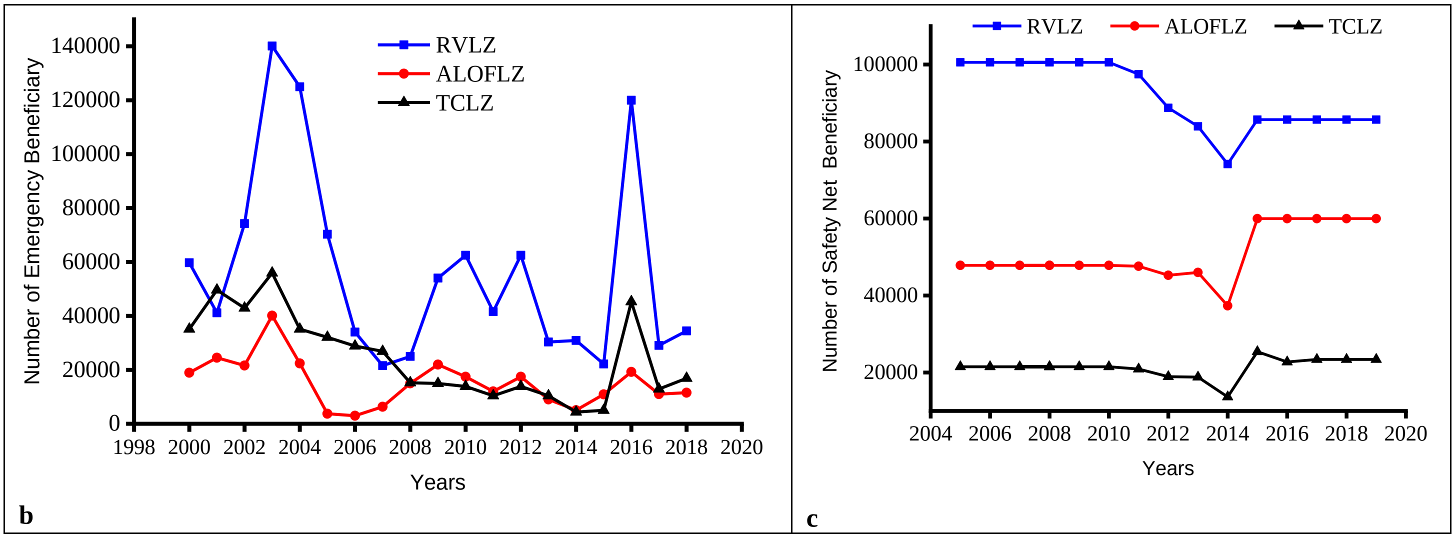


Figure 6.10. Annual spatial drought trends from 1984 to 2016 (a), number of emergency beneficiaries from 2000 to 2018(b) number of safety net beneficiaries from 2005 to 2019(c)

6.3.5. Synergetic Impacts on Livelihood Systems

Implications on water sources

Warming temperatures, erratic and extreme rainfall variability, frequent droughts, rapid LULC change, and other internal and external pressures contributed to serious water problems in the study LZs. LULC change has accelerated runoffs, aggravated land degradations, caused climate change, and affected rain patterns. Dibaba et al. (2020) revealed similar findings, stating that the main effects of LULC change in Finchaa Catchment have decreased productivity, biodiversity loss, extended aridity and drought, land and soil degradation, and water resource scarcity. Respondents between and within LZs had different perspectives on the magnitude of drought impacts and LULC change impacts on water resources in their perspective LZ. Due to increased rainfall coverage during good wet seasons before 2000, RVLZ respondents showed they had comparatively low water stress. However, TCLZ and ALOLZ respondents perceived they experienced severe water stress in a similar study period. Their perception is backed up by the study LZs' drought history and LULC change trends. Furthermore, since 2000, respondents in RVLZ have faced high water stress for their farmlands. However, water stress becomes moderate in ALOFLZ.

Implication on natural vegetation and further consequences

Landsat images and socioeconomic data revealed that deforestation from farmland and settlements expansion is alarming in all study LZs. However, natural vegetation shrinkage was significantly different between the three LZs. The FGD participants in RVLZ perceived the communal natural areas converted in their LZ. As FGD participants in RVLZ mentioned, except for state forest area and area closures, there has been no commonality in forest and area closures since 2015. Since 1983, the indigenous tree in TCLZ has been lost and replaced with plantations, according to FGD participants. Participants stated that the current young generation could not identify the early endogenous tree of the LZs. However, respondents in ALOFLZ have different perceptions of the deforestation rate in all study interval years. Due to differences in age (experiences), degree of awareness (education levels), and reliance on forests (income source), ALOFLZ respondents have differing perspectives on the impacts of deforestation on their households. The Tuffour-mills et al. (2020) study in Ghana found that human activities were the main driving factors for FL reduction from 1991 to 2015.

Degradation of natural resources and local climate changes consequences human-wildlife conflicts in RVLZ. The fluctuation of land cover trends and native forest extinct combined with climate variability trends, frequent drought, and high levels of livelihood system unreality had impacts on ecosystem services (for example, pollinations), local climate stability (disrupting rainfall patterns and temperatures), agricultural productivities (reducing production due to degradations), and livestock sectors (reducing forage sources), and social values. Similarly, some wildlife like mega antelope and carnivorous and some birds are locally extinct due to deforestation and ecosystem changes in all study areas. According to KII, the research areas are lefts with small antelopes, monkeys, baboons, warthogs, hyenas, and certain seasonal birds. Hyena killed seven people between 2011 and 2019 and injured five in RVLZ. Hyena and leopards ambushed hundreds of livestock in diurnal, and monkeys and baboons invaded villages and farm areas. The current study coincides with the Eixeira et al. (2012) findings that revealed LULC change by humans was profoundly driver and affects ecosystem services such as water flow, pests, and disease regulations.

Furthermore, all the FGD participants reported having fuelwood and raw materials issues (particularly in villages), a lack of free space, and a scarcity of grazing lands. Previously, their communities obtained firewood from nearby areas. However, in recent times local community has used Eucalyptus only as a firewood source and will be in the future.

Implications of land degradation

FGD participants in RVLZ elaborated that rainfall intensity and coverage were high in the past, but soil degradation was low due to better forest coverage. However, the rainfall intensity and spatial coverage are now fragmented, but the land degradation is high in the mountains. This result was sported by the Dibaba et al. (2020) study, which revealed the increasing cultivation of steep slopes increased the risk of erosion and sedimentations in Fincha Catchment in Northwestern Ethiopia. Most FGD participants in TCLZ resolved that there was no significant land degradation and severity of gully formation due to LULC change before two decades (2000). However, from 2000-to 2019, respondents in TCLZ perceived severe gully formation and land degradation consequences on the vulnerable land units. This study supported by Liyew et al. (2019) reported that uncovered continued expansion of cultivated land combined with population positively linked the increase of gully erosion and surface runoff potential in contrasting agroecological environments of Ethiopia from 1982 to 2017. This study also sported by Balabathina et al. (2020) findings that founds soil erosion was one of the environmental challenges in the northern catchment of Lake Tana Sub-basin, Upper Blue Nile Basin, Northwest Ethiopia.

The RVLZ and TCLZ have similar land patterns, and the impacts of drought and LULC change can affect most of their habitats depending on their livelihood systems. However, FGD participants in ALOFLZ have different perspectives on the severity of gully formation and the extent of land degradation. According to RVLZ FGD participants, before 2000, there were no significant land degradation and severity of gully formation. However, since 2000 participants perceived the extent of land degradation seen on the vulnerable land units in RVLZ. FGD participants of TCLZ and ALOFLZ believed the land given for youth was sloppy. The sloppy area is not appropriate for farmlands and has consequences for gully formation and land degradation. The Balabathina et al. (2020) study in the northern catchment of Lake Tana uncovered soil erosion was most sensitive to topography and crop management. Further, Meshesha et al. (2014) study revealed land degradation due to LULC change was made large areas unsuitable for agriculture and has reduced crop productivity in Eastern Ethiopian highlands.

Implications on grazing lands and livestock

According to interviews with livestock experts and satellite data results, grazing land showed shrinkage in all study LZs over the study years (1983-2019). On the other hand, drought impacts increase temporally and spatially in all study LZs, particularly RVZL. According to ALOFLZ livestock experts, they have three land-use zones: agricultural land, conservation land, and grazing land. However, they said their grazing land is decreasing with time. This view coincides with Landsat image processing results. Some FGD participants in TCLZ and ALOFLZ perceived that their grazing land was converted into other land use. However, the rest of the FGD participants in TCLZ and ALOFLZ answered that they have some extent of remaining grazing lands. According to key informant interviews and FGD in RVLZ, their grazing lands have converted to farmland and settlements. This study is also in line with the Landsat image processing results and the Gidey et al. (2017) study on decreasing trends of GL in RVLZ.

Investors are converting thousands of hectares into farmland in RVLZ. Natural vegetation conversion directly affected grazing land and fuels wood sources. Free grazing land, bush and shrublands, forests, and cactus were forage sources for livestock during drought and drought-free years. Firewood used for household consumption and burning cactus for animal food during dry seasons disappeared. Due to grazing land conversions and frequent drought occurrences, livestock number was decreasing in RVLZ. However, livestock was a means for households during the drought period in RVLZ.

Interview with livestock experts in RVLZ revealed that in 1993/94, in one village ((kebele), they vaccinated more than 7000 cattle, but now there are not more than 1000 cattle in the same villages. Further, the experts elaborated that the average household had more than 40 cattle before 20 years (before 2000). But today, because of drought, land-use change, and cactus diseases, farmers shifted their livestock from large ruminants (Cattle, dairy, or beef) to small ruminants (sheep, Goat) and poultry. Poultry is a primary alternative income source in this current land-use system. Before 2010, the number of small ruminants in RVLZ was around 10,000, but there are roughly 100,000 ruminants now. In the past, large animal numbers were owned by a few hands (people) in ALOFLZ. However, each household now has few livestock numbers, but overall, many more animals than previously. According to ALOFLZ livestock experts, the number of animals is growing, but their grazing land capacity cannot keep up with the demand.

Interviews with key informants and FGD participants of all LZs reported that before 20 years (before year2000), there was no tendency to harvest agricultural residue for animal forages in all LZ. But, due to drought frequencies and LULC change affecting forage sources, everything is harvested during production seasons for the dry season. This trend affects the soil fertility and productivity of their farmland. According to the Lerouge et al. (2014) study, cover crops and crop residues protect soil from erosions, enhance soil strictures, and build rich organic soil.

Implications on agricultural productivity

Kiremt and Belg are the research area's long and short rainy seasons. A lack of precipitation severely impacts rain-fed agriculture systems during these rainy seasons. However, regarding the agricultural productivity of the study LZ, there were different perspectives among the LZs respondents. Participants of FGD in RVLZ stated productivity decreased from 80 quintals to less than 30 quintals per hectare due to erratic rainfalls and declining soil fertility. This result coincided with the Othow et al. (2017) study, which reported the conversion of natural vegetation has led to a decline in agricultural yield per pot of land in Gog District, Gambella Regional State, from 1990 to 2017. According to the FGD participants in RVLZ, their communities did not use inorganic fertilizers to maximize production due to the moisture scarcity of their LZ. However, FGD participants in TCLZ had different perspectives on the production trends in all study intervals. The reasons for their different perceptions are that some parts of the LZ are more vulnerable to a dry spell, drought, and deforestation that aggravates soil fertility decline and degradation.

Besides the respondents of ALOFLZ, they have different experiences from RVLZ and TCLZ in productivity and production trends. The respondents' perceived production was better from the year 2000 to 2019. According to the Key informants and FGD results, before two decades (2000), crop production in ALOFLZ was affected by frost, marsh, and soil degradations. In ALOFLZ, FGD and key informants stated due to using agricultural inputs and intensive management in small farmlands forbore weather conditions due to climate change, the productivity of the same plot is better compared to the past. However, they threatened for side effects of agricultural input in ALOFLZ. Farmland in ALOFLZ is already addicted to chemicals and inorganic fertilizers. Chemicals and inorganic fertilizers affect the land's ecosystem services and future value. Participants of the FGD in all LZ discussed soil fertility of their area was decreasing since the residue and post-harvesting of the crop were removed from the farm area for firewood and forage sources for livestock. This trend affects the farmlands' natural soil fertility, mineral contents, and moisture conservation. The litter from forests is reduced and affects the soil fertility and productivity of the lands. Consequently, invaded herbs and insects increased and influenced the land’s fertility and productivity. According to the Congreso et al. (2014) study, loss of biological control can consequences pest densities, affects pollinator services, and causes environmental degradation.

6.4. Conclusions

The author has identified synergistic effects of drought and land use and land cover change in the community’s livelihood system in three livelihood zones in Ethiopia’s Rift Valley’s Northwestern Escarpment. To investigate the synergetic effects, the author looked at the area’s climate variability, drought trends, land use and land cover change, and drought vulnerability. Hence, the findings revealed that all study LZs showed significant and non-significant Tmin and Tmax trends at measured time scales from 1983 to 2016. On the other hand, annual rainfall trends did not show any significant positive or negative changes in any of the LZs studied. However, rainfall trends in the Belg rainy season, the basis for farming and moisture sources for local ecosystems, imply diminishing trends, but statistically insignificantly in all LZ. However, during the Kiremt rain season, the study reveals statistically significant changes in RVLZ and TCLZ. On the other hand, all LZ saw significant and severe rainfall variability in Kiremt.

