Addis Ababa University

College of Social Sciences

Department of Geography and Environmental Studies

Indigenous climate-smart agricultural practices in a changing climate: Exploring adaptation strategies and impacts on crop production in the UNESCO designated cultural landscapes of Konso, Ethiopia

A Dissertation Submitted for the Partial Fulfillment of the Requirement for the Degree of Doctor of Philosophy in Geography and Environmental Studies (Environment and Natural Resources Management)

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DISSERTATION APPROVAL SHEET

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This is to certify that the dissertation prepared by Sibilo Gashure Roba, entitled " **Indigenous climate-smart agricultural practices in a changing climate: Exploring adaptation strategies and impacts on crop production in the UNESCO designated cultural landscapes of Konso, Ethiopia**" and submitted for the partial fulfillment of the requirement for the Degree of Doctor of Philosophy in Geography and Environmental Studies (Environment and Natural Resources Management), complies with the regulations of the University and meets the accepted standards regarding originality and quality.

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DEDICATION

This Ph.D. dissertation is dedicated to my father, Gashure Roba Kagna, and to my mother, Kasana Guyo Galma, who are still working hard on farms under a blazing sun in the Konso hot lowlands to see my success.

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AUTHOR STATEMENT

I, the undersigned, hereby declare that this dissertation is entirely my work and I have dully acknowledged all sources and materials used in this work.

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This dissertation has been submitted for examination with my approval as Addis Ababa University supervisor.

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ABBREVIATIONS

AEZ	Agroecological zone
CIAT	International Center for Tropical Agriculture
CSA	Climate-Smart Agriculture
CV	Coefficient of Variation
DEM	Digital Elevation Model
DFID	Department for International Development
EPRDF	Ethiopian People’s Revolutionary Democratic Front
ESR	Endogenous Switching Regression
FDRE	Federal Democratic Republic of Ethiopia
FGD	Focus group discussion
GDP	Growth Domestic Product
IPCC	Intergovernmental Panel on Climate Change
MK	Mann-Kendall
MNL	Multinomial logit
NetCDF	Networks Common Data Form
NGO	Nongovernmental Organization
NMA	National Meteorological Agency
PSNP	Productive Safety Nets Programme
SLMP	Sustainable Land Management Programs
SPI	Standardized Precipitation Index
SSA	Sub-Saharan African
TRI	Terrain Ruggedness Index
UNESCO	United Nations Educational, Scientific and Cultural Organization
WMO	World Meteorological Organization

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Indigenous climate-smart agricultural practices in a changing climate: Exploring adaptation strategies and impacts on crop production in the UNESCO designated cultural landscapes of Konso, Ethiopia

GENERAL ABSTRACT

The main aim of this study was to explore climate variability and indigenous climate-smart agricultural (CSA) practices in Konso. The study was mainly based on primary data gathered through household surveys, focus group discussions, key informant interviews, and direct field observation. Rainfall and temperature trends were analyzed using the Mann-Kendall trend test, while the spatiotemporal distribution of drought incidents was analyzed and mapped using a standardized precipitation index (SPI). Spatial covariance and correlations were examined using ArcGIS 10.5 band collection statistics tools. A multinomial logistic model was employed to assess the factors that determine adoption of the indigenous CSA practices. While multiple linear regression was employed to assess the impacts of climate variables on crop production, endogenous switching regression was used to assess the effects of indigenous CSA practices on crop production. The findings revealed an increase in annual and summer (Kiremt) season rainfall by 3.16 mm and 0.42 mm per year, respectively. However, the spring (Belg) season rainfall shows a decrease of 1.12 mm per year. The observed episodes of drought indicate that smallholder farmers are already exposed to the adverse impacts of climate change and that rainfed agriculture will be further challenged in the future. A multinomial logistic model showed that the main determinants of adoption of terracing, agroforestry, and intercropping were education, size of landholding, income, access to climate information, credit, and extension services. The multiple linear regression model indicated that climate variability explains 37.4–47.5% of the annual variation in crop production ($p<0.05$). Thus, the high variability in rainfall and warming temperatures result in a decreasing trend in crop production. The results also reveal that application of CSA practices such as crop diversification, terracing, manure, irrigation, and rainwater harvesting have positive impacts on crop production. Households that use CSA practices show a significant ($p<0.01$) increase in crop production compared to non-users. Furthermore, the qualitative analysis shows that sociocultural values, norms, cooperative labor groups, and indigenous political institutions have served as the pillars for the survival and sustainability of indigenous CSA practices for hundreds of years. External support in the form of reliable regular weather forecasts, affordable credit, crop insurance, and livelihood diversification would further support local livelihoods and the sustainability of the Konso indigenous farming system. To ensure the long-term sustainability of indigenous CSA practices in Konso, the community, local government, and NGOs should work in collaboration to restore and promote sociocultural norms, values, and indigenous institutions.

Keywords*: Climate variability, agroecology, SPI, terracing, indigenous CSA practices, endogenous switching regression, sustainability, indigenous institution, sociocultural norm.*

1. GENERAL INTRODUCTION

1.1. Background and justification of the study

Climate change is the statistically confirmed state of a climate based on changes in the average and/or variation of its properties over a long time (IPCC, 2014). Climate variability, however, refers to changes in the climate's average condition over time and space that go beyond individual weather events (IPCC, 2014). There is overwhelming scientific evidence that the climate of the Earth is changing (IPCC, 2007). For example, the global average temperature showed a warming of 0.78°C over the period of 1850 to 2012 (IPCC, 2014), and the current projections for the near-term (2021–2040) indicate that the global average temperature will rise by 1.5 degrees Celsius (IPCC, 2022). Despite being a global phenomenon, climate change can differ considerably across continents and countries (Bewket et al., 2015). For example, East Africa has witnessed increasing trends in maximum and minimum temperatures as well as high seasonal rainfall variability (Cattani et al., 2018; Gebrechorkos et al., 2019). The amount of rainfall is also expected to decrease in most parts of Sub-Saharan Africa, while its variability is expected to rise in the coming years (IPCC, 2022).

A wide range of adverse impacts and associated losses and damages to nature and humans have been caused by human-induced climate change (IPCC, 2022). People and systems that are vulnerable are disproportionately impacted across regions and sectors. For instance, East Africa is one of the global hotspots of high vulnerability due to poverty, governance challenges, limited access to basic services, and resources (IPCC, 2022). Natural rain-based agriculture accounts for approximately 95% of food production in Sub-Saharan Africa (SSA), making it extremely vulnerable to the negative impacts of climate variability and change (FAO, 2016). The warming in Africa is higher than the global average across the continent in all seasons (IPCC, 2007). During the 21st century, maximum and minimum temperatures will be warmer by up to 3.7°C and 2.8°C than the baseline period in East Africa (Gebrechorkos et al., 2019). Owing to seasonal rainfall variability and extreme weather events, East Africa is becoming one of the world's most food-insecure regions and requires humanitarian assistance (Busso & Fernández, 2017; WMO, 2020). Climate change is expected to reduce maize yields by over 12% in SSA in

2050 (Tesfaye et al., 2015). The negative impacts of climate variability and change are much pronounced in arid and semiarid areas of SSA, where water resources and agricultural yields are very sensitive to climate variability (Yadeta et al., 2020). Schlenker and Lobell (2010), for example, in SSA, found a significant decrease in yield of groundnut, maize, millet, and sorghum by 18 percent, 22 percent, 17 percent, and 8 percent, respectively. Similarly, Davenport et al. (2018) reported a reduction of maize yields by 7–11% in SSA and thus urged the implementation of adaptation strategies to increase maize yields. Ethiopia is among the East African countries that are at risk from climate change impacts on agricultural productivity and food insecurity (Alemayehu & Bewket, 2016a; Evangelista et al., 2013).

In Ethiopia, many studies on various spatiotemporal scales have shown persistent warming and a rise in annual temperatures over the last three decades (Ademe et al., 2020; Degefu et al., 2021; Matewos & Tefera, 2020; Tesfamariam et al., 2019). NMA (2007) reported that the mean annual minimum temperature in the country has risen by 0.25°C every decade, while the average annual maximum temperature has risen by 0.1°C every decade. Moreover, McSweeney et al. (2008) noted an increasing trend of approximately 0.28°C per ten years for the average annual temperature in Ethiopia. NMA (2007) projected that the average annual temperature over Ethiopia is expected to rise by 0.9–1.1°C, 1.7–2.1°C, and 2.7–3.4°C in 2030, 2050, and 2080, respectively. Previous studies also revealed statistically significant increases in *Kiremt* (June–September) and *Belg* (February–May) season temperatures (Asfaw et al., 2018; Mulugeta et al., 2017).

Regarding rainfall, the patterns were not consistent in Ethiopia. According to some studies, annual rainfall trends have been highly variable since 1980 and have shown a statistically significant decrease (Belihu et al., 2018; Hessebo et al., 2021; Matewos & Tefera, 2020). Other studies, however, found a statistically insignificant increase in annual rainfall (Alemayehu & Bewket, 2017; Belay et al., 2021; Mengistu et al., 2019). In addition, seasonal patterns of rainfall are inconsistent. Some studies reported a statistically significant increase in rainfall in the *Kiremt* seasons (Muluneh et al., 2016; Teyso & Anjulo, 2016), while other studies showed a statistically significant decrease in the trend of rainfall in the *Kiremt* and *Belg* seasons (Ademe et al., 2020; Belay et al., 2021; Belihu et al., 2018; Hessebo et al., 2021). However, Abrha and Simhadri (2015) and Suryabhagavan (2017) reported no change in either annual or seasonal precipitation. Drought is another aspect of rainfall studies that has become more common in Ethiopia over the last fifty years (Degefie et al., 2019; Mekonen et al., 2020; Mera, 2018). In terms of causing massive food shortages for a large part of the population that relied on subsistence-rain-fed agriculture, droughts that occurred in 1984, 1999, 2009, 2015, and 2016 are the worst droughts in the country's history (Degefie et al., 2019). According to Degefie et al. (2019) and Mekonen et al. (2020), the droughts that occurred in 1984, 1999, 2009, 2015, and 2016 caused massive food shortages for large parts of the population that relied on subsistence-rain-fed agriculture.

Agriculture, which is the pillar of Ethiopia's economy, is negatively affected by erratic rainfall and extreme climatic events (Evangelista et al., 2013). Ethiopia agriculture is highly susceptible to the effects of climate change, owing to its dependence on natural rainfall (Bewket et al., 2015). Studies conducted to date in Ethiopia indicate that rising temperatures, unreliable rainfall patterns, shortening rainy seasons, and lower seasonal rainfall were the reasons behind declining crop production (Kassaye et al., 2021; Tesfaye, Kruseman, Cairns, Zaman-allah, et al., 2018). Yang et al. (2020) noted that Ethiopian cereal production has decreased substantially over the last four decades due to unreliable rainfall and rising temperatures. Furthermore, Kassaye et al. (2021) predict that significant rainfall reductions will lead to an 18.1% reduction in sorghum production in Ethiopia by the end of the 21st century. Moreover, Muluneh et al. (2016) indicated that by the 2080s, rainfall variability will cause maize productivity to decline by 46% in semiarid areas of Ethiopia. In contrast, Araro et al. (2020) reported significant increases in sorghum, maize, and teff yields as a result of increased rainfall in southern Ethiopia. Similarly, Alemayehu and Bewket (2016) found that an increase in rainfall in Ethiopia's central highlands led to a statistically insignificant increase in maize and sorghum yields. Regarding the effects of temperature on crop yields, previous studies found an inverse relationship between crop yields and temperature trends in Ethiopia (Alemayehu & Bewket, 2016a; Kassaye et al., 2021; Tesfaye, Kruseman, Cairns, Zaman-allah, et al., 2018). The anticipated effects of climate change, such as higher temperatures, extreme weather events, water shortages, ecosystem disruption, and biodiversity loss, are expected to negatively affect rainfall-fed crop production and pastures (FAO, 2018).

The FAO and the World Bank have recommended climate-smart agriculture (CSA) as one of the best technological and policy solutions for reducing the impacts of climate variability on crop production and ensuring food security for the growing world population (Taylor, 2018). CSA was launched by FAO in 2010 and has received widespread interest and attention (FAO, 2018). FAO underlined that to sustainably improve productivity, increase adaptation, and minimize greenhouse gas emissions, CSAs need to recognize and address tradeoffs and synergies between productivity, adaptation, and mitigation (FAO, 2010, 2013, 2016).

The primary aims of CSA are food security and development while adaptation, productivity, and mitigation are the three interlinked pillars required for attaining this aim (FAO, 2013). Attaining this aim requires an integrated tactic that is responsive to specific local environments. Coordination and collaboration across agricultural sectors (e.g., crops, livestock, forestry, and fisheries) as well as other sectors, such as with water and energy sector development is essential to benefit from potential synergies, reduce trade-offs and optimize the use of ecosystem services and natural resources (FAO, 2013). CSA differs from sustainable agriculture because it explicitly addresses climate change adaptation and mitigation while working towards food security for all. In essence, CSA is sustainable agriculture that aims to lower greenhouse gas emissions while also taking resilience issues into account. CSA strives to increase productivity in an environmentally and socially sustainable way, strengthen farmers' resilience to climate change, and reduce agriculture's contribution to climate change by reducing greenhouse gas emissions and increasing carbon storage on farmland (FAO, 2010). The CSA comprises conservation farming, crop rotation, agroforestry, improved grazing, integrated crop-livestock management, intercropping, mulching, organic fertilization, improved water management, and growing drought- and disease-resistant crops (FAO, 2013, 2016). Various CSA practices are implemented in Ethiopia, including sustainable land management, agroforestry, crop residue management, and the promotion of improved livestock feed and rangeland management (FAO, 2016).

A growing body of literature highlights the key role of CSA in addressing climate-related challenges to improve smallholders' livelihoods. Numerous studies in Ethiopia have noted a positive association between smallholders' implementation of climate-smart practices and crop productivity (Adego et al., 2019; Asrat & Simane, 2018; Bedeke et al., 2018; Teklewold et al., 2019). In northwest Ethiopia, Adego et al. (2019) reported a 2.79 quintal/year increase in maize productivity due to the use of CSA practices. Furthermore, Asrat and Simane (2017) found that smallholders who used CSA practices produced 24.1 percent more than non-users in the Dabus watershed in northwest Ethiopia. In terms of adaptation to climate change impacts, numerous studies indicate that smallholders who use climate-smart strategies are less vulnerable to impacts than non-users (Asrat & Simane, 2018; Bedeke et al., 2018; Belay et al., 2017). Previous studies showed that the climate-smart practices (intercropping, agroforestry, crop rotation, and crop varieties) that have been implemented by smallholders not only increase crop productivity and enhance adaptation to climate variability and change effects but also reduce emissions of greenhouse gases (Abegaz et al., 2021; Jirata et al., 2016).

Despite their potential benefits for adaptation, productivity increases, and mitigation efforts, most CSA practices are adopted at a low-to-medium rate among Ethiopian smallholders (CIAT & USAID, 2017). Smallholders' adoption of CSA practices appears to be strongly influenced by institutional, socioeconomic, and biophysical factors (Bedeke et al., 2018; Marie et al., 2020; Sertse et al., 2021). By transferring knowledge and creating awareness, extension agents positively influence the adoption of CSA practices (Bedeke et al., 2018). Likewise, access to financial capital plays a fundamental role in reducing the financial constraints of smallholders and promoting the adoption of CSA practices (Wainaina et al., 2016). According to Asfaw et al. (2013) and Nhemachena et al. (2014), access to credit services may alleviate smallholders' cash constraints and thus be positively associated with the use of CSA practices. Marie et al. (2020) and Sertse et al. (2021) conclusively showed that a lack of credit services and money were the major constraints on smallholders' willingness to adopt climate change adaptation strategies in Ethiopia. Similarly, recent studies have also revealed that a lack of information about the potential impacts of climate variability, climate projections, and a lack of knowledge about appropriate adaptation options were the major constraints on smallholders' preparedness to adopt CSA practices (Ali et al., 2021; Marie et al., 2020; Sertse et al., 2021).

In terms of socioeconomic factors that influence the adoption of CSA practices, previous studies have found that educational level is positively associated with smallholders' climate change adaptation decisions, implying that educated smallholders are more likely to be aware of the risks associated with climate change (Asrat & Simane, 2017; Belay et al., 2017). In addition to educational status, evidence points out that the availability of economically active household members favors the adoption of labor-demanding agricultural technologies and the probability of using CSA practices (Asfaw et al., 2013; Asrat & Simane, 2018). Besides educational status and household size, earlier studies underlined that older farmers are more experienced in farming and past climatic conditions, and better at adopting CSA practices (Asrat & Simane, 2018; Belay et al., 2017). In addition to the age of the household head, previous studies have again demonstrated that landholding has a positive effect on the adoption of CSA practices (Asrat & Simane, 2017; Belay et al., 2017). In addition to on-farm activities, Ethiopian smallholders are also involved in off-farm economic activities. Asrat and Simane (2018) have shown that involvement in off-farm and diversified sources of income positively influences the decision of households to adopt CSA practices. Moreover, Sani et al. (2017) reported that the availability of off-farm income activities improves smallholders' financial position, which, in turn, enables them to purchase farm inputs such as improved seeds and fertilizers.

Despite Ethiopian smallholders' adoption of both indigenous and modern climate-smart practices, the adverse climate change impacts remain a critical challenge in the country. This suggests the need for evidence on the sustainability of agricultural practices. Agricultural sustainability is a more complex concept (Hayati et al., 2011), and operationalizing it on the ground requires the consideration of various factors, including economic, environmental, physical, and sociocultural dimensions, as well as interactions among them (Veisi et al., 2013). Wittman (2009) underscored that any study of agricultural sustainability should consider its socioecological nature and the fact that agriculture produces landscapes that are both sociocultural and ecological. In this regard, Bacon et al. (2012) also pointed out that agricultural sustainability cannot easily be defined at a farm or landscape level since it is part of a socioecological system.

It is essential to select the Konso community for this study because of its long-term and well-known indigenous CSA practices to understand climate variability, adoption of CSA practices, and sustainability. Konso farmers have practiced a sophisticated indigenous brand of terracing, agroforestry, intercropping, traditional irrigation, and manure management for a long time. As a result of its indigenous terracing practices, Konso was registered as a World Heritage Site. Despite long-term indigenous CSA practices, the Konso community is increasingly vulnerable to the adverse impacts of climate change and variability. However, currently, most Konso people are abandoning soil and water conservation (SWC) practices because of a persistent decline in farm productivity caused by a lack of rainfall, declining soil fertility, and land fragmentation. As a result, youth participation in these practices is declining because they prefer to be involved in non-agricultural activities rather than agricultural activities. The SWC practices are currently being overstretched by high climate variability and recurrent droughts, declining soil fertility, population pressure, urbanization, lack of finance, and the weakening of social norms. This dissertation attempts to interrogate how Konso's indigenous CSA practices endured changes and, at the same time, why are Konso's livelihoods becoming more vulnerable to recent biophysical and sociocultural changes?

1.2. Statement of the problem

Climate change is emerging as a significant threat to agriculture and food security, affecting millions of people worldwide (IPCC, 2014). Numerous studies show that crop production is significantly impacted by an increase in temperature (Alemayehu & Bewket, 2016a; Kassaye et al., 2021; Tesfaye, Kruseman, Cairns, Zaman-allah, et al., 2018), erratic rainfall, and droughts (Asrat & Simane, 2017; Evangelista et al., 2013; Yang et al., 2020). Climate change impacts on cereal crop yields in different regions can result in yield losses of up to 50% for sorghum and 60% for maize, depending on the location (IPCC, 2014). Especially in Sub-Saharan Africa (SSA), smallholders' agriculture and food security are threatened by climate change (Wheeler & Braun, 2013). Additionally, it is anticipated that climate change will significantly lower agricultural productivity, particularly in tropical and subtropical areas (Knox et al., 2012; Zhang et al., 2017). Most of Africa, especially the semi-arid region of Sub-Saharan Africa, suffers from climate change and variability that harms agriculture (Laux et al., 2010; Tan et al., 2010; Thornton et al., 2011). Climate variation continues to be a significant obstacle to achieving food security in Sub-Saharan Africa because of the prevalence of high temperatures and erratic rainfall patterns, as well as the low adoption of modern technologies (IPCC, 2022).

Agriculture contributes 42% of Ethiopia's GDP, 80% of employment, and nearly all commodity exports (FAO, 2016). Despite this, the country's agriculture sector is highly susceptible to climate change (Amare & Simane, 2017a) and food security has been and will continue to be a major challenge (Yang et al., 2020). A lack of growing season rainfall in semiarid parts of Ethiopia threatens rain-fed crops (Kassie et al., 2014). Moreover, rising temperatures and recurrent droughts pose serious challenges to the livelihoods of most farmers in Ethiopia, including the highlands (Amare & Simane, 2017a). Furthermore, at the end of the 21st century, climate projections suggest that a substantial rise in temperature and decline in rainfall could result in a reduction of 18.1% in sorghum yield and 13.2% in wheat yield in Ethiopia (Kassaye et al., 2021). Therefore, there is a need to use climate-smart practices to withstand the adverse effects of climate change and variability in Ethiopia. Adaptation options that sustainably boost productivity, improve resilience to severe climate events, and minimize greenhouse gas emissions are referred to as climate-smart agricultural practices (FAO, 2010). In Ethiopia, there are the following research gaps concerning climate variability and its impact on crop production, adoption of CSA practices, and sustainability.

To date, studies conducted in Ethiopia on climate change and variability have reported consistently rising temperatures and erratic rainfall patterns, but they have their own limitations (Gedefaw et al., 2018; Mulugeta et al., 2017; Mulugeta et al., 2019; Muluneh et al., 2016). These studies have heavily relied on climate data from a few weather stations in cities and towns, which may have resulted in a poor representation of remote rural areas. Moreover, some studies (Degefu & Bewket, 2014; Mengistu, 2015; Mengistu et al., 2019; Tesfamariam et al., 2019) have mainly focused on broader geographical scales and river basins, which tend to conceal the severity and intensity of local climate variability and change due to complex rainfall patterns. Therefore, local studies of rainfall and temperature variability and patterns are essential for understanding local indicators of climate variability and patterns and designing site/location-specific adaptation and mitigation interventions. Some studies neglected to look at serial autocorrelation and the consistency of the data, which could lead to errors in trend detection (Abrha & Simhadri, 2015; Gebrehiwot & Veen, 2013; Hessebo et al., 2019; Teyso & Anjulo, 2016). Although Konso is one of the most drought-prone areas in the nation, the spatial and temporal characteristics of meteorological droughts across the area's agro-ecological zones have not yet been investigated. Furthermore, so far no study employs ArcGIS band collection statistics (covariance and correlation) among layers (rainfall, temperature, altitude, agroecology, and topographic roughness index) to assess the association among them.

Because of its semiarid climate conditions, Konso is highly susceptible to climate variability and extremes, which threaten the livelihoods of smallholders and expose people to food insecurity (Araro et al., 2020; GebreMichael, 2019; M. Tadesse, 2010). CSA practices and interventions for climate risk management have to match localized vulnerabilities and impacts on smallholders. However, previously published studies that attempted to analyze the adoption of CSA in Ethiopia have focused on national-level surveys (CIAT & USAID, 2017; FAO, 2016; Jirata et al., 2016). The aggregated results from these studies provide little information about smallholders' adoption of CSA practices at the household level in specific locations. Moreover, most of the existing studies on smallholders' adoption of CSA practices have largely focused on the highlands of Ethiopia rather than on semiarid lowland areas (Amare & Simane, 2017b; Asrat & Simane, 2017, 2018; Teklewold et al., 2019). Due to its location in the semiarid Rift Valley region of Ethiopia and its culturally interwoven soil and water conservation structures, as well as its paradoxical vulnerability to climate variability and extremes, the

Konso area provides a unique opportunity to study the adoption of indigenous CSA practices.

FAO (2013) highlighted that CSA practices sustainably boost agricultural productivity, enhance adaptation and minimize greenhouse gas emissions in a changing climate. However, earlier climate change studies in Ethiopia have focused only on evaluating the effects of variation in the climate on agricultural production without taking into account the role of CSA in enhancing adaptation and mitigating such impacts on crop productivity (Alemayehu & Bewket, 2016a; Tesfaye, Kruseman, Cairns, Zaman-allah, et al., 2018; Yang et al., 2020). Although the promotion of CSA in Ethiopia is ongoing as part of sustainable agricultural development policy (FDRE, 2019), empirical evidence is very limited. Even though the Southern Rift Valley Basin of Ethiopia is very susceptible to climate change, there have only been a few studies on how CSA practices and climate change affect crop production. The few existing studies (Alemayehu & Bewket, 2016a; Getachew, 2017; Tesfaye, Kruseman, Cairns, Zaman-allah, et al., 2018) were confined to the Ethiopian highlands, where climate stress appears to be lower than in the lowlands, while the most susceptible semiarid lowlands, which include Konso, have received less attention.

Furthermore, to understand the historical sustainability, status, and prospects of indigenous CSA practices, I selected the UNESCO-designated Konso cultural landscape because it is well known for its deep-rooted indigenous CSA practices, but at the same time, it is chronically food insecure (GebreMichael, 2019; M. Tadesse, 2010). In addition, studies on the sustainability of indigenous CSA practices with a focus on the role played by sociocultural and informal institutions are very limited in Ethiopia. In earlier studies on the sustainability of CSA in Ethiopia, much attention has been given to the technical, environmental, economic, and formal institutional dimensions rather than the social-cultural values and informal institutions that support CSA technology (Adego et al., 2018; Simane & Zaitchik, 2014). Thus, research on the social-cultural values, norms, and informal institutional dimensions that contribute to the sustainability of conservation technologies has been limited. Therefore, this dissertation explores climate variability and its impacts on crop production, the adoption of indigenous CSA practices, and their sustainability in Konso.

1.3. Objectives of the study

The general objective of this study is to explore climate variability and indigenous climate-smart agriculture (CSA) practices in Konso. Specifically, the study intends

1. To examine spatiotemporal rainfall, drought and temperature variability, and trends;
2. To assess smallholders' adoption of CSA practices;
3. To examine the impacts of climate variability and CSA practices on crop production; and
4. To explore the role of sociocultural values and informal indigenous institutions in the survival and sustainability of CSA practices in Konso.

1.4. Hypotheses and research questions

A major focus of this study is historical climate variability and outcome variables, such as crop production and adoption of CSA practices. Therefore, this dissertation attempts to address the following hypotheses, which are followed by specific research questions:

Hypothesis 1: There is a statistically significant variation in rainfall, temperature, and drought incidences across altitudes, agroecologies, and topographic ruggedness. In line with this hypothesis, two research questions were attempted to be answered:

i. What are the spatiotemporal patterns and variability of rainfall, drought, and temperature?
ii. What effects do altitude, agroecology, and the topographic ruggedness index have on the spatial distribution of drought and rainfall in the study area?

Hypothesis 2: The adoption of CSA practices varies significantly across agroecological zones; and (sub-hypothesis): socioeconomic, institutional, and physical factors determine the success and failure of CSA adoption. Based on this hypothesis, two research questions were asked to be answered by the study:

i. How do smallholders adopt CSA practices across various agroecologies?
ii. How do socioeconomic, institutional, and physical factors determine the success or failure of CSA practices?

Hypothesis 3: The correlation between rainfall and crop production is positive, whereas the correlation between maximum and minimum temperatures is negative. Taking this hypothesis into account, three research questions were posed by the study:

i. How do rainfall and temperature variability affect crop production?
ii. Is there a significant statistical variation in cereal (sorghum, maize, and *teff*) production in response to variations in rainfall and temperatures?
iii. How do CSA practices affect crop production?

Hypothesis 4: The long-term sustainability of CSA practices in Konso is determined by indigenous sociocultural values and informal institutions. Under this hypothesis, I raised three research questions:

i. What roles do sociocultural values and informal indigenous institutions play in contributing to the survival and sustainability of CSA practices?
ii. To what extent do indigenous institutions function today, and how do they perform along with powerful formal government institutions?
iii. To what extent do external factors, such as urbanization and modern conservation initiatives, foster or weaken the performance of indigenous sociocultural norms and institutions?

1.5. Significance of the study

This dissertation provides methodological insights into applying ArcGIS band collection statistics (spatial covariance and correlation) to calculate the spatial relationship among layers (rainfall, standardized precipitation index, altitude, agroecology, and terrain ruggedness index) on a pixel basis, which could be applied to further climate change studies in Ethiopia and elsewhere. Furthermore, the novel application of advanced econometric models to study the adoption of indigenous CSA practices is significant in the field of climate change research. The dissertation contributes to the existing knowledge of climate variability by providing site-specific information about the distribution and severity of meteorological droughts across agroecologies. This agroecological-based drought intensity information will help decision makers in designing adaptation and mitigation plans. This dissertation also provides empirical evidence to policymakers, researchers, academicians, and stakeholders about local climate patterns and their implications for crop production. It is essential to provide vital information about the agroecology-based adoption of indigenous CSA practices and how they survived for several generations. The findings of the study may be useful in areas of similar agroecologies and socioeconomic settings in Ethiopia and elsewhere. I hope it will assist policymakers in incorporating indigenous CSA practices into the design of climate change adaptation and mitigation policies and strategies. It also provides unique insight and essential information about the role of sociocultural values, social norms, indigenous institutions, and social learning to ensure the survival and sustainability of soil and water conservation practices over several generations.

1.6. Scope of the study

Thematically, this study encompasses climate variability, smallholders' adoption of CSA practices (terracing, agroforestry, manure, crop varieties, intercropping, reduced tillage, and traditional irrigation), and the impacts of climate variability and CSA practices on crop production in Konso. From the three pillars of CSA, adaptation and productivity were the primary focus of the study. Moreover, the role of sociocultural values and indigenous institutions in ensuring the survival and sustainability of CSA across multiple generations was also addressed. The analysis of CSA adoption and the impacts of CSA on crop production were performed at the household level, while sustainability analysis was performed at the community level.

1.7. Limitations of the study

Similar to other types of statistical analysis, there may be a non-natural connection between the given econometric models where two variables are correlated but causally unrelated. Therefore, a wide-range review of the literature and expert consultations were performed to obtain good findings. This study is based on survey data collected from February 14 to June 13, 2020, but second-round field and participant observations were conducted from January 3 to February 15, 2022. This may be inadequate to address the changing circumstances of CSA practices that have survived for hundreds of years. To circumvent this problem, I used archival information (for example, crop data from the Central Statistical Agency and Konso Bureau of Agriculture and Natural Resource Management) and peer debriefing for qualitative data.

1.8. Structure of the dissertation

I organized this dissertation into eight chapters. The introduction of the dissertation is provided in the first chapter, which includes background, problem statement, objectives, research hypotheses, significance, and limitations of the study. The second chapter provides a literature review. While the third chapter deals with the general methodology of the study, the fourth chapter examines spatiotemporal climate variability and trends in Konso, which was published in the *African Geographical Review*. Whereas the fifth chapter addresses smallholders' adoption of climate-smart practices in Konso, Ethiopia, which was published in the *International Journal of Environmental Studies*. The impacts of climate variability and climate-smart agricultural practices on crop production are discussed at length in chapter six. The manuscript is currently being resubmitted after major revisions to the journal *Theoretical and Applied Climatology*. Chapter seven presents the sustainability of the long-term indigenous climate-smart agricultural practices in the UNESCO designated cultural landscapes of Konso, Ethiopia. The final section of the thesis presents a synthesis, conclusion, and recommendations. I provided the list of references and annexes at the end of the dissertation.

2. LITERATURE REVIEW

2.1. Concepts and definition of climate-smart agriculture

Climate-smart agriculture (CSA) is defined as agriculture that sustainably increases productivity, increases resilience/adaptation, reduces/removes greenhouse gases (GHG)/mitigation, and enhances the achievement of national development and food security goals (FAO, 2010). In this definition, the primary aims of CSA are food security and development while adaptation, productivity, and mitigation are the three interlinked pillars required for attaining this aim (FAO, 2013). Attaining this aim requires an integrated tactic that is responsive to specific local environments. Coordination and collaboration across agricultural sectors (e.g., crops, livestock, forestry, and fisheries) as well as other sectors, such as with water and energy sector development is essential to benefit from potential synergies, reduce trade-offs and optimize the use of ecosystem services and natural resources (FAO, 2013).

CSA strives to increase productivity in an environmentally and socially sustainable way, strengthen farmers' resilience to climate change, and reduce agriculture's contribution to climate change by reducing greenhouse gas emissions and increasing carbon storage on farmland (FAO, 2010). The CSA comprises conservation farming, crop rotation, agroforestry, improved grazing, integrated crop-livestock management, intercropping, mulching, organic fertilization, improved water management, and growing drought- and disease-resistant crops (FAO, 2013, 2016). It is about getting existing technologies off the shelf and into the hands of farmers and developing new technologies such as drought or flood-tolerant crops to meet the demands of the changing climate (FAO, 2016).

2.2. Theoretical Framework

The theoretical framework for this study is political ecology. Political ecology is selected for the theoretical perspective of this study because climate and society are represented as two distinct systems or domains, one physical and the other sociocultural, that relate to each other through a series of ongoing, reciprocal influences. Having separated the two on ontological grounds, climate and society are then seen to interact with each other as external entities. Society can influence the climate through activities that capture carbon from the atmosphere or release greenhouse gases that result in anthropogenic climate change. Climate, in turn, impacts back upon society through a series of stimuli, shocks, and stresses that range from extreme weather events to subtler shifts in temperature and precipitation. Political ecology deals with (i) how both nature and societal structures determine each other and (ii) how constructed concepts of nature and society determine human-environment interactions (Schubert, 2005). Theoretical approaches to political ecology are marked by a plurality of disciplinary (anthropology, economics, geography, political science, sociology, history, and management) backgrounds. Therefore, this theory can best fit this study in Konso, where there is a continuous interaction between the physical environment and society.

2.3. Empirical Studies

2.3. 1. Climate variability and change

In recent years, the worsening of climate change by global warming has become a significant concern for climate scientists and academics around the world (Zhang et al., 2009). Changes in temperature trends in certain parts of the world are more likely to become hotter (Gebrehiwot & Veen, 2013). The average global surface temperature rose by 0.8 degrees Celsius over the last century and 0.6 degrees Celsius over the last three decades (IPCC, 2007). The latest global average temperature estimate at the end of 21st century is between 1.5°C and 2°C (IPCC, 2013). While a global phenomenon, the magnitude of the negative impacts of climate change can vary considerably across continents and countries (Bewket et al., 2015; IPCC, 2014). In Africa, temperatures have risen dramatically by more than 0.5^{o}C in the last 50–100 years, while rainfall variability is expected to increase (IPCC, 2014). The African temperature increase, which could reach 4°C in the late 21st century, is expected to increase faster than anywhere in the world (IPCC, 2014). Countries in the East African region are especially susceptible to severe weather events such as droughts and floods (Cheung et al., 2008). East Africa is facing growing trends in minimum and maximum temperatures and high seasonal rainfall variability (Gebrechorkos et al., 2019). Due to the high variation in rainfall and the occurrence of extreme events, the region is becoming one of the most food-insecure regions in the world in quest of humanitarian assistance (Busso & Fernández, 2017).

Ethiopia is among the countries most likely to experience climate variability during shorter and longer periods in the world. Climate models predict that the mean annual temperature in Ethiopia will rise by 0.9–1.1 degrees Celsius by 2030 and 1.7–2.1 degrees Celsius by 2050 (NMA, 2007).In Ethiopia, various studies at different spatial and temporal scales have shown persistent warming in annual temperature over the last few decades (Ademe et al., 2020; Arega et al., 2019; Asfaw et al., 2018; Belihu et al., 2018; Esayas et al., 2018; Gebrehiwot & Veen, 2013; Matewos & Tefera, 2019; Tesfamariam et al., 2019; Teyso & Anjulo, 2016). Similarly, studies found a statistically significant increase in temperatures during the Kiremt (June–September) and Belg (February–May) seasons (Asfaw et al., 2018; Mengistu et al., 2014; Mulugeta et al., 2017).

In Ethiopia, rainfall studies have not shown uniform patterns. Despite their spatiotemporal difference, some studies in Ethiopia indicated that annual rainfall trends have been statistically significant decreasing trends over the few past decades (Ademe et al., 2020; Arega et al., 2019; Asfaw et al., 2018; Belihu et al., 2018; Gebrehiwot & Veen, 2013; Hessebo et al., 2019; Matewos & Tefera, 2019; Tesfamariam et al., 2019). Contrarily, other studies in Ethiopia have shown statistically insignificant increasing patterns in annual rainfall (Alemayehu & Bewket, 2017; Mengistu et al., 2014; Mengistu et al., 2019). At a seasonal level, some studies in Ethiopia have shown a statistically significant increase in the *Kiremt* season's rainfall trend (Muluneh et al., 2016; Teyso & Anjulo, 2016). Whereas other studies have shown a statistically significant decrease in the trend of the *Kiremt* and *Belg* seasons rainfall (Ademe et al., 2020; Arega, et al., 2019; Belihu et al., 2018; Hessebo et al., 2019; Matewos & Tefera, 2019; Mengistu et al.,2019). However, in the other studies, there has been no change in annual and seasonal precipitation in recent decades (Abrha & Simhadri, 2015; Cheung et al., 2008; Suryabhagavan, 2017).

2.3.2. Impacts of climate variability on crop production

Agriculture is inherently susceptible to climate variability and climate change is expected to increase this vulnerability (Rosenzweig et al., 2014; Thornton et al., 2011). Climate change has already decreased crop yields in several regions (Lobell & Field, 2007).

Several global and regional studies have warned that progressive climate change will harm crop productivity in most regions of the world (Knox et al., 2012). Climate change's expected impacts are a serious threat to crop production and the sustainability of the agricultural system (Intergovernmental Panel on Climate Change (IPCC), 2014). Climate change is also expected to significantly reduce agricultural productivity, particularly in tropical and subtropical regions (Knox et al., 2012; Zhang et al., 2017). Climate variability and change harm agriculture in most parts of Africa, particularly in semi-arid Sub-Saharan Africa (Laux et al., 2010; Tan et al., 2010; Thornton et al., 2011). Due to the prevalence of high temperatures and irregular rainfall regimes, coupled with the low adoption of modern technologies, climate variation continues to be a major challenge in achieving food security in Sub-Saharan Africa (IPCC, 2007). In countries like Ethiopia, where agriculture is dependent on rainfall, the influence of variation in climate on crop production is generally large. Although agriculture is the cornerstone of Ethiopia's economy (FDRE, 2019), it is highly dependent on natural rainfall (Mann & Warner, 2017). In Ethiopia, there were a few studies on the impacts of climate variability on crop production (Alemayehu & Bewket, 2016a; Bewket, 2012; Getachew, 2017; Tesfaye, Kruseman, Cairns, Zaman-Allah, et al., 2018; Yang et al., 2020). Some empirical studies indicated that rising temperatures, erratic rainfall, shortened rainy seasons, and lower amounts of seasonal rains are reducing crop production (Abera et al., 2018; Alemayehu & Bewket, 2016a; Gasu, 2017; Shuai et al., 2018; Tesfaye, Kruseman, Cairns, Zaman-Allah, et al., 2018). According to Alemayehu and Bewket (2016), climate change and crop production have strong associations. Yang et al. (2020) found a negative association between yield and temperature, suggesting that yield has decreased dramatically over the last four decades. Tesfaye et al. (2018) reported the threat of climate change to crop production reductions in areas of high temperatures and variable rainfall conditions. The study of Abrha and Simhadri (2015) showed that both the *Belg* and *Kiremt* rainy seasons are diminishing, reducing the amount of seasonal rain available for crop production. Current climate variability contributes to lower agricultural productivity, and the sector's future sustainability is dependent on the types of coping and adaptation strategies employed by farmers (Alemayehu & Bewket, 2016a).