Additionally, the study investigated metrological drought in spatial and temporal trends in Belg, Kiremt, combined rainy seasons and annual scales. This result helps the author see how climate variability's effects on drought induce both temporally and spatially within and along the study livelihood zones. As a result, this study discovered that high climate variability trends had a positive functional association with spatial and temporal drought history, further exacerbating livelihood system drought vulnerabilities in the studied livelihood zones. This study uncovers seasonal and annual recurrent droughts that vary in intensity, frequency, and duration within and between livelihood zones. Further, the study investigated the changes in LULC in three livelihood zones of drought-prone areas. The study explored that human activities negatively influence productivity and changing weather systems and intensify environmental degradation, desertification, and biodiversity loss. The changes have long-term ramifications for community livelihood systems that rely on rain-fed systems and their basics in studying livelihood systems.

Further, the results show that all the study's LZs are highly vulnerable to drought impacts due to the significant exposition, susceptibility, and inadequate adaptive capacity.

To sum up, RVLZ was synergistically affected by increasing temperature trends, erratic rainfall, extreme rainfall variability, frequent seasonal and annual drought occurrences, rapid LULC change, and high drought vulnerable livelihood systems followed by TCLZ. Consequently, the change affected the livelihood system and disrupted the local ecosystems of the study area. These combined effects consequence agricultural production and productivity reduction that impacted smallholder farmers of the study areas. These combined effects also point to the possible impacts on crop productivity and forage growth by exposing them to high-temperature stress, droughts, and LULC change, resulting in economic loss for local communities and affecting land-use systems and ecosystems disrupts in the study areas.

This study provides insight into how synergistic impacts of drought and LULC change on the livelihood system have more significant effects than independently or the sum of their results. Further, this enabled the researchers to investigate how synergetic drought and LULC change affect livelihood systems at livelihood zone levels. This new approach can be used as input for strategies and policymakers to integrate relevant sectors to reduce the synergetic impacts of drought and LULC change livelihood systems at LZ levels. The study will be input to improve the current drought, and LULC changes the monitoring system and build resilience at the household level.

The study revealed that LZs need vertical and horizontal integrated solutions depending on the vulnerability's causes. Communities should consider diversifying their livelihood system rather than relying on crop-livestock mixed methods, which are more vulnerable to drought and LULC change impacts. Further, communities should practice improved, market-oriented farming systems that fit their climate variability trends and local ecosystems. The coping approach in all study livelihood zones was not diverse, robust, or long-term to combat drought-induced consequences. As a result, giving initiatives and emphasis to the current moisture harvesting system, soil conservation, and afforestation practices is important to mitigate natural and human-induced drought impacts at the livelihood zone and on-farm levels. Further, attention is needed to change cultural practices that affect the saving capacity, exacerbating the community's vulnerability to drought and LULC change impacts.

The provincial government needed to integrate relevant sectors under one umbrella rather than individual responses at regional levels. It needs awareness creation and holistic and cooperative responses from all relevant sectors. For immediate intervention, moisture conservation techniques are essential, and irrigation sectors are required for long-term sustainability to promote the production of drought-tolerant and market-oriented crops. As a result, livelihood-based interventions and climate-smart farming techniques are urgently needed in all study LZs to transfer vulnerable communities and reduce possible risks and their impacts. To reduce drought vulnerability and achieve sustainable development, rainwater harvesting with reservoirs needs in all livelihood zones. Also, the concerned body in RVLZ needs to focus on efficiently using the existing and proposed groundwater projects. Harvesting rain and groundwater for agriculture are necessary to reduce drought vulnerability and achieve sustainable development. Further, farm activities should be eco-friends instead of depending on intensive chemical inputs to increase the productivity of the land. Additionally, a more in-depth study needs to see the Belg and Kiremt rainfall onsets, durations, terminations, and variabilities trends to put appropriate agricultural activities.

The federal government should consider anticipated and ongoing active risk management measures, policies, and initiatives rather than being introduced after a disaster. The agricultural sector needed to consider the long-term crop growth patterns, rainfall variability, and dry spell effects to reduce crop failures and forage problems by updating local meteorological data and technological inputs. Integrating and projected land use plans will reduce the vulnerability and risks of LULC change and associated climate impacts in the future. Therefore, government and all interested stakeholders should reform appropriate land use policy, which benefits local farmers and their ecosystems. There is a lack of a proper information system on agricultural productivities data recorded in villages and households from local to federal levels. Therefore systems need holistically registered agricultural histories at household and village levels.

7. Chapter Seven: General Discussions/Conclusions and Recommendations

7.1. Introduction

Drought has been and continues to be the primary driving force behind periodic famine in Northern Ethiopia (Eze *et al*., 2020). Consequently, drought impact is one of Northern Ethiopia's strategic foes, necessitating considerable local mitigating measures. Furthermore, Ethiopia's northern provinces have been home to sedentary agriculture for thousands of years (Andargie, 2014). Specifically, the Ethiopian Rift Valley's northwestern escarpment is one of the most drought-prone and millennia of unrelenting land exploitation have resulted in significant environmental modifications and degradation (Gidey *et al*., 2017a). In the Northwestern Ethiopian escarpment, the Raya Valley livelihood Zone (RVLZ), Alagie–Ofla livelihood Zone (ALOFLZ), and Tsirare Catchment Livelihood Zones (TCLZ) are among the most vulnerable to climate variability, recurrent drought impacts, and uncertainty. As a result, significant dry climate events and severe environmental changes commonly affected agriculture production and livestock in the studied area (Tefera & Bello, 2019; Abrha & Simhadri, 2015).

Recent studies have identified climate-related extreme events as the primary drivers of LULC change (Reef *et al.,* 2015). Balabathina *et al*. (2020), Betru *et al*. (2019), Gidey *et al*. (2017b), Selassie (2015), and Wolka *et al*. (2015) have addressed the urgent attention needed for LULC change challenges in different parts of Ethiopia. Most research in Tigray has concentrated on regional or zonal scales, particularly in southern Tigray (the current study area) (Gidey *et al*., 2017a, 2017b; Annys *et al.,* 2016; Demissie, 2016). Some studies explored climate change, local community perceptions, food security, and drought. Rapid LULC changes, according to these studies, worsened food insecurity and had social, environmental, and economic consequences. Drought, combined with a shift in LULC, has long been regarded as Ethiopia's key food security challenge (Berhe, 2011).

The author acclaimed all the research the study looked at for their scholarly contributions in priority areas. However, the studies the author reviewed did not systematically assess the synergetic effects of drought and LULC change on livelihood systems. They did not even cover all of the parameter combinations this study discussed. This study is also unique because it used a wide range of data, including meteorological, Landsat pictures, ground surveys, socioeconomic data, reports, and reviews from scientific papers. In addition, unlike most scholars, the author concentrated their research on livelihood systems at the livelihood zone level rather than agro-ecological zones.

The author hypothesized that the combined effects of drought and LULC change on the livelihood system would be more significant than the sum of their results. Drought and LULC change have feedback effects, so their frequency, magnitude, and geographic coverage are larger than the sum of independent or isolated influences. As a result, empirical evidence of the synergistic effects of drought and LULC change on livelihood systems is crucial for effective and proactive drought management and a sustainable land-use system in Ethiopia, particularly for studying livelihood zones (Reichhuber *et al.*, 2019). To reduce repetition, the authors summarized the data analysis methods for each study objective in Figure 7.1. See each study chapter under the data set and methodology for detailed data analysis procedures. Further, this study posed the following specific research questions:

I. What are the seasonal and annual climate variability trends and characteristics across and within the study livelihood zones?
II. What are seasonal and spatial meteorological drought frequencies, magnitudes, and duration trends across and within the three livelihood zones?
III. What are the trends and drivers of land use and land cover dynamics along the three livelihood zones?
IV. How vulnerable are the livelihood systems to climate variability trends, drought impacts, and LULC changes along and within the three livelihood zones?
V. How does the synergy of drought, land use, and land cover changes affect livelihood systems within the three livelihood zones?

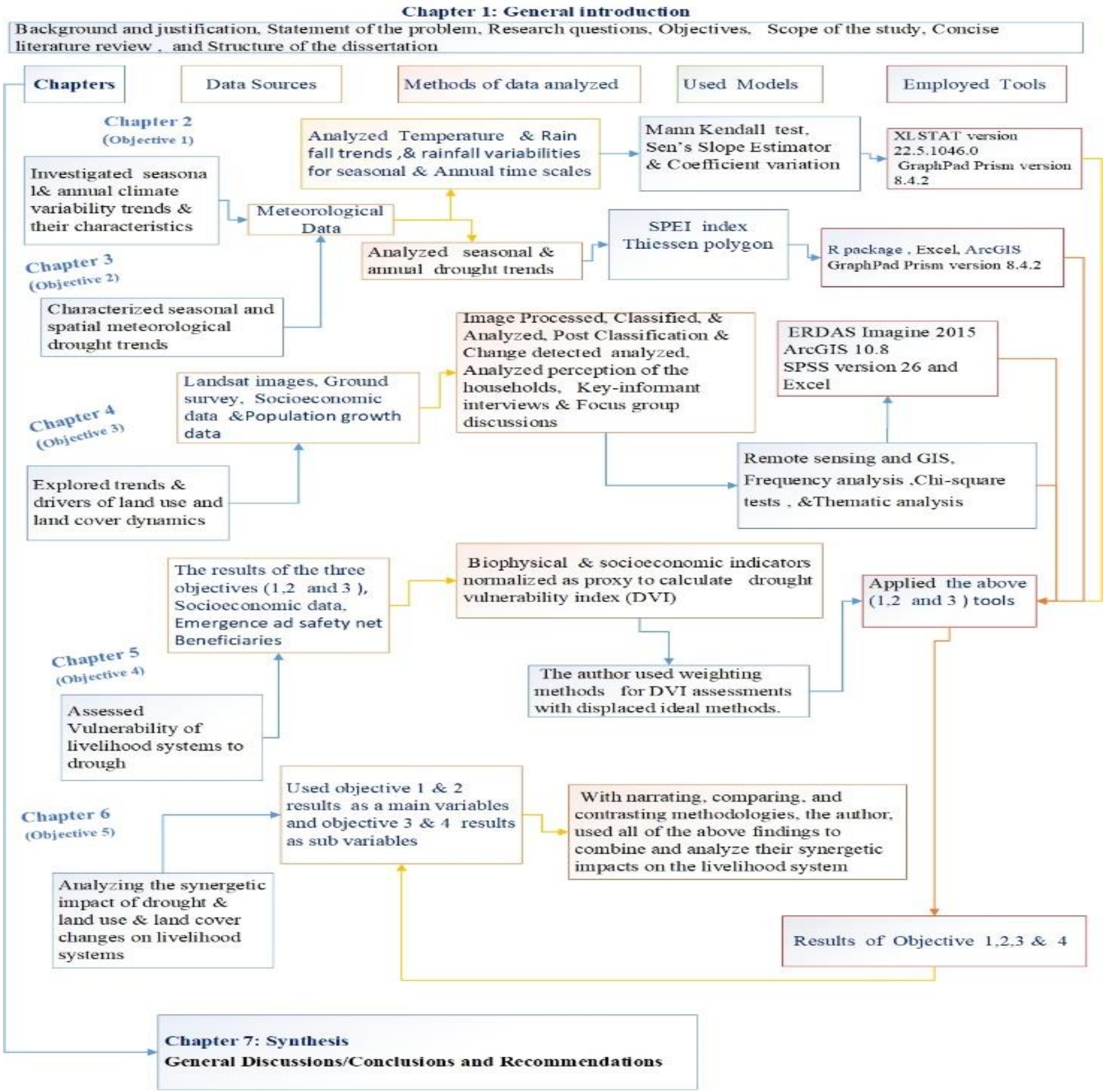


Figure 7.1. Outline analysis of the synergy of drought and land use and land cover changes impact livelihood systems within the three livelihood zones

7.2. General Discussions

I. What are the seasonal and annual climate variability trends and characteristics across and within the study livelihood zones? (Chapter 2)

The first research question explores yearly and seasonal climate variability using temperature and rainfall data for 34 years. The study compares maximum and minimum temperature, rainfall trends, and variability between and within livelihood zones. The author's analysis revealed that the temperature is warming, and the rainfall has shown high irregularities and various seasonal and annual timescales. Besides, spatially the rainfall variability trends within inter-seasonal and inter-annual trends of CV fluctuated between and within the LZs. The yearly minimum temperature increased with statistical significance in all study LZ. Also, annual *T*max is rising significance in TCLZ and the RVLZ. The Belg records show that the *T*max trend increased significantly in all study livelihood zones. This result coincides with (Ademe *et al.,* 2020; Dechassa *et al.*, 2020; Esayas *et al.,* 2019; Teklegiorgis *et al.,* 2016) findings on increasing seasonal and annual temperature trends in different parts of Ethiopia.

All study LV zones had seasonal and annual uncertainty in rainfall patterns. Besides rainfall trends, only the Kiremt rainfall shows significant trends in the RVLZ and TCLZ. The current result also coincides with the Mekuyie and Mulu (2021) finding that reported significantly increasing Kiremt rainfall trends. But different studies (Bayable *et al.*, 2021; Ademe *et al*., 2020; Benti & Abara, 2019) revealed that rainfall decreased in the Kiremt season in different parts of Ethiopia. This study further explored that the Belg rainfall trends are declining in all study livelihood zones. Annual rainfall trends were declining in the RVLZ but increasing ALOFLZ and TCLZ. The current result coincides with the (Bayable *et al.*, 2021; Ademe *et al.*, 2020; Benti & Abara, 2019; Esayas *et al.*, 2019; Asfaw *et al*., 2018; Kedir & Tekalign, 2016) studies of the Belg and annual rainfall trends that declined but were not significant. On the contrary, the Geremew *et al*. (2020) study in Northwest Ethiopia revealed that annual rainfall trends were increasing but statistically insignificant, which agrees with ALOFLZ and TCLZ rainfall trends.

This study also showed the rainfall was highly irregular and varied in seasonal and annual time scales in all LZs and grid-wise levels. The Belg rainfall variability was higher than Kiremt and yearly variability in all livelihood zones. The current findings strengthened by (Alemayehu *et al*., 2020; Dechassa *et al*., 2020; Feleke & Abera, 2020; Mekonen & Berlie, 2019; Asfaw *et al.*, 2018) reports that rainfall variability is extremely high in their study area.

Combined seasonal and annual rapidly warming temperatures with high rainfall irregularities affected the agricultural productivity of smallholder farmers in all LZs of the study area. These inconsistencies and fluctuated variability also indicate the possibility of extreme events that impact farm productivity and forage growth by exposing them to high-temperature stress, increasing evapotranspiration demands, resulting in economic loss for local communities, and disrupting the study areas' ecosystem.

II. What are seasonal and spatial meteorological drought frequencies, magnitudes, and duration trends across and within the three livelihood zones? (Chapter 3)

The second research question aimed to detect seasonal and spatial meteorological drought trends at livelihood zone and grid levels for 34 years(1983-2016). This study enabled the researchers to investigate the impacts of seasonal and annual climate variability (Chapter 2) on inducing meteorological drought across and within the study livelihood zones. Consequently, the result revealed high drought frequencies, mild to extreme severity, and long drought durations within and between the livelihood zones. The results indicated that severe drought occurred in all livelihoods zone of the study area from 1983 to 1991, while ALOFLZ and TCLZ have recorded relatively higher drought severity. The current study agreed with the (Wossenyeleh, 2022; Haile & Tang, 2019; Gidey *et al*., 2018a; Mohammed, 2018; Zeleke, 2017; Kenawy *et al*., 2016) findings on the drought severity and frequencies in their study areas. However, through the study years, drought frequency and persistence have been increasing in RVLZ, followed by TCLZs. In most study years, there have been seasonally or yearly human or climate-induced droughts in grid point levels or livelihood zone scales in RVLZ and TCLZ. In the last thirteen years (2003-2016), the RVLZ has suffered from persistent mild to moderate drought. However, in the same years, the central parts of ALOFLZ have been less vulnerable to drought than others.

In addition, the study discovered that there had been Belg or Kiremt or both drought seasons in most study areas. From 1989 to 2016, the severity and frequency of droughts increased during the Belg season but decreased in Kiremt. However, the frequencies and severity of drought were slight differences between the livelihood zones. In this study, the severity and frequencies of the Kiremt drought evolved from higher in 1983 to moderate in 2016. Seasonal Kiremt drought impacts were becoming locally fragmented even at village levels. As the frequencies and persistence of mild drought impacts have increased, the intensity and precipitation are too small to cultivate crops and forage growth.

As this study uncovered, long before 25 years, drought causalities were tremendous in the lives of humans and livestock in the study area. However, the study area's recent drought incidents have more livestock fatalities than human suffering. Human Bing may search for alternative sources like power sales, remittance income sources, relief supports, and firewood sales to sustain the household. The current drought conditions in some portions of Somali and Borena in Ethiopia bolster these conclusions. In Somali and Borena, the present drought impact (2021/2022) is more severe on cattle than humans. Thousands of livestock died in Somali and Borena due to the severe drought. According to American Amharic Radio news, over 573 animals died, and over 400,0000 livestock were severely malnourished due to extreme drought impacts in the Borena zone reported on March 13/2022 (9:00 -4: 00 PM). Further, this study sported by the current drought situation evidence of UNICEF, that reported on 1 February 2022- Addis Ababa as follows:

"*Three consecutive failed rainy seasons have brought on a severe drought in Ethiopia's lowland regions of Afar, Oromia, the Southern Nations, Nationalities, and Peoples' (SNNPR) and Somali regions drying up water wells, killing livestock and crops and pushing hundreds of thousands of children and their families to the brink."* https://www.unicef.org/press-releases/prolonged-drought-pushing-families-ethiopia-brink (Accessed : March 18, 2022,6:36).

III. What are the trends and drivers of land use and land cover dynamics along the three livelihood zones? (Chapter 4)

Chapters 2 and 3 investigated the livelihood zones affected by high climate variability and drought impacts due to natural and anthropogenic factors. Consequently, the author' intended to examine trends and characteristics in land use and land cover dynamics throughout the three climate variability and drought vulnerable livelihood zones using the third research question (chapter 4). The study used remote sensing and geographic information systems (GIS), key informant interviews, and focus group discussions showing substantial LULC change over the last 34 years. Nine LULC classes were examined in each of the three LZs using a supervised technique and a maximum likelihood classification system. The CL was the most common LULC type in all livelihood zones. In all research years, RVLZ had a substantial CL share flowed by TCLZ from the three LZs. SBL was the second most common LULC type in all LZ during the study period (1985-2019). Shrublands/bushland, on the other hand, decreased drastically in all LZ over the study period.

CL and BA in all LZs and FP in RVLZ and TCLZ showed significant increasing trends, primarily at the expense of other LULC types. More expansion of the cultivated lands was at the cost of natural vegetation covers that has intensified the soil erosion problems through land degradation and destructing soil water infiltration and holding capacity. This study coincides with (Angessa *et al.,* 2019; Liyew *et al*., 2019; Gidey *et al.*, 2017b; Hermans-Neumann *et al.*, 2017; Annys *et al.*, 2016; Meshesha *et al*., 2014) studies that revealed severe LULC changes in their study area. In RVLZ, the wetland area increased, but in ALOFLZ, it dropped. SBL, GL, and BL, on the other hand, decreased significantly over the study period. CL and SBL change was fast and fluctuated within studies LZs. In the RVLZ, SBL shrinkages started in the year 2010. There are links between SBL reduction and CL expansions due to pressures from the growth of the internal and immigrant population and large and medium agricultural investors in RVLZ. In all LZs, major LULC exchanges occurred between CL and SBL over study years. GL and FL were a source of additional land for CL and BA in all LZs.

Due to population pressures, the need for land grows year after year. Internal population pressures mostly drive land-use change in the ALOFLZ and TCLZ. In all LZs, population pressures from a lack of other revenue sources and family fuelwood demands, a lack of adequate land use procedures, disturbance of local climate patterns, and recurrent droughts were among the LULC change driving variables. This result agreed with (Damtew *et al.*, 2021; Munthali *et al.*, 2019; Onuoha *et al.,* 2018 Kindu & Schneider, 2015), which discovered all or some of the above LULC change driving factories in their study area. The main driver of LULC change in RVLZ was population pressures from residents and immigrants from nearby regions. Large and medium agricultural investors were likewise the primary drivers of LULC change in RVLZ. Communities in RVLZ are left without contingency land for their youths and coming generations.

As a result, without a peak and a stable ecosystem, the ecosystem service will be unable to support natural ecosystem cycles and human requirements. Drought impacts are more likely in a constantly disrupted environment, resulting in local climate system instability and affecting the agricultural output of LZs in the study. With quick and destabilizing ecosystems in the research LZs, these temperature variations point to future drought risks and land-use system unsteadiness, impacting agricultural productivity, forage growth, and climate systems in the study areas.

IV. How vulnerable are the livelihood systems to climate variability trends, drought impacts, and LULC changes along and within the three livelihood zones? (Chapter 5)

The fourth research topic looks at the drought vulnerability of livelihood systems at the level of livelihood zones. The results of chapters two, three, and four were used as indicators with other socioeconomic data to see their synergy as drought vulnerability index for livelihood systems of the study livelihood zones. Drought intensity, frequencies and duration, temperature and rainfall trends, and rainfall variability were studied using meteorological data. LULC change detections were analyzed using Landsat images and ground truth points to investigate the ecosystem disturbance. The author used socioeconomic data from households, focus group discussions, and key informants to model the study's LZs' susceptibility to drought. Each variable of drought vulnerability was normalized as proxy indicators to calculate exposure, sensitivity, and adaptive capacity indexes.

The study LZs' composite drought vulnerability index reveal considerable vulnerability to drought impacts. Similarly, the studies of (Balaganesh *et al.,* 2020; Choden *et al.*, 2020; Gupta *et al.,* 2020a; Xiangbo Xu *et al.*, 2020; Peng et al., 2018; Congreso *et al.*, 2014) revealed substantial vulnerability results in the areas of climate and drought. According to the exposure index, the RVLZ has a larger exposure to drought impacts and associated hazards than the other two livelihood zones. Institutional constraints, biophysical threats, environmental disturbances, socio-cultural consequences, and climate variability tendencies are more prevalent in the Raya valley livelihood zone. Similarly, climate variability affects RVLZ the most, followed by livelihood system, institutional, and ecosystem sensitivity. RVLZ has the lowest adaptation capacity in copying strategy, followed by weak natural conservations, weak social networks, and fragile livelihood strategy.

TCLZ has the lowest resilience in natural conservations, followed by copying, social networks, and livelihood strategies. Therefore, the TCLZ has a lower adaptation potential than the livelihood zones of Raya Valley and Alagie Ofla. The LZ is more vulnerable and subject to drought threats than Alagie Ofla's livelihood zones. Biophysical risks are the most prevalent in the TCLZ, followed by sensitive socio-cultural practices, climate-related risks, institutional constraints, and ecological disruption. On the other hand, communities in the LZ are particularly vulnerable to climate change, environmental changes, inadequate livelihood systems, and institutional sensitivities.

Furthermore, while the ALOLZ is less drought vulnerable than the RVLZ and TCLZ, it has a lower adaptation capacity and is more susceptible to drought events and associated hazards. Biophysical concerns were the greatest threat to the ALOFLA, followed by sensitive socio-cultural factors, environmental disruptions, climate variability events, and institutional constraints. Weak institutional services, a frail livelihood system, ecological sensitivity, and climate unpredictability are more sensitive to communities in the ALOFLZ. Furthermore, the LZ was less resilient in nature conservation, with a copying approach, poor social networks, and fragile livelihood strategy coming in second and third, respectively.

V. How does the synergy of drought, land use, and land cover changes affect livelihood systems within the three livelihood zones? (Chapter 6)

To investigate the synergetic effects of drought and LULC change on the community's livelihood system, the author first studied the area's climate variability, drought trends, LULC change, and drought vulnerability. Using these results and other socioeconomic surveys, meteorological data, Landsat images, and drought vulnerability patterns are all used in the study. Consequently, this study revealed high climate variability trends (chapter 2), spatial and temporal drought impacts (chapter 3), rapid LULC change (chapter 4), and exacerbated livelihood systems' vulnerability to drought effects (chapter 5) in the studied livelihood zones. The author has identified the synergistic effects of drought and land use and land cover change in the community's livelihood system in three livelihood zones. This research discovered that high climate variability trends positively correlated with spatial and temporal drought history, exacerbating livelihood system drought vulnerabilities in the study areas. Human activities also negatively impact productivity and changing weather systems and intensify environmental degradation, desertification, and biodiversity loss. The changes have long-term ramifications for community livelihood systems that rely on rain-fed systems and their basics in studying livelihood systems. Furthermore, due to the most substantial exposures, sensitivity, and low adaptive ability, all of the study's LZs are extremely sensitive to drought impacts.

Consequently, the synergy affected the livelihood system and disrupted the local ecosystems of the study area. RVLZ was synergistically affected by increasing temperature trends, erratic rainfall, extreme rainfall variability, frequent seasonal and annual drought occurrences, rapid LULC change, high drought vulnerable livelihood systems, followed by TCLZ, then ALOFLZ. These combined effects have decreased agricultural production and productivity, which has impacted smallholder farmers in the study areas. These synergistic effects further affected the livelihood system and destabilized the local ecosystems in the study area. These combined effects also point to the possible impacts on crop productivity and forage growth by exposing them to high-temperature stress, droughts, and LULC change, resulting in economic loss for local communities and disrupting land-use systems of s study areas.