2.3.4. Impacts of climate-smart practices on crop production

To curb the effect of climate variability on crop yield, climate-smart agriculture (CSA) practices need to be developed and assessed for their impact on crop productivity. CSA sustainably increases productivity, increases adaptation/resilience, and enhances mitigation (FAO, 2010). Intercropping, mulching, conservation agriculture, integrated crop-livestock management, crop rotation, agroforestry, improved grazing, organic fertilization, improved water management, and growing drought, flood, pest, and disease tolerant crops are all part of CSA (FAO, 2013, 2016). The previous study has demonstrated that CSA practices have the potential to significantly reduce the negative impacts of climate variability on crop production (Challinor et al., 2014). However, previous studies on climate change in Ethiopia have often been limited to assessing the impacts of climate variability on agricultural production without accounting for the impacts of CSA practices on crop productivity (Alemayehu & Bewket, 2016b; Bewket, 2012; Getachew, 2017; Tesfaye, Kruseman, Cairns, Zaman-Allah, et al., 2018; Yang et al., 2020). In contrast, some other studies assessed the impacts of CSA practices on crop production without assessing the impacts of climate variability on crop production (Asrat & Simane, 2018; Teklewold et al., 2019). Adego et al. (2019) showed climate-smart agriculture's ability to increase crop yields and reduce crop failure. Households that used CSA practices produced 24.1% more than non-users (Asrat & Simane, 2017). Adego et al. (2019) reported that CSA gave a 2.79 quintal/year increase in maize yields. Di Falco et al. (2012) also indicated that soil conservation and use of crop variety resulted in increased crop yield among farm households in Ethiopia. Farmers can increase productivity by combining mixed maize-legume cropping, terracing, and conservation tillage with drought-resistant maize varieties (Bedeke et al., 2018).

2.3.5. Determinants of the adoption of climate-smart agricultural practices

These CSA practices (agroforestry, intercropping, crop rotation, and crop varieties) that have been implemented by smallholder farmers not only increase crop productivity and enhance adaptation to impacts but also reduce greenhouse gases emissions into the atmosphere (Abegaz et al., 2021; CIAT & USAID, 2017; Jirata et al., 2016). Although they have potential benefits for adaptation, productivity increases, and mitigation efforts, most of the CSA practices are adopted at a low-to-medium rate among Ethiopian smallholder farmers (CIAT & USAID, 2017). The CSA practices' adoption is influenced by institutional (extension services, access to credit, climate information, and relief aid), socio-economic (gender, educational status, household size, age, landholding, off-farm income, livestock ownership), and biophysical (agroecology, farm and market distance, rainfall, and temperature) factors (Amare & Simane, 2017; Asrat & Simane, 2018; Bedeke et al., 2018; Deressa et al., 2011; Marie et al., 2020; Sertse et al., 2021).

The institutional services provided by extension agents positively impact the CSA practices' adoption through knowledge transfer and awareness creation (Bedeke et al., 2018). Likewise, access to financial capital plays a crucial role in reducing the financial constraints of smallholder farmers (Wainaina et al., 2016). According to Asfaw et al. (2013) and Nhemachena et al. (2014), access to credit services may alleviate farmers' cash constraints and thus be associated with the use of CSA practices. Marie et al. (2020) and Sertse et al. (2021) conclusively revealed that lack of credit services was the major constraint to smallholder farmers' willingness to adopt adaptation strategies in Ethiopia. Furthermore, smallholder farmers' access to climate technological information reduces the climate risk by informing adaptation practices (Deressa et al., 2009; Kassie et al., 2013). Recent studies have revealed that lack of information about the climate variability and lack of knowledge about appropriate adaptation options were the major constraints to smallholder farmers' preparedness to adopt CSA practices (Ali et al., 2021; Marie et al., 2020; Sertse et al., 2021).

In terms of socio-economic factors that affect the usage of CSA practices, many studies have found that male-headed families are more expected to use new agricultural technologies than female-headed households (Guteta & Abegaz, 2015; Deressa et al., 2011; Asrat & Simane, 2018). Concerning household heads' educational level, previous studies have found that educational level is positively associated with smallholder farmers' climate change adaptation decisions (Asrat & Simane, 2017; Belay et al., 2017). Besides educational status, data from several empirical studies suggest that the availability of economically active household members favors the adoption of labor-demanding agricultural technologies and the probability of using CSA practices (Asfaw et al., 2013; Asrat & Simane, 2018; Sani et al., 2016). In addition to educational level and household size, Asrat and Simane (2018) and Belay et al. (2017) observed that older farmers have more experience in farming and previous climatic conditions. Besides the household head' age, previous studies have demonstrated that landholding has a positive effect on the CSA practices' adoption (Asrat & Simane, 2017; Belay et al., 2017). Some farming practices, such as agroforestry and intercropping, may not be suitable for implementation on small pieces of land, as smallholder farmers aim to maximize land under cultivation of the main crop.

Besides on-farm activities, Ethiopian smallholders are also involved in off-farm economic activities. Asrat and Simane (2018) have shown that the involvement in off-farm and diversified sources of income positively influences the decision of the household to adopt the CSA practice. Furthermore, Sani et al. (2016) reported that the availability of off-farm income activities improves smallholder farmers' financial position, which, in turn, enables them to purchase farm inputs such as seeds and fertilizers. Concerning physical factors, previous studies showed a significant variation in the CSA practices across agroecologies (Kidanu et al., 2016; G. Tadesse, 2017). Distance from farmers' homes to farmland harms farmers' CSA practices' adoption (Adego et al., 2019; Ali et al., 2021; Asrat & Simane, 2018; Sani et al., 2017).

2.3.6. Sustainability of indigenous CSA practices and the role of sociocultural factors

Agricultural sustainability is a more complex concept with no agreed-upon dimensions among scholars (Hayati et al., 2011). Thus, operationalizing the sustainability of an agricultural system on the ground entails taking into account a variety of factors, including physical, environmental, social, cultural, and economic dimensions, as well as their interactions (Veisi et al., 2013). In terms of method, Herrmann et al. (2011) also underlined that assessing agricultural sustainability must take into account the dynamic interactions between socioeconomic and biophysical elements in the system. Moreover, Streimikis and Baležentis (2020) highlighted that assessing agricultural sustainability must consider the dynamic nature of government policies regarding sustainable development, rural development, climate change, and the environment. Thus, any attempts to study agricultural sustainability must focus on the social-ecological context and a proper understanding of agricultural landscapes as a product of sociocultural and ecological systems (Wittman, 2009). In contrast, Bacon et al. (2012) argued that agricultural sustainability cannot easily be defined at the farm or landscape level because it is part of a social-ecological system. Hence, the ecological dimensions of agriculture cannot be dissociated from its social dimensions because agriculture is a continuous nexus of society and ecology (Wells, 2011). Despite such a high level of ecological and social entanglement in agriculture, previous studies appear to neglect the pivotal role of sociocultural and informal institutions in the long-term sustainability of CSA practices (Adego et al., 2018; Nigussie et al., 2018; Simane & Zaitchik, 2014).

Based on previous literature reviews, the following research gaps were identified. First, most of the earlier studies are limited to a large watershed scale (e.g., Asfaw et al., 2018; Belihu et al., 2018; Hessebo et al., 2019; Kassie et al., 2013; Mengistu et al., 2014; Mengistu et al., 2019; Tesfamariam et al., 2019), while some relied on meteorological ground-based stations' data, which were only located only in towns and cities (Kassie et al., 2013; Mulugeta et al., 2017; Mulugeta & Ayana, 2019; Muluneh et al., 2016; Teyso & Anjulo, 2016). Second, some of the studies did not check the consistency of the data and did not consider serial autocorrelation, which could result in trend detection errors (Abrha & Simhadri, 2015; Gebrehiwot & Veen, 2013; Hessebo et al., 2019; Teyso & Anjulo, 2016). Third, although Konso is at the top of the country's drought-prone areas, the spatial and temporal characteristics of meteorological droughts across agro-ecological zones in the area are not studied yet. Fourth, the studies dealing with spatial and temporal variability and trends in rainfall and temperature that include high-resolution maps for adaptation and mitigation plans are also limited. Furthermore, so far no study employs ArcGIS band collection statistics to examine covariance and correlation among layers such as rainfall, temperature, altitude, agroecology, and topographic roughness index.

From the literature reviews about the impacts of climate variability on crop production, the local level information on the impacts of climate variability and CSA adaptation strategies on crop yield is very scanty. Even though Ethiopia's Southern Rift Valley Basin is highly vulnerable to climate variability, studies on the effects of climate variability and

CSA practices on crop production are limited. Moreover, most of the available studies have focused on the highlands of Ethiopia, where climatic shocks appear to be less severe than in semi-arid regions (Adego et al., 2019; Asrat & Simane, 2017; Bedeke et al., 2018; Di Falco et al., 2012).

CSA practices and climate risk management interventions need to match localized vulnerabilities and impacts on smallholder farmers. However, previously published studies that attempted to analyze the CSA practices' adoption in Ethiopia have focused on national-level surveys (CIAT and USAID 2017; FAO 2016; Jirata et al. 2016). The aggregated results from these studies provide little information about smallholder farmers' CSA practices' adoption at the household level in specific locations. The UNESCO-designated cultural landscape of Konso provides a unique opportunity to study the impact of the adoption of CSA practices on agriculture because of its location in the semi-arid Rift Valley region of Ethiopia and its culturally interwoven conservation structures.

To understand the historical sustainability and prospects of CSA practices, we selected the Konso community because it is well known for its deep-rooted indigenous CSA practices but is chronically food insecure. Moreover, to the best of our knowledge, studies on the sustainability of indigenous CSA practices by focusing on sociocultural and informal institutions are very limited in Ethiopia. In previous studies on the sustainability of CSA in Ethiopia, much attention has thus been given to the technical, environmental, economic, and formal institutional dimensions rather than the social-cultural values and informal institutions that support technology (Adego et al., 2018; Simane & Zaitchik, 2014). Therefore, this study intends to explore the climate variability, adoption of indigenous CSA practices, and the role of sociocultural values and informal indigenous institutions in the survival and sustainability of CSA practices in Konso.

2.4. Conceptual framework

In designing the conceptual framework, it is assumed that smallholders' CSA practices adoption and sustainability are influenced by a variety of factors. The conceptualization of the framework has been supported by empirical evidence (Ali et al., 2021; Asrat &

Simane, 2018; Bedeke et al., 2018; Belay et al., 2017; DFID, 2011; Guteta & Abegaz, 2016; Marie et al., 2020; Sertse et al., 2021; Teklewold et al., 2019). Therefore, the relationships among institutional, socioeconomic, biophysical, and sociocultural factors, agricultural productivity, CSA practices, as well as climate variability, and policies are shown in Figure 1.

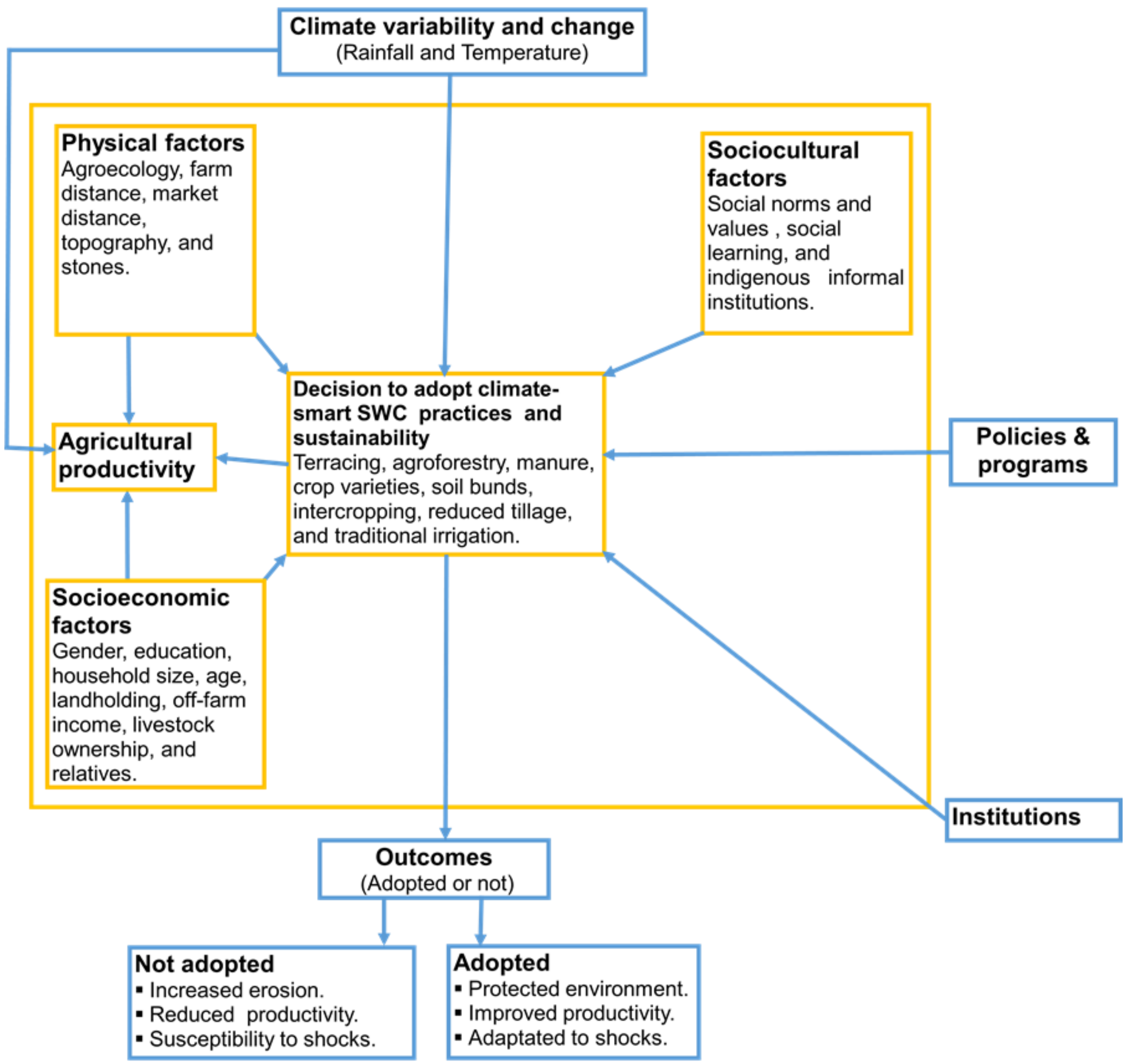

Figure 2.1. Conceptual framework.

The review of various literature in previous sections points out that smallholders' CSA practices adoption is influenced by institutional (extension services, access to credit, and climate information), socioeconomic (gender, educational status, household size, age, landholding, off-farm income, livestock ownership), and biophysical (agroecology, farm and market distance, rainfall, and temperature) factors (Bedeke et al., 2018; Marie et al., 2020; Sertse et al., 2021). Climate variability (the rising temperatures and high variability in rainfall) has a direct effect on crop productivity. Smallholders' adoption of CSA practices directly affects their crop productivity. Therefore, the adoption of CSA practices results in improved productivity, protects the environment (conserves soil and water), and allows adaptation to climatic shocks. Moreover, socioeconomic factors directly affect the adoption of CSA practices and crop productivity. Key components (agricultural productivity, CSA practices, socioeconomic, biophysical, and sociocultural factors) of the framework, and their interactions, can also be influenced by climate variability and policies and programs as well as by intuitions. In the Konso context, sociocultural factors have a positive impact on the adoption of CSA practices, while the policies and programs can directly affect the adoption situation. Physical factors can also have an impact on the adoption of CSA practices. Figure 1 illustrates the interrelationships among climate change and variability, physical, socioeconomic, sociocultural, and institutional factors that influence smallholders' adoption of CSA practices and their sustainability.

3. GENERAL METHODOLOGY

3.1. The study area descriptions

3.1.1. Location

Intensively terraced Konso Cultural Landscapes are found in Ethiopia's southern Rift Valley region (ARCCH, 2009). Astronomically, it is located between 5° 12'−5° 40' N and 37° 01'−37° 43' E (Figure 1). It covers an area of 2273.38 km^2. The cultural landscape exemplifies the spectacular engineering ingenuity of humans in their struggle to survive in harsh environments. Although oral traditions claim that Konso cultural landscape sculpture has existed for 400 years as part of ongoing cultural practices to tame the hostile environment for human habitation, archaeological confirmation has yet to be obtained.

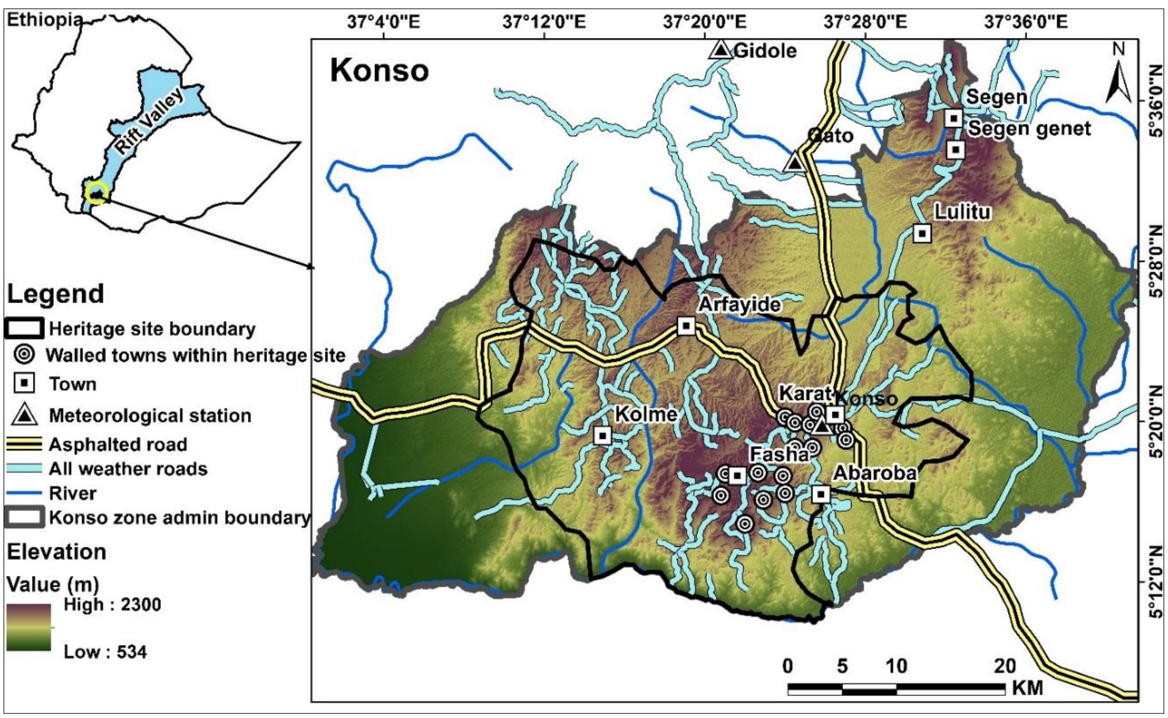

Figure 3.1. Location map of Konso showing elevation, towns, meteorological stations, roads, rivers, and the heritage site.

3.1.2. Climate

According to the traditional agroecological zone (AEZ) classification, 80 percent of the Konso landscape is semiarid (*Kolla*), with elevations ranging from 500 – 1500 m, and 20 percent is sub-humid (*Woynadega*), with elevations ranging from 1500 – 2300 m. It has a mean yearly temperature and rainfall of 23°C and 801.96 mm, respectively. Spring (*Belg*) is the main rainy season in Konso. It accounts for about 49% of the annual rainfall. As indicated in Figure 2, the dark grey color shows surplus rainfall while the light grey indicates rainfall deficit.

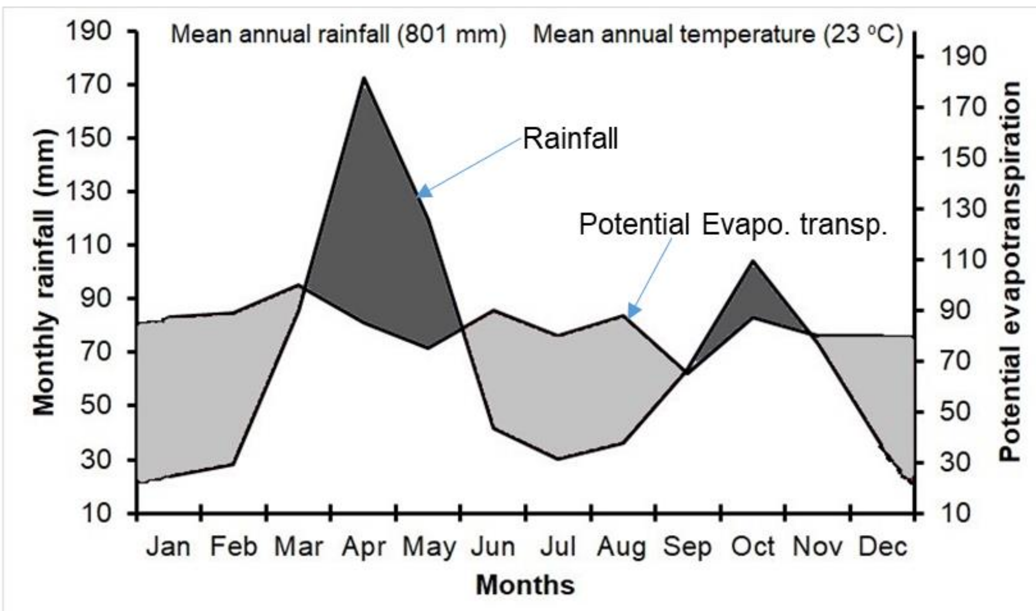

Figure 3.2. Climate diagram of Konso (1983-2016).

3.1.3. Topography and soils

Topographically, the Konso landscape has rugged surfaces of varied elevations characterized by mountainous terrain intersected by ravens and valleys. The northern part is covered by a hilly undulated configuration while the southern part is covered by mountainous relief which is intersected by valleys. There are plains along the borders of the South Omo zone and Burji Special Woreda in the western and eastern sections of Konso, respectively. Both western and eastern plains of Konso are found along the major rivers which pass through the zone. The altitude of the Konso ranges from 534–2300 above mean sea level. The major soils found in the Konso zone include Cambisols, Luvisols, Vertisols, Regosols, Nitosols, Fluvisols, and Leptosol (Figure 3).

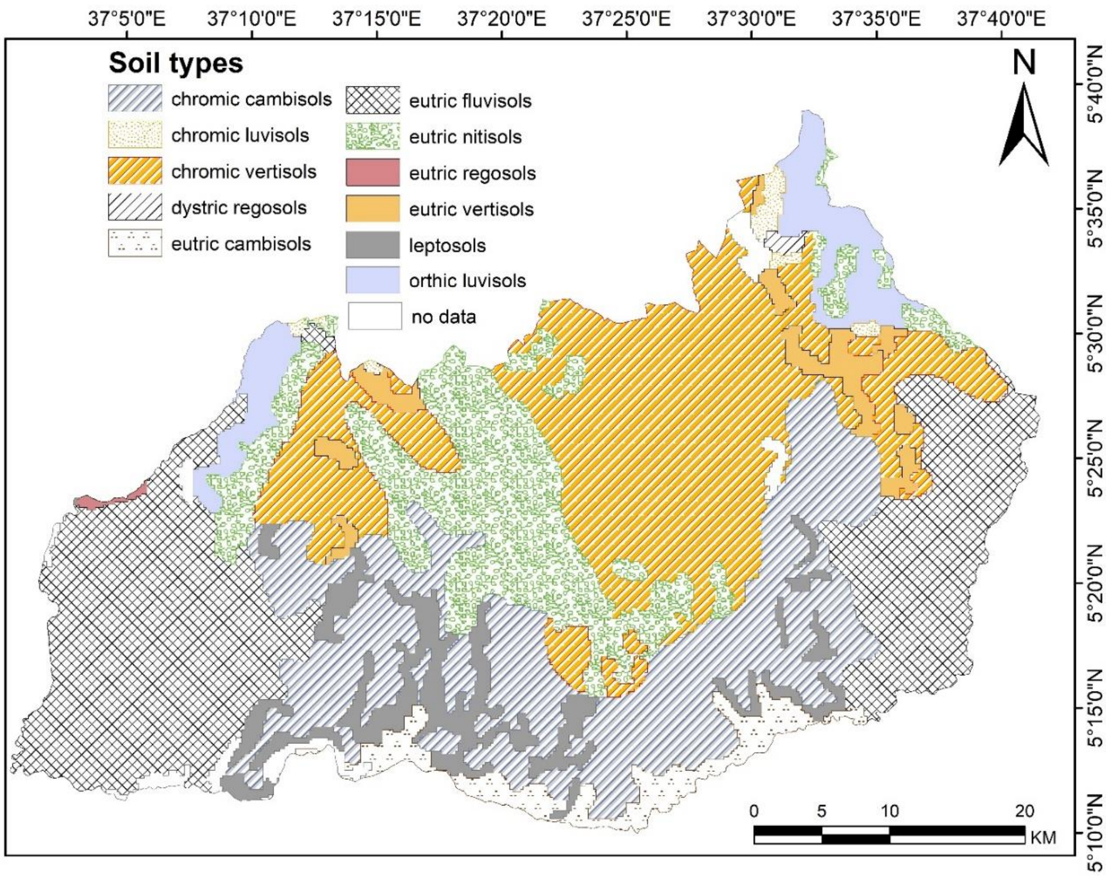

Figure 3.3. Soil map of Konso (Ethio-GIS, 2007).

3.1.4. Population

The total population of Konso in 2007 was 277 964 people within 55 673 households (Central Statistical Agency, 2007). From this total population 144, 263 (51.9%) are females and 133, 701 (48.1%) are males. The average household size of Konso is 5.8, which appears to be greater than the rural national average of 4.8 persons. According to a population projection (Central Statistical Agency, 2020), Konso's current crude population density is approximately 126 people per square kilometer, while its agricultural density is about 365.

3.1.5. Agricultural systems

The Konso community's livelihood is mainly based on livestock and crop production, with sorghum serving as a staple food crop. The native Konso traditionally practices sustainable agriculture which involves the construction and preserving of stone-walled terraces and fertilizing the farmlands with manure. The Konso landscape was renovated by people into an amazing landscape of stone-walled terraces and channels, protecting the soil from any erosion. In addition to terracing, the most noticeable characteristics of agriculture are intercropping various crops in integration with the various tree species. The major food crops grown in the area include sorghum, maize, teff, haricot beans, millet, wheat, and barley. A great variety of cereals, pulses, pigeon pea, root crops, and cash crops are also cultivated in two agroecologies. Cassava is the major root crop. *Moringa stenopetala* is the major cabbage tree and is part of the everyday meal where the fresh green leaves serve as a vegetable cooked and eaten as a staple food in the household's regular meals. Concerning water conservation, stone canals and mud banks take water from rivers onto nearby fields (Förch, 2003; Hallpike, 2008; Watson, 2009).

Livestock is an integral part of the agricultural production system in Konso. The Konso keep sheep, goats, cattle, and sometimes donkeys and chickens. In the *Woynadega*, mostly the livestock is kept in houses with stall feeding which permits manuring of farmlands that are close to villages, while in lowland areas majority of the livestock are kept as herds left on open fields on communal or private grazing lands. Manuring is a prominent character of the Konso agricultural system. Unlike in many other parts of Ethiopia, dung is never used as fuel. It is an essential part of the farming system to maintain an intensive continuous cropping cycle. Manure of animals is collected. It is either directly applied to the fields or left to rot in heaps or pits, together with other organic wastes before being applied to the fields.

3.2. The study design

The convergent mixed research design was employed for this study because the study was based on both quantitative and qualitative data. In this design, the researcher collects both quantitative and qualitative forms of data at the same time during the study and then integrates the information into the interpretation of the overall results. Thus, one database could help explain the other database (Creswell, 2014).

3.3. Types and sources of data

Primary data sources: Primary data was collected from household heads, elderly people, youth, indigenous and religious leaders, development agents, and district and zone heads of agriculture in the Konso zone.

Secondary data sources: The Central Statistical Agency and the Konso Zone Agricultural Office provided crop production data (1983–2016), while the National Meteorological Agency provided gridded monthly climate (rainfall and temperature) data for assessing the impacts of climate variability on cereal crops (sorghum, maize, and teff) production. The gridded dataset is preferred because it is highly valuable where weather stations are scarce, irregularly spaced, suffer from missing data, and have a narrow observation period.

3.4. Sampling techniques and sample size

The study followed a multistage sampling technique. First, the traditional agro-ecological zoning, having two distinct semi-arid (*Kolla)* and sub-humid (*Woynadega*) AEZs was followed. In second stage, the three lower administrative units (K*ebeles*) were selected randomly from each agro-ecological zones. Finally, using a systematic random sampling technique, 355 households were proportionally selected from the Kebeles. Thus, the unit of analysis was households and the sampling frame was the list of households, which was obtained from the *kebeles* administration. The sample size (355) was determined based on Kothari's (2004) sample size determination formula:

$$n = \frac{z^2.p.q.N}{e^2(N-1)+z^2.p.q} \qquad (1)$$

where, n is the desired total sample size; N is a total number of households, z is the upper point $\alpha/2$ of standard normal distribution at 95% confidence, which is equal to 1.96; *e* is an allowable error or precision [0.5*(q)]; p is the farm household units variable in terms of percentage and q is 1-p.

3.5. Data collection instruments

The major tools for gathering primary data include household survey questionnaires, focus group discussions, key informant interviews, and observation.

Household survey questionnaire

The study used cross-sectional survey data obtained from smallholder farmers' households to examine the impact of climate-smart agricultural practices on crop production. A questionnaire survey was distributed to the selected 355 household heads to collect information about socioeconomic characteristics, CSA practices (terracing, soil bunds, and micro-basins, crop diversification, intercropping, manure, agroforestry, water conservation, and reduced tillage), and crop yield.

Focus group discussion (FGD)

Data from the FGDs' was used to complement the information obtained through a household survey to have a better understanding of the condition of the CSA practices in a changing climate. There will be six focus-group discussions to be held in six kebeles (i.e three kebeles in *Kolla* and three kebeles in *Woynadega*) of which three will be in *Kolla* and three in *Woynadega*. Six FGDs were held, each having 6–10 participants, comprising elders (men and women), youth (age from 18–30 years), and local leaders.

Key Informants Interview (KII)

The informants' interviews were important in getting information pertinent to the various aspects of the CSA practices, challenges, and mechanisms to improve the current condition and sustainability. The KIIs were conducted with Kebele development agents, district, and zone heads of agriculture, and rural development agents to corroborate household survey data.

Observation

The researcher observed farmland. For observation, the observation guide was prepared. The observation was focused on the types, nature, and the current status of CSA practices of an individual farmer's farm plot. During the observation, keynotes were taken based on an observation guide.

3.6. Data analysis techniques

The data analysis for this study was performed using various methods. The variability in rainfall and temperature was analyzed using the standard deviation and coefficient of variation. The spatiotemporal distribution of drought incidents was analyzed and mapped by a standardized precipitation index (SPI). Moreover, the rainfall and temperature trends were analyzed using the Mann-Kendall trend test. Furthermore, the spatial variation was analyzed by the ordinary kriging method and ArcGIS 10.5 band collection statistics. The Chi-square test was used to assess the statistical differences between groups concerning the adoption of the indigenous CSA practices, while multinomial logit was employed to assess the factors that determine the adoption of the indigenous CSA practices. A bivariate correlation was employed to evaluate the relationship between climate variables and crop production, while multiple linear regression was employed to assess the impacts of climate variables on crop production. Endogenous switching regression was used to assess the effects of indigenous CSA practices on crop production. Thematic analysis was employed to explore the roles of sociocultural values and informal indigenous institutions in the survival and sustainability of CSA practices.

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4. SPATIOTEMPORAL CLIMATE VARIABILITY AND TRENDS IN UNESCO DESIGNATED CULTURAL LANDSCAPES OF KONSO, ETHIOPIA[1]

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ABSTRACT

Understanding spatiotemporal patterns of climate variability and trends is essential to designing context-specific adaptation and mitigation interventions for climate change impacts. To this end, this paper examines the 1983–2016 rainfall and temperature variability and trends using merged satellite-gauge station data in the UNESCO designated Cultural Landscapes of Konso, Ethiopia. We have employed a non-parametric Mann-Kendall test to analyze rainfall and temperature trends, whereas the coefficient of variation (CV) has been used for variability analysis. The distribution and severity of meteorological droughts were mapped using the Standardized Precipitation Index (SPI). Our findings revealed an increase in annual and summer (*Kiremt*) season rainfall by 3.16 mm and 0.42 mm per year, respectively. However, rainfall in the spring (*Belg*) season decreased by 1.12 mm per year. Our findings also showed substantial spatiotemporal variability in drought events due to variations in rainfall and topography. Consequently, the observed increase in frequency and the spatial extent of drought pose potential threats to rainfed farming, which gradually exposes smallholders to food insecurity and socioeconomic vulnerability. Therefore, agroecological-based local adaptation and mitigation interventions to climate variability are needed to enhance the resilience of smallholder farmers and ensure the continuity of the Konso cultural landscapes.

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4.1. Introduction

Global warming has become a significant concern for climate scientists and academics around the world (Zhang et al., 2009). The average world surface temperature rose by 0.8 degrees Celsius in the last century (IPCC, 2007). The last six years (ending in 2020) were particularly the warmest on record (WMO, 2020). In the last 50–100 years, temperatures in Africa have risen by more than 0.5°C (IPCC, 2014; Nicholson et al., 2013). The amount of rainfall is expected to decrease in most parts of Sub-Saharan Africa, while its variability is expected to rise in the coming years (IPCC, 2014). East Africa has seen increasing trends in maximum and minimum temperatures and high seasonal rainfall variability (Cattani et al., 2018; Gebrechorkos et al., 2019). While it is a global phenomenon, the magnitude of the adverse effects of climate change can vary considerably across continents, countries, and socioeconomic classes (Bewket et al., 2015; IPCC, 2014). Because of the high variability in seasonal rainfall and the occurrence of extreme events, East Africa is becoming one of the most food-insecure regions in the world and needs humanitarian assistance (Busso & Fernández, 2018; WMO, 2020). Ethiopia is among the countries that have been experiencing climate variability and change for shorter and longer periods (see Suryabhagavan, 2017). The mean annual temperature over Ethiopia is expected to rise by 0.9–1.1°C in 2030, 1.7–2.1°C in 2050, and 2.7–3.4°C in 2080 (NMA, 2007). In Ethiopia, various studies at different spatial and temporal scales have shown a persistent warming and rising trend in annual temperature in the last three decades (Ademe et al., 2020; Asfaw et al., 2018; Belihu et al., 2018; Esayas et al., 2018; Gebrehiwot & van der Veen, 2013; Matewos & Tefera, 2020; Tesfamariam et al., 2019). Similarly, studies also indicated statistically significant increases in *Kiremt* (June–September) and *Belg* (February–May) season temperatures (Asfaw et al., 2018; Mulugeta et al., 2017).

Rainfall patterns do not show a consistent pattern in Ethiopia. Studies have indicated that annual rainfall trends were highly variable, with a statistically significant decrease since 1980 (Ademe et al., 2020; Asfaw et al., 2018; Belihu et al., 2018; Gebrehiwot & van der Veen, 2013; Hessebo et al., 2019; Matewos & Tefera, 2020; Tesfamariam et al., 2019). Other studies have shown an increasing rainfall trend, albeit statistically insignificant (Alemayehu & Bewket, 2017; Gedefaw et al., 2018; Mengistu et al., 2019). Similarly, seasonal rainfall is inconsistent because there has been a statistically significant increase in *Kiremt* rainfall in the last three decades (Degefu & Bewket, 2014; Muluneh et al., 2017; Teyso & Anjulo, 2016) as well as a statistically significant decrease in the trend of *Kiremt* and *Belg* season rainfall (Ademe et al., 2020; Belihu et al., 2018; Hessebo et al., 2019; Matewos & Tefera, 2020; Mengistu et al., 2019). Again, other studies have reported the absence of changes in both annual and seasonal precipitation in the past three decades (Abrha & Simhadri, 2015; Cheung et al., 2008; Suryabhagavan, 2017). Drought is the other dimension of rainfall studies. In the last fifty years, droughts have become a more common phenomenon in Ethiopia. Some regions are more prone to them than others (Mera, 2018). The droughts of 1984, 1999, 2009, 2015, and 2016 were the most devastating in the history of the country in terms of causing massive food shortages for a large proportion of the population that relied on subsistence-rain-fed agriculture (Degefie et al., 2019; Mekonen et al., 2020; Mera, 2018).

Previous studies that have reported consistent rising temperatures and erratic rainfall patterns have their own limitations (Gedefaw et al., 2018; Mulugeta et al., 2017; Mulugeta et al., 2019; Muluneh et al., 2017; Teyso & Anjulo, 2016). These studies have heavily relied on data collected from meteorological stations located in a few towns and cities, which is believed to have resulted in the poor spatial representation of remote rural areas. In addition, some of them (Adnew & Bewket, 2014; Mengistu et al., 2014; Mengistu et al., 2019; Tesfamariam et al., 2019) have focused on broader geographical scales and river basins (with areas larger than 50,000 km^2). Naturally, large basins have a tendency to disguise the severity and magnitude of local climate variability and change due to their complex rainfall patterns. As a result, local studies of rainfall and temperature variability and patterns are indispensable for understanding local manifestations of climate variability and trends and developing location-specific adaptation and mitigation interventions. Moreover, studies about the spatiotemporal variability of rainfall with high-resolution maps to identify drought hotspot areas, which should be prioritized in adaptation and mitigation plans, are limited, especially for drought-prone regions such as the UNESCO designated Cultural Landscapes of Konso (hereafter ‘Konso’) (Watson, 2009). Drought frequently hits Konso, but the frequency of meteorological droughts and their spatiotemporal distribution have not been studied using merged satellite-gauge station data. Therefore, this study examines the spatiotemporal rainfall and temperature variability and trends using merged satellite-gauge station data in Konso and maps meteorological droughts using a standardized precipitation index.

4.2. Materials and methods

4.2.1. Data preparation and quality control

To validate the dataset, the strength of the relationship between gridded and meteorological station data was examined using Pearson correlation coefficients (r). The mean rainfall and temperature data from gridded and meteorological stations have strong positive correlations of r = 0.70 and r = 0.76, respectively. The prime source of the grid data information was done by Dinku et al. (2018). In Ethiopia, Dinku et al. (2018) found that the correlation coefficients between monthly meteorological station rainfall data and gridded data such as ARC2, TAMSAT3, CHIRP, and CHIRPS were 0.86, 0.91, 0.92, and 0.93, respectively. Before analysis, monthly rainfall and temperature data were aggregated, and seasonal and annual means were generated. Serial autocorrelation was calculated by the autocorrelation function (acf) using the (modifiedmk) package of R version 3.5.3 software. The lag-1 autocorrelation coefficient was calculated to remove the autoregressive component from the detrended series. When the autocorrelation coefficient of lag-1 was significant, the autocorrelation component was removed from the series using prewhitening by Eq. (1) and the MK (Eq. 5 to 8) test; otherwise, the original data series was used with the following formula:

$$Y_1 = Y_t - r_1 Y_{t\text{-}1} \tag{1}$$

where Y_1 is a series without an autoregressive part, Y_t is the detrended series, and r_1 is the lag-1 autocorrelation coefficient.

4.2.2. Data analysis

2.2.1. Variability analysis

The coefficient of variation was used to calculate rainfall variability. A CV is specified as:

$$CV = \frac{\sigma}{\mu} x\, 100 \quad (2)$$

where CV is the coefficient of variation, σ is the standard deviation and μ is the mean rainfall. We evaluated the results of rainfall anomalies based on the drought classification scales of McKee *et al*. (1993). According to these scholars, there are five groups of drought severity: extreme drought (SPI ≤–2), severe drought (SPI −1.5 to −2), moderate drought (SPI −1.00 to −1.49), mild drought (SPI −0.99 to 0) and no drought (SPI ≥ 0). The annual and seasonal precipitation averages were used to calculate the rainfall anomaly. Based on McKee et al. (1993), we computed a standardized precipitation index as:

$$SPI = \frac{X_i - \mu}{\sigma} \quad (3)$$

where SPI is a standardized precipitation index; X_i is the annual/seasonal rainfall of a particular year; μ is the mean; and σ is the standard deviation of the annual/seasonal rainfall.

Furthermore, the standard deviation was calculated with the following formula:

$$\sigma = \frac{\sqrt{\sum (X_i - \mu)^2}}{n} \quad (4)$$

where σ is the deviation of the data from the average values; x_i is the rainfall of a given year; μ is the average rainfall; and n is the number of months or years in a study period.

2.2.2. Trend analysis

The Mann-Kendall trend test was used to calculate rainfall and temperature trends. The Mann-Kendall test is based on the statistic S, in which each pair of observed values x_j and x_k of the random variable is examined to determine whether $x_k > x_j$ or $x_k < x_j$. We calculated the tests statistics as:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn\left(x_j - x_k\right) \quad (5)$$

where x_j and x_k are the values of the data series and N is the length of the data set:

$$\mathrm{sgn}(X_j - X_k) = \begin{cases} 1 & \text{if } X_j - X_k > 0 \\ 0 & \text{if } X_j - X_k = 0 \\ -1 & \text{if } X_j - X_k < 0 \end{cases} \tag{6}$$

The variance, Var(S) is computed as:

$$\mathrm{Var}(S) = \frac{n(n-1)(2n+5)}{18} \tag{7}$$

Then, the Z score is calculated as:

$$Z = \begin{cases} \dfrac{S-1}{[\mathrm{Var}(S)]^{1/2}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{[\mathrm{Var}(S)]^{1/2}} & \text{if } S < 0 \end{cases} \tag{8}$$

The magnitude of changes was analyzed for significant trends by estimating slope. Thus, slope (β) is defined as:

$$\beta = \frac{X_j - X_k}{j - k} \tag{9}$$

where X_j and X_k are data values at times j and k (j > k). The median of N values β is represented as Sen's slope, which is computed as $Q_{med} = \beta_{(N+1)/2}$ if N exists as odd and taken as $Q_{med} = [\beta_{N/2} + \beta_{(N+2/2)}]$ if N appears as even. A positive value of Q_{med} indicates a rising trend in the data series, while a negative value indicates a declining trend.

2.2.3. Spatial analysis

The ArcGIS 10.5 map algebra was used to combine multiple Networks Common Data Form (NetCDF) raster files to spatially show the study period's seasonal and annual average rainfall and temperature. We interpolated the gridded point rainfall and temperature data using the ordinary kriging method given in Eq. (10) to create a continuous surface. We wrote the model of Kriging as:

$$\hat{Z}(S_0) = \sum_{i=1}^{N} \lambda_i Z(S_i) \qquad (10)$$

where S_0 = estimated place; N= total calculated values $Z(s_i)$ = the calculated value at the i^{th} place; λ_i = required weight for the calculated value at the i^{th} place.

We also used covariance and correlation for this study. We calculated the covariance and correlation using the ArcGIS 10.5 band collection statistics tool.

$$Cov_{ij} = \frac{\sum_{k=1}^{N} (Z_{ik} - \mu_i)(Z_{jk} - \mu_j)}{N-1} \qquad (11)$$

where Z is the value of a cell; i and j are layers of a stack; μ is the mean of a layer; N is the number of cells; and k denotes a particular cell. The correlation between the layers is specified as:

$$r_{ij} = \frac{Cov_{ij}}{\sigma_i \sigma_j} \qquad (12)$$

We generated the terrain ruggedness index (TRI) to compute the terrain ruggedness. The difference in elevation between adjacent digital elevation model (DEM) cells is expressed as TRI. Riley et al. (1993) classified the TRI values into seven classes, in which the lowest class value (1) indicates level (smooth) ground while the high-class value (7) indicates extremely rugged terrain.

4.3. Results and discussion

4.3.1. Annual and seasonal rainfall variability and trends

We analyzed the annual and seasonal variability in rainfall data over 34 years (1983–2016) in Konso, Ethiopia. The distribution of rainfall over the years under consideration was highly variable. The mean annual rainfall in the study period was 801.98 mm, with a standard deviation of 140.40 mm and a CV of 17.51% (see Table 4.1). The minimum and maximum recorded annual rainfall was 570.69 mm in 1984 (driest year) and 1085 mm in 1989 (wettest year), respectively (also see Table 4.1). The Mann-Kendall (MK) test showed an increasing trend in annual rainfall by 3.16 mm/year in Konso. Alemayehu and

Bewket (2017) reported an increasing trend in annual rainfall of 2.63 mm in the north-central highlands of Ethiopia. However, Ademe et al. (2020) reported a decline of 4.44 mm/year in annual rainfall in the Choke Mountain watersheds in Ethiopia.

Table 4.1. Monthly, seasonal, annual, and MK trend test of rainfall (1983–2016).

Months	Min	Max	Mean	St.D	CV (%)	MK test	Sen's Slope
January	0.00	92.29	24.08	26.52	110.10	-1.14**	-0.35
February	0.00	137.17	27.43	34.10	124.32	-0.56	-0.13
March	8.95	217.44	85.97	50.74	59.02	0.59	0.45
April	64.26	324.37	169.14	58.85	34.80	0.06	0.09
May	43.79	290.15	116.99	52.53	44.90	-0.53	-0.59
June	5.84	120.33	41.24	31.17	75.58	0.06	0.04
July	0.98	114.35	30.35	22.72	74.85	-1.01	-0.28
August	0.75	102.38	32.55	26.90	82.64	1.33	0.68
September	7.58	182.06	62.46	42.31	67.74	0.39	0.31
October	36.26	192.02	103.60	40.45	39.04	1.78	1.51
November	4.00	282.83	71.49	59.85	83.71	1.66**	1.04
December	0.00	198.94	36.67	45.20	123.25	-0.10	-0.02
Belg(FMAM)	253.44	674.60	399.52	107.55	26.92	-0.44	-1.12
Kiremt (JJAS)	72.92	400.40	166.61	80.76	48.47	0.27	0.42
Annual	570.69	1084.66	801.98	140.40	17.51	1.01	3.16

Rainfall is insufficient in Konso and rarely occurs at the expected time (Watson, 2009). When heavy rains fall, flooding can be a problem in the lower parts of streams (Watson, 2009). Drought is a frequently occurring natural disaster along with erratic rainfall. Because of a rainfall shortage, the Konso area is hot most of the year. Because of rainfall shortages, there is most often an acute shortage of water for both people and animals. During the dry season, women travel for several hours to fetch water.

The spatial annual rainfall analysis indicated that the southeastern parts in *Kolla* AEZ received a low amount of annual rainfall (571 − 600 mm), while the southwest and northern parts in *Kolla* and *Woynadega* AEZs received more annual rainfall (900 − 1085 mm). The central parts in the *Kolla* AEZ received an annual rainfall of 600 − 800 mm (Figure 4.1). This spatial variation in annual rainfall distribution is because of differences in altitude, aspect, and directions of prevailing southeastern trade winds and equatorial westerlies (Gemechu, 1977). Altitude and terrain ruggedness pose a substantial influence on the spatiotemporal distribution of annual rainfall. The positive spatial correlation partly evidenced this between annual rainfall and altitude. Furthermore, there is a positive relationship between the annual rainfall distribution and the terrain ruggedness index (TRI). The situation is worsened because of unreliable rainfall that occurs in the *Belg* and *Kiremt* seasons.

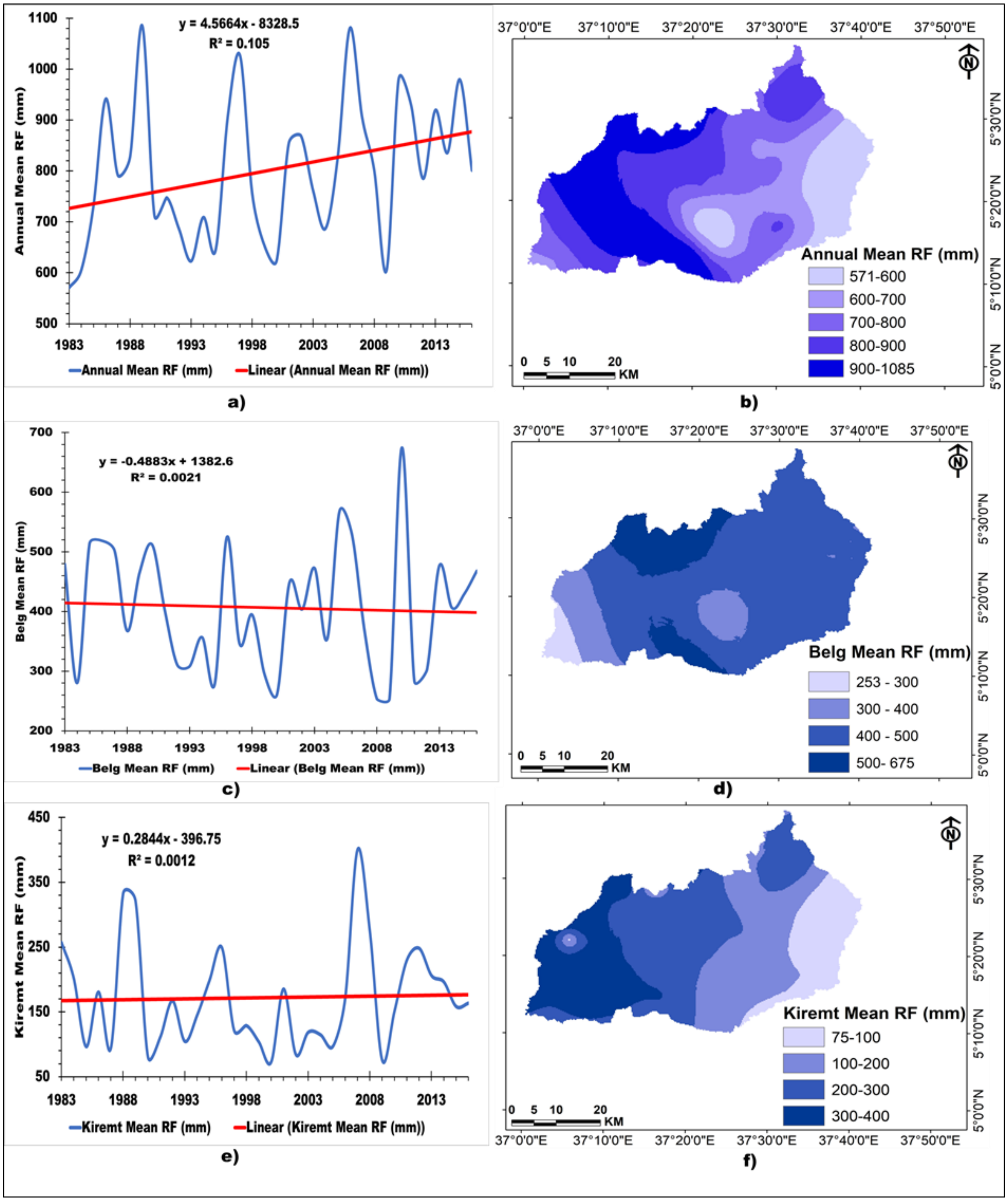

Figure 4.1. Distribution of mean annual and seasonal rainfall in Konso (1983–2016).

The *Belg* is the main rainy season in Konso. *Belg* rain accounts for approximately half (49.82%) of the annual rainfall (see Table 4.1). During the study period, the mean rainfall for the *Belg* season (February–May) was 399.52 mm, with a standard deviation of 107.55 mm and a CV of 26.92%. Indeed, the rainfall in the *Belg* season showed a decline at a rate of 1.12 mm/year (see Table 4.1). Similar trends have been reported, indicating declining trends in *Belg* season rainfall in Ethiopia (Hessebo et al., 2019; Matewos & Tefera, 2020; Mengistu et al., 2019). During the *Belg* season, the northern parts in *Woynadega* AEZ received a high amount of rainfall (500 − 675 mm) (Figure 4.1 (d)), whereas the western tip in *Kolla* AEZ and the small area in the central parts received low rainfall (253 − 300 mm). Table 4.2 demonstrates a strong positive spatiotemporal correlation (r = 0.53) between altitude and *Belg* season rainfall distribution. Orographic rainfall is the primary cause of the statistically significant positive relationship between *Belg* rainfall and altitude. Similarly, the spatial correlation between *Belg* season rainfall and TRI is positive, although weaker (r = 0.24). Mengistu et al. (2019), Mulugeta et al. (2019), and Tesfamariam et al. (2019) reported high annual and seasonal rainfall for *Woynadega* and low rainfall for *Kolla* AEZs in Ethiopia. Because of the significant differences in altitude, terrain ruggedness, and topographic aspect, there is a difference in rainfall even within the same AEZ. Even though there is moderate rainfall variability (CV = 26.92%) in the *Belg* season, it has negative consequences for agricultural production.

One of the major crop production constraints in Konso is the lack and unreliability of rainfall (Tadesse, 2010). In each of the cropping seasons, rain usually begins either very late or quite very early before the crop becomes mature. Heat stress, coupled with moisture deficit, contributes to frequent crop failures in Konso. For instance, from 2008 to 2009, there was a drought caused by a shortage of rainfall. Drought damages *Belg* crops and results in a massive food shortage (Tadesse, 2010). In contrast, erratic and intense heavy rains cause serious crop damage, leaving no chance for smallholder farmers to salvage the losses. In Konso, the construction and repair of soil and water conservation structures was an ongoing process, especially after heavy rains. Because of high seasonal rainfall variability combined with poor access to off-farm economic activities, people living in these areas often suffer from poverty and are vulnerable to threats of food insecurity (Tadesse, 2010).

The *Kiremt* season mean rainfall during the study period was 166.61 mm with a standard deviation of 80.76 mm and a CV of 48.47%. The Mann-Kendall trend test showed increasing trends in *Kiremt* season rainfall by 0.42 mm (see Table 4.1). Alemayehu and Bewket (2017) revealed that *Kiremt* season rainfall in Ethiopia's central highlands was increased by 6.17 mm per year. However, Ademe et al. (2020) reported a decline of 2.94 mm/year in *Kiremt* season rainfall in the Choke Mountains of the north-central highlands of Ethiopia. During the *Kiremt* season, the western and northern tips of Konso received high rainfall (300–400 mm), while the eastern and southeast parts of Konso received low rainfall (<100 mm). The southern, central, and northern parts received rainfall of 100–300 mm (Figure 4.1). Generally, during the *Kiremt* season, rainfall intensity decreases from northwest to southeast (Figure 4.1). Tesfamariam et al. (2019) reported a decrease in *Kiremt* rainfall from northwest to southeast in the Rift Valley Lakes Basin of Ethiopia, where Konso is part. The results also revealed a positive but weak spatial correlation (r = 0.04) between *Kiremt* rainfall and TRI. The *Kiremt* rainfall showed a higher variability (CV = 48.47%) than the *Belg* rainfall (CV = 26.92%) (also see Table 4.2). This study shows contradictory results to the findings of previous studies (Asfaw et al., 2018) that reported a higher CV (56.57%) for *Belg* rainfall than for *Kiremt* rainfall (CV = 17.51%) in north-central Ethiopia. In Konso, the high variability of rainfall observed during the *Kiremt* season contributed to crop failures or decreases (personal communication with the head of the Konso Zone Agriculture Department).

Table 4.2. Spatial correlation among rainfall, drought indices, altitude, AEZ, and TRI.

Layers	Annual rainfall	*Belg* rainfall	*Kiremt* rainfall	Annual SPI	*Belg* SPI	*Kiremt* SPI	Altitude	AEZ	TRI
Annual rainfall		0.36	0.83**	0.96**	0.35	0.84**	0.04	0.09	0.19
Belg rainfall	0.36		0.06	0.36	0.94**	0	0.53**	0.2	0.24
Kiremt rainfall	0.83**	0.06		0.83**	0.07	0.98**	0.11	0.11	0.04
Annual SPI	0.96**	0.35	0.84**		0.35	0.84**	0.03	0.10	0.21
Belg SPI	0.35	0.94**	0.07	0.35		0.01	0.53**	0.2	0.27
Kiremt SPI	0.84**	0	0.98**	0.84**	0.01		0.11	0.14	0.04
Altitude	0.04	0.53**	0.11	0.03	0.53**	0.11		0.14	0.24
AEZ	0.09	0.2	0.11	0.10	0.2	0.14	0.67**		0.12
TRI	0.19	0.24	0.04	0.21	0.27	0.04	0.24	0.12	

** Correlation is significant at a 0.05 level.

4.3.2. Spatiotemporal distribution of drought incidents

We used an annual and seasonal standard precipitation index (SPI) to calculate the severity of droughts. We chose the SPI to examine meteorological drought because precipitation is the only input variable. Again, the SPI can be determined at different time scales and is helpful in evaluating the severity of drought (World Meteorological Organization (WMO), 2012). As mentioned earlier, Konso is one of the drought-prone areas in the Ethiopian Rift Valley region. Significant spatial variability in drought incidents characterizes the Konso area. The major factors for such variations in drought incidences are related to variations in rainfall, altitude, terrain ruggedness, and topographic aspect. The drought occurrences follow the pattern of rainfall distribution (see Figures 4.2 and Figures 4.3). Annual rainfall patterns and annual SPI, for example, have a strong positive spatial correlation (r = 0.96).

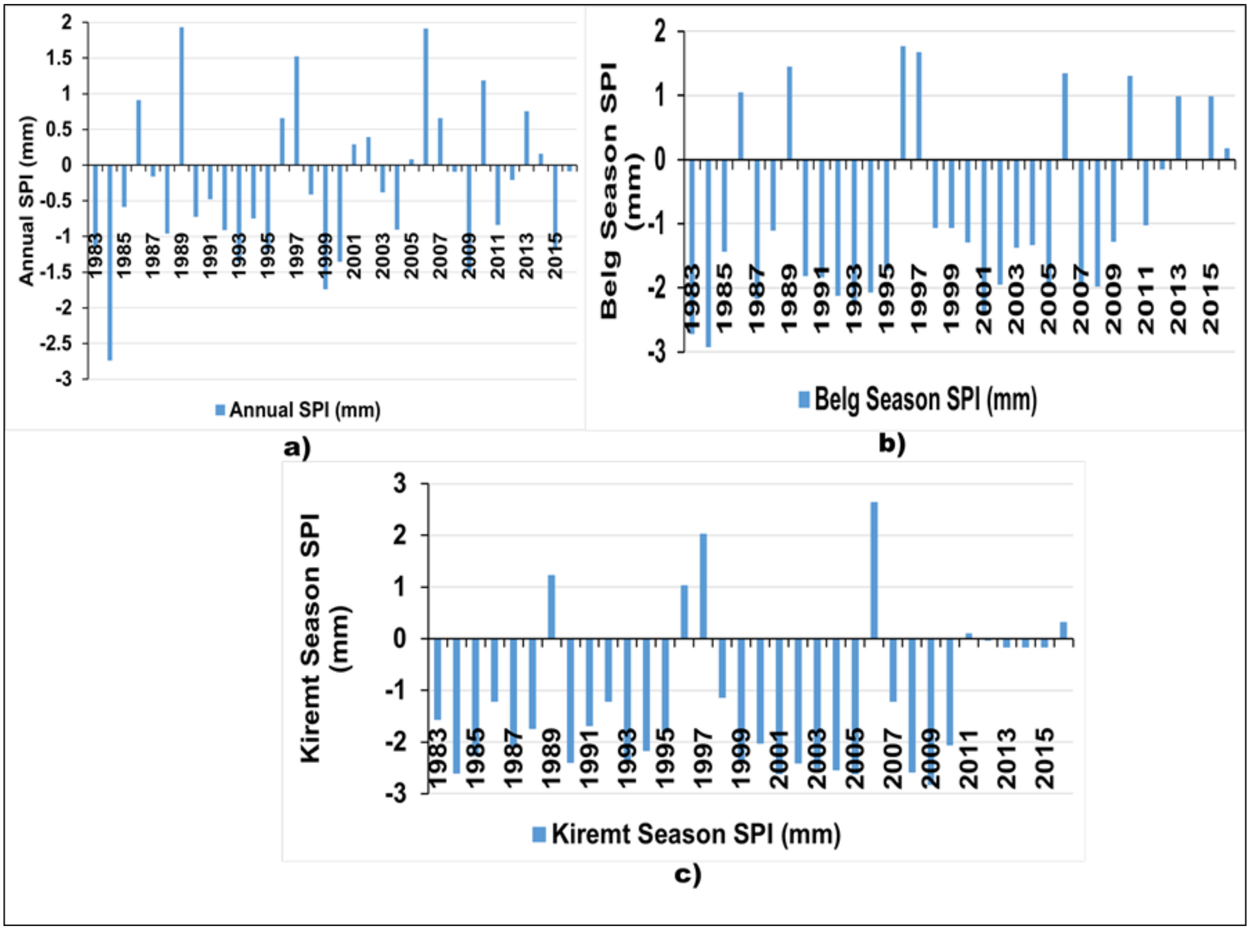

Figure 4.2. The SPI anomalies a) Annual SPI b) Belg season SPI c) Kiremt season SPI.

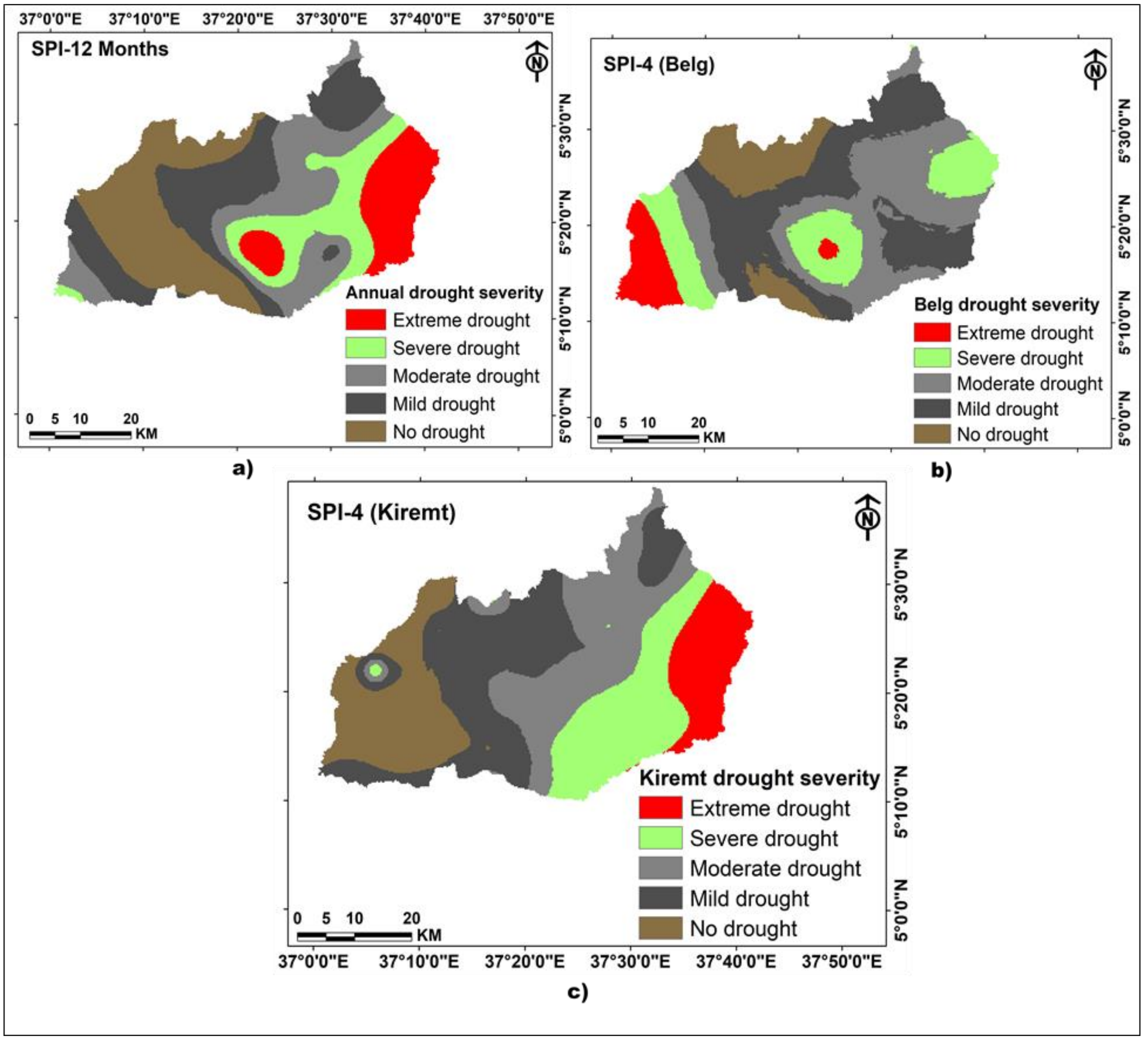

Figure 4.3. Spatiotemporal distribution of drought in Konso (1983–2016).

This result shows that areas of low rainfall are areas where extreme and severe droughts occur. Moreover, the spatiotemporal analysis results of annual SPI have indicated the incidence of extreme and severe droughts in the southeastern parts of the *Kolla* AEZ. Furthermore, moderate and mild droughts occurred in the southern, central, and some northern parts in the *Kolla* and *Woynadega* AEZs (Figure 4.3(a)). On an annual basis, the total areas of Konso under extreme, severe, moderate, and mild droughts were 320.48 km^2 (14.1%), 331.93 km^2 (14.6%), 491.92 km^2 (21.64%), and 570.55 km^2 (25.1%), respectively (Table 4.4). Agroecologically, the total area under drought was 1391.35 km^2 (61.2%) in *Kolla* and 323.54 km^2 (14.23%) in *Woynadega* AEZs (also see Table 4.4). Concerning the recurrence of drought, the findings show that drought has hit Konso several times, causing significant crop failure and harvest losses. For example, in the major drought years (1983, 1984, 1992, 1993, 1995, 1999, 2000, 2004, 2009, 2011, and 2015), the SPI values were less than – 0.99 (see Table 4.3 and Figure 4.2). Moreover, 41.8% of observations experienced mild droughts, while 2.94%, 5.88%, and 14.71% of observations experienced extreme, severe, and moderate droughts, respectively (also see Table 4.3 and Figure 4.2).

The SPI results for the last three decades have revealed that the area has experienced twenty-two annual droughts, one of which was extreme, two severe, and five moderate (Table 4.3). The most horrible droughts were recorded in 1984, 1999, and 2009, with severity peaks of SPI values of −2.73, −1.73, and −1.49, respectively.

Table 4.3. Drought severity and years of occurrences (1983–2016).

Drought severity	Years	Peak SPI-value	Frequency (%)
Extreme drought	1984	−2.73	1 (2.94%)
Severe drought	1999, 2009	−1.73	2 (5.88%)
Moderate drought	1983, 1993, 1995, 2000, 2015	−1.36	5 (14.71%)
Mild drought	1985, 1987, 1988, 1990, 1991, 1992, 1994, 1998, 2003, 2004, 2008, 2011, 2012, 2016	−0.96	14 (41.18%)

Of course, the devastating famine of 1983–1984 was the deadliest in the country's history and affected almost the entire country (Degefie et al., 2019; Mera, 2018). It handled millions of deaths, mostly in the northern part of the country (Mekonen et al., 2020). It caused the eviction of thousands of rural residents from drought-affected areas (Degefie et al., 2019). The year 1999 experienced a severe drought, and the Konso area experienced food shortages (Watson, 2009). In 2009, the area again suffered from a severe drought that forced most of the local farms to produce less (Tadesse, 2010). The drought of 2015–2016 also affected a large portion of the country (Mera, 2018). Konso was no exception.

The occurrence of drought incidents varies across seasons and agroecological zones (AEZs). During the *Belg* season, an extreme drought occurred in the western tip of

Konso in the *Kolla* AEZ, while severe, moderate, and mild droughts prevailed in the eastern, southern, and central parts in the *Kolla* and *Woynadega* AEZs (Figure 4.3(c)). In this season, the total areas under extreme, severe, moderate, and mild droughts were 160.44 km^2 (7.06%), 407.19 km^2 (17.91%), 680.03 km^2 (29.91%), and 742.22 km^2 (32.65%), respectively (see Table 4.4). Based on agroecology, a 1699.98 km^2 (74.78%) area in *Kolla* and a 289.9 km^2 (12.75%) area in *Woynadega* AEZs were under drought in the *Belg* season. The results revealed a strong positive spatial correlation ($r = 0.94$) between *Belg* season rainfall and its SPI. Furthermore, the *Belg* season SPI and TRI are positively correlated ($r = 0.27$). The *Belg* season SPI is also strongly correlated ($r = 0.53$) with altitude (see Figures 4.3 and 4.4). Since *Belg* is the principal rainy season in the study area, extreme, severe, moderate, and mild droughts impact crop production and local livelihoods. This was particularly true when we considered the cereal crop maize, which exhibited a positive correlation ($r = 0.38$) between *Belg* season maize production and rainfall.

Table 4. 4. Spatiotemporal distribution of drought across agroecology (1983–2016).

		Agroecology			
	Droughts	*Kolla* (km^2)	*Woynadega* (km^2)	Total area (km^2)	Total area (%)
Belg	Extreme	148.74	11.7	160.44	7.06
	Severe	306.42	100.77	407.19	17.91
	Moderate	620.5	59.53	680.03	29.91
	Mild	624.32	117.9	742.22	32.65
	No	127.47	156.03	283.5	12.47
	Total	1827.45	445.93	2273.38	100
Kiremt	Extreme	246.15	0	246.15	10.83
	Severe	400.84	18.59	419.43	18.45
	Moderate	372.67	170.44	543.11	23.89
	Mild	413.12	232.27	645.39	28.39
	No	394.84	24.46	419.3	18.44
	Total	1827.62	445.77	2273.38	100
Annual	Extreme	268.86	51.62	320.48	14.1
	Severe	268.65	63.28	331.93	14.6
	Moderate	445.54	46.38	491.92	21.64
	Mild	408.3	162.26	570.55	25.1
	No	436.41	122.08	558.49	24.57
	Total	1827.76	445.62	2273.38	100

In the years of drought, maize production was below its average. For example, the production of maize was approximately 20.73% below its 12-year (2004–2016) average in drought years (2005, 2008, 2009, 2011, 2012, 2015, and 2016). According to the results, the 1984 *Belg* season was the driest of the drought years. The incidence of drought also showed an increasing tendency in the *Belg* season nationally. Mekonen et al. (2020) indicated an increase in the frequency of drought incidences during the *Belg* season in Ethiopia's northeastern highlands. In the same vein, *Belg* rains failed in Konso in 1998 and resulted in the loss of cereals and pulse harvests (Förch, 2003). Due to severe droughts, other harvest failures occurred in the area in 1999, and nearly total *Belg* crop failure occurred in 2008/2009 (Tadesse, 2010).

In the *Kiremt* season, an extreme drought occurred in the eastern parts of Konso in the *Kolla* AEZ, but the central, southern, and most northern parts of the *Kolla* and *Woynadega* AEZs were under severe, moderate, and mild droughts. In this season, drought severity increased from northwest to southeast (Figure 4.3(c)), with a total area of 1432.78 km^2 (63.02%) in *Kolla* and 421.3 km^2 (18.53%) in *Woynadega* AEZs (Table 4.4). In the *Kiremt* season, rainfall and its SPI values are strongly correlated ($r = 0.98$). Moreover, the *Kiremt* season SPI showed a positive but weak correlation ($r = 0.11$) with altitude. The leeward sides are more vulnerable to drought episodes than the windward sides (Figure 4.3). The five driest years of the *Kiremt* season on record were 1984, 2001, 2005, 2008, and 2009. Similarly, Mekonen et al. (2020) reported extreme droughts in the *Kiremt* season in Ethiopia's northeastern highlands in 1984 and 2009. Lyon (2014) also discovered that the *Kiremt* season rainfall in 1984 was below average for a prolonged time because of drought incidents, which caused the most devastation in northern Ethiopia. Generally, terrain ruggedness and its aspect influence both the annual and seasonal distributions of rainfall and drought.

During an interview with the Konso Zone head of the Agriculture Department, the head of the department stated that currently, the adaptation and coping mechanisms of smallholder farmers have gradually become less adequate to absorb and bounce back from drought shocks than in previous times. Drought and other economic stresses exhausted them. He added that farmers from all socioeconomic groups now share nearly identical perspectives on the causes: unreliability of rainfall and drought as a divine act in response to sins (also see Tadesse, 2010).

4.3.3. Annual and seasonal variability and trends of temperature

In the study area, the mean minimum temperature (minimum temperature), mean maximum temperature (maximum temperature) and mean temperatures vary across space and time (1983–2016). The annual minimum, maximum, and mean temperatures were 15.41, 31.43, and 22.7 degrees Celsius, respectively (Table 4.5). The temperature figures show that temperatures are on the rise, with the annual rates of change for minimum, maximum, and mean temperatures being 0.01, 0.005, and 0.0008°C, respectively (Table 4.5). Asfaw et al. (2018) and Mengistu et al. (2014) revealed that the annual increase in the minimum temperature is higher than the maximum temperature in Ethiopia. This implies the importance of agricultural adaptation strategies that focus on the growth of heat-tolerant crops.

Table 4.5. Seasonal and annual maximum, minimum, mean and MK trend test of temperature (1983–2016).

Temperatures		*Belg*	*Kiremt*	Annual
Minimum		16.15	15.24	15.41
Maximum		31.43	28.47	31.43
Mean		23.67	21.8	22.7
MinT	↑MK_z	0.36	2.46**	1.93
	Slope	0.003	0.03	0.01
MaxT	↑MK_z	0.17	0.36	0.47
	Slope	0.002	0.006	0.005
MeanT	↑MK_z	1.07	0.97**	0.01
	Slope	0.01	0.008	0.0008

**Significant at a 0.05 significance level.

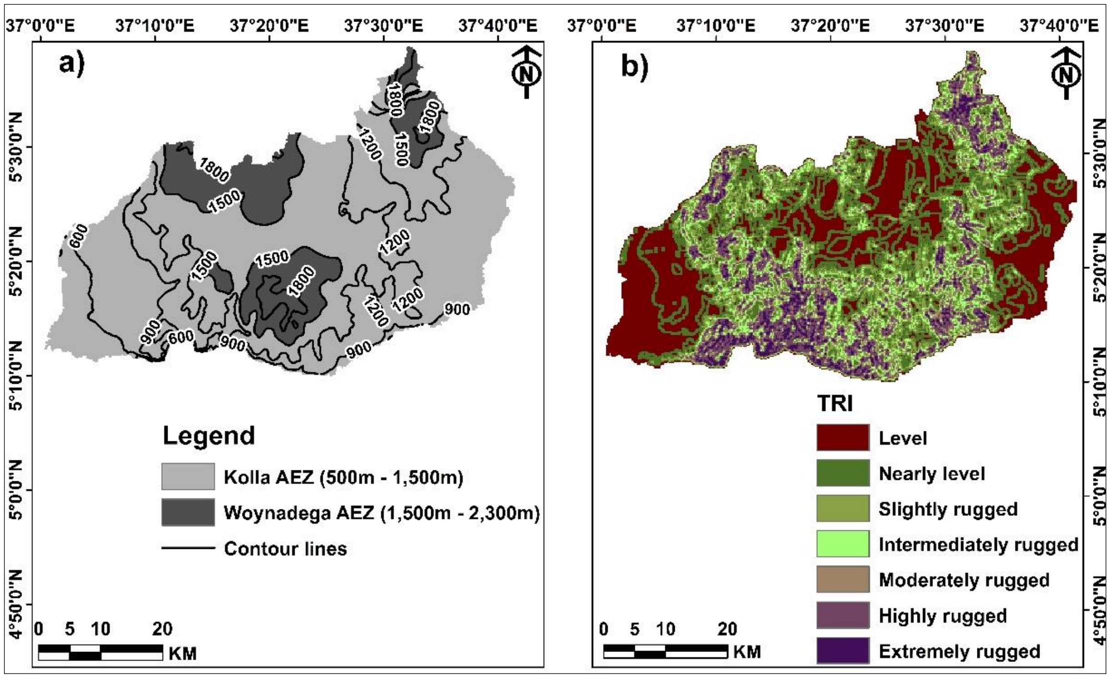

Figure 4.4. Spatial distribution of a) agroecological zones (AEZs) and b) terrain ruggedness index (TRI).