7.3. Conclusions and Recommendations

First, this study analyzed the seasonal and annual climate variability trend using MKT and SSE at 5% significance levels and rainfall variability using CV from 1983 to 2016. The study revealed that the temperature is warming, and the rainfall has shown high irregularities and various seasonal and annual timescales. Besides, spatially the rainfall variability trends within inter-seasonal and inter-annual trends of CV fluctuated between and within the LZs.

Second, this study analyzed the trends of spatiotemporal seasonal drought frequencies, durations, and severity in LZ levels. The Belg and Kiremt temporal drought had an inverse relationship with drought histories in the study area within-study years. If Kiremt gets good rain in some years, the Belg did not get. From 1989 to 2016, drought frequencies have increased in Belg and decreased in Kiremt within the study years. However, the frequencies and severity of drought were slight differences between the livelihood zones. Seasonal Kiremt drought events were becoming locally fragmented even at village levels.

Drought causalities were tremendous in the lives of humans and livestock in the study area before 25 years. However, mild drought frequencies and persistence have recently increased, and the intensity and precipitation amount are too small to cultivate crops and forage growth. Consequently, the study area's recent drought incidents have more livestock fatalities than human suffering. Human Bing may search for alternative sources like power sales, remittance income sources, relief supports, and firewood sales to sustain the household.

The author found seasonally recurring droughts that vary in severity, frequencies, and durations within and between the livelihood zones. Drought frequency and persistence have been increasing in RVLZ, followed by TCLZs. In most study years, there have been seasonally or yearly human or climate-induced droughts in grid point levels or livelihood zone scales in RVLZ and TCLZ. In the last thirteen years (2003-2016), the RVLZ has suffered from persistent drought. However, in the same years, the central parts of ALOFLZ have been less vulnerable to drought than others.

Third, the study revealed substantial LULC dynamics over the past 34 years using remote sensing and geographical information systems (GIS), key informant interviews, and focus discussion analysis. The study uncovered that CL was the dominant LULC type in all livelihood zones throughout the study years. The results of the LULC change detection showed a rapid change in land use and land cover in all LZs. There were no climaxes and stabilization of LULC types within the study years in all LZs. The overall land use and land cover detection analysis shows RVLZ is highly (largely) LULC shifted than the ALOFLZ and TCLZs. Relatively, ecosystem disturbances are higher in RVLZ than in ALOFLZ and TCLZ. Without a climax and stabilized ecosystem, the ecosystem service cannot support natural ecosystem cycles and human needs. A continuously disrupted ecosystem is more exposed to drought hazards that result in local climate system disturbances and affect the agricultural productivity of LZs in the study.

The demand for land is increasing each year due to population pressures. Population pressures from lack of alternative income sources and fuelwood demands for household consumption, lack of appropriate land use mechanisms, land demands for agriculture and settlement, disruption of local climate patterns, and frequent droughts were among the LULC change driving factors in all LZs. Internal population pressure is the main driving force of land change in ALOFLZ and TCLZ. Population pressures from the residents and immigrants from neighboring were the main driving LULC change in RVLZ. In RVLZ, large and medium agricultural investors were also the main driving force behind the change in LULC. Communities in RVLZ are left without contingency land for their youths and coming generations.

Due to grazing land conversions, livestock number was decreasing in RVLZ. Livestock was a means for a household's livelihood during the drought period in RVLZ. Before 20 years, there was no trend to harvest agricultural residues for animal feed in all LZ. However, recently everything has been gathered during the production season for the dry season. This trend will affect the soil fertility and productivity of their farmland.

Fourth, this study aimed to explore the drought vulnerability in three livelihood zone. The study gathered meteorological, spatial, and socioeconomic data to develop a drought vulnerability index at livelihood zone levels. Drought intensity, temperature and rainfall trends, and rainfall variability were studied using meteorological data. LULC change detections were analyzed using Landsat images and ground truth points to investigate the ecosystem disturbance. This study used socioeconomic data from households, focus group discussions, and key informants to model the study's LZs' susceptibility to drought. The composite drought vulnerability indexes of all study LZs show high vulnerability to drought impacts. However, the RVLZ is relatively more vulnerable to drought than the TCLZ and ALOFLZ.

The studied LZs are more vulnerable to drought and LULC change impacts due to present levels of institutional interventions. Institutional services, such as training to increase agricultural efficiencies, adequate market networks, up-to-date information, and good livestock services, are institutional interventions that can minimize a community's vulnerability to drought risks and effects. However, in all studies of LZs, there was a lack of appropriate market network and information (lack of market linkage counsel, market network expansion advice, the market for stock and their products, and updated market information). In all of the study LZs, there was a dearth of veterinarian services and access to better stock breeds.

Finally, the author has identified synergistic effects of drought and land use and land cover change in the community’s livelihood system in three study livelihood zones. To investigate the synergetic effects, the author looked at the study area’s climate variability, drought trends, land use and land cover change, and drought vulnerability. The results show that RVLZ was synergistically affected by increasing temperature trends, erratic rainfall, extreme rainfall variability, frequent seasonal and annual drought occurrences, rapid LULC change, and high drought vulnerable livelihood systems, followed by TCLZ then ALOFLZ. Consequently, the change affected the livelihood system and disrupted the local ecosystems of the study LZs. These combined effects consequence agricultural production and productivity reduction that impacted smallholder farmers of the study areas. These combined effects also point to the possible impacts on crop productivity and forage growth by exposing them to high-temperature stress, droughts, and LULC change, resulting in economic loss for local communities and disrupting land-use systems and ecosystems in the study areas.

This study provides insight into how synergistic impacts of drought and LULC change on the livelihood system have more significant effects than independently or the sum of their results. Since drought and LULC change have feedback effects, the impact's frequency, magnitude, and spatial coverage are higher than the independent or isolated impact sum. Further, this enabled the researchers to investigate how synergetic drought and LULC change affect livelihood systems at livelihood zone levels. The study will improve the current drought and LULC changes monitoring system and build resilience at the household level. This result can be used as input for strategies and policymakers to integrate relevant sectors to reduce the synergetic impacts of drought and LULC change livelihood systems at LZ levels. The study revealed that LZs need vertical and horizontal integrated solutions depending on the vulnerability’s causes.

At community levels:

The coping approach in all study livelihood zones was not diverse, robust, or long-term to combat drought-induced consequences. Therefore, communities should consider diversifying their livelihoods rather than relying on crop-livestock mixed methods, which are more vulnerable to drought and LULC change impacts. Further, communities should practice improved, market-oriented farming systems that fit their climate variability trends and local ecosystems. All the research LZs rely on rain-fed agricultural systems. Recently, the local population used residue and post-harvesting crops for fuel and fodder supplies. This trend impacts natural soil fertility, mineral content, and moisture conservation. Invasive herbs and insects are wreaking havoc on land fertility and productivity. Therefore, initiatives and emphasis should be given to the current moisture harvesting system, soil conservation, and afforestation practices to mitigate natural and human-induced drought impacts at the livelihood zone and on-farm levels.

The synergy of climate variability, drought frequency, and LULC change has ramifications for pathogenic growth, pests, insects, and weeds, impacting crop, livestock, and human health. Pathogens, insects, and herpes evolved, changing their nature, kinds, and emergence times. Insects and herpes have an increased impact on crop productivity in all study LZs. The new herbs impacted agricultural productivity, but they also affected animal forages. The fertilizers and compose used for productivity have implications on herbs emergencies. Furthermore, the plant and insect sides have impacted the quality of cereals, bees, and honey. Therefore, farm activities should be environmentally benign instead of relying on intensive chemical inputs to boost land productivity.

Further, attention is needed to change cultural practices that affect the saving capacity of the community (over expense for weddings, funerals, and other cultural events and ceremonies), which exacerbates the community's vulnerability to drought and LULC change impacts. As a result, they need more efforts to develop skills and raise knowledge about turning surplus production and resources into assets in all LZs.

At regional levels:

The provincial government should integrate responses through health, food, water, education, crop, livestock, securities, transport, markets, information services, and early warning services under one umbrella rather than individual responses. It needs awareness creation and holistic and cooperative responses from all relevant sectors.

Communities' responses and adaptations to climate-induced threats have important cultural components. Social networks, such as the community's financial saving system ("Ekub") and Zakat, are essential in reducing financial constraints. Communities benefit from increased participation in community organization for community development and community management system at mirage, funerals, and other social crises and events ("Eddir"). Christian communities hold monthly gatherings as group members ("Mahber") for ceremonies or to assist one another in times of financial need. On-farm labor-sharing ("Lifent") and free services "Ofera" for a plow, weeding, and harvesting, as well as other social issues such as housing constructions, are considered among the primary social networks that can help the community's vulnerability against drought hazards and its impacts. Community Care Collages and Village Saving Associations were also local organizations formed by the community to provide credit and savings without interest rates and assist one another in times of need. It is incomparable to government-provided emergency assistance rather than the government, and it is the victims who receive early aid. Mosques and churches, for example, have contributed to assisting people during drought. As a result, the aforementioned local community association can reach out to victims and vulnerable individuals. Further, the regional government should consider strengthening and aiding these communities in social networks to mitigate drought and other environmental and social repercussions.

The copying technique used in all study livelihood zones was not diverse, resilient, or long-term to resist drought-induced impacts. As a result, livelihood zone-based interventions and climate-smart farming practices are critical in all study LZs for transferring vulnerable communities and reducing the risk of drought. This problem needs special considerations to reduce natural and human-induced drought impacts. Afforestation with indigenous species, moisture conservation, and soil conservation measures should be the top priorities at livelihood and on-farm levels. Ended, it needs to consider solutions for short and long drought impacts. For immediate intervention, moisture conservation techniques are essential, and irrigation sectors are required for long-term sustainability to promote the production of drought-tolerant and market-oriented crops. Rainwater harvesting with reservoirs needs in all livelihood zones. Also, the concerned body in RVLZ needs to focus on efficiently using the existing and proposed groundwater projects. Harvesting rain and groundwater for agriculture are necessary to reduce drought vulnerability and achieve sustainable development. The agriculture sectors should consider the long-cycle crop growth patterns to reduce crop failures and forage problems.

In addition, the credit system does not allow all community members to diversify their sources of income. The credit's interest rate ignores the communities' capabilities. Amounts of financial credit are also limited. The market network is a major issue in practices, particularly for farmers. Muslim communities are not part of the credit system due to religious restrictions. With agro-processing technologies and markets, there is difficulty with value chains. Also, there is little collaboration amongst government sectors regarding community development. Credit organizations did not collaborate with the initiative to facilitate on-farm and off-farm activities to help the communities stay afloat. Therefore the regional government should consider these regards to develop sustainable livelihood systems.

Strong institutions for early warning systems and emergency relief, such as agricultural technologies, financial availability, and community development engagement, are among the most important measures for reducing community susceptibility to drought and LULC change impacts. In the RVLZ, however, there was a greater lack of access to agricultural technologies and credit than in the other two LZs. The study community requested a group of at least ten individuals to obtain the herb and insect sides from the agriculture offices. This procedure, however, requires time and bureaucracy. Due to a lack of early warning and institutional capacity to prepare for and respond to drought hazards, RVLZ is more vulnerable. As a result, well-developed and anticipated information systems and holistic and cooperative responses from all relevant sectors are essential.

Furthermore, TCLZ and ALOFLZ have higher socio-cultural exposures. As a result, they will have to put in more effort to improve their skills and knowledge about turning surplus production and resources into assets.

At federal levels:

The federal government should consider anticipated and ongoing active risk management measures, policies, and initiatives rather than being introduced after a disaster. As a result, agricultural development practitioners and policymakers should consider the seasonal unpredictability of rainfall in livelihood zones to boost future productivity. The agricultural sector should consider the long-cycle crop growth patterns, rainfall variability, and dry spell effects to reduce crop failures and forage problems by updating local meteorological data and technological inputs.

Integrating and projected land use plans will reduce the vulnerability and risks of LULC change and associated climate impacts in the future. Therefore, government and all interested stakeholders should reform appropriate land use policy, which benefits local farmers and their ecosystems. There is a lack of a proper information system on agricultural productivities data records in villages and households from local to federal levels. Therefore, strategies need holistically recorded agricultural histories at household and village levels.

7.4. Contribution of the Study

7.4.1. Overview

The author praised all the research this study looked at for their scholarly contributions in their priority areas. However, the studies the author looked at did not analyze the synergetic impacts of drought and LULC modification on livelihood systems as the study the author did. They didn't even cover all the parameter combinations; this study discussed synergistic impacts. This study is also different because it used a wide range of data, including meteorological, Landsat images, ground surveys, socioeconomic data, reports, and reviews from scientific papers. In addition, unlike most scholars, the author concentrated their research on livelihood systems at the livelihood zone level rather than agro-ecological zones. Therefore, the author believes policymakers need this research to design synergetic solutions at the livelihood system level. Further, the author believes this empirical proof of the synergistic effects of drought and LULC change on livelihood systems will contribute to the existing scientific knowledge.

7.4.2. Contributions for Knowledge

In terms of the study area, this study evaluated the synergetic effects of drought and LULC change on livelihood systems at livelihood zone levels in a systematic way. Characteristics of livelihood zones influence the primary land use and land cover driving and human-induced drought factors. Therefore, the author focused their study on the livelihood systems at livelihood zone levels rather than most researchers concentrating on agro-ecological zones. Since livelihood zones are grouped based on geographic similarities where households have broadly shared similar livelihood patterns, they are fundamental to include all parameters to study synergetic impacts on their livelihood system. Consequently, this study found remarkable synergetic effects on livelihood systems that differ between the study livelihood zones. The result will be a source of scientific knowledge and a baseline for further studies at the level of the livelihood zone.

The study used four broad research areas: climate variability trends, meteorological drought, land use and land cover change, drought vulnerability and their synergetic impacts on livelihood systems in livelihood zones. These areas are independently complex and broad to study in-depth. There are many ways to explore, with one “driving” the other “feedback” relationship of climate variability within drought, LULC change, drought vulnerability, and then reverses. This study used drought and LULC change as the main pillars, with climate variability trends and drought vulnerability as additional factors. This method provides insight into how synergistic impacts of drought and LULC change on the livelihood system have more significant effects than independently or the sum of their results.

The study used comprehensive data covering meteorological (CHIRPS and ENACTS), Landsat images, ground surveys, socioeconomic data, reports, and reviews from scientific documents in terms of data sources. Unrepresentative data could not demonstrate a complete picture of the results researchers intended to study.

In terms of methodology, this study analyzed climate variability trends using MKT and SSE, and long recorded data from uniformly distributed meteorological grids have high implications for revealed trends and characteristics of climate variability at LZ levels. Studies concerning local climate variability trends at livelihood zones indicate the gap that policymakers should be concerned about, and the local communities flow to resilience in the future.

Analysis of spatiotemporal drought trends using SPEI and long recorded data from uniformly distributed meteorological grids has high implications for revealed drought impacts and characteristics at LZ levels. This study enabled the researchers to investigate the drought frequencies, severity, and durations at livelihood zone and grid levels. This study calculated each drought magnitude (mild, moderate, severe, and extreme severe) and area coverages for the 231 grids in the three livelihood zones for the drought years. The short and medium time scales (3 and 6 months) have positive implications for seeing spatiotemporal drought frequencies, magnitudes, and severities.

To examine the trends and drivers of LULC dynamics, ERDAS Imagine 2015 was used for Landsat image processing, while ArcGIS 10.8 was used for LULC change analyses. A pixel-based image mosaic algorithm was applied to have a wider field of view. Besides, the Universal Transverse Mercator (UTM) Adindan Zone 37 was used to correct geometric errors. A supervised pixel-based classification with the maximum likelihood technique was used to create signatures and map LULC classes using ground truths data. Using change detection "from-to," cross-tabulation was performed to identify the nature of changes, extent, and patterns of one LULC change to other types. Using matrix areas of simultaneous gross gain, loss, persistence, and swamping between LULC classes were computed. Thematic analysis was used for key-informant interviews and focus group discussions on revealing the LULC change drivers and the consequences. Using these comprehensive methodologies, the author showed significant LULC change trends and drivers at livelihood zone levels. This method enabled us to see the spatial and temporal LULC change trend differences between the livelihood zones. Since the perception levels, the decision of individuals, and the communities are affected by socioeconomic, geographical locations, and technological inputs, this study found that the livelihood zones are fundamental to including these parameters as an umbrella.

This study provides insight into how drought vulnerability differs between livelihood zones. Normalized exposure, sensitivity, and adaptive capacity indexes were used as proxy indicators to calculate the drought vulnerability index (DVI). This study used the objective weighting (index-based approaches) methodology to determine the index's weight using data from the observation value of each indicator.

To investigate the synergetic effects of drought and land use and cover LULC change on the community’s livelihood system, the author first studied the study area’s climate variability, drought trends, LULC change, and drought vulnerability. Consequently, this study revealed high climate variability trends, spatial and temporal drought impacts, rapid LULC change, and exacerbated livelihood systems' vulnerability to drought effects in the studied livelihood zones. This methodology provides insight into how synergistic implications of drought and LULC change on the livelihood system have more significant effects. This method helps us to hint at improving the current drought impact, and LULC changes the monitoring system and builds resilience at the household level with integrated solutions.

7.4.3. Contribution to Policy Implications

Combined seasonal and annual rapidly warming temperatures with high rainfall irregularities affected the agricultural productivity of smallholder farmers in all LZs of the study area. Rather than taking precautions during a crisis, integrated measures should be designed based on a projected and ongoing active risk management response. Climate variability research at the livelihood zone level has been updated and has good implications for climate-resilient agriculture development and long-term ecosystem services. Up-to-date and scientific climate data assists communities in adapting to low-risk agricultural operations and crop productivity through technological advances.

It is critical to investigate the spatiotemporal drought frequencies, durations, and severity at livelihood zones to identify vulnerable areas at the local level. These methodologies revealed distinct drought trends, allowing for the development of appropriate solutions to decrease drought consequences and protect residents' livelihoods. In most study years, the study area was affected by Belg, Kiremt or combined rainy season droughts. Seasonal Kiremt drought events were becoming locally fragmented even at village levels. As the frequencies and persistence of mild drought impacts have increased, the intensity and precipitation are too small to cultivate crops and forage growth. However, there are no effective early warning systems that continuously provide updated information before, during and post-drought events. There is no attention to the study area except when large-scale drought occurs at regional or nationwide scales. Gidey (2012) stated that an isolated drought event is hazardous for the affected people.

Concerned bodies can establish drought management that withstands the impact, strengthens communities' resilience, and conserves and sustainably uses their natural resources using the current results as an input. Furthermore, the historical context's outlook on local drought occurrences may make it easier to implement low-risk, long-term plans for establishing stable livelihood systems. As a result, this research will help as input information to improve the current household drought monitoring system. The findings will also help early warning systems, especially at the livelihood level in the study areas.

LULC change and its accompanying climatic impacts will be less vulnerable and risky in the future if land-use plans are integrated, updated, and predicted. Applying low-risk and long-term goals to establish sustainable livelihood systems that can endure the negative repercussions is not debatable when using integrated data to study LULC change patterns and their driving causes. Livelihood zone-level LULC change analysis was essential for clustering the changes and forecasting vulnerability to intervene with appropriate adaptation measures. The results of this study can help development practitioners build community resilience while conserving and using natural resources sustainably. In addition, it provided information to include integrated drought and LULC change on livelihood management rather than implementing steps alone. This study can be used as an input to simplify and provide insight into future land use management, decision-making, societal resilience, long-term planning, and capacity building in LULC change management.

In adopting low-risk and long-term plans to construct sustainable livelihood systems that can endure the negative repercussions, studying drought vulnerability using integrated data is not in doubt. The study found that identifying the drought vulnerability of livelihood systems at the livelihood zone level is critical for clustering exposure and susceptibility inductors in all livelihood zones. The result will help as inputs for interventions in climate resiliency agriculture systems and provide long-term ecosystem benefits. Furthermore, it will provide insights into incorporating integrated management for drought and LULC change on livelihood rather than implementing steps alone.

Several synergetic phenomena surround and maintain nature. Synergetic occurrences can be seen all over the place. Studying synergy has benefits in achieving many goals with efficiency, effectiveness, and equity. Looking for synergy is critical for lowering operating expenses and attaining efficient results. The study's subject was the synergistic influence of drought, LULC change, and drought vulnerability on livelihood systems at the livelihood zone level. The author discovered that drought impact and LULC change synergistically affect the livelihood system. The effects of drought and LULC change are greater than the isolated variables because they have feedback effects. As a result, drought and LULC change pose a threat requiring a proactive rather than reactive policy response.

A shift in strategy from a sector-specific emphasis to an integrated approach with policy coherence across sectors is needed to maximize benefits while avoiding negative consequences. This research can help us better understand how drought and LULC change policy instruments can work together to reduce synergistic effects on livelihood systems that directly affect household livelihoods. As a result, our research contributes to the current literature of study fields while generating new scientific contributions. The study will improve the current drought and LULC changes monitoring system and build resilience at the household level. This new approach can be used as input for strategies and policymakers to integrate relevant sectors to reduce the synergetic impacts of drought and LULC change livelihood systems at LZ levels.

7.5. Further Research Directions

This study faced challenges in methodology, data availability and accessibility, finances, local (pro and ongoing wars in northern parts of the country, particularly in the study area) and global (COVID 19) challenges.

This study focused on the synergistic impact of drought, LULC change, and drought vulnerability on livelihood systems at the livelihood zone level. However, drought, LULC change, and the livelihood system have multiple dimensions, interactions (synergy), and biophysical and socioeconomic contexts that are not always directly comparable. There is no standard approach to define the interactions between drought, LULC change, and livelihood systems. The author believes this limitation affects the results to boldly show direct interaction and impacts of drought and LULC change on livelihood systems. It was difficult to synthesize using empirical studies or models that can ideally produce measurable ($x+y= z$) outcomes. Therefore, the author pushed to analyze the synergetic impact parts (chapter 6) based on narrations, comparison, and contract methods.

The study was limited to household socioeconomic data to measure their wealth. This difficulty was rooted in political tensions pro-civil war in north Ethiopia. Most of the households were unwilling to use their detailed economic backgrounds and on some sensitive issues like land-use policy and their farmland size. Therefore, this study did not measure the impact on household income levels; rather, this study focused on available income sources and production trends. Further, this study did not get tangible crop and livestock productivity data from kebele to federal levels that commented at kebele levels. The author believes that these limitations hinder us from showing clear synergetic implications of drought and LULC change on the community's livelihood at household levels.

Furthermore, the availability of data, particularly meteorological data, affected the length of years of this study. There was no grid data before 1983, and after 2016 the Ethiopian National Meteorological Agency is currently processing it. As a result, the author had to limit themselves to gridded meteorological data from 1983 to 2016. Consequently, the author recommended the following research areas for further study.

- The Belg and Kiremt rainfall onsets, durations, terminations, and variabilities trends need in-depth investigations for proper agricultural activities. In that case, it will help put appropriate measurements and interventions to reduce crop failures and forage problems at local levels.
- Further research using household economic backgrounds is needed to investigate the synergetic effects of drought and LULC change on other livelihood zones to determine the amount and direction of the interaction of drought and LULC change on the livelihood systems and household levels.
- This study suggested that this study be repeated in agroclimatic zones with significant climate and growing seasons that are climatically favorable for certain crops and cultivations at the subnational and national levels.
- Furthermore, it will be essential to replicate this study with additional parameters in an agroecology zone with diverse ecological responses to homogeneous macro-climate areas regarding soil, climate, physiography, and conductive moisture availability.

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Appendices

Appendix 1: Focus Group Discussion Questionnaire

7.5.1. Part I: Drought Impact

1.1. In your area, what are the most common livelihood strategies?

1.2. What is your observation regarding rain onset and termination within the past 35 years?

1.3. What is the best way to explain drought?

1.4. What are the frequencies of drought history in your area?

1.5. What impact do droughts have on your community?

1.6. How did droughts impact the market system, and how did you respond?

1.7. How does your community cope with drought to maintain the livelihood system?

1.8. 8. What are some of the traditional drought-relieving practices?

1.9. What are the alternate water sources during a drought?

1.10. What are the government's drought-prevention, mitigation, and recovery initiatives, and how effective are they?

1.11. What role does the safety net program play in bridging the gap in food security?

7.5.2. Part II: Land Use Land Cover Change

2.1. What have been the trends in natural resource conditions in your area over the last three decades?
2.2. Which tree and wildlife species are extinct or on the verge of extinction?
2.3. What are the most common reasons for LULC changes?
2.4. 2.4. How do you assess the trends in private land ownership and farm size over the previous 35 years?
2.5. .What have been the trends in community land ownership over the last 35 years?
2.6. How does land distribution for the landless youth affect their livelihood system?
2.7. How does a land transfer to investors affect the community's livelihood system?
2.8. What are the trends of land productivity within the same plot in the last 35 years?
2.9. Is there any diversification in the community to maximize earnings (commercial or subsistence, irrigation or rain feed)?
2.10. Are there livestock varieties (upgraded and old, quality, volumes) to enhance community profits?
2.11. What have your area's forage source patterns over the last three decades?
2.12. How do changes in land use and land cover affect your social networks?
2.13. How do you assess technological accessibility, adaption (fertilizer, enhanced seeds, and livestock types), knowledge, and capacity building?
2.14. How do you measure the effectiveness of afforestation efforts?
2.15. What is the current trend in your area for fuelwood and alternative energy sources?
2.16. What are your impressions of your community's saving and working habits?

2.17. What are some cultural practices that exacerbate the lack of savings habits?
2.18. How accessible do credit and markets appear to be in your area?
2.19. How does the community learn from previous drought trends and land use land cover change?
2.20. In your community, what are the most pressing concerns that require attention?
2.21. What measures were taken by the government to tackle this issue, and how effective are they?