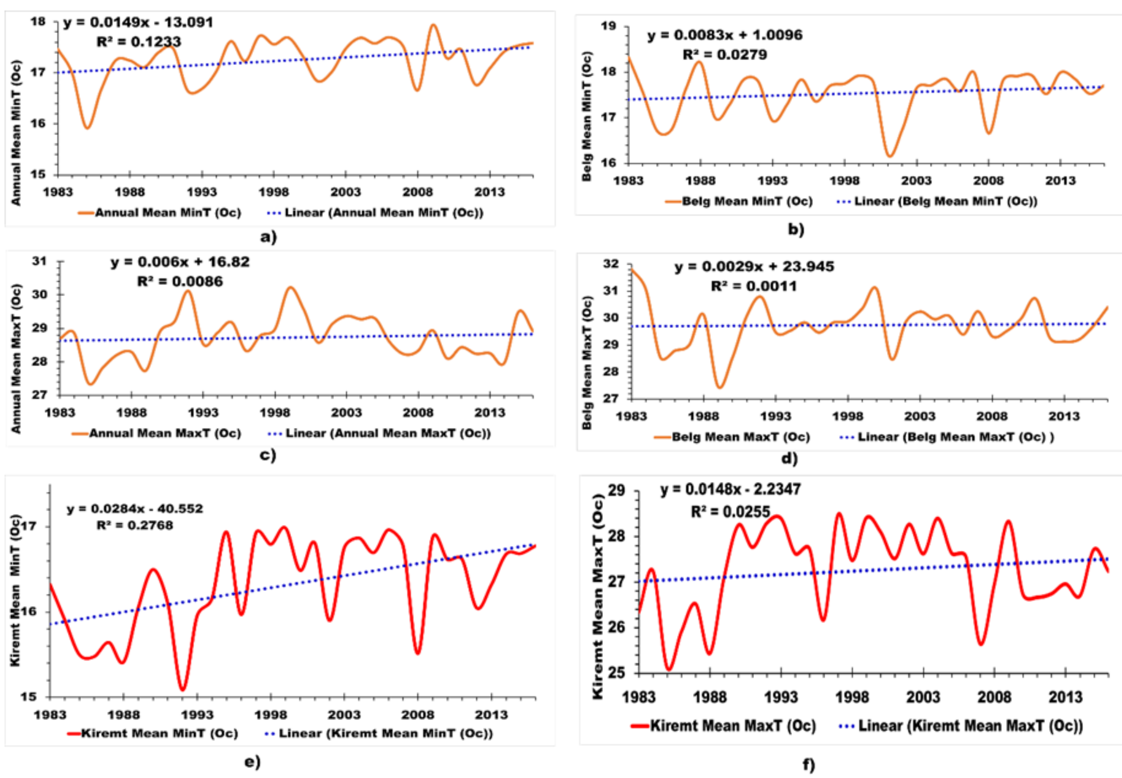

Figure 4.5. Annual and seasonal temperature patterns of Konso (1983–2016).

According to the MK trend test results, the minimum and maximum temperatures in the *Belg* season have been rising (Figure 4.5). For the *Belg* season, the rates of increase in minimum and maximum temperatures were 0.003 °C and 0.002 °C, respectively. Moreover, the rate of increase was 0.03 °C for the minimum temperature and 0.006 °C for the maximum temperature (see Table 4.5). Therefore, the rate of change in both seasons was higher for the minimum temperature than the maximum. The overall increase in the annual temperature recorded in the study area was due to the rise in the minimum temperature. This increase in temperature may result in a high evapotranspiration rate, adversely affecting rainfed crop production. Asfaw et al. (2018) and Mengistu et al. (2014) reported a higher increase in the minimum temperature than the maximum temperature in Ethiopia.

Generally, although there was spatial variation in all temperature variables with altitude and terrain ruggedness, the results did not indicate a direct relationship between temperature and altitude and terrain ruggedness (Figure 4.6).

The study also analyzed temperature anomalies from 1983 to 2016. The frequency of years with a positive anomaly of annual mean temperature showed an increase from the 1980s to the 2000s. The years with a positive annual temperature anomaly were 5.9% in the 1980s, 17.6% in the 1990s, and 20.6% in the 2000s (Figure 4.7). According to Alemayehu and Bewket (2017), the 2000s were the warmest period compared to the 1980s and 1990s. Likewise, Asfaw et al. (2018) reported that the 2000s are now the warmest period compared to the 1980s and 1990s. In Ethiopia, various studies at different spatial and temporal scales have also shown a persistent warming and highest frquency of rising in annual temperature since 2000s compared to 1980s and 1990s (Ademe et al., 2020; Asfaw et al., 2018; Belihu et al., 2018; Esayas et al., 2018; Matewos & Tefera, 2019; Tesfamariam et al., 2019; Teyso and Anjulo, 2016). Similarly, studies indicated the statistically significant increase in *Kiremt* (June–September) and *Belg* (February–May) seasons temperatures (Asfaw et al., 2018; Getachew, 2018; Mengistu et al., 2014; Mulugeta et al., 2017).

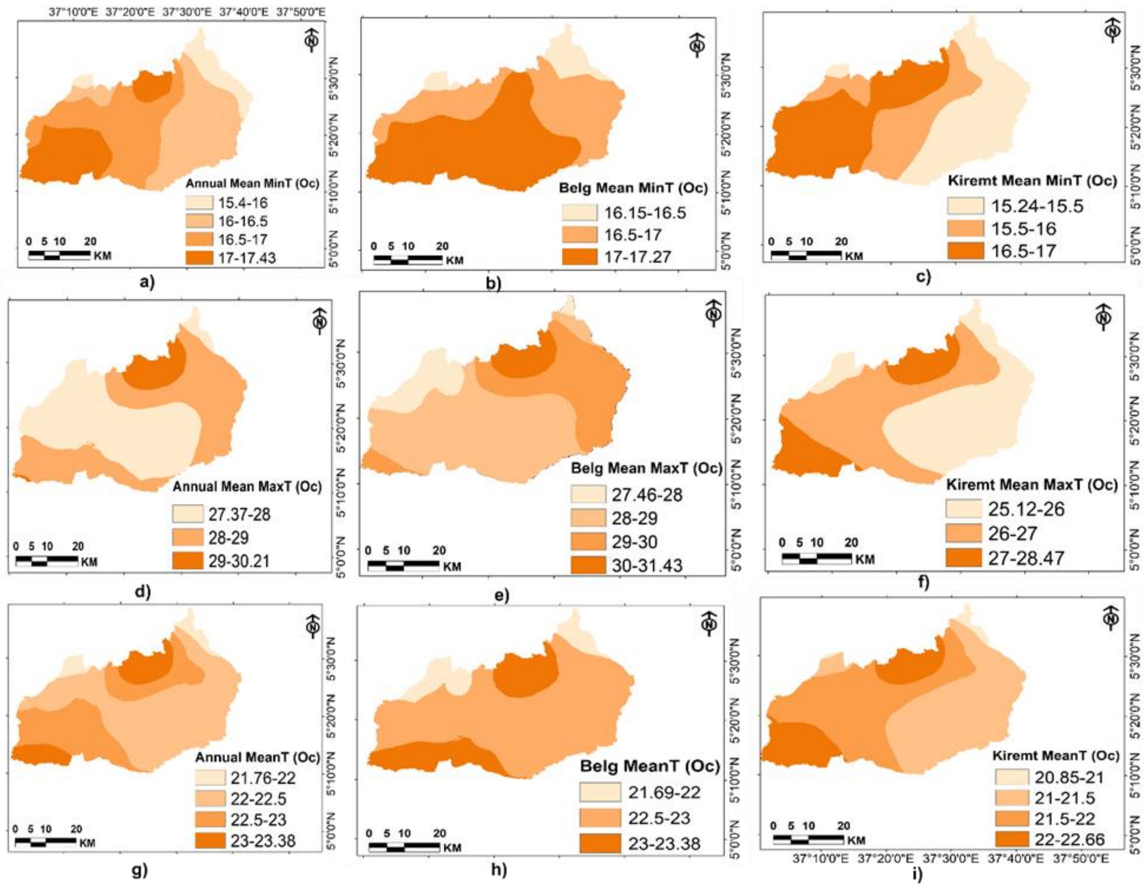

Figure 4.6. Spatiotemporal temperature patterns in Konso (1983–2016).

The frequency of years with a positive seasonal anomaly is also increasing. For instance, in the Belg season, the years with positive mean temperature anomalies were 8.8% in the 1980s, 23.5% in the 1990s, and 29.4% in the 2000s (Figure 4.7). Likewise, in the Kiremt season, the years with positive mean temperature anomalies were 2.9% in the 1980s, 2.9% in the 1990s, and 26.5% in the 2000s. The findings are consistent with similar studies conducted in Ethiopia, emphasizing that the 2000s were the warmest decade compared to the 1980s and 1990s (Asfaw et al., 2018).

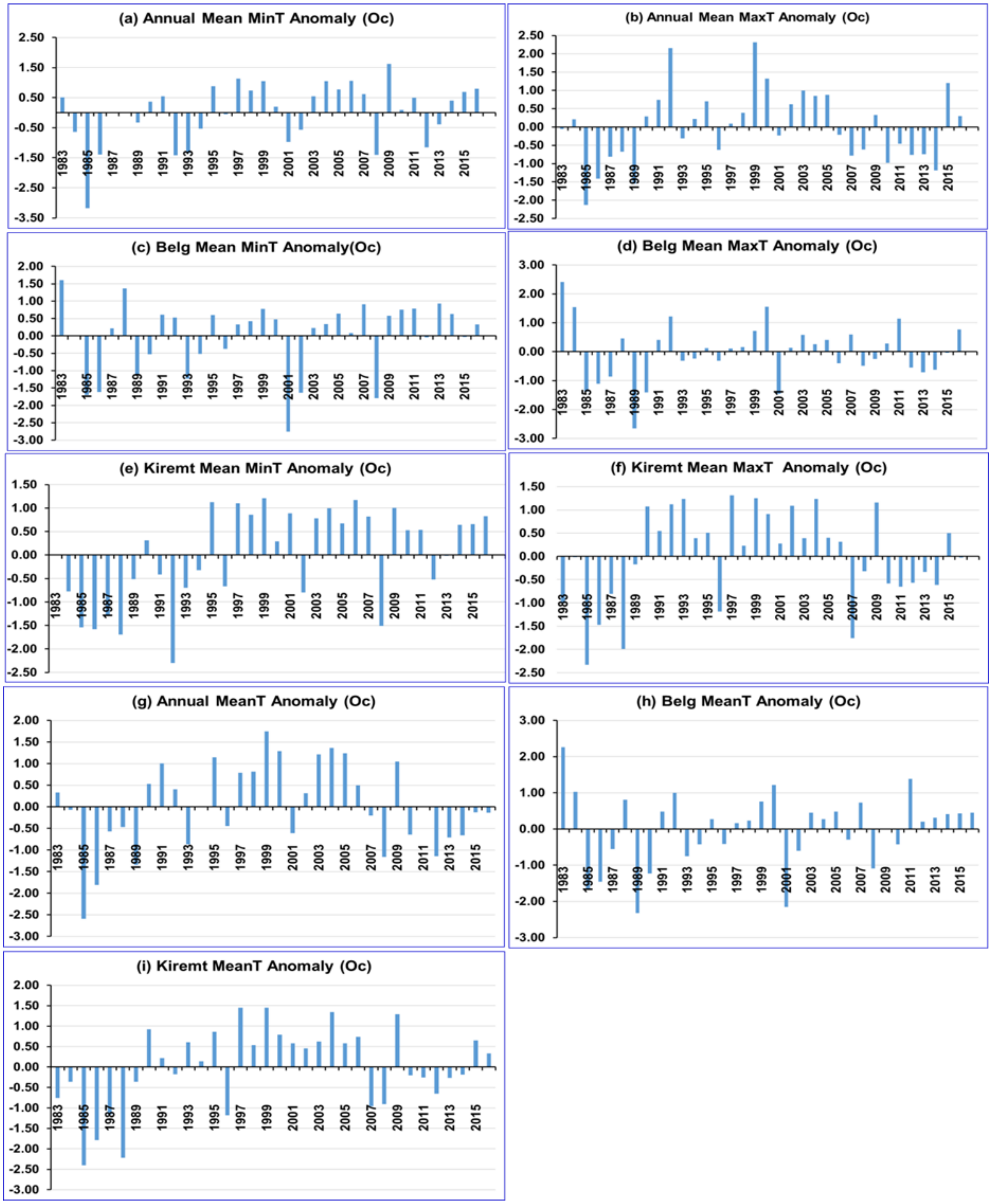

Figure 4.7. Temporal minimum, maximum and mean temperature anomalies in Konso (1983–2016).

4. Conclusion

Even though Konso is recognized as a world heritage cultural landscape for its ingenuity in managing landscapes, severe and frequent droughts can turn it into a disaster, resulting in massive loss of life and significant reductions in household assets, leading to further community impoverishment. If the tendency of drought persists into the future, as we have observed in this study, the threat of serious drought years may increase. The observed drought episodes have indicated that rainfed agriculture-dependent smallholder farmers are already exposed to the adverse impacts of climate change and that rainfed agriculture is likely to be further challenged by future climate change. The findings of our study also indicate a significant rise in the temperature trend that could worsen drought conditions by accelerating evapotranspiration and soil moisture loss. Therefore, agroecologically based and more localized adaptation and mitigation strategies to climate variability and change are critical to increasing the resilience of Konso smallholders. Finally, we recommend more in-depth research on the effects of spatiotemporal variability in rainfall on agricultural productivity, water resources, and the relationship between rainfall, El Niño, and La Niña episodes to better understand and design local and national adaptation policies.

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5. SMALLHOLDERS' ADOPTION OF CLIMATE-SMART PRACTICES IN KONSO, ETHIOPIA[2]

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ABSTRACT

Adoption of Climate-Smart-Agriculture (CSA) practices by smallholder farmers in the UNESCO-designated cultural landscape of Konso is assessed using household survey data, focus groups and key informant interviews. A multinomial logit model reveals that the main determinants of adoption of terracing, agroforestry and intercropping were education, size of landholding, income, access to climate information, credit, and extension services. Despite the farmers' best efforts, improving agricultural production has become increasingly constrained by recurrent droughts, unreliable rainfall, and rising temperatures over the last three decades. External support in the form of reliable regular weather forecasts, affordable credit and crop insurance would support Konso livelihoods and the sustainability of the indigenous farming system.

KEYWORDS

Terracing; intercropping; indigenous practices; multinomial logit model

[2] Gashure, S., & Wana, D. (2022). Smallholders ' adoption of climate-smart practices in Konso, Ethiopia. *International Journal of Environmental Studies*, 1–12. https://doi.org/https://doi.org/10.1080/00207233.2022.2043115 (Published). Note: Study area descriptions have been pooled together in chapter 3, section 3.1.

5.1. Introduction

In Ethiopia, agriculture accounts for 42% of GDP and 80% of employment. Smallholders account for over 90% of the output but they are at particular risk from land degradation. Fifty percent of Ethiopia's highlands are severely degraded. Drought is a further problem. In 2015 and 2017, approximately 10 million and 5 million people, respectively, were affected by severe drought and many more such events are expected (Alemu & Mengistu, 2019; Deressa, 2007). Climate-smart agriculture (CSA) is defined as agriculture that sustainably increases productivity, increases resilience/adaptation, reduces/removes greenhouse gases (GHG)/mitigation, and enhances the achievement of national development and food security goals (FAO, 2010). CSA includes intercropping, mulching, integration of crops and livestock, manuring, crop rotation, water harvesting, and growing drought-tolerant crops. Several studies in Ethiopia have found a positive relationship between smallholders' adoption of CSA and productivity; for instance, Adego et al. (Adego et al., 2019) reported that CSA gave a 2.79 quintal/ year increase in maize yields, and Asrat and Simane (Asrat & Simane, 2018) found that smallholders in the Dabus catchment in northwest Ethiopia gained almost 25% production compared to non-users.

Despite their potential benefits, most CSA practices are not universally adopted; uptake depends on institutional, socio-economic, and biophysical factors. Adoption is promoted by extension agents (Bedeke et al., 2018) but access to finance is crucial (Nhemachena et al., 2014; Wainaina et al., 2016); lack of money and credit surely limits willingness to adopt new practices (Marie et al., 2020; Sertse et al., 2021), and the same applies to smallholders' access to both climate and technology information (Ali et al., 2021). Previous studies have found that the uptake of new practices is influenced by educational level, experience, economically active household members, size of land holding, and diversified sources of income. These studies have focused on national-level surveys or they have been conducted in the highlands of Ethiopia, where climatic shocks appear to be less severe than in semi-arid regions. The UNESCO designated cultural landscape of Konso provides a unique opportunity to study the impact of the adoption of CSA because of its location in the semi-arid Rift Valley region and its culturally interwoven conservation structures. Konso smallholders have been using well-adapted soil and water conservation practices for hundreds of years; even though, they find themselves vulnerable to unreliable rainfall and increasing temperatures.

5.5.2. Materials and methods

5.2.1. Data sources

From February 14 to 13 June 2020 a household questionnaire survey and key informant interviews were undertaken; the questionnaire to the selected household heads gathered information about socio-economic characteristics, adoption of CSA practices, and constraints for their adoptions. To corroborate household survey data, key informant interviews were held with kebele development agents, district, and zone heads of agriculture. Focus group discussions (FGDs) and direct field observations were also undertaken; six FGDs were held, each having 6–10 participants, comprising elders (men and women), youth (age from 18–30 years), and local leaders.

5.2.2. Data analysis

A chi-square test was used to determine whether differences between groups are statistically significant, and we employed a multinomial logit (MNL) model to examine factors that influence the adoption of CSA practices. In this model, the individual selects one of more than two options, which allows the analysis of decisions across more than two categories and the determination of choice probabilities for different categories (Greene, 2012). To define the model, consider Y to be a random variable with values of 1, 2 . . . J for a positive integer J and X to be a set of variables (Marie et al., 2020), Y is a dependent variable and represents the CSA practices from the set of adaptation measures, and X represents the explanatory variables that influence the choice of the CSA practices. P_1, P_2 . . . P_j are associated probabilities, such that $P_1 + P_2 + . . . + P_j = 1$. This explains how a change in X affects the response probabilities P (y = j/x), where j = 1, 2 . . . J. Because the probabilities must add up to one, P (y = j/x) can be calculated once the probabilities for j = 2 . . . J are known.

$$P(y = 1/\mathrm{x}) = 1 - \left(P_2 + P_3 + \ldots P_j\right) \quad (1)$$

The MNL model was estimated for this study by normalising one category, which is referred to as the base category. Eight CSA practices were examined, and the base category was *no adoption of*

CSA practices. The theoretical explanation of the model is that, in all cases, the estimated coefficient should be compared with the base group. For an outcome variable with j categories, the generalised form of probabilities is as follows:

$$\Pr(y_i = \mathrm{j/x}) = \frac{\exp\left(x'\beta_{j'}\right)}{1 + \sum_{k=1}^{j} \exp\left(x'\beta_{j'}\right)}, \mathrm{j} = 1, 2\ldots\mathrm{J} \text{ for } \mathrm{j} > 1 \qquad (2)$$

Table 5.1 lists the variables considered and hypotheses for the outcome variable.

Table 5.1. Description of variables and hypotheses for the outcome variable.

Variables	Definition and measurement	Expected sign
Agroecology	1 if *Kolla* and 0 otherwise	±
Household head sex	1 if male and 0 otherwise	±
Age of household head, yr	Continuous	±
Education of household head, yr	Continuous	+
Household size	Continuous	+
Landholding, ha	Continuous	+
Off-farm activities	1 if there are and 0 otherwise	±
Access to climate information	1 if there is and 0 otherwise	+
Access to agricultural agents	1 if there is and 0 otherwise	+
Access to credit services	1 if there is and 0 otherwise	+
Distance to market, km	Continuous	–
Relatives in a village	Continuous	+
Livestock ownership	1 if there is and 0 otherwise	+
Access to relief aid	1 if there is and 0 otherwise	+

The MNL model parameter estimates provide only the direction of the effect of the independent variable on the dependent variable but do not show the magnitude of change. Thus, differentiating Eq. (2) in terms of the explanatory variables yields marginal effects of the explanatory variables as follows:

$$\frac{\partial p_j}{\partial \mathrm{xk}} = p_j \left(\beta_{\mathrm{jk}} = \sum_{k=0}^{j} p_j \, \beta_{\mathrm{jk}} \right) \qquad (3)$$

Multicollinearity may seriously affect parameter estimates of the logit model, so testing for Variance Inflation Factor (VIF) is important to determine whether there is a problem of multicollinearity among continuous explanatory variables. The VIF was calculated as follows:

$$\mathrm{VIF} = \frac{1}{1 - \mathrm{Ri}^2} \qquad (4)$$

where Ri^2 is the squared multiple correlation coefficient between X_i and other independent variables.

5.3. Results and discussion

5.3.1. Adoption of CSA practices

As shown in Table 5.2, 15–59% of smallholders in the *Woynadega* and 24 − 97% in the *Kolla* have adopted CSA technologies. This may be attributed to the inherent vulnerability of *Kolla* areas to the effects of climate variability and the experience of their farmers, as also reported from NW Ethiopia (Asrat & Simane, 2018). Konso is famous for its terraces (Figure 4.1(b)), and our data show that 83% of Kolla smallholders adopt and maintain stone-walled terraces, compared to only 31% in the *Woynadega*. The Konso call the terrace walls *kawwata*, but the terrace itself is called *xeeranta*. The indigenous terracing system allows cultivation of even the steepest slopes while preventing erosion and trapping soil water. Terraces are constructed with stone walls and can be up to 6 m high, with the width varying depending on the steepness of the slope. Construction is started by digging a trench 10–25 cm into the ground for the foundation. The walls are built by carefully fitting together large and small stones and filling the small gaps between the stones with soil.

Table 5.2. Smallholders' adoption of CSA practices across agroecologies.

Technology	*Woynadega* (N=88)		*Kolla* (N=267)		χ^2 –value	Impacts on three pillars of CSA		
	N	%	N	%		Productivity	Adaptation	Mitigation
Terracing	27	31	221	83	28.39 [a]	Increases yield	Reduces soil erosion Increases infiltration and soil water retention	Captures carbon
Agroforestry	40	45.5	258	97	26.63 [a]	Increases yield	Reduces soil erosion Diversifies production, including fuel and browse	Increases carbon capture and storage
Manure	37	42	229	86	12.17 [a]	Increases yield	Increases soil fertility	Reduces GHG emissions
Crop varieties	13	15	198	74	49.57 [a]	Increases yield	Combats pests, diseases and drought	Less use of chemicals
Soil bunds	38	43	99	37	14.23 [a]	Increases yield	Reduces erosion Promotes infiltration of rainwater	
Intercropping	35	40	65	24	27.13 [a]	Increases yield	Combats pests, disease, and droughts Draws nutrients and water from subsoil	Reduces emissions
Reduced tillage	52	59	85	32	59.95[a]	Increases yield	Minimises destruction of soil structure	Reduces emissions
Irrigation	38	43	134	50	3.7	Increases yield	Year-round cropping Mitigates drought impacts	Creates carbon sink

[a] Significant at $p<0.01$

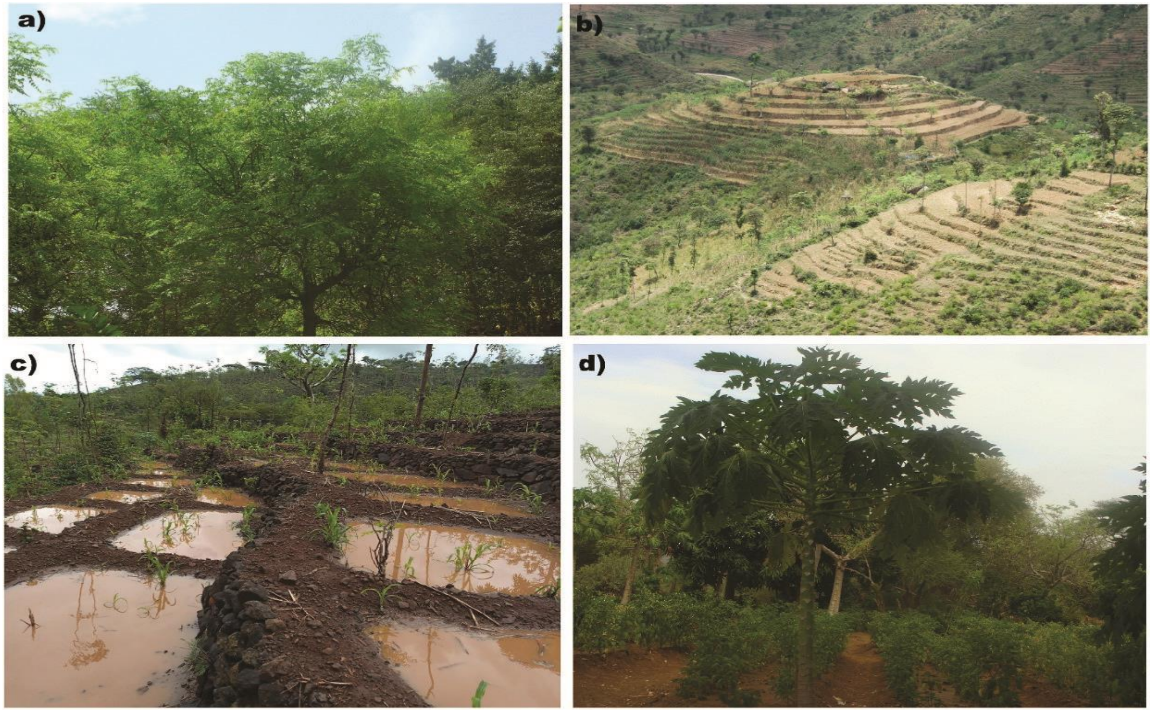

Figure 5.1. (a) Moringa stenopetala (b) Terraced landscape (c) Micro-basins (d) Fruit trees.

Terrace walls are typically 20–40 cm higher than the level of the fields they retain to prevent runoff from damaging the wall (Amborn, 1989) and spillways (*tehota*) 30–35 cm wide and slightly above the field level allow water to flow down from one terrace into the other. To enhance the capture of rainwater, micro-basins (*kolba/korayita*) are constructed on the terraces (Figure 5.1(c)). Flood protection walls (*toomota*) are built from boulders on the bank of a stream to protect surrounding fields from flooding. Focus groups recognised that terracing prevents soil erosion, and maximises rainwater infiltration and retention; GebreMichael (2015) also reported the advantages of water harvesting, stone removal from the fields, space for growing fodder, a fence for the farm plot, and a boundary between fields.

Besides terracing and micro-basins, 50% of smallholders in the *Kolla* adopted traditional irrigation, compared to 43% in the *Woynadega*. Small bunds and terrace walls are built to divert rainwater and spring flow away from roads and paths onto the fields; even the smallest springs are captured and redirected.

Traditional agroforestry focuses on multipurpose trees that diversify income, reduce soil erosion, provide soil organic matter, and supply browse for livestock, local construction, and fuelwood. The practice is rapidly increasing: it is adopted by 97% of smallholders in the *Kolla* and 45.5% in the *Woynadega*. GebreMichael (2019) reports that some smallholders have converted their cropland to multipurpose tree plots as an adaptation to recurrent drought; because trees demand less labour, thus allowing household labour to be engaged in daily wage labour in towns, crafts, and petty trades in villages, and because timber is in high demand.

The Konso cabbage tree, *Moringa stenopetala* (*shelaqta*), and *Terminalia brownii* (*oypata*) are the most common trees on farms in both *Woynadega* and *Kolla* (Figure 5.1(a)). *Moringa* is densely planted around compounds and makes villages shine bright green from the high points of the landscape (Figure 5.2(a)). The fresh leaves are cooked and eaten as a staple of most meals, and are traded in local markets; they also serve as medicine and water purifier. The tree is drought-tolerant and, once mature, will provide vegetable throughout the year but is periodically affected by pests (*setayta*) during the wet season. *Terminalia brownii* is the other most frequently planted or naturally regenerated tree on farmland; it serves as browse, construction timber and fuelwood. *Senegalia asak*, *Balanites aegyptiaca*, *Berchemia discolour*, *Cajanus cajan, Cordia africana, Ehretia cymosa, Ficus cycomorus*, and *Rhus natalensis* are other commonly used species. Fruit trees (mango, avocado, lemon, papaya, and banana) are grown particularly on farms that are irrigated. Coffee, qat, and tobacco are grown on a few farms in *Woynadega*.

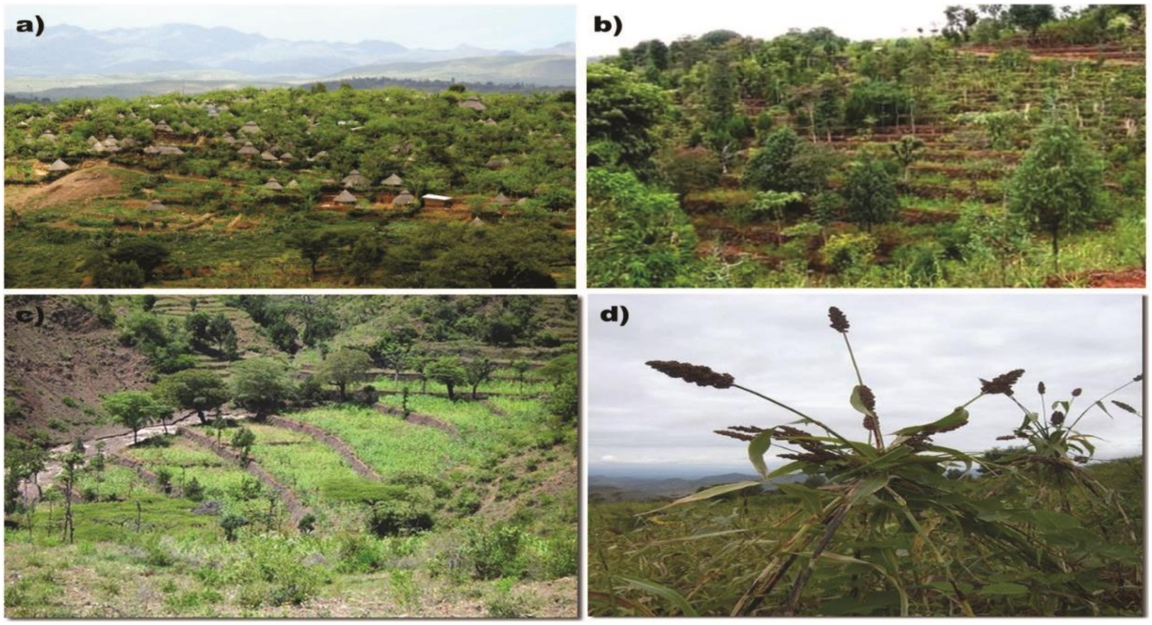

Figure 5.2. (a) Moringa stenopetala within the village (b) Agroforestry (c) Farmland along the riverbank (d) Sorghum intercropped with other crops.

Regarding intercropping, our results again show a statistically significant difference in adoption between the two agroecologies ($\chi^2 = 27.13$, $p < 0.01$). Nearly 40% of smallholders in the *Woynadega* adopted intercropping compared to only 24% in the *Kolla*. Some crops, such as sorghum, are drought-tolerant; others, such as haricot beans, mature early; and intercropping lessens disease-pest risks and allows crops to draw nutrients and water from different soil layers. Cassava is a fallback; if other crops fail, the tubers that grew the previous year when there was plenty of rain can be harvested, and when cassava is not required for consumption, it can be sold as a cash crop.

Many more smallholders in the *Kolla* have adopted improved crop varieties than in the *Woynadega* (74 and 15%, respectively). These new varieties are appreciated for their early maturity but commonly exhibit less resistance to pests and bird predation. Key informants and FGD participants stated that when compared to the crops of 30 years ago, the currently introduced crop varieties (*e.g.*, sorghum) are highly favoured by birds, which demands more labour to scare birds.

The terraced fields are fertilised with manure but there is a statistically significant difference in manuring practice between the two agroecologies ($\chi^2 = 12.1$, $p < 0.01$). Animals are kept on pastures or on uncultivated land around the villages but, to protect the crops, animals are tethered or stall-fed with sorghum and maize stover and browse cut from trees on the farm. Failed and thinned crops are also used for feeding livestock and/or for fodder sales. Plots near the homestead generally receive more manure than distant plots, and very distant plots do not at all, and manure has not been applied to riverbank farmlands (*yeela*) because such fields are expected to benefit from organic materials and soil transported from other areas and deposited via irrigation canals.

5.3.2. Crop productivity

In addition to enhancing adaptation to climate variability, CSA practices improve productivity. Smallholders in both AEZs stated that terracing reduces soil erosion and maintains soil moisture, which increases crop yield (Beshah, 2003; Tadesse, 2010; Watson, 2009) and, where and whenever possible, terraces are irrigated. Traditionally, Konso smallholders have integrated indigenous trees and shrubs for their various uses (Tadesse, 2010), including food and improved crop productivity.

Smallholders are intensive cultivators, depending on cereals (sorghum and maize) intercropped with many other crops, especially pulses (chickpea, cowpea, pigeon pea, haricot bean, common bean, hyacinth bean, horse bean, mung beans and lentils), oilseeds (sunflower, linseed, and castor), and tubers (cassava, taro, yam, sweet potato, and potato). The crop diversity is higher in the *Woynadega* (14–20 species), particularly near the homestead than in the *Kolla* (10–13 species); GebreMichael (2015) observed a minimum of seven different crops sown simultaneously and sequentially in the double-cropping system over the two rainy seasons in Konso. Watson (2009) described the fields as a ‘riot of different crops, with each farmer trying to obtain his or her staple food, combined with a few useful, or tasteful, additions’ – all of which reduce losses to pests and diseases. In addition to the early crops, smallholders grow improved crop varieties that mature quickly under rain-fed conditions and thus evade drought. The trick is to balance the mix to achieve food security in a bad year while also obtaining the highest possible cash crop yield in a good year.

5.3.3. Determinants of the adoption of CSA practices

We find a positive association between access to credit and adoption of terracing, agroforestry, manure, crop varieties, and irrigation (Table 5.3). For instance, having access to credit services has significantly influenced terracing, agroforestry, and irrigation by 8, 11, and 11%, respectively.

Table 5.3. Parameter estimates of modelled marginal effects for the adoption of CSA practices.

Variables	Terracing	Agroforestry	Manure	Crop varieties	Soil Bunds	Intercropping	Reduced tillage	Irrigation
Agroecology	0.409***	0.072	0.096	0.302***	−0.010	−0.155**	0.312***	−0.084
	(0.100)	(0.055)	(0.076)	(0.081)	(0.086)	(0.075)	(0.077)	(0.105)
Sex	−0.014	−0.272***	0.062	0.257	−0.001	−0.059	−0.219	0.239
	(0.108)	(0.094)	(0.114)	(0.155)	(0.130)	(0.119)	(0.148)	(0.147)
Age	−0.001	0.001	−0.004	−0.008**	0.006	0.004	0.005	0.003
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)
Education	0.050	0.020	−0.104	−0.158	0.039	0.335***	0.181	0.016
	(0.108)	(0.086)	(0.113)	(0.129)	(0.133)	(0.117)	(0.124)	(0.151)
HH size	0.005	0.026***	0.014	−0.005	0.006	−0.010	0.002	0.001
	(0.008)	(0.007)	(0.009)	(0.009)	(0.010)	(0.009)	(0.009)	(0.012)
Landholding	0.031	0.062***	0.069**	0.050	−0.002	−0.106***	0.055	0.072**
	(0.026)	(0.022)	(0.027)	(0.030)	(0.032)	(0.026)	(0.029)	(0.036)
Off-farm	−0.056	0.018	0.135	−0.108	−0.077	0.115	0.095	0.097
	(0.099)	(0.084)	(0.110)	(0.130)	(0.122)	(0.126)	(0.126)	(0.157)
Climate info	0.048	−0.009	0.014	−0.034	−0.045	−0.008	0.051	−0.109
	(0.079)	(0.063)	(0.087)	(0.095)	(0.099)	(0.087)	(0.090)	(0.123)
Agri. Agents	0.054	−0.078	0.094	−0.109	0.040	0.052	0.077	−0.028
	(0.096)	(0.071)	(0.096)	(0.103)	(0.106)	(0.090)	(0.099)	(0.131)
Credit	0.076	0.107	0.013	0.047	−0.044	−0.027	−0.038	0.111
	(0.050)	(0.062)	(0.058)	(0.053)	(0.058)	(0.059)	(0.051)	(0.063)
Market dist.	−0.036***	−0.009**	0.002	−0.014***	0.021***	−0.002	0.017***	0.007
	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)	(0.004)
Relatives	0.001	−0.001	−0.001	0.003**	−0.03	−0.001	−0.002**	−0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Livestock	−0.037	0.009	0.065	0.153**	−0.103	−0.113	−0.076	−0.091
	(0.054)	(0.055)	(0.068)	(0.063)	(0.067)	(0.067)	(0.061)	(0.071)
Relief	0.324***	0.038	0.136***	0.325***	−0.303	−0.097**	−0.327***	−0.207***
	(0.035)	(0.037)	(0.043)	(0.036)	(0.039)	(0.044)	(0.037)	(0.050)

*** and **significant at $p < 0.01$, and $p < 0.05$, respectively; standard errors in parentheses

We did not expect the inverse relationship between access to relief and some CSA practices, which suggests the onset of relief dependency, but key informants confirmed that some beneficiaries of food aid did not improve their livelihoods and often expected relief either from the government or NGOs. Access to relief increases the probability of adopting terracing, manure, and crop varieties by 32, 14, and 33%, respectively (p <

0.01), which may be related to the complementarity between the CSA practices: cash relief, for example, may assist smallholders in purchasing new crop varieties, seeds, or livestock, or in hiring labour to construct terraces. Bryan et al. (2009) in Kenya also found that smallholders who had more food aid had more confidence in combating climate change.

With regard to agroecological settings, the MNL model revealed that farming in the *Woynadega* increased the likelihood of using terracing, crop varieties, and implementation of reduced tillage by 41, 30 and 31%, respectively ($p < 0.01$). The likelihood of adopting terracing in *Woynadega* may increase because of the rugged topography and the abundance of stones. On the other hand, the analysis of marginal effects reveals that farming in the *Woynadega* decreases the probability of using soil bunds and irrigation by 1 and 8%, respectively, possibly because of the scarcity of perennial streams.

Being a female-headed household decreases the likelihood of using agroforestry, intercropping, and reduced tillage by 27, 6 and 22%, respectively. Women have many calls on their time and less access to information and other socio-economic opportunities than men. In relation to age, a unit increase in the age of the household head somewhat decreases the probability of adopting new crop varieties but somewhat increases the probability of adopting soil bunds and reduces tillage.

Educational status has both a positive and negative relationship with the adoption of CSA practices. Educated household heads can acquire and process information easily, which may have various consequences. Household size is positively associated with terracing, agroforestry, manure, soil bunds, reduced tillage and irrigation, probably because the main source of labour for farming activities is household members; the same applies to the availability of economically active household members. And a large landholding allows smallholders to diversify their crops.

The distance of farmlands from the market influences the adoption of CSA practices, significantly as market distances increased. Closeness to the market is an advantage for exchanging ideas and information. When smallholders are far from the market centre, the transaction costs for acquiring input and output will be high, which will, in turn, reduce the relative advantage of adopting new technologies.

5.3.4. Constraints of adoption of CSA practices

The main constraints to the adoption of CSA practices were poor irrigation potential, lack of finance, shortage of labour, lack of information and of extension and training services, and limited land resources (Figure 4.3). These barriers act interdependently to restrict the ability of households to adapt to climate variability and change.

Most (81%) smallholders are constrained by lack of money; key informants and FGD participants reported a lack of access to credit services in their area. Even though there are micro-finance institutions, only members can obtain a loan and they complain that the amount given is not enough to purchase necessary modern inputs. Smallholders also identified high-interest rates and the complicated process for obtaining a micro-loan. Moreover, paying back loans can be difficult because of frequent crop failures and livestock deaths, which result in the selling of other assets. Torrential rain may cause flooding which destroys irrigation and other soil and water conservation structures, but there is no insurance to cover these risks. These issues were also reported by Marie *et al*. [8] and Sertse *et al*. [9], who concluded that lack of credit services and money were major constraints to smallholders' willingness and ability to adopt climate change adaptation strategies.

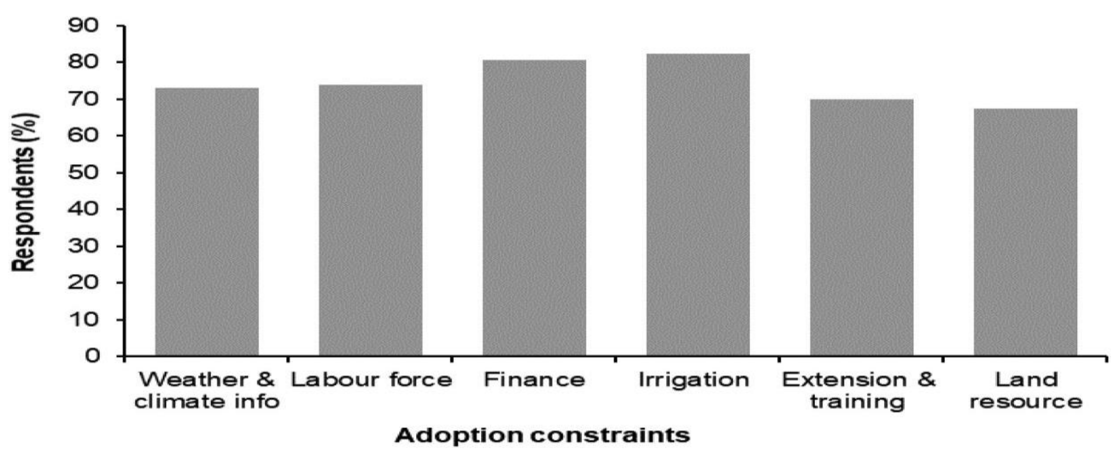

Figure 5.3. Constraints of adoption of CSA practices (percentages are based on multiple responses).

Lack of labour was mentioned by nearly 74% of smallholders as a major impediment. The key informants and FGD participants also reported the difficulty of obtaining a labour force for the construction and maintenance of soil and water conservation structures such as stone terraces and soil bunds, and that smallholders who live near towns prefer to work there rather than constructing stone terraces and soil bunds. This threatens the environmental protection of the study area and soil and water conservation practices in particular.

Poor irrigation potential was identified by 82% of respondents as a constraint on adaptation to climate variability. There are few streams in their locality, so irrigation depends on opportunistic rainwater harvesting and flood diversion. Weather forecasts and early warning are critical in developing coping strategies but 73% of smallholders in the study area have no access to reliable information, which is in line with previous studies (Ali et al., 2021; Marie et al., 2020; Sertse et al., 2021).

It goes without saying that, for smallholders, shortage of land is a fact of life, and FGD and key informants reported that increasing population means fragmentation of small holdings.

5.4. Conclusion

Smallholders respond to climate variability with multiple indigenous CSA practices. The maintenance of terracing in combination with integrated crop-tree-livestock systems, developed over hundreds of years, minimises exposure to climate change. The system is increasingly stressed by population growth, unreliable rainfall, and rising temperatures. Multiple, interwoven constraints include poor irrigation potential, lack of finance, labour shortage, intermittent extension and training services, and land shortage. It is recommended that female-headed households should be a focus of remedial help in all respects that are at present causing reduced participation in CSA.

6. IMPACTS OF CLIMATE VARIABILITY AND CLIMATE-SMART AGRICULTURAL PRACTICES ON CROP PRODUCTION IN UNESCO DESIGNATED CULTURAL LANDSCAPES OF KONSO, ETHIOPIA[3]

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Abstract

Climate variability negatively affected Sub-Saharan Africa's agricultural production. Due to drastic change in climate conditions and its adverse impacts on crop production, climate-smart agriculture (CSA) is considered as a technological and policy solution to mitigate the impact of climate variability on crop production. Climate-smart agriculture (CSA) is the sustainable form of agriculture that aims to increase productivity, improve adaptation, and reduce greenhouse gas emissions into the atmosphere. This study assesses the impacts of climate variability and CSA practices on crop production in Konso cultural landscapes, Ethiopia. The study employed multiple linear regression models to examine the effects of climate variability on crop production and an endogenous switching regression model to assess the impact of CSA practices on crop production. The findings show that climate variability explains 37.4–47.5% of the annual variation in crop production. During the study period (1983–2016), the seasonal production variability range was much wider (10–67%) for three crops: sorghum, maize, and *teff* (*Eragrostis tef*). The results also reveal that application of CSA practices such as crop diversification, terracing, manure, irrigation, and rainwater harvesting have positive impacts on crop production. Households that use CSA practices show a significant ($p<0.01$) increase in crop production compared to non-users. The high variability in rainfall and warming temperatures results in a decreasing trend in crop yield. On the other hand, the application of CSA practices results in a significant increase in crop productivity in the face of climate variability. In terms of broader policy implications, the culturally intertwined CSA practices in Konso could be used as a learning platform to plan and scale out by integrating them with innovative conservation technologies to achieve widespread adoption in other parts of Ethiopia and elsewhere.

Keywords: Climate variability, endogenous switching regression, terracing, manure, Konso

6.1. Introduction

Climate change and variability are two different things. The main distinction between climate change and climate variability is the trend and fluctuations in the climate's state on a spatiotemporal scale. Short-term variations in climate variables that are unusual and more severe than normal or average weather such as heat waves, cold waves, downpours, and droughts are referred to as climate variability (van der Wiel & Bintanja, 2021). However, climate change is defined as a long-term change (over 30 years) in the statistics of climate variables. However, climate change is defined as a long-term change (over 30 years) in the statistics of climate variables. The degree to which agriculture is vulnerable to the effects of climate variability varies by region. Natural rain-based agriculture contributes approximately 95% of food production in Sub-Saharan Africa (SSA), making it extremely vulnerable to the negative impacts of climate variability and change (FAO, 2016). The projected changes in rainfall over SSA in the late 21st century are uncertain, but recurrences and severity of extreme climatic events are highly likely. Climate change is expected to reduce maize yields by over 12% in SSA in 2050 (Tesfaye et al., 2015). The negative impacts of climate variability are much more pronounced in arid and semiarid areas of SSA, where water resources and agricultural yields are very sensitive to climate variability (Yadeta, 2020). Schlenker and Lobell (2010), for example, in SSA, found a significant decrease in maize and sorghum by 22 percent and 8 percent, respectively. Similarly, Davenport et al. (2018) reported a reduction of maize yields by 7–11% in SSA and thus urged the implementation of adaptation strategies to increase maize yields.

Various studies conducted in Ethiopia indicate that rising temperatures, erratic rainfall patterns, shortened rainy seasons, and lower amounts of seasonal rains reduce crop production (Kassaye et al., 2021; Tesfaye et al., 2018). Yang et al. (2020) indicated that Ethiopian crop production has declined significantly over the last four decades. Similarly, Tesfaye et al. (2018) found that seasonal variability in rainfall reduced maize yield. However, Araro et al. (2020) reported a statistically significant increase in sorghum, maize, and teff yields because of the increase in rainfall in southern Ethiopia. Similarly, Alemayehu and Bewket (2016) reported a statistically insignificant increase in maize and sorghum yield due to an increase in rainfall in their study sites in Ethiopia's central highlands. In the same connections, Kassaye et al. (2021) predict that significant rainfall reductions will lead to an 18.1% reduction in sorghum production in Ethiopia by the end of the 21st century. Furthermore, Muluneh et al. (2016) noted that maize productivity will be decreased by 46% as a result of rainfall variability in the semiarid areas of Ethiopia by the 2080s. In terms of the effects of temperature on crop yields, previous studies in Ethiopia revealed an inverse relationship between crop yields and temperature trends (Alemayehu & Bewket, 2016; Kassaye et al., 2021; Tesfaye et al., 2018).

Because of drastic change in climate conditions and its consequences on crop production multilateral organizations such as the World Bank and The FAO and the World Bank have recommended climate-smart agriculture (CSA) as one of the best technological and policy solutions for reducing the impacts of climate variability on crop production and ensuring food security for the growing world population (Taylor, 2018). The CSA comprises conservation farming, crop rotation, agroforestry, improved grazing, integrated crop-livestock management, intercropping, mulching, organic fertilization, improved water management, and growing drought- and disease-resistant crops (FAO, 2013, 2016). According to the FAO (2013), CSA practices increase agricultural productivity in a sustainable manner under a changing climate. However, previous climate change studies in Ethiopia have focused only on evaluating the effects of variation in the climate on agricultural production without taking into account the role of CSA in mitigating such impacts on crop productivity (Alemayehu & Bewket, 2016; Tesfaye et al., 2018; Yang et al., 2020). Although the promotion of CSA in Ethiopia is ongoing as part of sustainable agricultural development policy, empirical evidence is very few. Some of the few studies on the use of CSA practices found that they have a positive impact on crop production (Adego et al., 2019; Asrat & Simane, 2018; Bedeke et al., 2018; Teklewold et al., 2019). For example, Adego et al. (2019) reported a 2.79 quintal annual increase in maize yield due to CSA practices. Di Falco et al. (2012) also reported crop variety use and soil conservation resulted in higher crop yields in Ethiopian farm households in the Nile Basin. In northwestern Ethiopia, households that used CSA practices produced 24.1 percent higher than those that did not (Asrat and Simane 2017). The available few studies (Alemayehu & Bewket, 2016; Getachew, 2018; Tesfaye et al.,

2018) were confined to the Ethiopian highlands, whereas the most vulnerable semiarid lowlands, and the East African Great Rift Valley region, which includes Konso, have thus received little attention. Therefore, this paper aims to examine the effects of climate variability and CSA practices on crop production in Konso cultural landscapes in southwest Ethiopia.

6.2. Materials and Methods

6.2.1. Data sources

The Central Statistical Agency and the Konso Zone Agricultural Office provided crop production data (1983–2016), while the National Meteorological Agency provided gridded monthly climate (rainfall and temperature) data for assessing the impacts of climate variability on cereal crops (sorghum, maize, and *teff*) production. The period of 1983–2016 was chosen mainly because of the availability of most of the required data. In the case of crop data, missing cases were handled by averaging the preceding and succeeding years, especially for years in the 1980s. For triangulation, the production data obtained through a household questionnaire survey were used to validate the secondary data obtained from the Central Statistical Authority and zonal agricultural office. To check the reliability of these two data sources, we ran a Pearson correlation coefficient, which showed a strong positive correlation ($r = 0.78$), between archive and household survey data. We used cross-sectional survey data obtained from smallholder farmers' households to examine the impact of climate-smart agricultural practices on crop production. Interviews were conducted with Kebele development agents, district, and zone heads of agriculture, and rural development agents to corroborate household survey data.

6.2.2. Data Analysis

6.2.2.1 Bivariate correlation and multiple linear regressions

Bivariate correlation and multiple linear regression were used to analyze how climate variables relate to crop production. We used multiple linear regression because it fits all types of variables (Alemayehu & Bewket, 2016; Getachew, 2018). We also preferred to use this model because it indicates a more accurate and precise relationship between each climate factor and the outcome, such as crop production. The model for the outcome variable (crop production) was specified as:

$$Y = \mathrm{A} + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon \quad (1)$$

where Y= dependent variable (i.e. crop production); A = Y-intercept; β_1, β_2, β_3 are the coefficient values; X_1(rainfall), X_2(minimum temperature), and X_3(maximum temperature) are the independent variables; and ε=the error term. We expect that rainfall will have a positive impact on crop production, while both minimum and maximum temperatures will have a negative impact.

To assess spatial relationships between the climatic variables such as rainfall, minimum temperature, and maximum temperature and crop production, both the climate and crop production data were converted into a raster data format to create surface data using a geostatistical technique known as simple kriging in ArcGIS 10.5 software. From the survey data, a point feature was created, and yield data were interpolated from the points. We used the covariance and correlation in band collection statistics tools of ArcGIS 10.5 software to investigate the spatial association between climate variables (rainfall and temperature) and crop yield.

6.2.2.2 The specification of endogenous switching regression (ESR)

Ordinary least squares and propensity score matching are the mostly used econometric models for estimating the impact of climate variability and change adaptation on crop productivity (Amare & Simane, 2018; Asrat & Simane, 2017). These models are based on simple mean comparisons between adapters and non-adapters. If adaptation was randomly assigned, its impact on yield could be easily estimated by comparing users and non-users. Comparing farmers who use the strategy with those who do not may be biased if they behave differently. Skilled farmers will most likely adapt and increase productivity, but the impact of adaptation may be misinterpreted as a result of this unobservable omission (Adego et al., 2019). In cases where unobservable factors simultaneously affect farmers' productivity and their decisions about adaptation, endogenous switching is superior to ordinary least squares. Propensity score matching requires unconfoundedness (conditional independence), in which all variables influencing treatment and outcome must be observed, assuming no selection bias due to unobserved characteristics. Therefore, to evaluate the impact of CSA practices on crop productivity, an endogenous switch regression model was used. In this approach, binary variables are first used to model adoption decisions and then equations are developed for output variables (e.g., productivity) for both groups (users and non-users) of CSA practices. In the selection model, A* represents the latent variable that shows the expected benefits of adopting CSA practices versus not adopting them. The A* is specified as:

$$A_i^* = Z_{i\alpha} + \eta_i \quad \text{with} \quad A_i = \begin{cases} 1 & \text{if } A_i > 0 \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

where Ai = binary variable; 1=farm households that use CSA practices (terracing, soil bunds and micro-basins, crop diversification, intercropping, manure, agroforestry, water conservation, and reduced tillage); and 0 otherwise, while α is a parameter to be estimated and η= error term. The vector Z represents the characteristics of the farmer's household and farm that influence his decision to use CSA practices. The farmer's choice of CSA practice is expected to have an impact on crop productivity. Based on this assumption, separate outcome equations are specified for users and non-users.

$$\begin{aligned} Y_{Ai} &= X_{Ai}\beta_A + \varepsilon_{Ai} \text{ if } A_i = 1 \\ Y_{Ni} &= X_{Ni}\beta_N + \varepsilon_{Ni} \text{ if } A = 0 \end{aligned} \tag{3}$$

where Y_{Ai} and Y_{Ni} represent crop yield for users and non-users, measured as quintals/hectare, respectively. X indicates the set of independent variables (production inputs, household, farm characteristics). The vectors β_A and β_N are the estimated parameters. ε_{Ai} is an error term for users, while ε_{Ni} is an error term for non-users. The ESR can be used to predict the crop yield of the adopting farming household and the non-adopting farming household as defined using equations:

$$\begin{aligned} \text{Users } E[y_{1i} | A_i = 1] &= X_{1i}\beta_1 + \sigma_{1\eta}\lambda_{1i} \\ \text{Non-users } E[y_{2i} | A_i = 0] &= X_{2i}\beta_2 + \sigma_{2\eta}\lambda_{2i} \end{aligned} \tag{4}$$

Similarly, the equation for the counterfactual yield of users and nonusers is:

$$\begin{aligned} \text{Users counterfactual } E[y_{2i} | A_i = 1] &= X_{1i}\beta_2 + \sigma_{1\eta}\lambda_{2i} \\ \text{Non-users counterfactual } E[y_{1i} | A_i = 0] &= X_{2i}\beta_1 + \sigma_{1\eta}\lambda_{1i} \end{aligned} \tag{5}$$

Then, the average treated impact of yield for users is computed as:

$$\begin{aligned} ATT &= E[y_{1i}|A_i = 1] - E[y_{2i}|A_i = 1] \\ &= X_{1i}(\beta_1 - \beta_2) + (\sigma_{1\eta}\text{-}\sigma_{\eta 2})\lambda_{1i} \end{aligned} \tag{6}$$

The predicted effect of adoption on yield for nonusers (untreated) is:

$$\begin{aligned} ATU &= E[y_{1i}|A_i = 0] - E[y_{2i}|A_i = 0] \\ &= X_{2i}(\beta_1 - \beta_2) + (\sigma_{1\eta}\text{-}\sigma_{\eta 2})\lambda_{2i} \end{aligned} \tag{7}$$

where ATT = average treatment for the treated (users).

ATU = average treatment for the untreated (non-users).

The variables that were assumed to affect crop yield indirectly by determining the CSA are presented in Table 6.1.

Table 6.1. Description of variables and hypotheses for the outcome variable.

Explanatory variables*	Definition and measurement	Expected sign.	Sources
Household head sex	1 if male and 0 otherwise	±	(Adego et al., 2019; Belay et al., 2017; Gashure & Wana, 2022; Sertse et al., 2021)
Age of household head in years	Continuous	±	(Adego et al., 2019; Belay et al., 2017; Sertse et al. 2021)
Education of household head in years	Continuous	+	(Adego et al., 2019; Ali et al., 2021; Belay et al., 2017; Sani et al., 2017; Sertse et al., 2021)
Household size	Continuous	+	(Gashure & Wana, 2022; Marie et al., 2020)
Farm size in hectares	Continuous	+	(Belay et al., 2017; Gashure & Wana, 2022; Marie et al., 2020; Sani et al., 2017; Sertse et al., 2021)
Access to climate info	1 if there is and 0 otherwise	+	(Adego et al., 2019; Belay et al., 2017; Gashure & Wana, 2022; Marie et al., 2020; Sertse et al., 2021)
Access to agricultural agents	1 if there is and 0 otherwise	+	(Gashure & Wana, 2022; Marie et al., 2020; Sani et al., 2017; Sertse et al., 2021)
Off-farm activities	1 if there are and 0 otherwise	±	(Gashure & Wana, 2022)
Access to credit	1 if there is and 0 otherwise	+	(Adego et al., 2019; Belay et al., 2017; Marie et al., 2020; Sertse et al., 2021)
Distance to market in kilometer	Continuous	–	(Adego et al., 2019; Ali et al., 2021; Gashure & Wana, 2022; Sani et al., 2017)
Agroecology	1 if *Kolla* and 0 otherwise	±	(Gashure & Wana, 2022)

6.3. Results and Discussion

6.3.1. Climate variability impacts on crop production

The findings show that the mean annual rainfall in Konso was 801.96 mm with a coefficient of variation (CV) of 17% in the study period. The Mann-Kendall trend test revealed that both the annual and *Kiremt* season rainfall showed an increasing trend (Gashure & Wana, 2021). The annual rainfall increased at a rate of 3.16 mm per year. The mean rainfall for the *Belg* season (February–May) was 399.52 mm with a CV of 26.92%. The trend analysis result showed a decline in the *Belg* season rainfall by 1.12 mm per year. The average rainfall for the *Kiremt* season (June–September) was 166.61 mm with a CV of 48.47 percent, indicating a 0.42 mm increase per year. The annual minimum, maximum, and mean temperatures were 15.41, 31.43, and 22.7 degrees Celsius, respectively (Gashure & Wana, 2021). The trend analysis of the temperature data indicated a warming trend. The annual rates of change for the minimum, maximum, and mean temperatures were 0.01, 0.005, and 0.0008 °C, respectively. For the *Belg* season, the rates of increase in minimum and maximum temperatures were 0.003 °C and 0.002 °C, respectively. The rate of increase for the minimum temperature in the *Kiremt* season was 0.03 °C, while the rate of increase for the maximum temperature was 0.006 °C (Gashure & Wana, 2021).

Sorghum (*Sorghum bicolor*), maize (*Zea mayas*), and *teff* (*Eragrostis tef*) are the three major cereal crops produced in Konso. Sorghum production and annual and *Kiremt* rainfall (Table 6.2) are positively correlated ($p<0.05$). The annual sorghum yield varied from 4–20 quintals/ha/year with a coefficient of variation (CV) of 40% (Table 6.4). In the *Belg* season, sorghum yield varied from 3–15 quintals/ha/year with a CV of 42%. Sorghum yield in the *Kiremt* season varied from 1–5 quintals/ha/year with a CV of 50%. Because of the high rainfall variability and frequent droughts, 50% of annual and *Belg* sorghum production was lower than the study period average (7 quintals). The results also show that 67% of *Kiremt* sorghum production was below average due to declining rainfall. Alemayehu and Bewket (2016) reported even higher level of variability (CV=118%) in sorghum production due to variability of the of the annual rainfall in the central highlands of Ethiopia.

Concerning the relationship between maize production and rainfall, the results show that there was a significant positive relationship between *Kiremt* rainfall and maize production (Table 6.2). This implies that a rise in rainfall has a beneficial impact on maize production. Alemayehu and Bewket (2016) and Yang et al. (2020) noted a strong positive relationship between maize production and precipitation in Ethiopia. The relationship between rainfall and major cereal production also remains positive in the Eastern African region (Tesfaye et al., 2018). Maize's annual yield varied from 31–40 quintals/ha/year with a CV of 8.3%. The *Belg* season maize yield varied from 23.3–30 quintals/ha/year with a CV of 8.4%. In the *Kiremt* season, maize yield varied from 7.5–10 quintals/ha/year with a CV of 8.3% (Table 6.4). Fifty-eight percent of the annual maize production observations were below the average (28 quintals) because of the decreased rainfall.

The annual *teff* yield varied from 16–24 quintals/ha/year with a CV of 9%. Unlike maize and sorghum, *teff* production showed a negative correlation with rainfall variables (Table 6.2). This negative relationship requires further investigation. This may be caused by unreliable and erratic rainfall events and intermediate dry spells. For example, according to personal communication with the zonal agriculture head, *teff* production was lost or reduced due to torrential rains during the harvesting season. Heavy rain, hailstorms, and flooding can cause physical damage to the yield. Higher temperature and pressure gradients may cause an unexpected increase in rainfall and negatively affect crop yield (Altieri & Koohafkan, 2008).

The direction of the correlation between the three crop production and temperature variables was negative (Table 6.2). The negative relationship between crop production and temperature implies that a temperature rises above the threshold results in a decrease in crop production, indicating that a temperature rise harms crop production. A negative correlation between crop yield and minimum temperature was also observed in Ethiopia by Kassaye et al. (2021). The loss of soil organic content because of increasing soil temperature is a potentially significant climate change impact on farm production (Altieri & Koohafkan, 2008). Similarly, a previous study showed that higher air temperatures could hasten the decomposition of organic matter in the soil as well as chemical soil processes that enhance soil fertility (Altieri & Koohafkan, 2008).

Table 6.2. Correlation between cereal production and seasonal and annual rainfall and temperature (1983–2016).

	Season	Sorghum	Maize	*Teff*
Rainfall	*Belg*	0.258	0.383	-0.081
	Kiremt	0.588**	0.587**	-0.142
	Annual	0.576**	0.543	-0.019
MinT	*Belg*	-0.171	-0.247	-0.340
	Kiremt	-0.387	-0.308	-0.191
	Annual	-0.315	-0.195	-0.171
MaxT	*Belg*	-0.039	-0.081	-0.382
	Kiremt	-0.173	-0.593**	-0.056
	Annual	-0.098	-0.304	-0.445

** Significant at the 0.05 level

The annual and seasonal climate variables (rainfall and temperature) explained a variation in crop production, ranging from 10.4 to 67% (Table 6.3). Annually, 44%, 37.4%, and 47.5% of the variability in sorghum, maize, and *teff* production were explained by climate variability (rainfall and temperature), respectively. Getachew (2017) reported 5.2% and 82.6% variation in sorghum and pea production by rainfall and temperature in the south Gondar zone in Ethiopia, respectively. Alemayehu and Bewket (2016) also reported an 84.1% variation in sorghum production and a 93.1% variation in maize production due to variations in rainfall in Ethiopia's central highland. Rainfall and temperature explained 10.4%, 26.2%, and 50.1% of the variation in sorghum, maize, and teff production, respectively, during the *Belg* season (Table 6.3). *Kiremt* rainfall had a statistically significant impact on Kiremt sorghum production ($p<0.05$). Temperature increases may affect soil moisture, potential evapotranspiration, and crop heat stress. High temperatures mostly damage crops during the reproductive and even grain filling stages (Hatfield et al., 2011). Crop yields can drop by 5–10% when the average temperature rises by 1 °C (Lobell & Field, 2007). Temperatures above 30 °C can permanently harm plants and, when temperatures exceed 37 °C, can even harm seeds during storage (Wahid et al., 2007).

Table 6.3. Rainfall and temperature explained production variability (1983-2016).

			Coefficients		
Crop	Season	R^2	Rainfall	MinT	MaxT
Sorghum	*Belg*	0.104	0.279	0.189	0.10
	Kiremt	0.551	1.013**	0.505**	0.416
	Annual	0.44	0.598	0.314	0.032**
Maize	*Belg*	0.262	0.513	0.184	0.244
	Kiremt	0.67	0.353	0.543**	-0.499
	Annual	0.374	0.435	0.319	-0.25
Teff	*Belg*	0.501	-0.232	0.656**	-0.775**
	Kiremt	0.119	-0.384	0.22	-0.403
	Annual	0.475	-0.336	0.558	-0.867**

** Significant at the 0.05 level; R^2 is the coefficient of determination

The findings show that variations in rainfall and minimum temperature have a significant effect on Kiremt sorghum production ($p<0.05$). Minimum and maximum temperatures had a significant influence on teff production during the spring (*Belg*) season ($p<0.05$). When separately examining each climate factor, rainfall alone explained annual production variability by 33.2%, 29%, and 4% for sorghum, maize, and *teff* production, respectively. In contrast, minimum and maximum temperatures explained 17 percent, 23.3 percent, and 37.5 percent of annual sorghum, maize, and teff production, respectively (supplementary Table 2).

Among the three crops, sorghum shows the highest magnitude of annual yield variation (CV=40%) (Table 6.4). However, regarding the trend, maize showed the highest decline, with an average decline of 0.53 quintals/ha/year (supplementary Figure 2 and Figure 5). Due to high evapotranspiration requirements and physiological sensitivity, maize is extremely sensitive to water deficits during its critical period (flowering to grain filling) (Omoyo et al., 2015). The decreasing trend shown for all crop yields suggests that recent warming and rainfall variability have already harmed crop yields (see supplementary Figures 1 to 6). Moreover, interviewed smallholder farmers said that during the years of severe droughts and pest infestations, the yield loss was very high. Rising minimum and maximum temperatures, increasing evapotranspiration, and extreme seasonal rainfall fluctuations all have a negative effect on the length of the growing season, seed germination, and grain filling. The onset, termination, distribution, and amount of rainfall have all been shown to influence crop yields (Omoyo et al., 2015).

Table 6.4. Summary statistics on annual and seasonal yield (1983–2016).

		Yield (Qt./ha)			
Crop	Season	Minimum	Maximum	Mean	CV%
Sorghum	Annual	4	20	10	40
	Belg	3	15	7	42
	Kiremt	1	5	2	50
Maize	Annual	31	40	37.3	8.3
	Belg	23.3	30	28	8.4
	Kiremt	7.5	10	9.3	8.3
Teff	Annual	16	24	19	9
	Belg	12	15	13.5	9
	Kiremt	4.8	6	5	11.5

Household survey data showed that sorghum and maize were produced in both *Kolla* and *Woynadega* AEZ, while *teff* was primarily produced in *Woynadega* AEZ (Figure 6.1). Using the multivariate tool in ArcGIS, comparison was made between rainfall and temperature data to interpolated crop data in order to determine spatial association. The results of the spatial analysis revealed a positive relationship between rainfall and crop production. However, the spatial analysis revealed a negative association between temperature and crop production. To evaluate the impact of topography on crop production, a topographic ruggedness index (TRI), which is a proxy for moisture availability, was used (Figure 6.2d). The observed correlation between TRI and crop production was positive but weak. For instance, the correlation coefficient between sorghum yield and TRI was 0.14. The correlation coefficient between maize yield and TRI was 0.07. Moreover, the correlation coefficient between *teff* yield and TRI was 0.15. The analysis results of the relationship between rainfall distribution, crop patterns, and the terrain ruggedness index show that areas of low rainfall and level terrain are related to low yields.

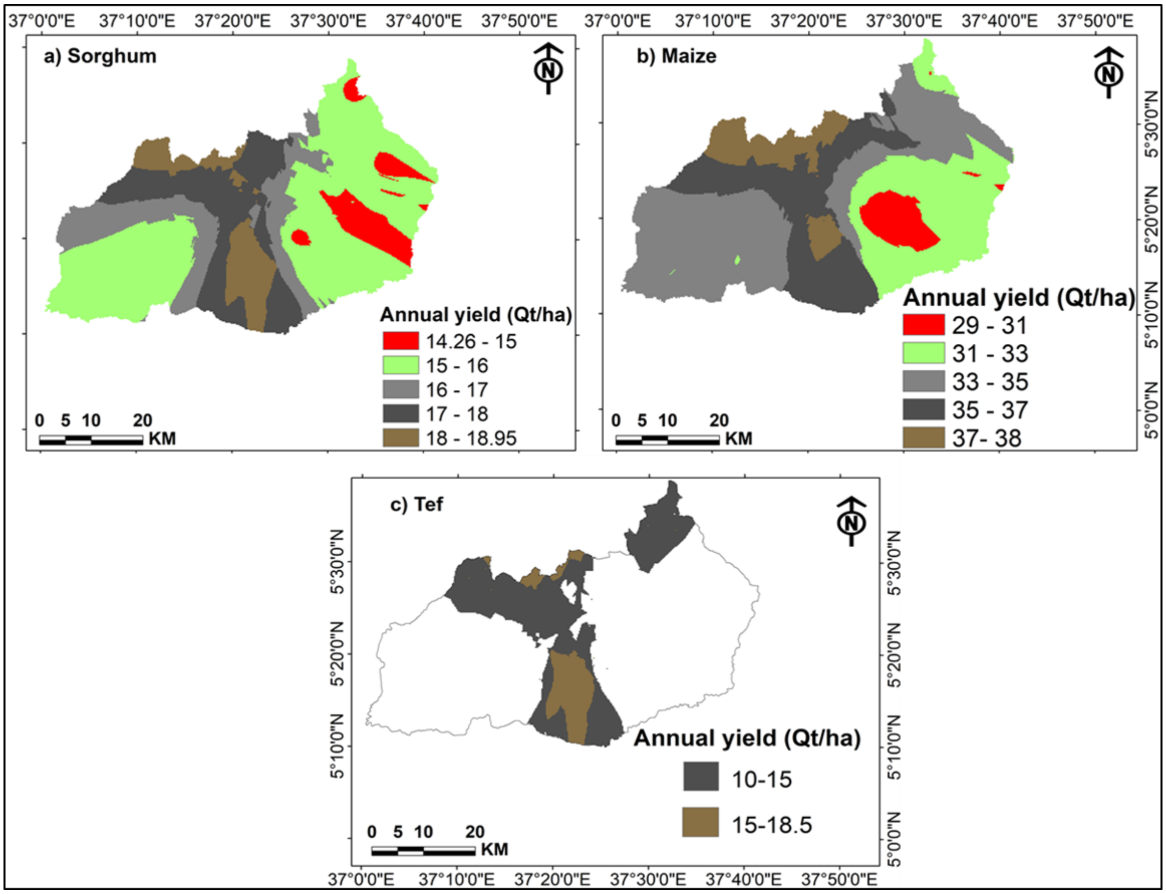

Figure 6.1. Annual yield patterns a) sorghum b) maize c) teff.

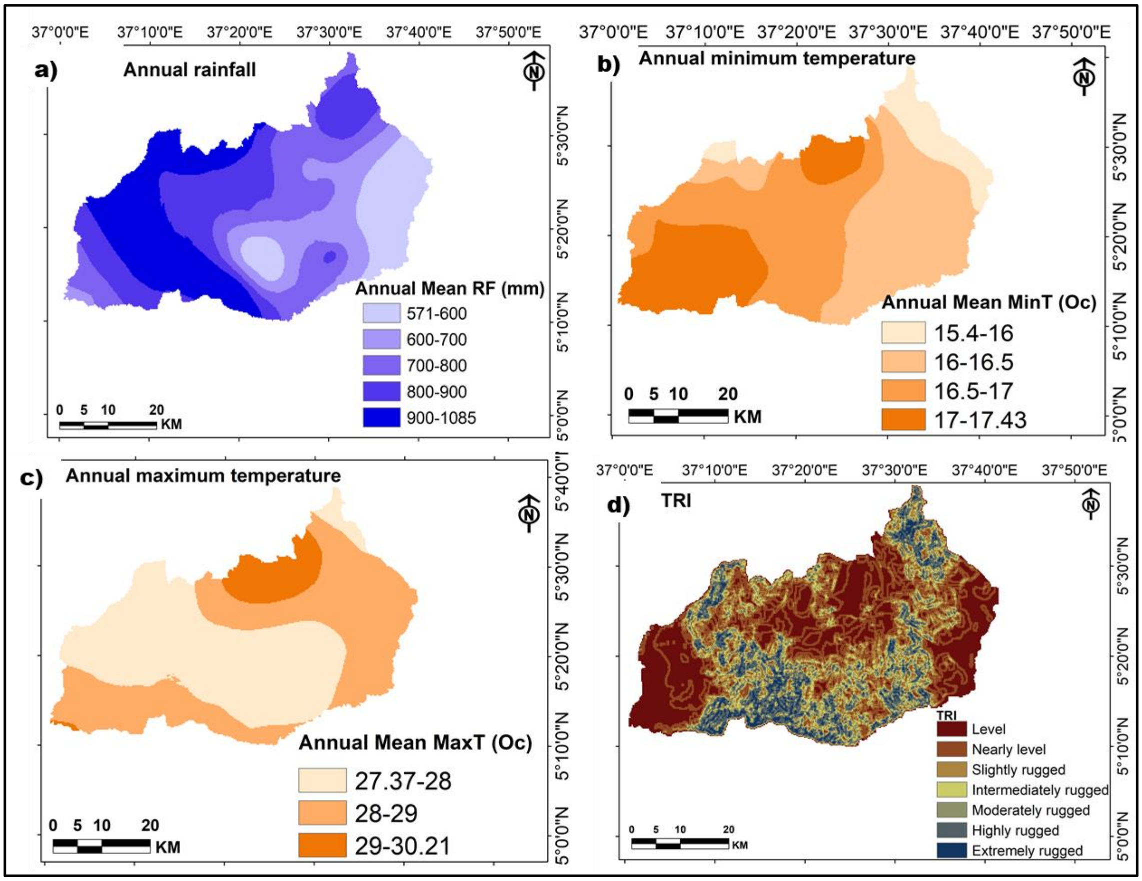

Figure 6.2. Annual rainfall and temperature patterns a) Annual rainfall b) Annual minimum temperature c) Annual maximum temperature d) TRI.

6.3.2 Impacts of climate-smart agricultural practices on the productivity of main crops: sorghum, maize, and teff

6.3.2.1. Household demographic and socio-economic characteristics

The study shows that there is a statistically significant difference in the mean age, educational status, household size, distance to market, involvement in off-farm activities, access to climate information, and credit services between users and non-users of CSA practices (Table 6.5). The mean age of CSA users is 44.24, while the mean age of non-users is 43.2 years. The mean household size for users is 6.6 while that of non-users is 4.5, which is statistically significant at $p<0.5$ (Table 6.5). In terms of access to climate information and credit services, there is a significant difference between users and non-users of CSA practices ($p< 0.01$). In addition, the findings reveal that there is a significant difference in participation in off-farm activities and the distance to the nearest main market between users and non-users of CSA practices (Table 6.5).

Table 6.5. Descriptive statistics of the explanatory variables that affect the adoption of climate-smart practices.

Explanatory variables	Users				Non-users				P-value
	Min	Max	Mean	Std. D	Min	Max	Mean	Std. D	
Sex of household head (1=male)	0	1	0.75	0.43	0	1	0.75	0.43	0.02**
Age of household head (years)	20	68	44.24	10.2	18	65	43.2	9.3	0.04**
Educational status (grades)	0	5	3.5	0.4	0	1	0.74	0.7	0.021**
Household size (number)	3	18	6.6	2.8	3	16	4.5	3.8	0.02**
Size of farmland (Ha)	0.25	6	0.5	0.9	0.27	3	0.5	0.8	0.413
Distance to the main market from home in kilometers	2	35	9.2	6.4	3	34	10	7	0.003***
Involving in off-farm activities (yes=1)	0	1	0.26	0.4	0	1	0.4	0.6	0.002***
Access to climate-related information(yes=1)	0	1	0.8	0.4	0	1	0.4	0.3	0.046***
Access to agricultural extension services (yes=1)	0	1	0.9	0.6	0	1	0.7	0.4	0.085
Access to credit services (yes=1)	0	1	0.6	0.5	0	1	0.5	0.4	0.001***
Agroecology (*Kolla*=1)	0	1	0.4	0.6	0	1	0.18	0.7	0.07

***and ** significant at $p<0.01$ and $p<0.05$, respectively.

6.3.2.2. Smallholders' adoption of the CSA practices

Smallholder farmers in Konso have been employing a variety of CSA practices to counter the negative impacts of climate variability (Table 6.6). In particular, stone terraces are distinctive features of Konso agriculture, which has been practiced over the 400 years and has passed through several generations. Even though terracing is a labor-intensive activity, farmers in Konso have incorporated it into their cultural symbols and survival strategy. In terms of adoption, 69.9% of smallholders adopted terracing while 31.1% did not adopt it. The results show that 83.9% of smallholders adopted agroforestry, whereas 16.1% did not adopt it. Regarding manure application, 74.9% of smallholders used it (Table 6.6). The study also indicates that more than half (61.4%) of smallholders have not adopted soil bunds. Moreover, 71.8% of smallholders did not adopt intercropping. Furthermore, the findings show that 51.5% of smallholders did not implement irrigation (Table 6.6).

Table 6.6. Adopters and non-adopters of the CSA practices in the study area.

Technology	Adopters		Non-adopters	
	N	%	N	%
Terracing	248	69.9	107	31.1
Agroforestry	298	83.9	57	16.1
Manure	266	74.9	89	25.1
Crop varieties	211	59.4	144	40.6
Soil bunds	137	38.6	218	61.4
Intercropping	100	28.2	255	71.8
Reduced tillage	137	38.6	218	61.4
Irrigation	172	48.5	183	51.5

In addition to categorizing smallholder households into adopters and non-adopters, the study analyzed the households' adoption of each CSA practice in the two agroecologies (*Kolla* and *Woynadega*). For example, the descriptive analysis highlighted that 82.8% of farmers adopted terracing in the *Kolla*, while only 30.7% adopted it in the *Woynadega* (Table 6.7). Smallholders in both agroecologies stated that terraces reduce erosion of soil, and increase rainwater infiltration and retention to maintain soil moisture.

FGD participants and key informants in both agroecologies also confirmed that terracing is the essential mechanism to maintain soil moisture and reduce the risk of crop failure from moisture stress. The other main CSA practice used by smallholders is agroforestry. Table 6.7 illustrates that more smallholder farmers (96.6%) in the *Kolla* adopted agroforestry than farmers in the *Woynadega* (45.5%). The key informants also indicated that the availability of many tree and shrub species provides local construction materials, livestock fodder, food, and fuelwood, and they also provide beneficial ecological services.