Appendix 2: Household Survey Questionnaire

Instruction: This study aims to assess the responses of the local communities to the synergetic impact of drought and LULC change in your area. The information you provide will help evaluate the leading causes of LULC change and drought trends that synergetically affect the livelihood systems of the community. Further, it will help us generate and provide helpful information for policymakers and development stakeholders to tackle the problem of drought impacts and LULC changes in the livelihood systems of the community. Your participation in this questionnaire will be voluntary. You have every right to choose not to be involved. Moreover, the information you provide us will be handled with strict confidentiality and not be used or transferred to any third party.

Note for interviewers

1. After greetings, introduce yourself.
2. State the objective of the study following the above information
3. Then, proceed with the questions.
4. Be patient in collecting reliable data.
5. Do not forget to THANK the respondent when you finish your questions.

.

7.5.3. Part I: Demographic and Socioeconomic Household Characteristics

Household identification number :	
Woreda	1. Woreda : 1) Raya Azebo 2) Raya Alamata 3) Oflla 4) Enadamehoni
Kebele**:**	
Gott/ kushet**:**	
Livelihood Zone	1) Raya Valley 2) Alagei Offla 3) Tsirare Catchment
Date of the Interview : ________________________	
Age of respondent :	
Sex of respondents	1. Female 2. Male
Household type :	1. Male head 2. Female head
Marital Status	1. Single, 2. Married, 3. Divorced, 4 Widowed
Family size	Female:

	Male: Total :
How many years have you lived here? **:**	
Educational Status	1. Illiterate (Unable to read and write), 2. Religious school 3. 'Literate (Able to read and write), 4. Primary School, 5. Secondary School, 6. Diploma, 7. 1st degree, 8. 2nd degree, 9. 3rd degree
Religion	1. Christian 2. Muslim 3. Others (specify)_____________
Source of income	1. Crop production only 2. Livestock raising only, 3. Mixed farming (both crop production and livestock raising) 4. Trade 5. Employed in the private sector 6. Governmental workers 7. Others (specify)
Enumerator Code:_________ Name:____________________ Signature:_____________	

To be completed at the field after the interview is done **………..**

Name and signature of supervisor**:** ____

Date: ___________________________________

7.5.4. Part II: Perception of the Local Community to Drought and its Impacts

2.1. Understanding of local communities for Climate change context

2.1.1. What was your observation or experiences regarding the temperature trend in your area for the last 35 years?

a. Increased (warmer)
b. Decreased (become cold)
c. No change
d. I don't know (I don't realize the difference)

Kindly elaborate more on your chosen answer: ....

2.1.2. What was your observation or experiences regarding the temperature trend in your area for the last 35 years? Choose all local indictors

Types of hazards/ problems	Dos the hazards/ problems in your area happen? 1. Yes 2. No	Do you think this is related to climate change? 1= Yes 2= No	Do people practice any solution to decrease the impact of the hazard? 1= Yes 2= No
Deforestation			
Increasing the frequency of drought			
Increasing the frequency of floods			
Snow			
Degradation of soil			
Decreasing agriculture production			
Disturbed timing of rainfall (Unexpected rain)			
Gully formation			
Degradation of rangelands			
Degradation of cultivated land			
Strong wind storm			
Increased transmitted and occurrence of new human disease			
Occurrence of new crop disease			
Emergences of new herbs			
Increased transmitted and occurrence of new animal disease			
Extinct of all/some wildlife from the area			
Increasing the frequency of migration for job			
Other (specify)____________			

2.1.3. List the extinct tree types ----------

2.1.4. In the last 35 years, how have you observed the commencement and termination of rainfall in your location throughout spring (Belg) and summer (Kiremt)?

Starting and end time of rain in Spring (Mar-May)	Years	
	2000-20119	Before 2000
Early start and late cessation		
Early start and early cessation		
Late start and early cessation		
Late start and late cessation		

Starting and end time of rain in summer (Jun-Aug)	Years	
	2000-2011	Before 2000
Early start and late cessation		
Early start and early cessation		
Late start and early cessation		
Late start and late cessation		

2.1.5. How long do you receive rainfall during the rainy season (Average estimation)?

Duration/time of the rainy season	Years	
	2000-2019	Before 2000
Three months		
Two months		
One month		
Two weeks		
One week		

2.1.6. Which water source do you utilize for your farm activity? (you can select more than one answer)

Years(in E.C)	Rainfall	Ponds	Groundwater	Springs	Rivers	Others (please specify)
2000-2019						
Before 2000						

2.1.8. How many seasonal and perennial water sources do you have/had?

Type	2000-2019		Before 2000	
	Perennial	Seasonal	Perennial	Seasonal
Rivers				
Springs				
Wetlands				
Ponds				
Lakes				

2.1. Perception of local communities in the context of drought and its impacts

2.1.1. Do you have any know-how about drought impacts? 1. Yes, 2. No

If your answer is yes:

2.1.2. How do you define drought as related to rainfall?
  a. Absence of rain for one month during the rainy season
  b. Lack of rain for two months during the rainy season
  c. Absence of rain for three months during the rainy season
  d. Absence of rain for six months in a year
  e. Absence of rain for one year and above

2.1.3. How do you define drought in terms of crop failure?
  a. When partial crop failure happens
  b. When total crop failure happens
  c. When complete crop failure occurred beyond one year

2.1.4. Which season of the crop cultivation year frequently suffers from erratic rainfall?

  a. Meher/
  b. Kermit (June- October)
  c. Belg (February-April)

2.1.5. How many quintals did you get from one hectare during a good rainy season (no drought time)?
  a. Cereals crop ----------------
  b. Cash crop ----------------

2.1.6. Have you ever faced crop failures because of drought?
  a. Yes
  b. No

2.1.7. How does the drought affect your productivity if you have ever faced drought events?
  a. Highly affects productivity (Total failure of a crop)
  b. Moderately affects productivity (half decrease in productivity)
  c. It slightly affects productivity (One-third decrease in crop production)
  d. It does not affect productivity (No crop production)

2.1.8. How many months/years can your family survive without aid if a drought occurs?
I sustain for 3months

2.1.9. Do you have saving habits? 1. Yes, 2. No

2.1.10. How many times have you experienced a drought in your life?

Years (E.C)	Time interval				
	1 times	2 times	3 times	4 times	5 times
2000-2019					
Before 2000					

2.1.11. Have you ever faced famine throughout your lifetime due to drought?
  1. Yes
  2. No

2.1.12. If yes,
  a. Please list the years and the duration of famine: ....
  b. Discusses the severity of each famine on your family: ....

2.1.13. Have you faced any livestock loss because of drought in your life?
  1. Yes
  2. No

2.1.14. If yes, please put the number of livestock you lost:

Livestock type	The number lost in the drought years	
	2000-2019	Before 2000
Cow		
Sheep		
Goat		
Mule		
Horse		
Donkey		
Camel		
Beehive		

2.1.15. How does drought affect your area's local market or market accessibility and situation?
  c. Availability of cereals,
  ....
  d. Price level ....
  e. Availability of goods..

2.1.16. How does a drought affect your social interactions? ....

2.1.17. What is your perception of drought impact?
  a. It is not typical and not threatening
  b. It is familiar and threatening
  c. It is common and unthreatening
  d. It is devastating to life and property

2.1.18. From your experience, how do the following factors aggravate your vulnerability to droughts?

Parameters	Level of impact (1. High,2. Medium, 3. Low, 4. None)
Poor saving habits	
Wedding ceremony	
Funeral ceremony	
“Sadaka or Teskar”	
“Mahber”	

Kirstina	

7.5.5. Part III: Perception of the Local Community to Land Use Land Cover Change and its Impact

3.1. Trends of landholding and crop Production through LULC changes

3.1.1. Do you have land for agricultural activities?

1. Yes
2. No

3.1.2. If yes, how did you get access to it?

a. Via land redistribution
b. Shared with relatives
c. Inherited from parents
d. Rented
e. Purchased
f. Other (specify)

3.1.3. Current Landholding and land use of the household

Land-use type	Total land owned (ha)	Land rented in (ha)	Rain-fed land (ha)	Irrigated land (ha)
Annual crops (field)				
Perennial crops (field)				
Forest/wood lots (field)				
Grazing/pasture area				
Homestead				
Settlement				
Other use				

3.1.4. Private land holding trends/farm size over the last 35 years:

Type of land	Approximate size of land (hectare/timad)	
	2000-2019	Before 2000
Homestead		
Irrigated land		
Non-irrigated land		
Private grazing land		
Closed area		
Abandoned		
Plantation		
Settlements area		
Bare area		

3.1.5. Communal land holding trends/farm size over the last 35 years:

Type of land	Approximate size of land (hectare/timad)	
	2000-2019	Before 2000
Communal grazing land		
Forest area		
Closed area		

Abandoned		
Gully		
Plantation		
Bare area		

3.1.6. How do you evaluate the land use and land cover change trend in your area?

Constraints	2000-2019	Before 2000
Severity of deforestation		
Extents of land degradation		
The severity of water stress		
The severity of climate change		
The severity of soil fertility decline		
The severity of gully formation		
The extent of settlement expansion		
The extent of farmland expansion		
The extent of grassing land decline		
Reduction of productivity		
Severity: 1. Light; 2. Moderate; 3. Sever; 4. Very severe Extent: 1. Absent; 2. Present on the vulnerable land unit, 3. Widespread everywhere Reduction: 1. Light; 2. Moderate; 3. Sever; 4. Very severe		

3.1. Trends of Livestock production through Land Use and Land Cover Change

3.1.1. Which livestock species are more suitable for your current land-use system? You can have more than one answer.

a. Small ruminants (sheep, Goat)
b. Large ruminants (Cattle; improved dairy or beef)
c. Camel
d. Equines (Donkey, Horse, or mule)
e. Chicken
f. Others (specify) there is no space, no forage, no animal raring
g. Bee
h. Poultry

3.1.2. Why do you select this animal for your current land-use system? You can have more than one answer.

a. More productive\More adaptable to the fluctuation of weather conditions
b. More flexible to the change of weather condition
c. Suitable to other farming practices (as draft power/ input like manure fertilizer
d. High market demand for that animals

3.1.3. What are the challenges and opportunities for rearing livestock in the existing land use system?

Opportunities:

a. Good Government support,
b. High demand,
c. Better productivity,
d. Integration with other farm activities
e. No opportunity

Challenges:

a. Resources scarcity
b. Limited technology,

c. No finance,
d. Lack of market,
e. Regulatory/policy problem

3.1.4. What negative impacts do land use and land cover changes have on livestock production in your area?

On Social impact:

a. Loss of prestige due to livestock reduction
b. Loss of culture (Livestock supported ceremonies/customs)
c. Spiritual (selected animal scarifies for the religious ceremony)
d. Recreation

Economic impact:

a. Reduce production/yield
b. Aggravated food insecurity
c. Reduce the number of animals/species and then their profits

Environmental impact:

a. Land competition for the other enterprises,
b. Loss of biodiversity,
c. Imbalance of ecosystem

3.1.5. Were the following parameters constraints for livestock rearing in the past 35 years?

Constraints	2000-2019 1. Yes, 2. No	Before 2000 1. Yes, 2. No
Shortage of grazing lands		
Lack of fodder		
Shortage of water		
Diseases		
Luck of sufficient veterinary services		
Failure to properly use stock products		
Lack of market for stock and their products		
Lack of access to better stock breeds		
Attack by wildlife		
Other specify		

3.1.6. What are primary forage and pasture sources based on their importance and availability?

Measures		2000-2019	Before 2000
Teff straw			
Wheat straw			
Sorghum Stover and green leaves			
Maize Stover and green leaves			
Millet Stover and green leave			
Feed cactus leave			
Hay from private pastures			
Hay from improved private pasture			
Hay from communal land			
Tree pods and fodder			
Grazing natural private pastures			
Grazing improved private pasture			
Grazing communal grazing land			
Grazing near homestead			

Grazing wetlands			

3.1.7. What is the contribution of livestock production to land-use change?
  a. Positive contribution (soil fertility)
  b. Negative contribution (like degradation) --
3.1.8. What is your general suggestion/opinion on the trends of land-use change concerning livestock production? ---------------------------
3.1.9. What strategies do you recommend for sustainable and profitable livestock-based land use? ------------------- ---

3.2. Natural resources problems through Land Use and Land cover Change

3.2.1. What are the significant issues associated with water resources in your area? ------------------
3.2.2. How do land use and land cover change affect water sources in your area? -------------------
3.2.3. What are the significant causes of deforestation in your area? ----------------------------

3.2.4. What is the extent of deforestation? 1. High 2. Medium 3. Low 4. I have no idea
3.2.5. What challenges have you and your community faced because of deforestation?
3.2.6. What are your fuelwood sources?

Fuel wood source	2000-2019	Before 2000
Charcoal		
Firewood		
Lamps		
Dugs		
Crop residues		
Electric power		
Moderate stove		
Solar energy		
Biogas		

3.2.7. Do you have a fuelwood problem in your area? 1. Yes, 2. No
3.2.8. If yes, can you please tell us the cause of the problem and the solution you used? ----------
3.2.9. What will be the fuelwood challenge in the future? ----------------------------
3.2.10. How has infrastructure development affected land cover and land use? ----------------------------
3.2.11. Are these changes affecting your life and your social system? 1. Yes, 2. No
3.2.12. What are the cultural practices which aggravate the vulnerability of land use land and cover change? -------
3.2.13. How does land distribution for the landless youth affect your livelihood system? ----------------------------
3.2.14. How does land distribution to investors affect your livelihood system? ----------------------
3.2.15. What benefits do you obtain from extension services regarding land use land cover change? -------------------
3.2.16. What have you learned from previous land use land and cover change trends?

7.5.6. Part IV: Drought Adoption, Coping Strategies, and Adaptive Capacity of the Local Community

4.1. Do you participate in community organizations?

1. Yes,
2. No

4.1. How do the following social factors help you to cope with drought impacts?

Parameters	Level of impact (1. High, 2. Medium, 3. Low, 4. None)
“Equb”	
“Mahber”	
“Eddir”	
“Ofera” (Helping others freely)	

“Zeka”/ “Mitswat”	
Tsebel	
Lifnt (Power sharing)	

4.2. Have you ever practiced diversification of agricultural activities to maximize profits due to the LULC changes? ----------------------------

1. Yes
2. No

4.3. If yes, what types of activities do you perform?

Type of plant	Presence and absence	
	2000-2019	Before 2000
Eucalyptus		
Chat		
Cotton		
“Gesho”		
Fruits (Like Banana, Mango, and Papaya)		

4.4. What are the driving factors for practicing annual cash crops, fruits, and vegetables? ---------------------------

4.5. Do you (your family) practice any climate change coping methods/strategies to withstand drought problems?

1. Yes
2. No

4.6. If yes, which strategies/methods do you practice to protect the household livelihood from drought shocks in crop production?

No	Practice	**Do you practice** **1. Yes** **2. No**	**Sources: Code 1a**: 1= Extension service/BoA; 2=NGO; 3=Research center; 4= Market; 5= Fellow farmers/ Model farmer 6= Own stalk/ Own experience; 7= Cooperative/union; 8=Community seed bank 9=Others (specify) 10 = Non
	Crop interring		
1	Crop diversification		
2	Applying fertilizer		
	Compost or manure		
3	Planting early/shortly maturing crop		
4	Planting drought-tolerant /moisture stress-resistant improved seeds		
5	Training on improved crop input use		
6	Training on improved production practices		
7	Extension advice on improved crop input use		
8	Pesticides		
9	Herbicides		
10	Applying physical soil and water conservation		
11	Use of traditional (diversion or pump)		
12	Use of improved irrigation (diversion or pump)		

13	Use of rainwater harvesting practice		
14	Applying water-efficient practices		
15	Applying row planting		
16	Applying repeated weeding		
17	Maintain proper crop density (spacing)		
18	Maintaining crop residue to maintain soil fertility		
19	Use of tractor for plow		
20	Use of deep tillage to enhance water storage in the soil		
21	Shifting to high value (better price) crops		
22	Practicing value addition process to attract high price		
23	Extension advice on marketing network		
24	Crop/livestock price information		
25	Market linkage advise		
26	Extension advice on marketing network		
27	Practicing agro-forestry on farmlands		
29	Others (specify)		

4.7. Do you practice strategies/methods to protect the household livelihood from drought shocks in livestock production?

No	Practice	1. Yes, 2. No
		Code 2a: 1= Extension service/BoA; 2=NGO; 3=Research center; 4= Market; 5= Fellow farmers/ Model farmer 6= Own stalk / Own experience; 7= Cooperative/union; 8=Community seed bank 9=Others (specify)
1	Using closure practice on pasture lands	
2	Improved chicken	
3	Improved dairy cow	
4	Use of artificial insemination	
5	Improved sheep/goats breeds	
6	Choosing few animals for the market than extensive herd keeping	
7	Practicing improved fodder production	
8	Improved beehive	
9	Practicing activities that result in better income like fattening (sheep, goat, ox)	
10	Practicing water harvesting (pond or reservoirs development) for livestock production purposes	

11	Livestock forage management and feed storage	
12	Use of cut and carry forage management	
13	Hay production for forage shortage period	
14	Veterinary service-vaccination	
	Veterinary service-treatment	
15	Practicing rotational/controlled grazing	
16	Market information	

4.8. What do you do during a drought event to sustain your livelihood needs?

Copping Strategy	2000-2019	Before 2000
Livestock movement to other grazing areas		
Destocking		
Migration to a nearby area		
Consuming fewer cost foods		
Borrowing grain from others		
Borrowing cash from a money lender		
Firewood and charcoal selling		
Rely on relief		
Lease outland		

4.9. Do you meet your household members' all-year-round food requirements from your farm?

1. Yes
2. No

4.10. On average, for how many months do you consume your production if you are not self-sufficient? ---------------

4.11. Did you gate emergency or safety net support in your life?

1. Yes
2. No

4.12. What are the positive and negative implications of the safety net programs:

a. your household ---

b. the environment---

4.13. After the occurrence of drought, how many months/years would you need to recover from the impacts of the drought? ---------------------------

4.14. According to your self-assessment, does your household:

Self-assessment	2000-2019	Before 2000
Food secure		
Food insecure		
It varies from year to year		
Not known		

4.15. Do you have any household members working in non-farm activities?

a. Yes
b. No

4.16. If yes, please list each activity and the amount earned per month?

Activity	Member involved	Time spent	Per month (birr)	Annually

4.17. What are the driving forces to participate in your household in off-farm ventures?

4.18. Does your income from non-farm activities enable you to buy food to fulfill your gap?

1. Yes
2. No

4.19. If none of your HH members is involved in non-farm activities, what are the reasons? Tick and rank them from (1 to 5) according to their importance.

Reason for not working	Yes	Rank
Lack of spare time for agriculture		
Lack of awareness about its contribution		
Lack of work skills		
Lack of job access		
Unable to work due to age		
Health problems		
Lack of startup capital		
Others (specify)		

7.5.7. Part V: Practices in Improving Land Management

5.1. Which of the following land management practices have you implemented to improve the soil fertility of your farmland, and who teaches you about the procedure?

Measures	If there were which one of the following Sources of the technologies 1=DA 2= Research institutions 3= NGO´s 4 = Own experiences		
	2000-2011	1989-1999	1976-1988
Soil and water conservation practices on farmlands			
Constructing flood diverting detach for farmlands			
Rainwater harvesting			
Crop rotation			
Fallowing			
Organic Fertilizer (manure and compost)			
Intercropping			
Leguminous tree			
Others (specify)			

7.5.8. Part VI: Policy Gap Assessment for Land Use, Emergency, and Relief Programs

6.1. Is there any early warning system?
1. Yes
2. No

If yes, please explain the strengths and the weakness of the system ----------------------------

6.2. Are there any extension services that create awareness regarding drought impacts and adaptation mechanisms?
1. Yes
2. No

If yes, please explain the awareness creation system:

6.3. Are there any Safety net program guidelines that define its purpose?
1. Yes
2. No

6.4. If yes, please explain the strength and the weakness of the guideline
The weakness:

6.5. Do you have enough access to agricultural technologies like fertilizer, improved seed, and information?

1. Yes
2. No

6.6. If not, what type of problems have you faced? ....

6.7. Were you or your community member involved in any development plan in your area?

1. Yes
2. No

6.8. If yes, how you/ your Community participate in project planning and implementation

	Activities	**1 = Yes** **2= No**	**Remarks (how) , if the answer is yes**
1	Preparation of plan		
2	Implementation of plan		
3	Operation and maintenance of the plan		
4	Monitoring of plan		
5	Community hearing on potential Environmental Impacts		

6.9. Discuss investment and land use policies, practices, and regulations that affect land management in your area at different times and their impacts:

2000-2019 ....

Before 2000..

Appendix 3: Interview with key informants

A. Early warning experts

Dear respondent:

Date of interviewee --

Interviewer--

District --

Name of interviewee---

Position ---

0rganization---

Professional ---

Experiences---and mobile number ---------------------------

Early warning and response

1.1. Is your area experiencing a severe drought?
1.2. How frequently does your area experience droughts?
1.3. How vulnerable is your area to drought?
1.4. How many people have been affected by past droughts?
1.5. How many peoples are now vulnerable to drought?
1.6. Is there any early warning system in place?

a. Yes, b. No

1.7. If you answered yes, please describe the strategy you used: ---------------------------

1.8. How can you evaluate the trends of policies, proclamations, programs, and guidelines in related drought response at the federal and regional levels? --

2. Which organizations are working toward early warning and response? --
3. Are there any extension services that create awareness regarding drought impacts and adaptation mechanisms?
   a. Yes
   b. No

If yes, please explain the awareness creation system: ....

4. How do you evaluate the efforts made? ---
5. What hasn't been accomplished so far, and what could have been better?--
6. What are the most priority issues in your locality that need early warning and response intervention? ------------
7. How community affected by drought ---
8. What are their sources of revenue during drought years to keep them afloat?---------------------------------------
9. What community does during drought fulfill their livelihood system? --
10. What are their alternative sources of water during drought years? --
11. How do droughts affect their market system, and what is it to challenge the situation? --------------------
12. What traditional practices are there to resist the drought --
13. What measures are taken by the government to tackle this issue, and how effective are they? --------------------
14. Access to extension services to early warning and response ---
15. Technological accessibility and adaptation
16. Alternative energy sources and firewood
17. Credit access
18. Long and short-term plans to solve the problem of drought
19. Internal and external challenges you face to implement each strategy
20. How does the community learn from previous trends?
21. What strategies do they flow to reduce each challenge?

B. Food Security Experts

Date of interviewee --

Interviewer--

District ---

Name of interviewee---

Position ---

0rganization--

Professional --

Experiences--and mobile number ---------------------------

Livelihoods:

1.1. Which organizations are working on food securities in the locality? ---

1.2. How do you evaluate the efforts made in the food security program ? ---

1.3. . What hasn't been accomplished so far, and what could have been better?---------------------------------

1.4. What are the most priority issues in your locality that need intervention in food security? ---------------- --

1.5. How is drought severe in your area?

1.6. What is the frequency of drought in your woreda?

1.7. How is your area vulnerable to drought?

1.8. How many people have been affected by drought in the past?

1.9. How many peoples are now vulnerable to drought?

1.10. If so, please describe the system you utilized.:...

1.11. How can you evaluate the trends of policies, proclamations, programs, and guidelines in related drought response at federal and regional levels?

1.12. Have you ever faced famine throughout your lifetime due to drought in your area? -----------

1. Yes
2. No

1.13. If yes, please list the years and the duration of famine:..

1.14. Discusses the severity of each famine on your family:...

1.15. After the occurrences of drought, how many months/years would your community need to recover from the impacts of the drought? ______________________

1.16. What are they do during a drought event to sustain their livelihood needs?

1.17. How does drought affect your area's local market or market accessibility and situation?

a. Availability of crops..
b. Price level...
c. Availability of goods..

1.18. Impact of drought on social network

1.19. How does a drought affect social interactions? ....

1.20. From your experience, how do the following factors aggravate the vulnerability to droughts?

Parameters	Level of impact (1. High,2. Medium, 3. Low, 4. None)
Poor saving habits	
Wedding ceremony	
Funeral ceremony	
“Sadaka or Teskar”	
“Mahber”	

1.21. How do the following social factors help to cope with drought impacts?

Parameters	Level of impact (1. High, 2. Medium, 3. Low, 4. None)
“Equb”	
“Mahber”	
“Eddir”	
“Ofera”	

“Zeka”	

1.22. What measures are taken by the government to tackle this issue of food security, and how effective are they?
  a. Alternative energy sources and firewood--
  b. Credit access ---
1.23. Do you have any household members working in non-farm activities in your community?
  c. Yes
  d. No
1.24. If yes, please list each activity and the amount earned per month?

1.25. What are the driving forces to participate in your household in off-farm ventures? ....

1.26. If none of your community members is involved in non-farm activities, what are the reasons?

1.27. Do they meet the all-year-round food requirements of their household members from their farm?

  a. Yes
  b. No
1.28. If they are not self-sufficient, on average, for how many months do they consume their production?......

1.29. Does their income from non-farm activities enable them to buy food to fulfill their gap?

  a. Yes
  b. No

1.30. Long and short-term plans to solve the problem of food security? --
1.31. The internal and external challenges they face in implementing each strategy regarding managing food security
1.32. How does the community learn from previous trends? ---
1.33. What strategies do they flow to reduce each challenge? ---

2. land cover and land use

2.1. How does infrastructures development affect land cover and land use?..

2.2. Are these changes affecting the community life and their social system? 1. Yes, 2. No

2.3. What are the cultural practices that aggravate land use vulnerability and land cover change? ....

2.4. How does land distribution for the landless youth affect the livelihood system of your community?............
2.5. What benefits do they obtain from extension services regarding land use land cover change? ....
2.6. Discuss practices and regulations that affect land management in your area at different times and their impacts:

Aftte1997 ....…………………………………

Before 1997...