The findings also reveal that manure application is the most prominent CSA adaptation strategy used by smallholders in both *Kolla* and *Woynadega* agroecologies. Table 6.7 demonstrates that more farmers in the *Kolla* (85.8%) used manure for fertilizer than farmers in the *Woynadega* (42%). Respondents asserted that using manure increases soil fertility, which in turn increases crop yield. Similarly, previous studies have indicated that manure application increases soil fertility, which increases crop yield (FAO 2016). In addition to manure, smallholders apply improved crop varieties to boost yields. The results demonstrate that 74.2% of smallholders in *Kolla* used crop varieties, while only 14.8% used it in *Woynadega*.

The other most striking features of CSA adaptation strategies of smallholders in Konso are intercropping of various cereals, grains, and tuber crops. Approximately 40% of smallholders in *Woynadega* used intercropping, compared to 24.3% of them in *Kolla*. Smallholders state that intercropping minimizes yield loss, and reduces crop damage risk due to pests, diseases, and droughts. Intercropping allows crops to draw nutrients and moisture from different layers. In addition to the aforementioned adaptation strategies, the results reveal that half (50.2%) of the farmers in the *Kolla* used small-scale irrigation, whereas 43.2% of the farmers in the *Woynadega used* it (Table 6.7). Smallholders underscored that irrigation improves yield, allows year-round cropping, and reduces water scarcity and drought impacts.

Table 6.7. Households' adoption of CSA practices between agroecologies.

Technology	*Woynadega* (N=88)		*Kolla* (N=267)		χ^2 –value
	N	%	N	%	
Terracing	27	30.7	221	82.8	28.39***
Agroforestry	40	45.5	258	96.6	26.63***
Manure	37	42.0	229	85.8	12.17***
Crop varieties	13	14.8	198	74.2	49.57***
Soil bunds	38	43.2	99	37.1	14.23***
Intercropping	35	39.8	65	24.3	27.13***
Reduced tillage	52	59.1	85	31.8	59.95***
Irrigation	38	43.2	134	50.2	3.7

*** Significant at p<0.01

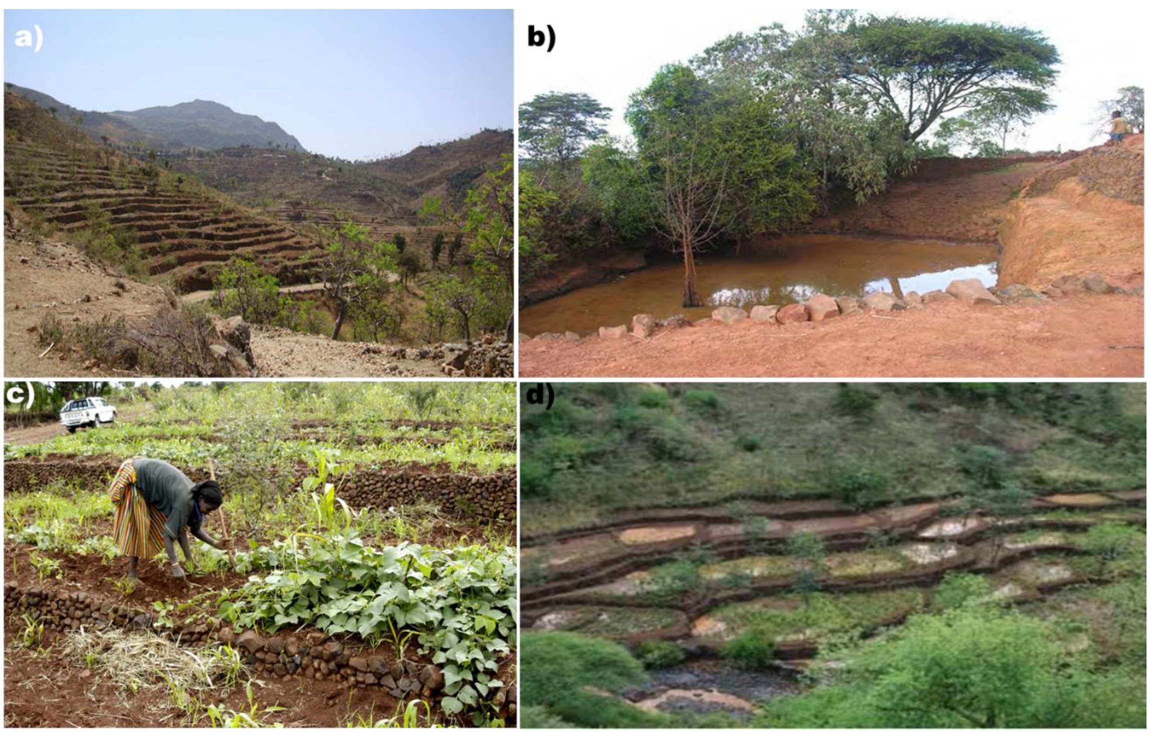

Figure 6.3. Water and soil conservation structures of Konso cultural landscapes: a) terraced landscape b) rainwater harvesting pond c) intercropped field d) micro-basins.

As mentioned in section 3.1, the three major crops produced in Konso are sorghum, maize, and teff. Table 6.8 shows that 80.6%, 67.6%, and 22.5% of households cultivated sorghum, maize, and *teff*, respectively. The impacts of CSA practices on the production of these three crops are presented in the next section.

Table 6.8. The sampled households that cultivated crops.

	Cultivators	
Crops	N	%
Sorghum	286	80.6
Maize	240	67.6
Teff	80	22.5

6.3.2.3. Impacts of adopting CSA practices on crop yield

The endogenous switching regression, which revealed a statistically significant relationship between sorghum yield and terrace application ($p<0.01$), also revealed that terraces had a positive effect on sorghum yield (Table 6.9). Similarly, other studies conducted in Konso (Watson, 2009) reported the crucial role of terracing in protecting soil from erosion, keeping water in farm fields, making hill farming possible, and increasing crop production. Di Falco et al. (2012) found that using terracing as a climate change adaptation strategy boosts farm productivity in Ethiopia's north-central highlands.

The Konso agricultural system is notable for its crop diversity within terraced fields. Crop diversification has a statistically positive significant effect on sorghum productivity ($p<0.05$), highlighting the importance of practice in increasing sorghum productivity. Smallholders in Konso are intensive agriculturists who rely primarily on sorghum cultivars intercropped with other food crops and trees. Cereals are frequently intercropped with grains and pulses to reduce crop failure due to drought and maximize yield. Smallholder farmers practice intercropping to ensure the availability of food from different crops and to obtain food in continuous supply. Some crops are drought tolerant (e.g., sorghum), while others (e.g., haricot beans) mature early. Intercropping also minimizes disease and pest risks. When pests affect sorghum, smallholder farmers may obtain production from pigeon peas and haricot beans, and vice versa. Adego et al. (2019) reported that using improved seed and crop diversification increases the probability of increasing yield.

Manure application positively and significantly influences sorghum productivity ($p<0.1$). In Konso, farmers apply manures in two ways. The first and most commonly used method is to collect manure from cattle barns and apply it directly to the field. The second way is a situation in which the household creates its own trash site and the dung and other waste materials from the home are collected in the household trash place, decomposed there, and applied to the field afterward. This implies crop-livestock complementarity in the smallholder farming system of Konso and elsewhere in the Ethiopian highlands (Asfaw et al., 2016).

According to the ESR model, conserving water has the potential to increase sorghum yield. Conservation of water has a significant and positive effect on maize productivity ($p<0.1$). Konso has a few perennial streams that can be used for irrigation. Small canals were built from stone and mud banks to take water from flooding rivers to the fields. The water produced by even the smallest spring is captured and redirected to the field (Watson, 2009). This helps to maintain soil moisture and reduce yield loss due to moisture stress. Teklewold et al. (2019) also indicated an increase in farm productivity with the use of agricultural water management practices.

Table 6.9 shows that having access to agricultural agents and credit is significantly associated with higher sorghum productivity ($p<0.01$, $p<0.05$). Access to credit has the likelihood of an increasing yield because accessing credit services may alleviate cash constraints for smallholders. The findings show that having access to an extension service has a positive relationship with crop yield. Previous study (Bedeke et al., 2018) also noted that having access to agricultural extension agents increases the tendency of CSA implementation and sorghum productivity. Access to climate change information through extension agents, meteorological services, the media, and social networks raises awareness of climate change (Asrat & Simane, 2018).

Smallholder farmers in the *Woynadega* agroecological zone have the likelihood of producing a high sorghum yield (Table 6.9). According to the results of the ESR model, increasing landholding increases the tendency of using CSA practices, which increases crop yields. Large land sizes enable smallholder farmers to diversify their crop and livestock options, thereby spreading the risk of loss associated with climate change (Bedeke et al., 2018; Belay et al., 2017).

Education was positively associated with smallholders' CSA adoption and increased sorghum yield. This suggests that literate smallholders are better to recognize the risks associated with climate change and make adaptation decisions than illiterate smallholders (Asrat & Simane, 2017; Belay et al., 2017). Literate household heads can acquire and process information easily, which may lead to more adoption of climate-smart agricultural practices (Asrat & Simane, 2018).

The ESR model results demonstrated that an increase in age is positively related to a higher likelihood of sorghum productivity for users and non-users alike. Old-age farmers are more experienced in farming and more exposed to past climatic conditions than young farmers. In contrast, Asfaw et al. (2016) found that crop productivity decreases with age, possibly because older people are more risk-averse. If the majority of family members are of working age, the household will have enough labor, and better to use CSA practices The practices of CSA and sorghum yield decrease as the distance from smallholders' homes and farmland to the market increases. When smallholder farmers are located far from the market center, the transaction costs for acquiring input and output are high, reducing the relative advantage of CSA technologies (Belay et al., 2017).

Table 6.9. Parameter estimates of CSA practice adoption and sorghum productivity.

Explanatory variables	CSA adoption	Users		Non-users	
Terracing	0.421(0.301)***	0.006***	(0.000)	-0.009***	(0.011)
Soil bunds and micro-basins	0.421(0.528)	0.048	(0.041)	-0.051**	(0.037)
Crop diversification	0.830(0.556)*	0.157**	(0.056)	0.045	(0.038)
Intercropping	0.842(0.717)	0.005	(0.098)	0.032	(0.037)
Manure	0.602(0.354)*	0.162*	(0.588)	-0.171	(0.578)
Agroforestry	0.811(0.792)	0.037	(0.234)	0.018	(0.067)
Irrigation	0.374(0.750)	0.051*	(0.074)	-0.073	(0.041)
Reduced tillage	0.348(0.420)	0.018	(0.048)	0.018	(0.036)
Sex	-0.362(0.611)	-0.006	(0.0432)	-0.006	(0.042)
Age	0.048(0.031)*	0.051***	(0.002)	0.003**	(0.002)
Education	0.067(0.041)	0.023**	(0.011)	0.002*	(0.003)
Household size	0.0468(0.090)	0.228***	(0.050)	0.003	(0.004)
Land size	0.375(0.316)	0.412**	(0.167)	-0.581	(0.343)
Access to climate info	0.968(0.428)*	0.007***	(0.003)	-0.018	(0.011)
Access to agri. agents	0.616(0.452)	0.006***	(0.002)	-0.033**	(0.014)
Off-farm activities	-0.118(0.462)**	-0.045***	(0.098)	0.015	(0.012)
Access to credit	0.113 (0.371)	0.015	(0.008)	0.013	(0.008)
Market distance	-0.082(0.035)*	-0.002***	(0.002)	-0.0052**	(0.003)
Agroecology	0.506(0.574)*	0.038**	(0.014)	0.028	(0.012)
Rainfall (Belg)	0.269(0.321)	0.041**	(0.004)	0.003**	(0.006)
Rainfall (Kiremt)	0.484(0.643)	0.038	(0.037)	0.136***	(0.043)
Max. temperature (Belg)	-0.029 (0.453)	-0.006***	(0.001)	-0.0328**	(0.013)
Max. temperature (Kiremt)	-0.033(0.329)	-0.002**	(0.005)	-0.0031**	(0.004)
Access to relief	0.324 (0.035) ***				
Sigma (σ) = 13.12					
Rho (ρ) = 0.202					
A number of obs. = 355					
Wald chi2(24) = 82.45					
Prob > chi2 = 0.1060					

***, ** and *significant at p<0.01, p<0.05 and p<0.1, respectively. The values in parentheses represent standard errors.

Concerning the impacts of CSA practices on maize yield, the ESR model revealed that terracing was significantly associated ($p<0.01$) with higher maize yields for users (Table 6.10). Asrat and Simane (2017) reported that households that implemented CSA practices such as terracing had 24.1% higher maize production than non-users in northwestern Ethiopia. Manure application positively and significantly influenced maize productivity ($p<0.05$) (Table 6.10). According to Pender and Gebremedhin (2006), the average value of production was higher in fertilizer-applied plots (2,184 EB/hectare) than in non-fertilized plots (1,684 EB/hectare). Water conservation increases maize productivity significantly ($p<0.05$). This signifies the role of the practice in sustaining crop productivity through conserving water and soil moisture. According to the FAO (2013), supplemental irrigation during critical times of the cropping season can reduce crop losses and increase productivity. In the absence of irrigation, smallholder farmers practice various forms of rainwater harvesting, including in-field rainwater harvesting ponds (Figure 6.3b). These techniques support farmers in keeping water for improved crop resilience to weather variability, particularly during mid-season dry spells. Soil bunds and micro-basins are effective in capturing rainfall water and maximizing infiltration. In Konso, Watson (2009) reported that soil ridges and basins retain water and improve infiltration.

Crop diversification also has a significant positive impact on maize yield ($p<0.05$). This signifies the role of the practice in maintaining crop productivity with drought-tolerant varieties. Intercropping of cereals with leguminous crops facilitates nitrogen fixation, improves yield, and buffers crop production from the effects of greater climate variability and extreme events (FAO, 2013). Access to agricultural agents and credit were significantly associated with higher maize yields ($p<0.05$, $p<0.1$) (Table 6.10).

Table 6.10. Parameter estimates of CSA practice adoption and maize productivity.

Explanatory variables	CSA adoption	Users		Non-users	
Terracing	0.262(0.313)	0.603***	(0.001)	0.306	(0.028)
Soil bunds	0.017(0.322)	0.337	(0.032)	0.420**	(0.056)
Crop diversification	1.181(1.561)	0.549**	(0.034)	0.420	(0.034)
Intercropping	0.202(0.532)	0.718	(0.071)	0.889	(0.076)
Manure	0.4344(0.362)*	0.748**	(0.042)	0.045	(0.048)
Agroforestry	0.085(0.764)	-0.175	(0.052)	0.001	(0.015)
Irrigation	1.038(1.646)**	0.233**	(0.029)	0.097	(0.068)
Reduced tillage	0.282(0.536)	0.948	(0.067)	0.089	(0.078)
Sex	-0.239(1.718)	-0.002	(0.056)	-0.248	(0.711)
Age	0.007(0.012)	0.002	(0.002)	0.003*	(0.001)
Education	0.056(0.045)*	0.002*	(0.001)	0.002**	(0.002)
Household size	0.072(0.092)	0.045	(0.027)	0.004	(0.003)
Land size	0.225(0.317)	0.852	(0.052)	0.243	(0.317)
Access to climate info	0.081(0.531)	0.012	(0.014)	0.011	(0.04)
Access to agri. agents	0.501(0.454)*	0.012**	(0.013)	0.041**	(0.041)
Off-farm activities	-0.361(0.467)	-0.018	(0.016)	-0.024	(0.016)
Access to credit	0.296(0.383)*	0.017*	(0.013)	0.011	(0.013)
Market distance	-0.035(0.037)**	-0.005**	(0.002)	-0.005**	(0.002)
Agroecology	0.554(0.498)*	0.002**	(0.015)	0.002	(0.015)
Rainfall (Belg)	0.258(0.222)	0.032**	(0.015)	0.002**	(0.005)
Rainfall (Kiremt)	0.493(0.532)	0.029	(0.038)	0.147***	(0.032)
Max. temperature (Belg)	-0.018 (0.342)	-0.005**	(0.002)	-0.0217**	(0.024)
Max. temperature (Kiremt)	-0.032(0.218)	-0.003**	(0.004)	-0.0022**	(0.003)
Access to relief	0.213 (0.024) **				
Sigma (σ) = 10.24					
Rho (ρ) = 0.279					
A number of obs. = 355					
Wald chi2(24) = 3486					
Prob. > chi2 = 0.002					

***, ** and *significant at p<0.01, p<0.05 and p<0.1, respectively. The values in parentheses represent standard errors.

Regarding the impacts of CSA practices on *teff* yield, the results of the ESR model revealed that terracing, crop diversification, manure, and water conservation improve *teff* yield. Terracing was found to be significantly related to higher teff yields in the model (p<0.01, p< 0.1). Adopting soil conservation as a climate change adaptation resulted in increased yield for Ethiopian farm households (Di Falco et al. 2012). Our findings also show that using manure increases teff yield (Table 6.11). Using manure positively and significantly influenced *teff* yield (p<0.1). Using organic fertilizers (manure, compost, and plant residues) provides the required crop nutrients, which increases productivity (FAO 2013). Conserving water has the likelihood of significantly increasing the *teff* yield (p<0.01, p<0.1). Table 6.11 shows that having access to agricultural agents is considerably related to higher *teff* yields (p<0.05, p<0.1).

Our results show that having access to agricultural agent extension and climate information services has a significant positive relationship with *teff* yield (p<0.05, p<0.1). Smallholder farmers in the *Woynadega* agroecological zone are likely to produce higher *teff* yields (Table 6.11). According to Adego et al. (2019), smallholder farmers in the *Dega* agroecological zone produce a higher *teff* yield than farmers in *Kolla*. According to the results of the ESR model, increasing farm size increases the of using CSA options, which increases total yield. The practices of CSA and *teff* yield decrease as the distance from smallholders' homes and farmland to the market increases.

Table 6.11. Parameter estimates of CSA practice adoption and teff productivity.

Explanatory variables	CSA adoption	Users		Non-users	
Terracing	0.069(0.129)*	0.008***	(0.012)	0.008***	(0.017)
Soil bunds and micro-basins	0.128(0.489)	0.278	(0.018)	-0.613	(0.028)
Crop diversification	0.856(0.457)*	0.077*	(0.038)	0.472	(0.068)
Intercropping	-0.281(1.038)	-0.177	(0.083)	-0.505	(0.015)
Manure	0.092(0.725)	0.361*	(0.072)	0.488	(0.077)
Agroforestry	0.242(0.1.136)	0.073	(0.073)	0.738	(0.078)
Irrigation	0.67(0.483)***	0.397*	(0.042)	0.638	(0.068)
Reduced tillage	0.005(0.076)	0.028	(0.028)	0.012	(0.024)
Sex	-1.233(0.504)*	-0.008	(0.063)	-0.012	(0.067)
Age	0.002(0.007)*	0.002***	(0.001)	.001**	(0.003)
Education	0.003(0.013) **	0.002**	(0.002)	0.019	(0.023)
Household size	0.049(0.027)	0.002	(0.004)	0.004	(0.006)
Land size	0.013(0.092)*	0.324**	(0.018)	-0.581	(0.342)
Access to climate info	0.101(0.125)	0.013***	(0.0141)	-0.017	(0.0415)
Access to agri. agents	0.022(0.134) *	0.051*	(0.015)	-0.035**	(0.211)
Off-farm activities	-0.415(0.865)*	-0.032***	(0.015)	0.035	(0.194)
Access to credit	0.094(0.111)	0.018	(0.011)	0.018	(0.021)
Market distance	-0.007(0.011)**	-0.005***	(0.002)	-.002**	(0.016)
Agroecology	0.008(0.144)	0.002**	(0.013)	0.001	(0.042)
Rainfall (Belg)	0.267(0.223)	0.041**	(0.016)	0.004**	(0.007)
Rainfall (Kiremt)	0.482(0.621)	0.038	(0.027)	0.238**	(0.041)
Max. temperature (Belg)	-0.019 (0.343)	-0.006**	(0.003)	-0.0218**	(0.026)
Max. temperature (Kiremt)	-0.033(0.219)	-0.004**	(0.005)	-0.0021**	(0.004)
Access to relief	0.214 (0.025) **				
Sigma (σ) = 18.3					
Rho (ρ) = 0.167					
A number of obs. = 355					
Wald chi2(24) = 72.35					
Prob > chi2 = 0.5173					

***, ** and *significant at p<0.01, p<0.05 and p<0.1, respectively. The values in parentheses represent standard errors.

The treatment effect results show that using CSA provides higher yields than not using it (Table 6.12). Smallholder farmers who did not use CSA practice would have gained more if they had used it. The treatment effects were 4.229, 2.039, and 2.51 quintals/ha/year for sorghum, maize, and *teff* for users, respectively. A previous study (Adego et al., 2019) reported increased crop yield productivity due to the use of adaptation practices in Ethiopia. The results reveal that smallholders who use CSA practices obtain a higher yield than non-users (Table 6.13).

Table 6.12. Average expected yield (Qt./ha/year) and net crop treatment effects.

		Decision		
Crop	Farm household	Used CSA	Not used CSA	Usage effects
Sorghum	That use	12.261 (0.512)	8.032 (0.644)	ATT=4.229 (0.823)**
	That did not use	12.025 (0.78)	9.012 (0.423)	ATU=3.013 (0.132)***
Maize	That use	34.250 (0.76)	32.211(0.566)	ATT=2.039 (0.055) ***
	That did not use	33.122(0.866)	30.014 (0.12)	ATU=3.108 (1.401) ***
Teff	That use	18.511 (0.693)	16.001 (0.434)	ATT=2.510 (0.022) ***
	That did not use	17.122(0.581)	15.033 (0.122)	ATU=2.089 (0.412) ***

*** and ** significant at p<0.01 and p<0.05, respectively. The values in parentheses represent standard errors. ATT=average treatment for CSA users; ATU= average treatment for nonusers.

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Table 6.13. The annual yield (Qt./ha/year) of each crop.

	Adoption categories		
Crop	Users	Non-users	Difference
Sorghum	12.261	9.012	3.598***
Maize	34.250	30.014	4.236***
Teff	18.511	15.033	3.478***

*** and ** significant at p<0.01 and p<0.05, respectively

6.4. Conclusion

The findings of this study show that crop yield has been declining due to high variability in rainfall and warming temperatures. Crops are exposed to moisture stress because of the delay, early termination, and lack of rainfall during the growing seasons, which leads to a decrease or loss of crop production. Increasing temperature will increase the evapotranspiration rate and crop water requirements, adding to frequent water stress. Thus, the current climate variability, coupled with land degradation, declining soil fertility, and low agricultural input use, will deteriorate the livelihoods of smallholder farmers. However, the adoption of climate-smart agricultural practices has a significant positive impact on crop productivity. Access to climate information, credit services, and agricultural agents played a crucial role in determining the application of CSA practices. CSA practices are vital to boosting and sustaining crop productivity under a changing climate. This is evidenced by the significant increase in sorghum, maize, and *teff* productivity for CSA users compared to non-users. In terms of wider policy implications, Konso's culturally intertwined CSA practices could be used as a learning platform to plan and scale out by integrating them with innovative conservation technologies and strategies to achieve widespread adoption in other parts of the country. Although this study is informative in providing the climate's role in the yield variability of sorghum, maize, and *teff*, like any empirical model-based study, it has its own limitations. The multiple linear regression used in this study did not consider smallholders' adaptive strategies and yield variability because of soil and water management practices and soil moisture. Aside from temperature and precipitation variability, a variety of other factors, such as solar radiation, soil moisture, and nutrient availability, can have an impact on crop yields. Finally, the study recommends that future studies should incorporate solar radiation, soil moisture and nutrient availability, soil and water management and conservation practices, and the onset, cessation, and duration of the rainy season into the model to better understand the causes of yield variability.

7. SUSTAINABILITY OF THE LONG-TERM INDIGENOUS CLIMATE-SMART AGRICULTURAL PRACTICES IN THE UNESCO DESIGNATED CULTURAL LANDSCAPES OF KONSO, ETHIOPIA[4]

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ABSTRACT

To develop viable agrarian strategies, it is essential to understand the historical sustainability pathways and prospects of long-term climate-smart-agricultural (CSA) practices in the face of sociocultural and climate changes. Therefore, this study aims to explore the role of sociocultural values and informal indigenous institutions in the survival and sustainability of CSA practices in Konso, Ethiopia. We used key informant interviews, focus group discussions, as well as participant observations to collect qualitative data. We coded the data and analyzed them thematically. The study shows that sociocultural values, norms, cooperative labor groups, and indigenous political institutions served as the backbone for the survival and sustainability of indigenous CSA practices for hundreds of years. However, recent trends in urbanization and the introduction of modern public administration have led to a gradual weakening of Konso indigenous political institutions and a decline in the acceptance of sociocultural values and norms. This in turn led to low performance of indigenous CSA practices and indigenous labor institutions and resulted in the weakening of CSA practices. Furthermore, the persisting decline in farmland productivity forced the youth to engage in off-farm activities rather than indigenous CSA practices. Therefore, to ensure the long-term sustainability of indigenous CSA practices in Konso, the local government and NGOs should work in collaboration to restore and promote sociocultural norms, values, and indigenous institutions.

Keywords: Sustainability, indigenous CSA practices, indigenous institution, sociocultural norms.

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[4] Gashure, S., & Wana, D. (submitted). Sustainability of the long-term indigenous climate-smart agricultural practices in the UNESCO designated cultural landscapes of Konso, Ethiopia. *International Journal of Agricultural Sustainability*.

7. 1. Introduction

Although smallholder farmers are adopting climate-smart agricultural (CSA) practices to reduce climate change impacts, it still poses serious challenges for agriculture in the Sub-Saharan African (SSA) region (Deressa, 2007). Approximately 95% of the food production in the SSA depends on rain-fed agriculture, which is highly vulnerable to droughts and erratic rainfall (FAO, 2016). This has triggered the recent national adaptation plan in Ethiopia to consider combating climate challenges as a crucial development priority (FDRE, 2019). Consequently, integrated watershed management was carried out through various projects and programs, namely, the Sustainable Land Management Programs (SLMP) and the Productive Safety Nets Programme (PSNP). The programs were implemented on a campaign basis with little integration and without a comprehensive view of rural landscapes. Consequently, adverse climate change impacts have continued to be a critical challenge for the sustainability of agriculture in SSA (Adego et al., 2018; Nigussie et al., 2018).

Agricultural sustainability is a more complex concept with no agreed-upon dimensions among scholars (Hayati et al., 2011). Thus, operationalizing the sustainability of an agricultural system on the ground entails taking into account a variety of factors, including physical, economic, and sociocultural dimensions, as well as interactions between them (Veisi et al., 2013). In terms of method, Herrmann et al. (2011) also underlined that assessing agricultural sustainability must take into account the dynamic interactions between socioeconomic and biophysical elements in the system. Similarly, Moreover, Streimikis and Baležentis (2020) highlighted that assessing agricultural sustainability must consider the dynamic nature of government policies regarding sustainable development, rural development, climate change, and the environment. Thus, any attempts to study agricultural sustainability must focus on the social-ecological context and a proper understanding of agricultural landscapes as a product of social, cultural, and ecological systems (Wittman, 2009). On the other hand, Bacon et al. (2012) argued that agricultural sustainability cannot easily be defined at the farm or landscape level because it is part of a social-ecological system. Consequently, agricultural ecology is inextricably linked to its social dimensions since agriculture is a continuous nexus of society and ecology (Wells, 2011). Despite such a high level of ecological and social entanglement in agriculture, previous studies appear to neglect the pivotal role of sociocultural and informal institutions in the long-term sustainability of CSA practices (Adego et al., 2018; Nigussie et al., 2018; Simane & Zaitchik, 2014).

Balbo & Puy (2017) noted that understanding historical sustainability pathways of conservation is critical for ensuring human well-being in rural areas and developing viable agrarian strategies. To understand the historical sustainability and prospects of CSA practices, we selected the Konso community because it is well known for its deep-rooted indigenous CSA practices but is chronically food insecure. In addition, to the best of our knowledge, studies on the sustainability of indigenous CSA practices by focusing on sociocultural and informal institutions are very limited in Ethiopia. The study of Watson (2009) was the only new insight into the Konso agricultural system that attempted to address the interconnectedness of the social and technical dimensions of agriculture in Konso. In previous studies on the sustainability of CSA in Ethiopia, much attention has thus been given to the technical, environmental, economic, and formal institutional dimensions rather than the social-cultural values and informal institutions that support technology (Adego et al., 2018; Simane & Zaitchik, 2014). As a result, research on the social-cultural values, norms, and informal institutional dimensions that contribute to the sustainability of conservation technologies has been limited. Therefore, this study aims to explore the role of sociocultural values and informal indigenous institutions in the survival and sustainability of CSA practices in Konso, southwest Ethiopia.

7. 2. Materials and Methods

7.2.1. Methods of data collection

From February 14 to June 13, 2020, and January 3 to February 15, 2022, data were gathered through key informant interviews, focus group discussions, and participant observations.

7.2.1.1. Key informants' interviews

We conducted both unstructured and semi-structured interviews with a key informant who can provide crucial information about the roles of indigenous sociopolitical institutions, sociocultural values, indigenous labor groups, the government in different regimes, population pressure, climate pattern and topography, crop productivity, and off-farm activities in the sustainability of CSA practices in Konso. To find key informants, we used a snowball sampling technique. Thus, we initially contacted individuals who could provide relevant information for the study, and then we used these people to contact other appropriate informants. Key informants were the knowledgeable people who were considered authorities about the history and culture of the community, institution, or place. We carried out in-depth interviews with 30 key informants concerning the sustainability of CSA practices. A recording of the interviews was made with the consent of the interviewee and transcribed later.

7.2.1.2. Participant observation

The first author participated in the construction and maintenance of CSA structures in four kebele (Jarso, Busso, Fuchcha, and Beayide) farmlands. Based on the observation guide, the focus was given to the types, nature, and current status of CSA practices on smallholder farmlands. During the participant observation, the first author took keynotes based on an observation guide, focusing on the status of CSA structures and indigenous political and labor institutions. The first author is a native of Konso. Thus, he had a chance to easily participate in the activities of labor groups, such as *ukanta*, *Parka*, *Kanta*, *Palleta*, and *Kaffa*. He is exposed to Konso's culture and experience in their social life of agriculture. He knows many people in the area, which enabled him to easily become immersed in the local culture and establish a good rapport with society during data collection from February 14 to June 13, 2020, and January 3 to 15, 2022. During fieldwork, he observed the status of various indigenous institutions and labor groups while they were performing CSA activities. In addition, during his stay in Konso, he took part in the social life of agriculture, mediation, and cultural sports in *Moora* (Figure 7.2d).

7. 2.1.3. Focus group discussion (FGD)

Six FGDs, each with 6–10 participants, were held in four kebeles: Jarso, Busso, Fuchcha, and Beayide. The participants of the FGD comprised elderly men and women from the community, youth (aged from 18–30 years), and local religious and indigenous leaders. The FGD was primarily used to ascertain the shared understandings of several individuals regarding the sustainability of CSA practices. Furthermore, the FGD aimed to triangulate the data obtained via key interviews and participant observation. Each FGD session lasted on average approximately 2 hours. During the discussions, the first author guided the discussion and took notes.

7. 2.2. Data analysis and validity

Coding and thematic analysis of qualitative data were performed. Codes were used to select and emphasize relevant information. Moreover, coding was used to eliminate extraneous information and focus on the types of information that were essential for the study. It provided a framework for organizing and thinking about the data. After coding, descriptive labels were grouped into themes. Thus, themes were created from the data. The identification of themes within the findings highlighted key subjects and allowed for the provision of theoretical explanations. The theme analysis enabled us to detect systematic category relationships (interactions) between various factors (sociocultural, indigenous political institution, economic, labor availability, government institutions, and physical) and the sustainability of CSA practices.

Data obtained from key informant interviews were triangulated using participant observations and focus groups. Moreover, member checking (asking some participants of the study) and peer debriefing of the findings was carried out from January 3 to February 15, 2022.

7. 3. Results and discussion

7. 3.1. Physical factors

7. 3.1.1. Climate variability

During the past three decades, the Konso area has experienced twenty-two annual droughts that pose threats to rainfed farming, which have gradually exposed smallholders to food insecurity and socioeconomic vulnerability (Gashure & Wana, 2021). Konso’s terrace-based agriculture shows signs of deterioration because of the alteration of its internal and external driving forces, mainly because of a shortage of rainfall (Beshah, 2003). Our key informant (Gade Kumisha), a 90-year-old woman from Busso Kebele, explained the impacts of climate variability as follows:

> There have been repeated droughts in Konso, which have caused significant crop failures and harvest losses. We have been exhausted by the drought and sometimes unable to bounce back from the effects, which resulted in the deterioration and depletion of our assets. However, torrential rain flooding destroys our CSA structures. The repair of the destroyed CSA is labor-intensive and requires huge capital to hire labor groups. During the last spring season in 2021, flooding destroyed some flood protection walls that protected the irrigated farmlands for a long time around the Karfura River, while no one paid attention to repairing them as it was in the 1980s.

Similarly, the *kebele* chairperson (Mr. Sokate Kussia) argued the case of flood protection walls in Busso as follows:

> The construction and repair of flood protection walls require a labor force that can be afforded at the ward (*Kanta*) or kebele (*Palleta*) level through community participation. However, currently, most people are not interested in free labor, such as repairing the destroyed protection walls of individual households. Money-based labor groups are always available, even if they are costly. Therefore, as we cannot force the community to repair their destroyed flood protection walls, individual households should pay for labor groups such as *mapara* to repair the walls.

The FGD participants in Beayide Kebele also pointed out that recurrent drought and heavy rains are the major threats to the sustainability of their CSA structures. The participants underscored that farmers are currently afraid of investing in CSA practices because drought results in frequent crop failure.

7. 3.1.2. Topography and stone availability

In addition to climate variability, topography and availability of construction materials play a pivotal role in the sustainability of CSA practices. The Konso area has rugged surfaces with varying elevations, where hills and mountains are intersected by valleys and gullies and dominate the area. This rugged nature of the terrain and soil erosion forced the Konso people to practice CSA practices for several generations. In Konso, the primary CSA structure construction materials are stone and soil. Konso land is arid and rocky (ARCCH, 2009). The Konso terrace walls are mostly made up of stones. Stones are usually collected from farmland, and they are abundant in highland areas, where terracing is intensively practiced. The abundance of stone enabled the Konso people to build terraces on their farms, flood protection walls along the riverbanks, walls around their traditional towns, cattle barns, fences around farms and homes, micro-dams along streams, and make a boundary between farmlands and houses. However, after 1947 (when Karat town was established as a modern administrative center of Konso), the stones were used for the construction of modern urban houses. Urbanization and the high demand for stones in urban areas in Konso and outside Konso are becoming critical challenges for the availability of stones for the building of terraces and repairing them. Furthermore, currently, many households are replacing their traditional woody and grass houses with modern corrugated iron sheets with cement floors, which results in a need for stones from terraced farmlands (Figure 7.1 (b)). Today, in rural areas that have access to transportation, some households sell stones to urban and traditional towns for house construction. In this regard, Mollo (2009) noted that in areas near towns, some people prefer to collect stones or gravel for sale rather than use them to build terraces on their farm plots. Sadly, some households are demolishing walls of the terrace to sell stones, which has a serious negative impact on the sustainability of CSA structures. In general, the growing demand for stones in urban and Konso traditional towns is the major threat to the sustainability of long-term CSA structures in Konso.

Figure 7.1. (a) Busso Palleta in 2000 (b) Busso in 2022 (c) Traditional hut with cement floors in traditional towns.

7. 3.2. Sociocultural factors

7. 3.2.1. Social norms and values

The terraced landscape of Konso is indigenous, produced by the people themselves, and has survived for hundreds of years. These long-term CSA practices allowed each member of the Konso community to acquire and practice CSA as a societal norm. Indigenous farming practices are therefore interwoven into the sociocultural fabric of the community, with a production and protection framework (GebreMichael, 2015). Konso considers CSA practices critical to survival, sustaining livelihoods, and living in harmonious and friendly relationships with the harsh physical environment. Collective action and labor-intensive CSA practices, such as the construction and maintenance of flood protection walls, public gathering places (*Moora*), traditional town walls, water wells (*Ela*), and rainwater harvesting ponds (*Harta*), help the people develop a sense of harmony and cooperation. Kedo Kensawa, a 60-year-old man from Fuchucha kebele, stated that the construction or maintenance of these structures also allows them to learn respect, acquire new skills, develop cooperativeness, and develop social values. He added that the Konso people's indigenous organizations of labor and the systems of governance that protect the farming system have allowed this system to thrive.

One of the core sociocultural values of the Konso community is masculinity and hard work. The Konso people are role models for perseverance and industriousness (ARCCH, 2009). They like to work very much and do all that they can do (Watson, 2009). They expect every able person to be able to feed himself or herself and their families by working hard. In particular, they need males to be strong to shoulder societal responsibilities such as withstanding arduous labor demands in agriculture. They seriously hate laziness, theft, begging, and litigation. Konso believes that every person should be able to live on their own sweat and hates litigation because it takes precious work time (Otto, 2004).

Cultural sports are another critical factor for the sustainability of CSA practices in Konso. The Konso people want everyone, especially males, to be physically strong because the building of stone-walled terraces and tied-ridges requires hard labor. Therefore, they use circular stones (*arumta*) as a cultural sports tool. In every traditional town (*palleta*), at each *Moora*, these circular stones of varying weights (ranging from 45–80 kg) are available for physical exercise (Figure 7.2). These circular stones, which are used to measure the weight-lifting capacity of Konso men, are carried and brought to the *Moora* by a class of men who handle the administration of traditional towns (Korra, 2011). In their free time, the men frequently lift boulders of various sizes to demonstrate their strength. From childhood to adulthood, males compete with their age-mates by lifting *arumatas* (Korra, 2011). Although the primary aim of weightlifting is to be strong for building CSA structures, the lifting of heavy stones also serves as a measurement of males' maturity for marriage and their capacity to engage in the front.

Figure 7.2. The cultural sports tool (arumta): (a) circular stones of various sizes and columnar stones erected to commemorate good administration skills and heroic achievements. (b) The largest circular stone of 80 kg. (c) Youngster (26 years old) lifting circular stone of 61 kg. (d) The first author lifting arumta in Moora palleta.

7.3.2.2. Social learning and youth participation

Social learning is crucial for achieving socioecological resilience and positive outcomes from conservation (Gerlak et al., 2019). Thus, Konso ancestral indigenous institutions and CSA practices transfer from generation to generation via social learning. Collective social learning takes place via various mechanisms, such as ritual ceremonies in *Moora*, elders' blessing speeches, folk dances, proverbs, riddles, tales, songs sung during various farming activities, oral history, gossip during the walk to various places (water points, farms, and marketplaces), institutional labor groups, and wedding and funeral processions. In particular, folk songs (*Sarra*) that admire and exalt models or better-off farmers and good farming practices such as strong terraces, permanent water points, and fertile farmlands play a pivotal role in knowledge and skill transfer from generation to generation. All members of the public know the poem and try to play *Sarra* attractively, focusing on the achievements of a person (Gelebo, 2016). In addition to collective social learning mechanisms, fathers share a wide range of issues with their children, particularly with sons (Beshah, 2003).

When we compare the current participation level of young people with that of elderly people in CSA practices, it is weakening. FGD participants in Busso kebele indicated that younger generations consider CSA practices too heavy and they also lack the necessary skills to engage in them. Young people also believe that small landholdings have lost their fertility and are no longer productive. Hence, they do not actively participate in CSA and prefer to participate in off-farm activities or temporarily migrate to other towns in southern Ethiopia. In addition, in the traditional Konso community, elderly people are viewed as "*experienced social experts"* who teach the community about what type of CSA structures to build, where how, and when to build them. Amborn (1989) succinctly expressed the role of elderly individuals as "*men of knowledge*". However, according to Halgeyo Qallo, a 55-year-old man from Fuchuchu Kebele, young people are no longer accepting elderly people's advice concerning CSA practices. Senbeto Gapo, a 59-year-old man from Jarso kebele, explained the situation as follows:

> The young generation did not accept CSA practices advice from the elderly. When you advised them about terraces, their reply was, "Go and build such terraces on your farms. Tell this advice to your peers."

This kind of disrespect has occurred due to the youth's consideration of elderly people's early lives as backward and the impact of globalization and urbanization. The expansion of Western culture in Ethiopia has resulted in the consideration of indigenous knowledge and practices as backward and contrary to modern science (Mekonnen et al., 2021). Due to the decline of respect for the elderly, social bonds weaken, free labor groups are declining, and CSA structures deteriorate. Consequently, it is common to observe the ruined terraces in different parts of Konso due to emerging disrespect among young people and increasing labor wages in activities other than CSA (Figure 7.3).

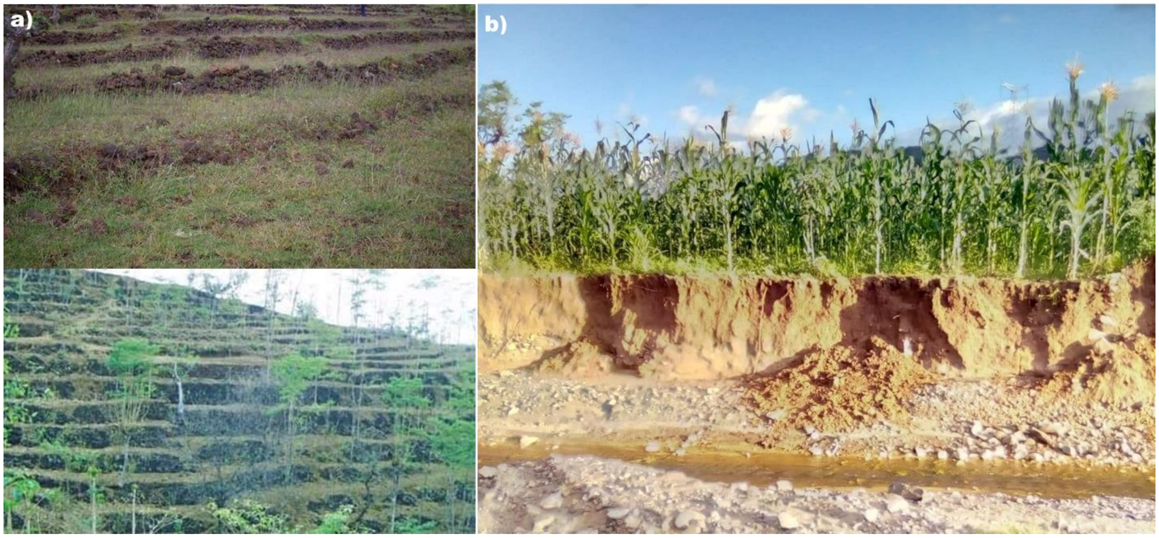

Figure 7.3 (a) Ruined terraces (b) Irrigated land (yeela) without flood protection walls (*toomota*).

7.3.2.3 Population pressure and indigenous birth control methods

Konso's population growth signals an imbalance between population and ecology. As cited in Hallpike (2008), according to the Ethiopian Evangelical Church's Mekane Yesus census compiled for famine relief in 1967 and 1975, the Konso's crude population density (persons per km^2) was 24.5 and 40.4, respectively. According to official census reports from 1984, 1994, and 2007, the Konso population density was 52.9, 81.9, and 122.3 persons/km^2, respectively (Central Statistical Agency, 2007). The Central Statistical Agency (2020) estimated that Konso's current crude population density is approximately 126 people per square kilometer, while its agricultural density is approximately 365. Possible reasons for the population increase include the abolition of *Farayyuma* (a traditional marriage-age restriction system) and improved access to modern treatment. *Farayyuma* is an indigenous birth control system that prohibits marriage until the age of 30. If pregnancy occurred during the *Farayyuma* stage, abortion was obligatory (Hallpike, 2008). The *Farayyuma* was important for controlling population size and preparing a body for laborious soil and water conservation practices such as building flood protection walls (Mollo, 2009). In addition to *Farayyuma*, during the nighttime, most Konso married men sleep at *Moora* to control birth. Konso assumes that men who expend much time with their wives lose strength and thus are unable to construct or maintain soil and water conservation structures (Korra, 2011). In addition, Konso believes that a man must not sleep with a woman unless it is to produce children. This is traditionally used to prevent a mother's pregnancy and allow a child to breastfeed for at least three years. Similarly, Hallpike (2008) reported that both married and single Konso men often stay in special men's houses at *Moora* during the nighttime to preserve their virility. Korra (2011) underlined that the tradition of sleeping at *Moora* serves as a form of cultural contraception because men must spend the night there. Moreover, when the first son marries and produces a child, the father and mother stop having children because they believe that it is bad for the son and his father to produce children at the same time. Gelebo (2016) pointed out that when the father and the son are begetting together, it is believed that God does not give rain and unnatural deaths happen within the family.

The Konso customary birth control system held the population in balance, and nature was treated with respect. However, the Derg regime outlawed *Farayyuma*, and other indigenous contraception methods (men sleeping at *Moora* during the nighttime, the taboo of simultaneous begetting of father and son) are gradually disappearing. Due to the avoidance of *Farayyuma* and other indigenous contraception methods, as well as the introduction of modern medical treatment, which reduces mortality rates, the population has increased significantly, particularly during the last four decades. Urmale Kurufo, a 65-year-old man from Jarso Kebele, explained the population pressure impact on the land as follows:

> Before 1974, most Konso people settled on the *Woynadega* agroecology, and farmers could obtain a sufficient yield from their intensively terraced farms. The *Kolla* agroecology was neglected because of the high prevalence of diseases such as malaria and tsetse flies and frequent conflict with surrounding pastoralists. Because of the high prevalence of yellow fever in the *Kolla*, the *Kolla* was called the areas of evil spirits (*orritta*). However, after 1974, because of the high population increase and the availability of modern medicine, the Konso people started cultivating hostile *Kolla* areas. Although farmlands are expanding to the

Kolla, the *Woynadega* is still cultivated, but CSA practices are becoming weaker. The CSA practices weakened *Woynadega* because farmers' focus was on fertile irrigated *Kolla* farmlands, which provide a better yield than the *Woynadega* farmlands.

In line with this, Beshah (2003) pointed out that farmers in the Turo area of Konso have abandoned terraces by shifting from hillside farming to gentle slopes with the help of oxen in the Kolla agroecology.

7.3.3. Indigenous political institution factors

7.3.3.1. Xhelta, Appa Timpa, and Poqalla institutions

Before its incorporation into the Ethiopian empire by emperor Menelik II in 1897, Konso land was autonomous, and its traditional towns (*palletas*) were overseen by indigenous political institutions such as *Xhelta, Appa Timpa, and Poqallas*. *Xhelta* is a class of all men who handle the administration of *palletas*. *Xhelta* is the backbone of the society that plays an important role in Konso, uniting residents from all neighborhoods (*Kanta*) and forming a single society in its traditional towns. *Xhelta* controls CSA practices and enforces the decisions made by other authorities (*Appa Timpa*, the elders, and *poqalla*). They protect the town stone walls that surround the settlements and repair them when damaged. They often supervise and evaluate the overall management of land and water resources at both the household and community levels in the neighborhood (*Kanta*). They receive reports of the destroyed terraces from community members and warn or fine households that do not repair their terraces on time. They are also responsible for mobilizing the neighborhood for assistance when the flood protection walls (*toomota*) of a particular household's farmland are damaged by flooding (Korra 2011).

Xhelta punishes individuals or households that do not participate in public CSA activities. The punishment, which is known as *xoraata,* may be in cash, in-kind, or labor. The amount of *xoraata* depends on the number of days a household member is absent from public work. However, in the case of repeated absenteeism without permission and justifiable reason, it may result in the exclusion of the household from social life. For the excluded household to return to social life results in high punishment, which is mostly the bull. Hallpike (2008) and Watson (2009) reported that if a person does not cooperate with his or her neighborhood, initially he or she will be fined, and then if his or her behavior does not improve, he or she will be "shut out." Thus, the indigenous mechanism for enforcing Konso traditional law has therefore enabled CSA practices to be passed from generation to generation.

Appa Timpa is the head of the traditional town (*Palleta*). The office of *Appa Timpa* supervises *Xhelta* and assesses the performances of the concerned CSA at the *Palleta* level. While *Xhelta* organizes the ward (*Kanta*) level public CSA campaign work, *Appa Timpa* organizes it at the *Palleta* level. The office of Appa Timpa is a non-spiritual institution and can, therefore, be considered the highest level of political and judicial authority at the traditional town level (Korra, 2011). For example, the special cases of reprimanding people who did not participate in the public CSA campaign work and frequently disturbed the neighborhood are referred to the office of *Appa Timpa*. *Appa Timpa* is both a supervisor of Xhelta and the supreme court of each *Palleta*. Each *Appa Timpa* holds the drum, which represents political authority, for one to three years and then transfers it to the next person in the cycle (Watson, 2009). Thus, *Appa Timpa* is the guardian of traditional law, who controls the performance of *Xhelta* concerning CSA and resolves conflicts among the people.

Poqalla is the clan head. There are nine exogamous clans (*kaffa*) in Konso. The power of *Poqalla* is hereditary. Economically, *Poqallas* are "wealthy families" that have large landholdings. They are at the top of the social hierarchy and give land to their clan members. They have the authority to follow up on the status of CSA structures on their own clan members' farmlands. Their offices have their own messengers (*Sara Poqalla*) who supervise their clan members' farmlands, with an emphasis on CSA structures twice a year. Messengers present the status reports of the CSA structures of their clan households to *Poqalla*. Poqalla makes different decisions based on the status report. He blesses the households that conserve the land properly. Households whose farms show small ruinations of terraces and tied-ridges are advised to properly conserve the land; otherwise, the rented-out land is taken back if the CSA practices are seriously damaged. *Poqallas* often take back their rented-out lands (*odayta*) in January (*Oyba*) every year. This time of the year was set by the community because it is the most suitable period to prepare the land for the main cropping season, spring (*Katana*). *Poqallas* are also responsible for organizing the *Kaffa's* work and have the power to fine clan members who are absent from the public work.

The protected, dense forest (*Mura*) around the homestead of a regional *poqalla* is a sacred *poqalla* forest. Some of the prominent *poqalla* forests in Konso are *Mura* Kalla (19.64 ha), *Mura* Pamalle (10.54 ha), and *Mura* Quffa (4.5 ha). Amazingly, these *Poqalla* forests are the main forest patches that are currently located at the center of Konso **(**Figure 7.4 (a)). Mekonnen et al. (2021) also stated that a local institution named *Gizit*, which embodies the religious value of the church played an important role in saving indigenous trees around the Debrelibanos Monastery in North Shewa. *Poqalla* forests are essential to environmental protection, but tree theft and domestic animal interference pose serious threats to the sustainability of these forests. In general, the *Xhelta*, *Appa Timpa*, and *Poqalla* are indigenous administrative structures that have played an essential role in strengthening CSA practices and in uniting people through social norms in Konso for several generations.

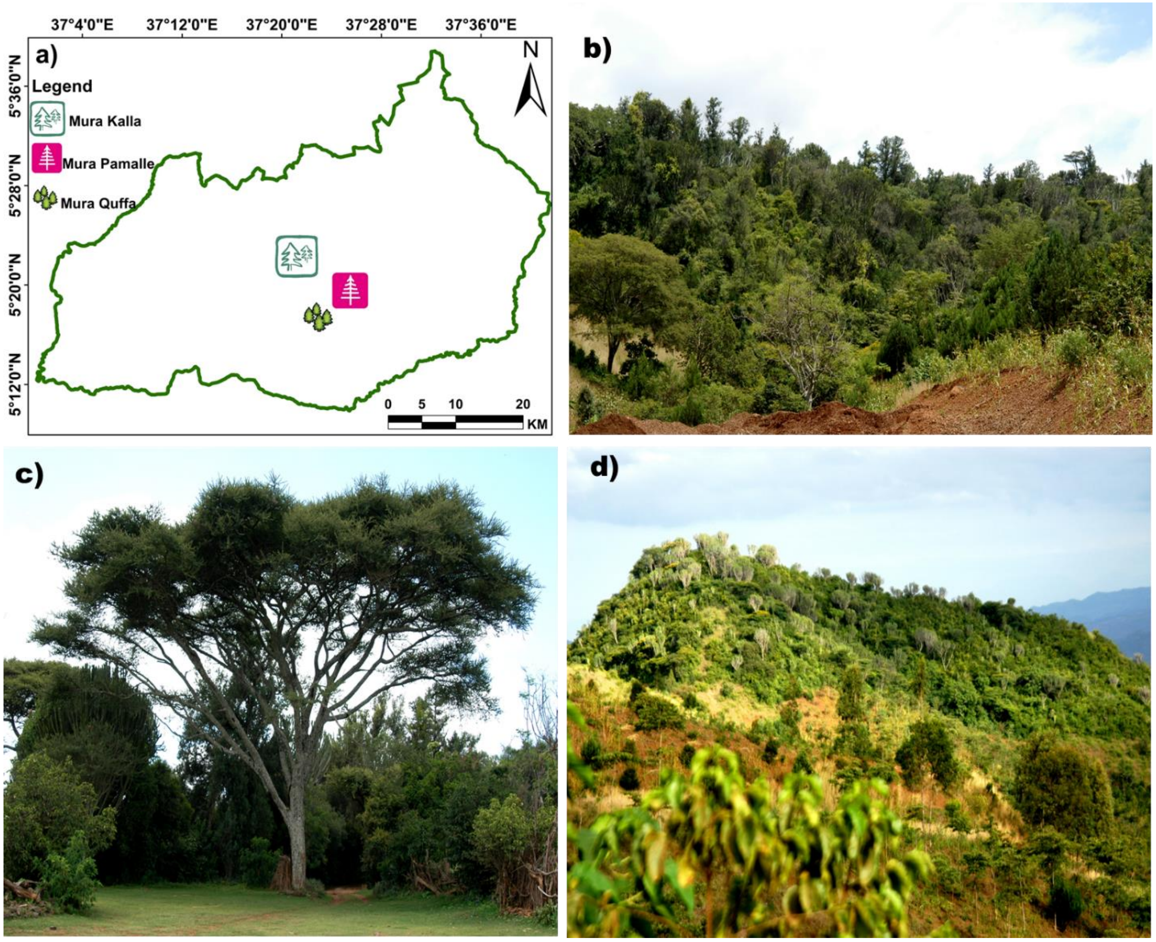

Figure 7.4. (a) Sacred *poqalla* forests in Konso (b) and (c) *Mura* Kalla (d) *Mura* Quffa.

7.3.4. Labor availability factors

3.4.1. Household labor

In Konso, CSA structures are mainly built by household members. Thus, community members informally evaluate each household's performance in CSA practices in their neighborhood. Based on their evaluation, households that properly perform CSA are highly respected in society, and they have a high opportunity to obtain a free labor force during a difficult or emergency time. In contrast, the less skilled people and 'lazy' households that do not properly conserve their farmlands did not receive assistance even during difficult or emergency times. This indicates that obtaining assistance, even during a difficult time in Konso, depends on the household performance in CSA practices. Moreover, households that do not properly maintain their CSA structures are reported by their farm neighbors and fined by the *Xhelta* organization. Similarly, in southern

Ethiopia, Engdawork and Bork (2014) reported that a person who does not maintain or construct terraces on his farmland is fined or cast out from social interaction.

In the Konso community, there are "special persons" from households who are highly skilled in CSA and are highly valued and respected by the community. These special people are known as *harmota*. In most cases, *harmota* are awarded thick local drinks (*cheqa*) mixed with honey, and sometimes goats or sheep are slaughtered for them after the successful accomplishment of heavy CSA work. The existence of *harmota* creates strong competition among community members to attain the status of *harmota* to obtain relevant social respect (Mollo, 2009). Therefore, the existence of *harmota* served as a significant sociocultural motivator for the strengthening and sustainability of CSA practices.

Currently, accessing labor for CSA is economically difficult in Konso because people prefer to engage in off-farm activities that pay better wages in urban areas than CSA activities. Consequently, economically better-off households are paying wages that are equal to labor wages in urban areas for the construction and maintenance of CSA structures. Thus, the affordability of labor is becoming the main bottleneck for the sustainability of CSA practices on farms of poor households. This implies that CSA structures are more sustainable on farms of better-off households than on farms of poor households in the face of a changing climate.

7.3.4.2. Indigenous institutional labor groups

The high labor demand for the construction and maintenance of CSA structures is one of the major constraints on the sustainability of CSA practices everywhere. However, the Konso community has its indigenous institutional groups for CSA practices. They collaborate to create visually appealing terraced landscapes and complex village compounds (Behailu et al., 2016). They often use the proverb "Living together is meaningful only via cooperation and sharing resources" to strengthen their unity. Even in modern management, social cohesion is the key to long-term sustainability (Harvey & Reed, 2007). Their indigenous institutional groups are not defined as institutions that govern behavior in irrigated agriculture (Ostrom, 1990), but they encourage cooperative work and are essential for the sustainability of intensive agriculture (Watson, 2009).

Their scope goes beyond the creation of a simple labor exchange mechanism by establishing labor markets, saving methods, mutual trust, and assistance. They include *ukanta, parka*, *alumala*, *mapara*, *kanta*, *palleta,* and *kaffa*.

Ukanta calls friends, relatives, and neighbors for assistance in CSA practices and other agricultural activities. Approximately 20–60 people can be involved in *ukanta* work on a single day. Currently, participation in *ukanta* has decreased as landholding and production have decreased, and people prefer to be involved in off-farm activities. Consequently, the opportunity to obtain U*kanta* labor is becoming a serious challenge, which results in workers shifting to other labor groups such as *parka* and *alumala*. *Parka* is a voluntary, self-organized labor group that provides free labor to all its members (10–20 people). Because the monetization of labor is skyrocketing, some *parkas* have been abandoned, and the group members are organizing themselves into money-based labor groups known as *alumala*. An *alumala* is composed of 5–15 people of the same age group and physical fitness level. The payment for an *alumala* increases from time to time, and most *alumala* groups are growing into large labor groups known as *mapara*, with 20–50 members.

The neighborhood (*Kanta*) is a social institution that provides mass assistance by coordinating neighboring households during serious problems. The *Kanta* work is coordinated by *Xhelta Kanta*. It is typically carried out when a *Kanta* member's flood protection walls (*toomota*) are damaged by floods, when one member of the household dies, or when fires and car accidents occur that result in the devastation of assets. Currently, *Kanta*'s work is widespread because it is supported by the government. The group of *kantas* forms a larger traditional town and work institution known as the *palleta*. *Palleta* work is collective action that does not work on particular household farms but on CSA activities that benefit the community. It includes the construction of flood protection walls, communal ponds, dry stone walls around villages, and other public infrastructure. It is becoming stronger and more widespread in Konso because it is supported and monitored by government organizations. *Palleta* consists of all nine clans (*Kaffa*) of Konso (Gelebo, 2016). The members of the same *Kaffa* have sympathy for each other and usually help each other in any difficult condition. *Kaffa's* work is usually performed by particular *Kaffa* members if their members face serious problems.

7.3.5. Economic factors

7.3.5.1. Farmland productivity

Konso households own an average of 0.5 ha of land, although this varies with wealth rank and agroecologies (GebreMichael, 2019). Farmland productivity can either encourage or prevent households from participating in CSA practices. The FGD participants in Beayide Kebele indicated that the productivity of their farmlands is declining from time to time, although CSA practices are being implemented to make productivity sustainable. The FGD participants pointed out that productivity decreased persistently due to recurrent droughts, erratic rainfall, a decline in soil fertility, and land fragmentation. The erratic nature of rainfall has an impact on farmers' production systems by reducing crop and livestock yields to the point of complete crop failure (Beshah, 2003). Asras Gebino, a 70-year-old man from the Beayide Kebele, highlighted that recurrent droughts and unreliable rainfall are the key reasons for the continuous productivity decline in Konso. This persistent productivity decline has led to a decrease in smallholders' investment in CSA practices. According to the FGD participants in Busso Kebele, their landholdings are so small that crop production that is sufficient for subsistence cannot be obtained unless some household members search for rental farmland in the lowlands and commit to participating in off-farm activities. Kuchulo Teyganto, a 50-year-old man from Jarso kebele, indicated soil fertility decline as one constraint for crop productivity in *Woynadega*. He described the situation as follows:

> Since our farmlands have been cultivated for thousands of years, they are losing their fertility. The fertile *Woynadega* farmlands, which produced a high sorghum yield three decades ago, are now invaded by witch weed (Striga sp.). Since sorghum growth is stunted, its head is small. We tried to maintain soil fertility via manure, but it was difficult to fertilize all the plots with manure. Because crop residue serves as forage for animals, most farmers do not use it to maintain soil fertility. We tried to apply artificial fertilizer, but due to frequent crop failures, we could not pay back our loans. This resulted in the sale of our meager household assets. Fallowing to restore soil fertility is not an option, since we do not have enough land to cultivate to support our households.

In *Kolla* agroecology, Kagna Nalle, an 80-year-old man, argued that soil fertility has declined in hoe-culture areas but remains fertile in oxen-plowed areas, while climate change and recurring droughts are the main reasons for persistent crop productivity decline. Indeed, erratic rainfall and recurrent droughts are the primary causes of productivity decline. In line with this, Mollo (2009) indicated that the decrease in the productivity of the farms in Konso was the combined effect of a decrease in rainfall, increased population pressure (land fragmentation), and a decrease in soil fertility. When crops fail, households sell some of their livestock or trees on the farm to purchase food. Some family members migrate to some towns in southern Ethiopia in search of jobs to support their families. Consequently, farm CSA structures are neglected to the point where some families are extremely frustrated with their maintenance (Beshah, 2003). This suggests that the persistent decline in yield due to recurrent drought, unreliable rainfall, soil fertility decline, and land fragmentation is becoming a threat to the sustainability of CSA practices.

7.3.6. Government institutions and political factors

7.3.6.1. Land tenure

Customary land rights were established in Konso during the time of the influx of various clans and the occupation of the current land territory (Beshah, 2003). Watson (2009) pointed out that the first land ownership is established by clearing or burning previously uncultivated land, while ownership of land after that is acquired by inheritance and purchase. Although there were various Ethiopian regimes' land policies, the land in Konso is both private and state-owned. Private land "ownership" means the right to use, sell, lend, or pass on to heirs (Watson, 2009). Theoretically, the imperial regime before 1941, the Derg regime, and the current government declared the land as state and public property, but practically, it is not applicable in Konso. The land is often sold informally, while the formal court does not recognize it. The buyers of the land are even remembered after their deaths via the statue (*Waakka*) and stone poles erected near their tombs. The number of erected stone poles near the grave indicates the number of farm plots the deceased person bought while he was alive. This suggests that private ownership of land in Konso society was institutionalized from the beginning and has been passed down from generation to generation.

Despite changing land policies over hundreds of years, Konso farmers still believe in private land ownership (Beshah, 2003). They frequently use the adage, “What is in your hand is yours until someone takes it away from you”. Thus, farmers build and maintain CSA structures in such a way that they can pass them from generation to generation without worrying about losing intensively conserved land due to changing government land policies. This implies that private and state land ownership greatly contributed to the sustained construction and maintenance of the CSA structures, which enabled them to pass from generation to generation.

7.3.6.2. Government policies and efforts under the various regimes

The forces of Menilik II, led by *Dejazmach* Leuelseged Atnafseged, conquered Konso in 1897. Following the conquest of Konso, the *gabar* system was introduced. In a *gabar* system, two-thirds of the land was appropriated by the state and distributed among officials and local landlords. Farmer (*gabar*) labor was used to cultivate the officials’ farmland. The *gabar* system frustrated farmers and led to the weakening of the CSA structures. However, after 1941, Haile Selassie’s economic reform policy sought to end the *gabar* system through land privatization (Yimam, 2011). The land privatization policy resulted in the restoration, rehabilitation, and strengthening of CSA structures on the farmlands in the Konso area.

The Konso farmers found Derg’s land nationalization programs more oppressive than the old *gabar* system. The Derg cadres banned *parkas*, forcing members to organize themselves into producer cooperatives, which resulted in many farmlands being left uncultivated at the time because of labor shortages. Amborn (1989) argued that the ban on indigenous labor institutions led to a decrease in labor organizations that increased individualization. In general, the Derg abolished the *Xhelta*, *Appa Timpa*, and *Poqalla* indigenous institutions in Konso (Hallpike, 2008) and replaced them with the Peasant Associations (Beshah, 2003). Derg’s land nationalization, agricultural and villagization policies, and the continuous conscription of the national army resulted in the ruining of Konso’s indigenous CSA structures.

The Ethiopian People's Revolutionary Democratic Front (EPRDF) values customs and traditions more than the Derg regime. Consequently, the *Appa Timpa*, *Xhelta*, and *Poqalla* indigenous institutions were reinstated. The reinstatement of these crucial indigenous institutions necessitated the revival and function of the customary practices. Although the Konso people are well-known (registered by UNESCO as a heritage site) for their CSA practices, introducing the technology from the top-down during EPRDF considered the community as new recipients of the technology. The rainwater harvesting pond technology that was recently introduced through the extension service to Konso was found to be ineffective (Behailu et al., 2016; GebreMichael, 2015; Mollo, 2009). The FGD participants in all kebeles criticized the fact that the newly introduced rainwater harvesting plastic cover ponds are smaller in size than the indigenous ponds, thus holding a small amount of water that cannot stay for a month after the cessation of the rainfall. They added that although the plastic cover ponds were built collectively on individual households' farmlands, they did not provide services to the community. This is because after their construction was completed, they were handed over to the owners of the farmland. Consequently, most newly introduced plastic cover ponds are abandoned now (Figure 7.5 (b)).

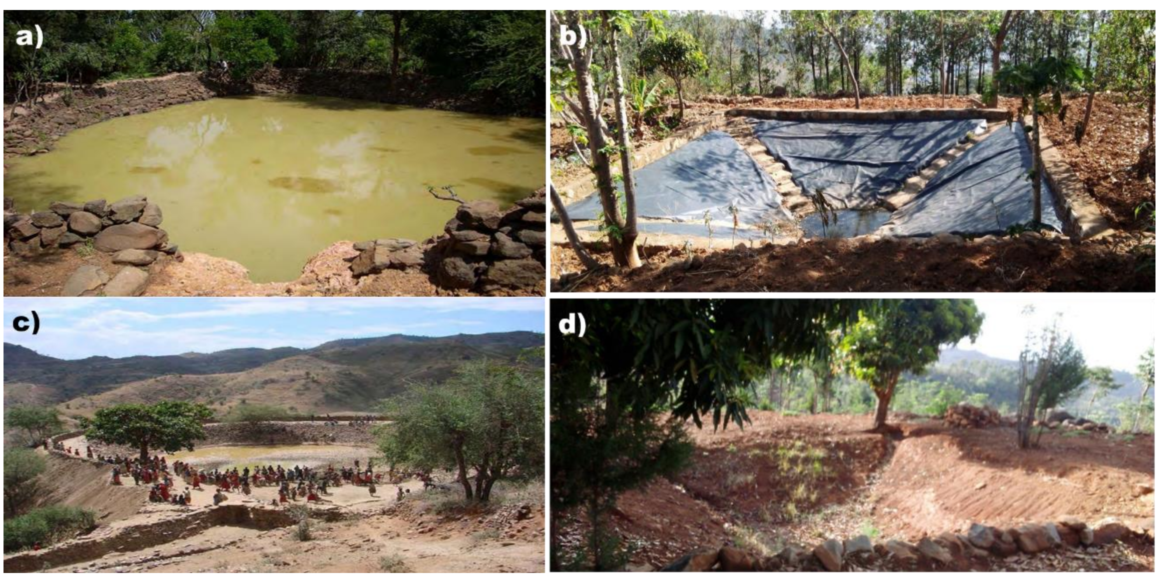

Figure 7.5. (a) and (c) indicate Konso indigenous rainwater harvesting ponds; (b) and (d) show defective introduced rainwater harvesting ponds (Photos 'b' and 'd' are taken by Yohannes Kusse Kulala in January 2022).

After the abandonment of most plastic cover ponds, the local government started paying closer attention to the role of indigenous institutions and local knowledge in natural resource management. As a result, the local government started working in collaboration with indigenous institutions such as *Xhelta*, *Appa Timpa*, and *Poqalla*. This collaborative work resulted in the rejuvenation of indigenous CSA structures, which led to its registration as a world heritage site in 2011. The designation of the Konso cultural landscape as a World Heritage Site contributed to the revitalization of indigenous institutions and labor organizations. According to the FGD and key informants, the community currently discusses development activities with the *palleta* (kebele) chairperson and *Xhelta* to decide whether to accept or reject new proposals. However, the key informants indicated that decision-making is dominated by government officials and development agents (DA).

In addition, the indigenous institutions complain and criticize the quality, strength, and duration of the terraces constructed by the beneficiaries of the PSNP. Similarly, in northwest Ethiopia, Adego et al. (2018) noted that the mass campaign work compromised quality since the usual goal of DAs was to cover a wide area in a short period. Indigenous institutions added that the terraces constructed by household members or labor groups can stay longer and can even pass from generation to generation than the terraces constructed by the PSNP beneficiaries. Similarly, Engdawork and Bork (2014) found that farmers perceive indigenous terraces to be more durable and last for a long time than introduced ones. The Konso farmers indicated that in their indigenous normal terracing system and agricultural practices, no terrace is demolished intentionally by a person unless it is ruined by itself. When a terrace is ruined, they only repair the ruined section of the terrace rather than destroy the entire terrace. This avoidance of demolishing terraces helps them to be stabilized, and even some plants can grow between the stones of the wall, which makes the terraces stronger and stay longer (Figure 7.6(c)). The PSNP campaign work, on the other hand, has been demolishing all of the existing terraces and constructing new straight terraces (Figure 7.6(b)), which function and last for a shorter period than the indigenous terraces. GebreMichael (2015) noted that the PSNP demolished indigenous CSA structures and replaced them with modern ones to ensure their access to food. In terms of duration, all FGDs and key informants appreciated the indigenous terraces more than the modern terraces built by the PSNP and Farm Africa projects. Indigenous terraced landscapes are presented as having an inherent feature of gradual development, as opposed to modern terrace developments, which can cover large areas in a single phase (Balbo & Puy, 2017). Our key informant, Sagare Gapo, an 85-year-old man from Jarso kebele, explained the durability of indigenous terraces and modern terraces as follows:

> The majority of the terraces built by Farm Africa in 1992 were destroyed, whereas indigenous terraces built since the 1970s still exist in the Jarso kebele with no problems (see Figure 7.6). The fate of terraces currently being constructed by PSNP beneficiaries is similar to that of Farm Africa's project.

Crosta et al. (2003) also found that when terraced landscapes are mismanaged or abandoned, they are more prone to erosion and landslides than woodland. For the sustainability of the CSA structures, Konso smallholders suggested repairing only the ruined part of the terraces rather than destroying the entire terrace. As a result, it is crucial to recognize the successful management practices of societies before introducing new technologies or management styles. GebreMichael (2015) noted that despite some of the undesired outcomes in the framework of sustainability, there is no doubt that modern agriculture has played a fundamental role in meeting the food demand of the increasing population. However, the integration of indigenous CSA practices with modern ones can greatly contribute to the sustainability of CSA practices in Konso. Mekonnen et al. (2021) also pointed out that both modern and indigenous knowledge have limitations; thus, integrating the two can provide an additive positive impact that can foster sustainable adaptation and build landscape resilience in the face of climate change.

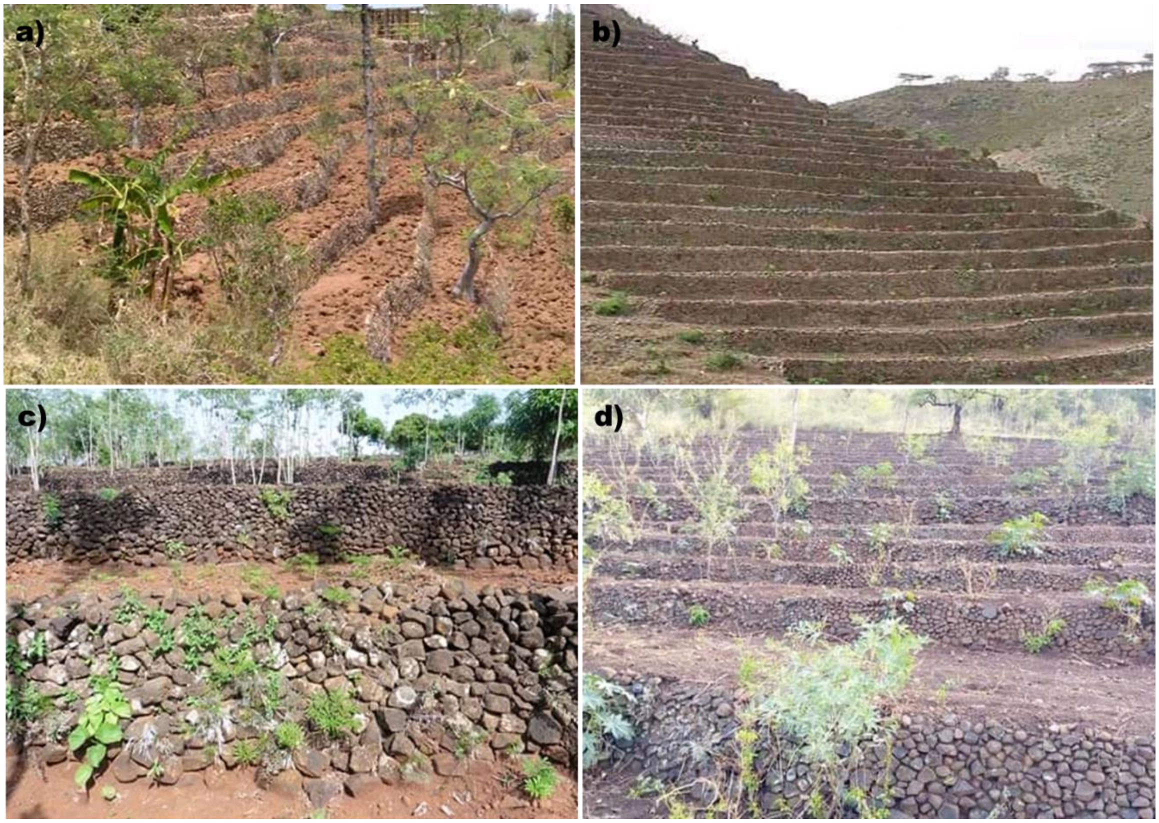

Figure 7.6. (a) Indigenous terraces, (b) modern terraces made by PSNP beneficiaries, (c) old indigenous terraces in Jarso kebele, and (d) old indigenous terraces in Busso kebele.

7.3.7. Interaction patterns and conceptualization of sustainability of the CSA practices

The rugged nature of the topography, frequent droughts, and soil moisture deficits forced the Konso people to commence indigenous CSA structures to adapt to the harsh physical environment. After the original settlers of the Konso commenced CSA practices, the practices have been sustained for hundreds of years through the interaction among various sociocultural, indigenous political institutions, household labor, indigenous cooperative labor institutions, and economic and physical factors (Figure 7.7). In particular, sociocultural values, norms, indigenous cooperative labor, and political institutions all played a pivotal role in the survival of CSA practices for hundreds of years. Sociocultural values such as believing in hard work and despising theft, begging, and litigation laid the foundation for every capable person to construct and maintain CSA structures. These sociocultural values are embedded in the culture of Konso society and are transferred from generation to generation through social learning. Respect for specialized professional terrace makers (*harmota*) and the elderly, as well as folk songs that praise strong terraces, permanent water points, and fertile farmlands, all played roles in knowledge and skill transfers from generation to generation. The Konso's labor organizations, indigenous population control methods, and indigenous governance systems that safeguard the indigenous farming system have allowed this system to thrive.

The long-term survival of the practices depended on the availability of cooperative and sympathetic indigenous labor organizations. The households and free labor groups, such as *ukanta*, *parka*, and *kaffa*, were essential for the survival of CSA structures on individual household farmlands, while collective actions, such as *Kanta* and *Palleta,* were crucial for the sustainability of water wells, rainwater harvesting ponds, flood protection walls, and traditional town walls. The effective administration of indigenous institutions such as the *Xhelta*, the *Appa Timpa*, and the *Poqalla* greatly assisted the continuation of CSA practices on both individual household farms and communal lands. The households that are in need have organized free labor groups such as *ukanta* and *parka*, while *Poqallas's* institutions organized *Kaffa's* work for their clan members who are in need. *Xhelta* supervised and managed CSA practices at both the household and the neighborhood (*Kanta*) level, while *Appa Timpa* supervised and managed at the traditional town (*Palleta*) level. *Appa Timpa* organized *Palleta's* work and safeguarded the traditional law. Economically, sufficient yield is critical to the long-term sustainability of CSA practices. In the past, the Konso population was small, and land could provide a sufficient yield to feed the population. Consequently, sufficient farmland productivity attracted people and made them more focused on the construction and maintenance of CSA practices than off-farm economic activities.

The dual land tenure enabled the people to maintain CSA structures for hundreds of years. The Konso people institutionalized the customary land rights that promote private ownership of land from the beginning of land tenure in the area. Farmers did not fear the loss of conserved land because of changing policies; thus, they often maintained the quality of the CSA structures, allowing for long-term duration. The introduction of modern administration greatly reduced the role of indigenous sociocultural and political institutions. Historically, the role of the state is very low in ensuring the survival of the CSA practices of the Konso. The imperial regime under Menilik II shook the Konso indigenous institutions' foundations, while the Derg regime completely dismantled them. The campaign work attempts made by both the Derg and EPRDF regimes did not reveal any signs of sustainability of CSA practices except for providing food aid for the ever-increasing Konso population. The EPRDF revitalized the Konso indigenous institutions and their role in CSA practices, but they could not effectively restore them because of they were overstretch by modernization, urbanization, population pressure, and external factors such as high climate variability and recurrent droughts.