C. Natural Resources Management Experts

Date of interviewee ---

Interviewer---

District ---

Name of interviewee--

Position --

0rganization---

Professional ---

Experiences---and mobile number ---------------------------

Natural Resources:

1.1. How do you evaluate the efforts made to natural resource management? ---
1.2. 1.2. What hasn't been accomplished so far, and what could have been done better------------------------------------
1.3. What are the most priority issues in your locality that need intervention regarding watershed management? -----
1.4. How does watershed management affect the productivity of your community farm? ---------------------------------
1.5. What traditional practices are there to harvest rainwater? ---
1.6. To which extent the community accepts and embraces the technology which reduces the shortage of water/ problem? ---
1.7. What are the significant issues associated with water resources in your area? ....
1.8. How do land use and land cover change affect water sources in your area? ---

1.9. How do you evaluate the land use and land cover change trend in your area?

Constraints	2000-2019	Before 2000
Severity of deforestation		
Extents of land degradation		
The severity of water stress		
The severity of Climate change		
The severity of soil fertility decline		
The severity of gully formation		
The extent of settlement expansion		
The extent of farmland expansion		
The extent of Grassing land expansion		
Reduction of productivity		

Severity: 1. Light; 2. Moderate; 3. Sever; 4. Very severe
Extent: 1. Absent; 2. Present on the vulnerable land unit, 3. Widespread everywhere
Reduction: 1. Light; 2. Moderate; 3. Sever; 4. Very severe

1.10. What challenges have you and your community faced as a result of deforestation? ....

1.11. Do you have a fuelwood problem in your area? 1. Yes, 2. No

If yes, can you please tell us the cause of the problem and the solution you used?

1.12. Which one of the following measures have you been using to rehabilitate your community area?

Measures	2000-2019	Before 2000
Terracing		
Afforestation		
Soil bund		
Stone bund		
Contour plowing		
Furrowing		
Strip cultivation		
Area closure		
Others (specify)		

1.13. What are the most priority issues in your locality that need intervention in forest conservation and development? ---

1.14. How do forest conservation and development affect the local agricultural products ? --

1.15. What traditional practices are there related to forest conservation and development? -----------------------------

1.16. What is the perceived level of community in related forest conservation and development? ------------------------

1.17. Afforestation activity and its success rate ………………………………………………

1.18. Long and short-term plan to solve the problem of forest conservation and development in the area ……………………………………………………………………………………………………

1.19. The internal and external challenges they face in implementing each strategy regarding forest conservation and development

D. Land Use and Management Experts

Date of interviewee ---

Interviewer--

District ---

Name of interviewee--

Position ---

0rganization---

Professional ---

Experiences---and mobile number ---------------------------

1. Impact on Productivity:

1. How can you evaluate the Private land holding trends/farm size over the last 35 years?
2. What about communal landholding trends/farm size over the last 35 years?
3. How do you evaluate current and past Ethiopian rural land-use policies?
4. What are the merit and demerit of the past and the current Ethiopian rural land-use policies?
5. What trends do you observe from the tendency of Ethiopian investment policies?
6. How can you evaluate the implication of investment policies on the environment and the local community's livelihood?
7. What are the cultural practices which aggravate the vulnerability of land use land and cover change?
8. What have you learned from previous land use land and cover change trends?
9. How does land distribution for the landless youth affect their livelihood system? ....
10. How does land distribution to investors affect their livelihood system?
11. How has infrastructure development affected land cover and land use?
12. Are these changes affecting your community life and their social system? 1. Yes, 2. No
13. What are the practices and regulations that affect land management in your area at different times and their impacts:

After 1997..………………………

Before 1997 ....………………………

14. Long and short-term plans to solve the problem of LULC changes in the area,
15. The internal and external challenges they face in implementing each strategy regarding managing LULC change
16. How the community learns from previous trends? ....

E. Crop Experts

Date of interviewee --

Interviewer---

District ---

Name of interviewee--

Position ---

0rganization---

Professional ---

Experiences---and mobile number ----------------------------

Agricultural productivity:

1. In the last 35 years, what have you noticed about the onset and termination of rainfall in your location throughout spring (Belg) and summer (Kiremt)?

Starting and end time of rain in Spring (Mar-May)	Years	
	2000-20119	Before 2000
Early start and late cessation		
Early start and early cessation		
Late start and early cessation		
Late start and late cessation		

Starting and end time of rain in summer (Jun-Aug)	Years	
	2000-2011	Before 2000
Early start and late cessation		
Early start and early cessation		
Late start and early cessation		
Late start and late cessation		

2. How long do you receive rainfall during the rainy season (Average estimation)?

Duration/time of the rainy season	Years	
	2000-2019	Before 2000
Three months		
Two months		
One month		
Two weeks		
One week		

3. Within the last 35 years, how many times have you faced drought occurrences in your area? ------------------
4. How can droughts affect crop productivity, and what strategies are employed to boost productivity t?
5. What are your alternative sources of water during drought years?
6. What was your observation or experiences regarding the temperature trend in your area for the last 35 years?
   e. Increasing
   f. Decreasing
   g. No change

h. I have no idea

Kindly elaborate more on your chosen answer: ....

7. What crops have grown in your area in the last 35 years?
8. What crops have grown during the summer season in the last 35 years (Kiremt)?
9. What crops have grown in the last 35 years during the spring season (Belg)?
10. How many quintals can get from one hectare during a good rainy season (no drought time)?
    a. Cereals crop -------------
    b. Cash crop ----------------
11. Does your community have enough access to agricultural technologies like fertilizer, improved seed, and information?
    a. Yes
    b. No
12. How do they access fertilizer, and what challenges have they faced?
13. How do they access improved seeds, and what benefits do they derive from them? ....
14. Have you ever faced crop failures because of drought in your area?
    a. Yes,
    b. No

If yes, how does the drought affect productivity?

a. Highly affects productivity (Total failure of a crop)
b. Moderately affects productivity (half decrease in productivity)
c. It slightly affects productivity (One-third decrease in crop production)
d. It does not affect productivity (No crop production)

15. How many months/years can your people survive without aid if a drought occurs?
16. What traditional practices are there to resist crop failure from drought? ---
17. Have your community ever practiced diversification of agricultural activities to maximize profits due to the LULC changes?
    Yes
    1. . No
18. If yes, what types of activities do you perform? --
19. What are the driving factors to practice annual cash crops, fruits, and vegetables?...........................
20. Which of the following land management practices have you implemented to improve the production of your community?

Measures	2000-2019	Before 2000
Crop rotation		
Use of chemical fertilizer		
Herbicides		
Insecticides		
Irrigation		
Others (specify)		

21. Which land management practices have you implemented to improve the soil fertility of your community farmland?

Measures	2000-2019	Before 2000
Crop rotation		
Fallowing		
Organic Fertilizer (manure and compost)		
Intercropping		
Leguminous tree		
Others (specify)		

F. Livestock Experts

Date of interviewee ---

Interviewer---

District ---

Name of interviewee---

Position ---

0rganization---

Professional ---

Experiences--and mobile number ---------------------------

1. What types of livestock are reared in your area?

Time interval	Types of livestock						
	Camel	Cattle	Goat	Sheep	Donkey	Horse	Beekeeping
2000-2019							
Before 2000							

2. Have you faced any livestock loss because of drought in your area?
   a. Yes
   b. No
3. What measures does the community take to fulfill their livestock's demand in the case of drought? ----------
4. How do droughts affect Livestock products, and what is it used to increase their products? --------------------
5. What are the alternative sources of water during the drought period? ---
6. How do droughts affect their market system, and what means do they solve the situation? ---------------------
7. What traditional practices are there to resist the drought impact on Livestock resources? -----------------------
8. How do they access improved livestock, and how does it help them adapt to drought impacts?
9. Which livestock species are more suitable for the current land-use system?

a. Small ruminants (sheep, Goat)

b. Large ruminants (Cattle; dairy or beef)
c. Camel
d. Equines (Donkey, Horse or mule)
e. Chicken
f. Others (specify) ________________

10. Why do they select these animals for their current land use system? You can have more than one answer.

a. More productive\More adaptable to the fluctuation of weather conditions
b. Suitable to other farming practices (as draft power/ input like manure fertilizer More productive
c. More flexible to the change of weather condition
d. Suitable to other farming practices (as draft power/ input like manure fertilizer
e. High market demand for that animals

11. What are the challenges and opportunities for rearing livestock in the existing land use system?

Opportunities

a. Good Government support,
b. High demand,
c. Better productivity,
d. Integration with other farm activities

Challenges

a. Resources scarcity
b. Limited technology,
c. No finance,
d. Lack of market,
e. Regulatory/policy problem

12. What negative impacts do land use and land cover changes have on livestock production in the study region?

On Social impact:

a. Loss of prestige
b. Loss of culture (Livestock supported ceremonies/customs)
c. Spiritual (selected animal scarifies for the religious ceremony)
d. Recreation

Economic impact:

a. Reduce production/yield
b. Aggravated food insecurity
c. Reduce the number of animals/species and then their profits

Environmental impact:

a. Land competition for the other enterprises,
b. Loss of biodiversity,
c. Imbalance of ecosystem
d. Climate variability

13. Can you rank the following parameters as constraints for livestock rearing in the past 35 years?

Constraints	Level of severity. 1. Very high 2. high 3. Medium 4. Low	
	2000-2019	Before 2000
Shortage of grazing lands		
Lack of fodder		
Shortage of water		
Diseases		
Luck of sufficient veterinary services		
Failure to properly use stock products		
Lack of market for stock and their products		
Lack of access to better stock breeds		
Attack by wildlife		
Other specify		

14. What are primary forage and pasture sources based on their importance and availability?

	Degree of utilization or dependency 1. Full dependent 2. Sometimes, 3. Rarely	
Measures	2000-2019	Before 2000
Teff straw		
Wheat straw		
Sorghum Stover and green leaves		
Maize Stover and green leaves		
Millet Stover and green leave		
Feed cactus leave		

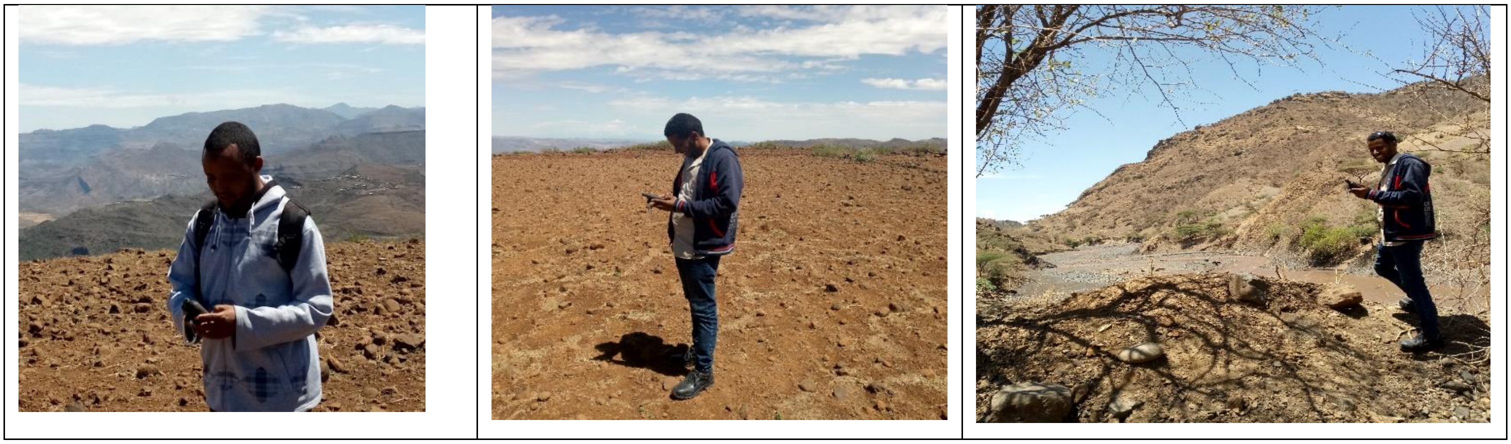
Hay from private pastures		
Hay from improved private pasture		
Hay from communal land		
Tree pods and fodder		
Grazing natural private pastures		
Grazing improved private pasture		
Grazing communal grazing land		
Grazing near homestead		
Grazing wetlands		
Grazing reserves for the dry season		

15. What is the contribution of livestock production to land-use change?
    i. Positive contribution (soil fertility)---
    ii. Negative contributions like: ---
16. What is your general suggestion/opinion on the trends of land-use change concerning livestock production?
17. What strategies do you recommend for sustainable and profitable livestock-based land use
18. What type of livestock production systems helps reduce their effects on land use and land cover change? (Intensive, semi-intensive, Extensive) ?

Appendix 4: Focus Group Discussions, Data Collectors Training, and Ground Survey Photos

A supervised ground survey in the Rvaly livelihood zone

A supervised ground survey in ALOFLZ



A supervised ground survey in TCLZ

A

B

C

D

Focus group discussions in- A = TCLZ and RVLZ at Alamata Town, B = RVLZ only at Mohoni town, C= ALOFLZ and TCLZ at Machew town, and D=LAOFLZ and TCLZ at Korem town

A

B

C

A = Training for data collectors, B= Interview with household head in TCLZ, C= Informal group discussions with communities in RVLZ