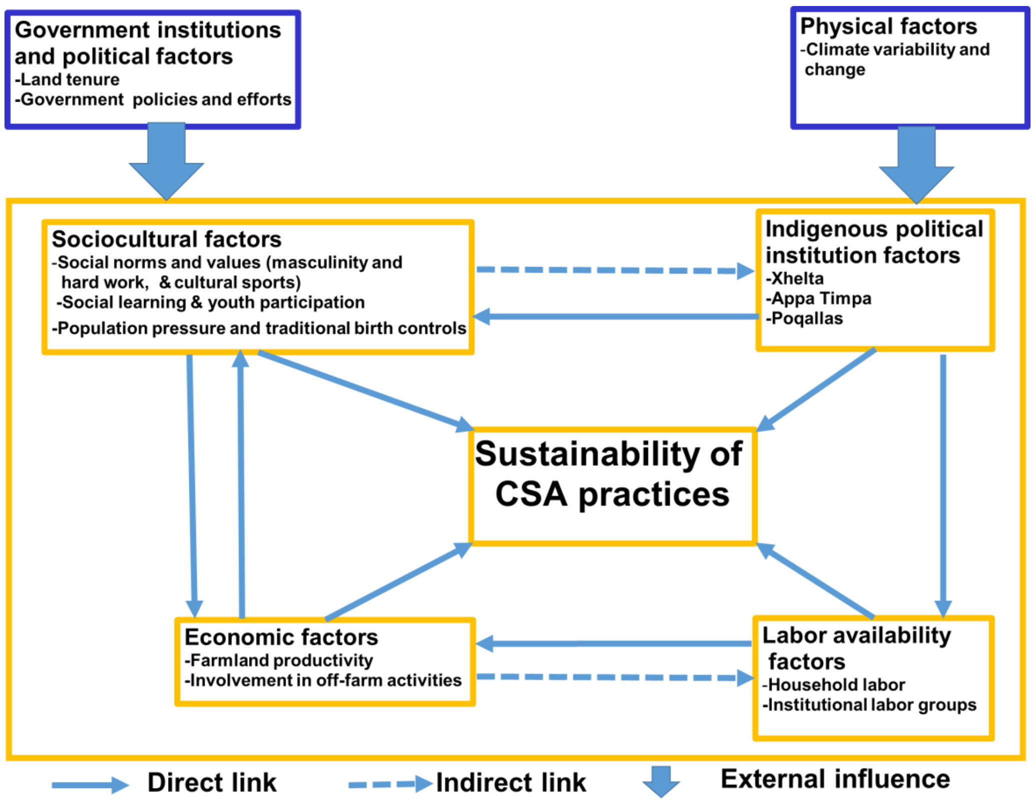

Figure 7.7. A conceptual framework for CSA practice sustainability analysis (source: Authors' conceptualization).

7.4. Conclusion

The study indicates that the long-term CSA structures of the Konso people developed gradually over hundreds of years and covered thousands of square kilometers. For at least 400 years, CSA practices have been sustained through the various essential roles played by deep-rooted sociocultural values and norms, collaborative labor groups, indigenous sociopolitical institutions, and social learning. However, the practices are currently being overstretched by modernization, urbanization, and population pressure. Due to the undermining of social-cultural values and indigenous institutions, long-term CSA practices are deteriorating. Modern administration has led to a gradual weakening of social bonds and respect, which has led to the low performance of free labor groups. Thus, modern interventions in CSA practices should consider local people's success stories before introducing new technologies and management styles. People's exposure to various cultures in urban areas results in disrespect for their cultural values and norms. In the past, the Konso population was relatively small due to indigenous contraception methods, and they could obtain sufficient yields from their intensively conserved farmland while respecting indigenous sociocultural norms and indigenous political institutions. However, currently, farmland productivity is consistently declining, and it is unable to feed the fast-growing population. Therefore, youth prefer to engage in off-farm activities rather than focus on CSA practices, which causes the deterioration of CSA structures. Due to a lack of maintenance, the Konso's CSA practices, once admired and considered a model for others, are in serious threat. Therefore, to effectively restore and ensure the sustainability of Konso's valued indigenous CSA practices, local government should focus on sociocultural forums that emphasize the importance of sociocultural norms and indigenous institutions. Furthermore, government and non-governmental organizations (conservation NGOs) should work together to promote sociocultural norms, values, and indigenous conservation institutions at various administrative levels.

8. SYNTHESIS, CONCLUSION AND RECOMMENDATIONS

8.1. Synthesis

Scientific evidence indicates that the climate of the earth is changing. While a global phenomenon, the magnitude of the negative impacts of climate change can vary considerably across continents and countries (Bewket et al., 2015; IPCC, 2014). East Africa is facing growing trends in minimum and maximum temperatures and high seasonal rainfall variability (Gebrechorkos et al., 2019). Ethiopia is among the countries most likely to experience climate variability during shorter and longer periods in east Africa. Different parts of Ethiopia experience different trends and variability in rainfall. This study (**Gashure & Wana, 2021**) shows an increase in annual and summer rainfall incidences in contrast to previous studies (Belihu et al., 2018; Hessebo et al., 2021; Matewos & Tefera, 2020; Tesfamariam et al., 2019), which indicated a decrease in annual and summer rainfall in the Ethiopian Rift Valley region. Furthermore, in contrast to previous studies, the findings (**Gashure & Wana, 2021**) reported an increase in the frequency of meteorological droughts and high summer rainfall variability (CV = 48.47) as opposed to the usually reported high spring rainfall variability in the Ethiopian highlands (Ademe et al., 2020; Alemayehu & Bewket, 2017; Asfaw et al., 2018) and the Rift Valley region (Matewos & Tefera, 2020; Tesfamariam et al., 2019). On the other hand, this study concurs with earlier studies (Degefu et al., 2021; Mengistu et al., 2019) that reported a decreasing trend in spring rainfall in Ethiopia.

In line with both global and Ethiopian local studies (Ademe et al., 2020; Esayas et al., 2018; IPCC, 2022; WMO, 2020) on climate change, **Gashure and Wana (2021**) show that temperature patterns are continuing to rise, which could aggravate drought conditions by accelerating evapotranspiration and soil moisture loss. In Ethiopia, most of the previous studies on climate change were limited to a large geographical area in highlands. Although Konso is at the top of the country's drought-prone areas, the climate change and spatiotemporal characteristics of the droughts across agro-ecological zones are not studied yet. Thus, this study provides site-specific information about the distribution and severity of droughts across agroecologies and will contribute to the existing knowledge of spatiotemporal climate variability and drought incidents that assists policymakers in designing site-specific adaptation and mitigation policies. So far no previous study was used to examine spatiotemporal associations among various layers, such as rainfall, standardized precipitation index, altitude, agroecology, and terrain ruggedness index, using ArcGIS band collection statistics. Thus, using ArcGIS band collection statistics to study climate change and variability offers new methodological insights.

Agriculture is inherently susceptible to climate variability and climate change is expected to increase this vulnerability (Rosenzweig et al., 2014; Thornton et al., 2011). Global and regional studies have warned that progressive climate change will harm crop productivity in most regions of the world (Knox et al., 2012). Although Ethiopia's Southern Rift Valley Basin, where Konso is located, is highly vulnerable to climate variability, studies on the effects of climate variability on crop production are limited. However, this study, which was conducted in Konso shows that crop production was adversely affected by unreliable rainfall, recurrent droughts, and persistently rising temperatures. Consistent with previous studies (Kassaye et al., 2021; Muluneh et al., 2016; Tesfaye, Kruseman, Cairns, Zaman-allah, et al., 2018; Yang et al., 2020), this study found that crop production has been persistently declining owing to continued warming temperatures (especially minimum temperature), delays, early termination, and a lack of rainfall during the growing season **(Chapter 6)**. Persistent rising temperatures, erratic rainfall, and recurrent droughts, coupled with land fragmentation and declining soil fertility, resulted in declining crop production, which led to the deteriorating livelihoods of smallholders.

A study has demonstrated that CSA practices have the potential to significantly reduce the negative impacts of climate variability on crop production (Challinor et al., 2014). The smallholders' adoption of the various indigenous CSA practices is evidence of their response to the adverse impacts of climate change and variability. In the context of Konso, smallholders autonomously respond to the effects of climate variability and change by adopting multiple indigenous CSA practices, such as terracing, agroforestry, manure application, improved crop varieties, soil bunds, intercropping, reduced tillage, and traditional irrigation (**Gashure & Wana, 2022**). The study pointed out that smallholders' CSA practices adoption is influenced by institutional, socioeconomic, and biophysical factors. Previous studies have also conceptualized that socioeconomic, institutional, and biophysical factors play an essential role in either enhancing or limiting the adoption of CSA practices. However, it is noteworthy that this study has made an extension and modification of the conceptual frameworks used by previous studies by including sociocultural factors, such as social values, norms, and informal indigenous institutions, all of which are important for the adoption and sustainability of CSA practices in Konso and can be applied elsewhere. The sociocultural dimension is included in the framework because the ecological dimensions of agriculture cannot be separated from their social dimensions, as agriculture is the continuous nexus of society and ecology (Wells, 2011). Therefore, the study noted that the adoption and sustainability of CSA practices are the outcomes of socioeconomic, institutional, physical, and sociocultural factors and their interactions (**Gashure & Wana, 2022**).

Despite smallholders' adoption of multiple CSA practices, improving agricultural production has become increasingly overstretched by recurrent droughts, unreliable rainfall, and limited labor and financial resources, particularly over the last three decades (**Gashure & Wana, 2022**). This indicates that the autonomous adoption of indigenous CSA practices is not only knowledge-intensive but also resource-intensive and may be beyond the capacity of smallholders because of the limited resources available. The results of this study agree with the findings of other studies (Ali et al., 2021; Marie et al., 2020; Sertse et al., 2021) in which the adoption of indigenous CSA practices has been influenced by multiple interweaved barriers (poor irrigation potential, lack of finance, labor shortage, intermittent extension and training services, and a shortage of farmland). It is a fact that the adoption of CSA practices improves crop production in a changing climate. This study (**Chapter 6**) produced results that corroborate the findings of the empirical studies (Adego et al., 2019; Asrat & Simane, 2018; Bedeke et al., 2018; Teklewold et al., 2019), which highlighted that the adoption of CSA practices has significantly improved crop productivity. The use of CSA practices assisted smallholders in both the *Kolla* and *Woynadega* agroecologies in minimizing threats that could lead to declines in crop production. The significant increase in sorghum, maize, and *teff* productivity for CSA users demonstrates the essential role of various CSA practices in boosting crop productivity in a changing climate. However, access to climate information, credit services, and agricultural agents also play a key role in determining the application of various CSA practices (**Chapter 6**).

The sustainability of CSA practices is the outcome of various physical, socioeconomic, and cultural factors. On the ground, operationalizing the sustainability of an agricultural system involves a variety of factors, including physical, sociocultural, and economic factors, as well as their interactions (Veisi et al., 2013). It is also noted that any attempt to study agricultural sustainability must focus on the social-ecological context and a proper understanding of agricultural landscapes as a product of social, cultural, and ecological systems (Wittman, 2009). In the context of Konso, the rugged nature of the topography, high susceptibility to erosion, recurrent droughts, and unreliable rainfall have provoked farmers to autonomously develop sophisticated indigenous CSA practices for hundreds of years. The Konso indigenous CSA practices survived and thrived for hundreds of years due to deeply rooted social values, norms, cooperative labor groups, and indigenous political institutions (**Chapter 7)**. However, urbanization and modernization have weakened indigenous institutions and undermined sociocultural values and norms, resulting in a weakening of CSA practices. Furthermore, the persisting decline in farmland productivity due to a lack of rainfall and recurrent droughts, declining soil fertility, and land fragmentation forced the youth to engage in off-farm activities rather than indigenous CSA practices (**Chapter 7**). Consequently, the long-term chains of terraces in Konso are continuously deteriorating because of a lack of maintenance. This suggests that indigenous CSA practices that have sustained the environment and livelihoods for hundreds of years are at risk, and their sustainability is in threat.

8.2. Conclusion

The study shows high seasonal rainfall variability and increasing drought incidents in the study area. The evidence indicates a decrease in *Belg* season rainfall but an increase in annual and *Kiremt* season rainfall. The study also shows that there was substantial spatiotemporal variability in drought incidents due to variations in rainfall, altitude, agroecology, terrain ruggedness, and topographic aspect. The findings demonstrate that the occurrence of drought is positively correlated to altitude and terrain ruggedness. The leeward side regions, particularly at low altitudes in the *Kolla* agroecology in the eastern and western parts of Konso, are highly exposed to severe and extreme drought incidences. Both the annual and seasonal frequency of drought incidents also increased from the 1980s to the 2000s. The observed time-space drought incidents indicate a potential threat to rainfed farming practices, which gradually expose smallholders to socioeconomic vulnerability.

On the other hand, the results indicate an increase in both annual and seasonal minimum and maximum temperatures. Both the annual and seasonal increases in the minimum temperature were higher than the maximum temperature. Thus, the overall increase in the annual temperature recorded in the study area was due to a rise in the minimum temperature. This significant warming trend further intensifies drought conditions as it raises the rate of evapotranspiration in the areas where rainfall is already in deficit. The study provides scientific evidence about annual and seasonal spatiotemporal patterns of rainfall, drought incidents, and temperature for decision-makers to develop local adaptation and mitigation plans. Therefore, based on the drought intensity maps, local and regional decision-makers have to develop adaptation and mitigation plans for climate variability and change impacts.

The findings reveal a positive association between crop (sorghum and maize) production and rainfall in Konso. A multiple linear regression model showed that annual variability in rainfall alone explained the annual production variability of sorghum by 33.2% and maize by 29%. The results also show that climate variability (rainfall and temperature) explains 37.4–47.5% of the annual and 10–67% of the seasonal variations in crop production. The study demonstrates that the high variability in rainfall and the warming trend in temperatures result in a decreasing trend in crop yield. Among the three crops, sorghum showed the highest magnitude of annual yield variation, while maize showed the highest decline. The main causes of the yield decline were a delay, early termination, and lack of rainfall during the growing season that exposed crops to moisture stress. Thus, the high variability in rainfall and warming temperatures suggest that rainfed agriculture is already impacted by climate variability and is likely to be further challenged by future climate change. On the other hand, the study indicates the inverse relationship between crop production and temperature, suggesting the increasing rate of evapotranspiration and crop water requirements that aggravate frequent water stress events due to droughts. The different effects of climate variables on crop production also recommend the need for careful designing and targeting of agro-ecological based adaptation strategies in Konso. I conclude that, with clear evidence of growing stress in smallholder farming systems from climate variability in Konso, greater implementation of diversified cropping systems, crop varieties, and irrigation can significantly improve crop yields.

The study indicates that smallholders respond to the effects of climate variability and change by adopting multiple indigenous CSA practices such as terracing, agroforestry, manure application, improved crop varieties, soil bunds, intercropping, reduced tillage, and traditional irrigation. The study reveals a statistically significant difference in the adoption of the CSA practices between the *Kolla* and *Woynadega* agro-ecological zones. A high percentage (83%) of smallholders in *Kolla* adopted terracing that allowed the cultivation of even the steepest slopes and the prevention of erosion and trapping water. The Konso traditional agroforestry focuses on multipurpose trees (*Moringa stenopetala* and *Terminalia brownii*) that diversify income, reduce soil erosion, provide soil organic matter, and supply browse for livestock, local construction, and fuelwood. The study shows a statistically significant difference in the adoption of intercropping between the two agroecologies. Crop diversity is higher in *Woynadega* than in the *Kolla* agro-ecological zone. However, more smallholders in the *Kolla* have adopted improved crop varieties than in the *Woynadega.* The intention of crop diversification and using improved varieties is to balance the mix to achieve food security in a bad year while also obtaining the highest possible cash crop yield in a good year. Thus, the adoption of terracing in combination with integrated crop-tree-livestock systems has shown greater effectiveness in minimizing the risk of exposure to climate variability and change.

Various institutional (e.g., access to climate information, credit, and extension services) and socioeconomic factors influenced the adoption of indigenous CSA practices. The study reveals a positive association between access to credit and the adoption of terracing, agroforestry, manure, crop varieties, and traditional irrigation. The multinomial logit model revealed that educational status, landholding, and family size positively influence the adoption of terracing, agroforestry, soil bunds, and traditional irrigation. Furthermore, access to climate information, agricultural extension services, and credit positively influence the adoption of terracing and manure. Hence, it is important to enhance farmers' adaptive capacity by facilitating access to reliable climate information, agricultural extension, and credit services. In addition, the model revealed that farming in the *Woynadega* increased the likelihood of using terracing, crop varieties, and implementation of reduced tillage.

This study highlights that the indigenous CSA practices were autonomously developed in Konso through generations by the smallholder farmers. The rugged nature of the topography, high susceptibility to erosion, recurrent droughts, and unreliable rainfall have provoked them to develop indigenous CSA practices for hundreds of years. Even though the autonomous CSA practices have long served them to withstand the effects of climate variability and change, the impacts of climate change have already overstretched the meager resources and local adaptation limits due to the increased frequency of droughts and stochastic rainfall. In addition, recently, the adoption of indigenous CSA practices has been influenced by multiple interweaved barriers, which include poor irrigation potential, lack of finance, labor shortage, intermittent extension and training services, and a shortage of farmlands. This study, therefore, informs the need to interject external support in the form of regular weather information, reliable and affordable credit services, and crop insurance to support the local livelihoods and ensure the sustainability of the Konso traditional farming system. Furthermore, policy-driven actions to provide drought-resistant and early-maturing crop varieties and livelihood diversification into non-farm/off-farm employment opportunities are important strategies to reduce stallholders' vulnerability to climate change in Konso.

The ESR model showed strong evidence of the positive impact of the adoption of CSA practices that reduce the adverse effect of climate variability and change on households' crop production in the study area. The model results show a significant positive association between crop yield and CSA practices such as terracing, crop diversification, manure, and traditional irrigation. The treatment effect shows that the average sorghum, maize, and *teff* productivity of CSA users is significantly higher than that of non-users. However, the smallholders' crop productivity is influenced by various institutional and socioeconomic factors. Institutional factors such as access to climate information, credit services, and agricultural agents have played a significant role in increasing the adoption of CSA practices and crop productivity. In addition, socio-economic factors such as age, education, landholding, household size, and off-farm activities have a significant positive effect on the adoption of CSA practices and crop productivity. Therefore, planning and implementation of CSA practices should consider access to climate information, credit service, and agricultural agents as well as socioeconomic factors.

Through the interaction between various sociocultural, indigenous political institutions, household labor, indigenous cooperative labor institutions, and economic and physical factors, the CSA practices of the Konso have been sustained for hundreds of years. Sociocultural values such as believing in hard work and despising theft, begging, and litigation laid the foundation for every capable person to construct and maintain CSA structures. Nonetheless, modernization, urbanization, and population growth are putting a strain on these practices. CSA practices are deteriorating due to the undermining of social-cultural values and indigenous institutions. As a result of modern administration, free labor groups have shown low performance as social bonds and respect weaken gradually. People's exposure to various cultures in urban areas results in disrespect for their cultural values and norms. In the past, as a result of indigenous contraception methods, the Konso had a relatively small population and could obtain enough yield from their intensively conserved fields. Currently, farmland productivity is consistently declining, and it is unable to feed the fast-growing population. Therefore, youth prefer to engage in off-farm activities rather than focus on CSA practices, which causes the deterioration of CSA structures and Konso's indigenous CSA practices. Therefore, to effectively restore and ensure the sustainability of Konso's valued indigenous CSA practices, Konso bureaus of culture, tourism, and agriculture should focus on sociocultural forums that emphasize the importance of sociocultural norms and indigenous institutions. Moreover, governments and non-governmental organizations (conservation NGOs) should work together to promote socio-cultural norms and values and indigenous conservation institutions at various administrative levels.

8.3. Recommendations and the way forward

- The study reveals high variability in seasonal rainfall, rising temperatures, and increasing drought episodes in Konso. The agroecological-based analysis of the drought incidents indicates that a large percentage of the *Kolla* agroecological zone was under drought. This suggests the need for interventions based on agro-ecological zones, with greater emphasis on the *Kolla* agro-ecological zone. Thus, based on these empirical findings, policy-driven actions to provide drought-resistant, early-maturing improved crop varieties, and agroforestry are suggested, particularly for the *Kolla* agro-ecological zone. Rainwater harvesting and small-scale irrigation also need to be strengthened and expanded as part of interventions.
- The study shows a statistically significant difference in the usage of the indigenous CSA practices between the *Kolla* and *Woynadega* agro-ecological zones. This recommends the need for interventions to focus on agro-ecological zones by considering the types of indigenous climate-smart practices in each agro-ecological zone.
- Various institutional and socioeconomic factors influenced the adoption of indigenous CSA practices. Access to climate information, agricultural extension services, and credit positively influence the adoption of terracing and manure. Therefore, to enhance the usage of indigenous CSA practices, institutional support such as improved extension services, credit services, and reliable climate information are indispensable at the household level in Konso.
- The adoption of indigenous CSA practices has been constrained by a shortage of farmland. Hence, livelihood diversification into nonfarm/off-farm employment opportunities is an important strategy to reduce the pressure on the farmland in Konso. Also agro-processing (value chain development) is important to strengthen local service sector Establishing an industrial park in Konso could create job opportunities for many people. Furthermore, investing in education can relieve much of the pressure from the agricultural sector. To increase CSA adoption and crop

productivity, institutional factors such as climate information, credit services, and agricultural agents have played a significant role. Therefore, climate information, credit services, agricultural agents, and socioeconomic factors should be taken into account when planning the implementation of CSA practices. To enhance farmers' preparedness for extreme events and to develop prompt disaster risk response strategies, local weather forecasting systems and implications must be improved. The lack of finance and credit services is the major bottleneck for the use of indigenous climate-smart practices. Therefore, external support in the form of reliable and affordable credit services and crop insurance to support the implementation of practices is essential.

- Indigenous institutions and values such as hard work, despising theft, begging, and litigation laid the foundation for every capable person to build and maintain CSA structures in Konso. However, these indigenous institutions and socio-cultural values are becoming weak. Therefore, the study recommends sociocultural platforms that emphasize the role of sociocultural values and indigenous institutions in Konso.
- The study pointed out that indigenous CSA practices are currently being overstretched by modernization and urbanization, which has led to the deterioration of long-term CSA practices due to a gradual weakening of social bonds and respect. Thus, modern interventions in CSA practices should consider local people's success stories before introducing new technologies and management styles.
- In Konso, currently, the youth disrespect the sociocultural values and prefer to engage in off-farm activities rather than focus on indigenous CSA practices, which causes the deterioration of CSA structures. Therefore, to effectively restore and ensure the sustainability of Konso's valued indigenous CSA practices, the Konso bureau of culture and tourism should focus on sociocultural forums that emphasize the importance of sociocultural norms and indigenous institutions.

Finally, this dissertation attempted to explore historical climate variability and drought incidents, but climate predictions, future climate impacts on crop production, and community vulnerability were not addressed. Thus, future research needs to focus on climate predictions, future climate impacts on crop production, and community vulnerability. My dissertation examined the impacts of only rainfall and temperature variability on sorghum, maize, and *teff* yields. Hence, I recommend that future studies incorporate solar radiation, soil moisture, nutrient availability, and the onset, cessation, and duration of the rainy season into the model to better understand the causes of yield variability. It is also important to note that my study focused on the adoption of adaptation practices to climate variability and change, while the community's resilience and greenhouse gas emission reduction potential were not addressed. Therefore, any future studies should focus on community resilience and the greenhouse gas emission reduction potential of indigenous CSA practices to enhance our understanding of climate change impacts. Furthermore, the study assessed the impact of indigenous CSA practices on crop production. However, the study did not examine the impacts of implementing indigenous CSA practices on household food security. Therefore, future research should focus on the impacts of the practices on household food security.

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ANNEXES

Annex 1. **Household survey questionnaire**

Department of Geography and Environmental Studies

Household survey questionnaire

Introduction

Dear respondent, the aim of this study is to explore indigenous climate-smart agricultural (CSA) practices of Konso people in a changing climate with the main focus on adaptation strategies and crop productivity. It is purely academic research to be conducted to acquire a Doctor of Philosophy (Ph.D.) Degree in Geography and Environmental Studies with specialization in Environment and Natural Resources Management. Therefore, your kind cooperation with true answers to the questionnaire will be important to the overall success of the study. Hence, you have to feel free to complete the questionnaire. I would like to appreciate your cooperation in advance!

General Instruction

- ☞ For the close-ended questions close-ended questions make a tick mark ☑ in the box provided or encircle the chosen response!
- ☞ You can use the blank space provided for additional information or justification!

Part 1: Household Identification

Date_______________ Time: Start: _________Finish______________

Enumerator name:__________________ Signature: ______________

1. Household ID. No_ _____________

2. *Woreda* (district): __________________

3. *Kebele* (sub-district):_____________________________

4. Village: _________________

5. Agroecology: 0. Lowland (*Kolla*) 1. Midland (*Woynadega*)

Part 2: Household head demographic information

6. Gender: 0. Female 1. Male

7. Age:_________(years)

8. Educational status: 0. Illiterate 1. Literate:___________(years of formal education)

9. Family size: Male: ________Female: _________ Total family size: __________

10. Occupation: 1. Farming 2. Trade 3. Hand craft 4. Wage Labor 5. Gov't employee Others(specify)____

Part 3: Household land ownership

11. Do you own farmland? 1. Yes 0. No

12. If yes, what is its size in hectares? _______ (ha). Number of plots: _______________ average size of your plots: ________________

13. Do you think that the yield of your plots is enough to support your family? 1. Yes 0. No

14. If no, what are the reasons? Multiple answers are possible. 1. Lack of agricultural inputs 2. Soil fertility decline 3. Small size of land 4. Large family size 5. Others (specify) ______________________________________

Part 4: Crop productivity and adoption of climate-smart practices

15. Productivity of your farmland from time to time? 1. Increasing 2. Decreasing 3. The same 4. Not sure

16. If it is increasing, what are the reasons? Multiple answers are possible. 1. Increased soil fertility 2. Strong soil and water conservation practices 3. Strong extension service 4. Suitable weather conditions 5. Use of improved technologies (improved seed, fertilizer) 6. Others (specify) _____________________.

17. If it is decreasing, what are the reasons for the decrement of your cultivated land productivity? Multiple answers are possible. 1. Decline in soil fertility 2. Weak extension service 3. Occurrence of frequent droughts 4. Weakening of soil and water conservation practices 5. Others (specify) _____________________

18. What are the major constraints to your farmland productivity? Multiple responses are possible. Identify the four key impediments to crop productivity and rank them based on their order of importance.

Constraint	Rank (1st, 2nd, 3rd)
1. Erratic rainfall and recurrent droughts	
2. Land degradation	
3. Lack of inputs	
4. Soil infertility	
5. Pests and crop diseases	
6. Others (specify)_________________________	

19. Do you have irrigated farmland? 1. Yes 0. No. If yes, __________hectares?

Crop production (2006-2011 E.C.)

Produced crop type	2011		2010		2009		2008		2007		2006	
	Plot area	Qt	Plot area	Qt	Plot area	Qt	Plot area	Qt	Plot area	Qt	Plot area	Qt
1. Sorghum												
2. Maize												
3. Haricot bean												
4. Finger millet												
5. Pea												
6. Cassava												
7. Others (specify)												
Total income in birr												

20. Have you ever faced crop failure? 1. Yes 0. No
21. What are the major causes of crop failure? ______________________________
22. Did you get relief? 1. Yes 0. No
23. If yes, from whom did you get it? ___________________________
24. Have you applied CSA practices? 1. Yes 0. No

25. If you apply CSA practices, which one did you use from the following?

Climate smart agricultural practices	1.Yes	0. No
1. Terracing Application of		
2. Agroforestry		
3. New crop varieties		
4. Soil bunds		
5. Intercropping		
6. Reduced tillage		
7. Use of animal manure for fertilizer		
8. Improved water conservation (irrigation, pond, harvesting rainwater.)		
9. Others (specify)		

26. Please list the both advantages and disadvantages of climate-smart agricultural practices

Climate-smart agricultural practices	Advantages	Disadvantages
Terracing Application of		
Agroforestry		
New crop varieties		
Soil bunds		
Intercropping		
Reduced tillage		
Use of animal manure for fertilizer		
Improved water conservation		
Others (specify)		

27. What are the major problems that impede the implementation of the above-listed climate-smart practices?

Constraints	1.Yes	0. No
1. Poor irrigation potential		
2. Lack of finance		
3. Shortage of labour		
4. Lack of extension and training services		
5. Limited land resources		

Part 5: Livestock Ownership

28. Do you have livestock? 1. Yes 0. No

Animal	Size in number	
	Local	Improved
1) Cattle		
2) Goat		
3) Sheep		
4) Donkey		
5) Poultry		
6) Others (specify)		

29. Did you sell livestock this year? 1. Yes 0. No

30. If yes, why did you sell livestock? Multiple responses are possible.

1. For buying food and other consumer
2. goods
3. For buying agricultural inputs
4. To pay loan
5. To reduce drought risk
6. For buying clothes
7. Other (specify) ________

Part 6: Access to weather and climate information

31. Do you have access to climate-related information? 1. Yes 0. No

32. If yes, what is the source of information? 1. Radio 2. Television 3. Neighbor/friends 4. Extension agent 5. Social institution 6. Local meeting 7. Indigenous knowledge 8. Other (specify)_________________________

33. How did you use this information? 1. Change land management 2. Change crop variety 3. Change timing of activities 4. Implement soil and water conservation activities 5. Others (specify) _____________________________

34. How often have you been informed about the potential risk of natural disasters (erratic rainfall, flooding, outbreak of crop pests and diseases) 1. Frequently 2. Occasionally 3. Rarely

35. How do you rate reliability and the contribution of the early warning system for you to withstand the shocks? 3. High 2. Medium 1. Low

Part 7: Access to agricultural extension services

36. . Do you have access to agricultural extension services? 1. Yes 0. No

37. How often does the extension agent visit you to provide extension information? 1. Daily 2. Weekly 3. Once in two weeks 4. Monthly 5. Once in three months 6. Not at all

Part 8: Involvement in off-farm activities

38. Do your household members participate in off-farm activities? 1. Yes 0. No

39. If yes, what are the activities and the amount of income from the job? Multiple answers are possible.

Type of off-farm activity	Income per year (Birr)
1. Government employee	
2. Petty trade	
3. Pottery	
4. Firewood collection and sale	
5. Charcoal making and sale	
6. Daily laborer	
7. Tanning	

8. Wavering	
9. Carpentry	
10. Jewelry and Welding	
11. Other (specify)______________	
12. Total income from nonfarm	

Part 9: Access to credit

40. Access to credit services? 1. Yes 0. No

41. If yes, what are the source, amount of credit received and purpose?

Source of credit	Amount of credit received (Birr)	The purpose for which you received the money? (use codes next to table).
1. Bank		
2. Omo microfinance inst.		
3. Local money lender		
4. Friends/relatives		
5. Saving and credit associations		
6. Iddir		
7. Equib		
8. Marketing cooperative		
9. NGOs		
10. Others (specify)		

Codes for reasons. 1. Input purchase for crop production 2. Animal purchase 2. Food grain purchase 4. Petty trade 5. Other income generating activities 6. Repay debt 7. Others (specify)____.

42. If No, what was the problem? (Multiple answers are possible). 1. I did not want to take loan 2. I couldn't find a loan that met my needs 3. I afraid that I couldn't pay back 4. There are no loan providers in our locality 5. High interest rate 6. Others (specify) ______________

Part 10. Access to market

43. Distance from your home to the main market? ____________km.

44. Market linkage for selling your agricultural products? 1. Yes 0. No

45. Market price for your agricultural products is sufficient? 1. Yes 0. No

Part 11: Social networks

46. How many relatives and friends do you have in your locality? _________________

47. In the last 12 months, which of the following types of help did you receive or provide to relatives (more than one option possible)

Type of help	Help given (√)	Help received (√)
Land tillage and preparation		
Planting		
Weeding		
Harvesting		
Sell animal products or other goods		
Attending sick animals		
Constructing soil and water conservation structures		
During human sickness		
Building/maintenance of house		
Borrowing money		
Borrowing or Providing seed		
During death		
During marriage		
Mediating conflicts		
Other (Specify)		

Part 12. Sustainability

48. Make a tick (√)

Status of the	Strengthening	Weakening	No change	Not sure
Social norms concerning CSA practices from time to time.				
Participation in CSA practices from time to time				
Participation of young/new generation in constructing and maintaining CSA structures				
Construction of new CSA				
Maintenance of existing structures from time to time.				
Labor availability of for CSA				
Quality CSA structures from time to time				

Thank you!!

Annex 2. **Guide for key informant interviews and FGDs**

1. Do you think that there is a change in temperature, rainfall, and drought incidents in your locality?
2. Do you think that rising temperatures, erratic rainfall, and recurrent droughts have an adverse impact on crop production? What are the impacts?
3. How did you overcome the adverse impacts of climate change and variability?
4. What CSA practices do you use in response to changing climate conditions?
5. Do soil and water conservation practices have an impact on reducing climate change and variability impacts on crop production?
6. How can climate smart practices increase crop productivity?
7. What are the advantages and disadvantages of CSA practices such as terracing, agroforestry, intercropping, new crop varieties, manuring, reduced tillage, and irrigation?
8. What are the key constraints to the usage of CSA practices?
9. Do Konso social values and norms contribute to the adoption and sustainability of CSA practices?
10. Are there platforms for social learning in the Konso community that support the transfer of indigenous CSA practices from generation to generation?
11. Where and when does social learning take place?
12. Do young people have the skills and are actively involved in CSA practices?
13. Are there indigenous political institutions that assist in the adoption, survival, and sustainability of indigenous CSA practices?
14. What are the fundamental roles of each indigenous political institution in natural resource conservation?
15. Are there indigenous free labor organizations in your locality?
16. What are the names of the indigenous labor organizations and their major roles in CSA practices?
17. How has your farmland productivity been over the last 30 years?
18. Are you involved in off-farm activities? What are them?
19. Do you earn better income from off-farm activities than the agricultural activities?
20. Does the current land tenure encourage CSA practices?
21. Do government policies encourage indigenous CSA practices?
22. Based on your experience, which regimes encouraged sociocultural values, norms, and indigenous institutions?
23. Is there a shortage of CSA structures' construction and maintenance materials in your area?
24. What are the major challenges to the sustainability of CSA practices in your area?
25. What do you suggest for the sustainability of indigenous CSA practices in your area?

Annex 3. **Observation guide**

1. Topography and the stone availability.
2. The nature, types, and current status of CSA structures on smallholder farmlands.
3. Currently, built or repaired indigenous or introduced CSA structures.
4. Demolished conservation structures.
5. Labor groups both at work and feast.
6. Indigenous institutions such as Xhelta, Poqalla, and Appa Timpa.
7. Public gathering places (Moora).
8. Public discussions and fining offenders.
9. Folk song singing and dancing areas.
10. Traditional town walls.
11. Flood protection walls along the rivers.
12. Rainwater harvesting ponds and water wells.
13. Both traditional and modern irrigation.

Annex 4. **Parameter estimates of the MNL model for CSA practices adoption**

Variables	Terracing	Agroforestry	Manure	Crop varieties	Soil Bunds	Intercrop.	Reduced tillage	Irrigation
Agroecology	3.596*** (0.959)	0.729 (0.560)	0.617 (0.491)	2.070*** (0.593)	-0.056 (0.505)	-1.029** (0.504)	2.261*** (0.606)	-0.378 (0.476)
Sex	-0.124 (0.952)	-2.739*** (0.982)	-0.395 (0.736)	1.758*** (1.070)	-0.007 (0.764)	-0.390 (0.789)	-1.585 (1.083)	1.076 (0.672)
Age	-0.012 (0.027)	0.008 (0.030)	-0.023 (0.022)	-0.058** (0.023)	0.038 (0.021)	0.029 (0.023)	0.038 (0.023)	0.013 (0.018)
Education	0.442 (0.951)	0.199 (0.866)	-0.665 (0.727)	-1.078 (0.886)	0.229 (0.783)	2.214*** (0.801)	1.314 (0.910)	0.073 (0.681)
HH size	0.043 (0.073)	0.261*** (0.079)	0.090 (0.061)	-0.033 (0.064)	0.035 (0.059)	-0.069 (0.063)	0.011 (0.066)	0.004 (0.052)
Landholding	0.269 (0.233)	0.621*** (0.224)	0.443** (0.178)	0.342 (0.208)	-0.013 (0.185)	-0.70*** (0.182)	0.401 (0.218)	0.325** (0.166)
Off-farm	-0.492 (0.873)	0.180 (0.840)	0.871 (0.712)	-0.739 (0.894)	-0.455 (0.719)	0.758 (0.837)	0.691 (0.915)	0.435 (0.710)
Climate info	0.426 (0.697)	-0.092 (0.633)	0.090 (0.559)	-0.231 (0.649)	-0.267 (0.582)	-0.055 (0.574)	0.373 (0.652)	-0.493 (0.555)
Agri. Agents	0.473 (0.841)	-0.780 (0.715)	0.605 (0.621)	-0.748 (0.710)	0.237 (0.624)	0.346 (0.599)	0.558 (0.719)	-0.128 (0.592)
Credit	0.666 (0.440)	1.073 (0.624)	0.084 (0.374)	0.324 (0.364)	-0.262 (0.342)	-0.179 (0.390)	-0.277 (0.373)	0.502 (0.287)
Market dist.	-0.31*** (0.049)	-0.088** (0.040)	0.016 (0.025)	-.096*** (0.031)	0.125*** (0.030)	-0.011 (0.026)	0.125*** (0.033)	0.033 (0.020)
Relatives	0.010 (0.008)	-0.009 (0.009)	-0.005 (0.007)	0.017** (0.007)	-0.015** (0.007)	-0.008 (0.007)	0.015** (0.007)	-0.008 (0.006)
Livestock	-0.328 (0.472)	0.091 (0.555)	0.415 (0.440)	1.045** (0.443)	-0.603 (0.401)	-0.748 (0.448)	-0.555 (0.449)	-0.411 (0.323)
Relief	2.855*** (0.434)	0.381 (0.373)	0.87*** (0.291)	2.226*** (0.331)	-1.72*** (0.290)	-.643** (0.297)	-2.36*** (0.354)	-.93*** (0.243)
No of obs.	= 355							
Pseudo R^2	= 0.4217							
Model $\chi^2(14)$	= 181.21							

*** and **significant at p<0.01, and p<0.05, respectively; R^2 coefficient of determination; standard errors in the parentheses

Annex 5. **Annual rainfall and temperature explained production variability (1983-2016).**

Crop	Annual rainfall and temperatures	R^2
Sorghum	Annual rainfall	0.332
	Annual minimum and maximum temperatures	0.17
Maize	Annual rainfall	0.29
	Annual minimum and maximum temperatures	0.233
Teff	Annual rainfall	0.04
	Annual minimum and maximum temperatures	0.375

Annex 6. **Supplementary Figures.**

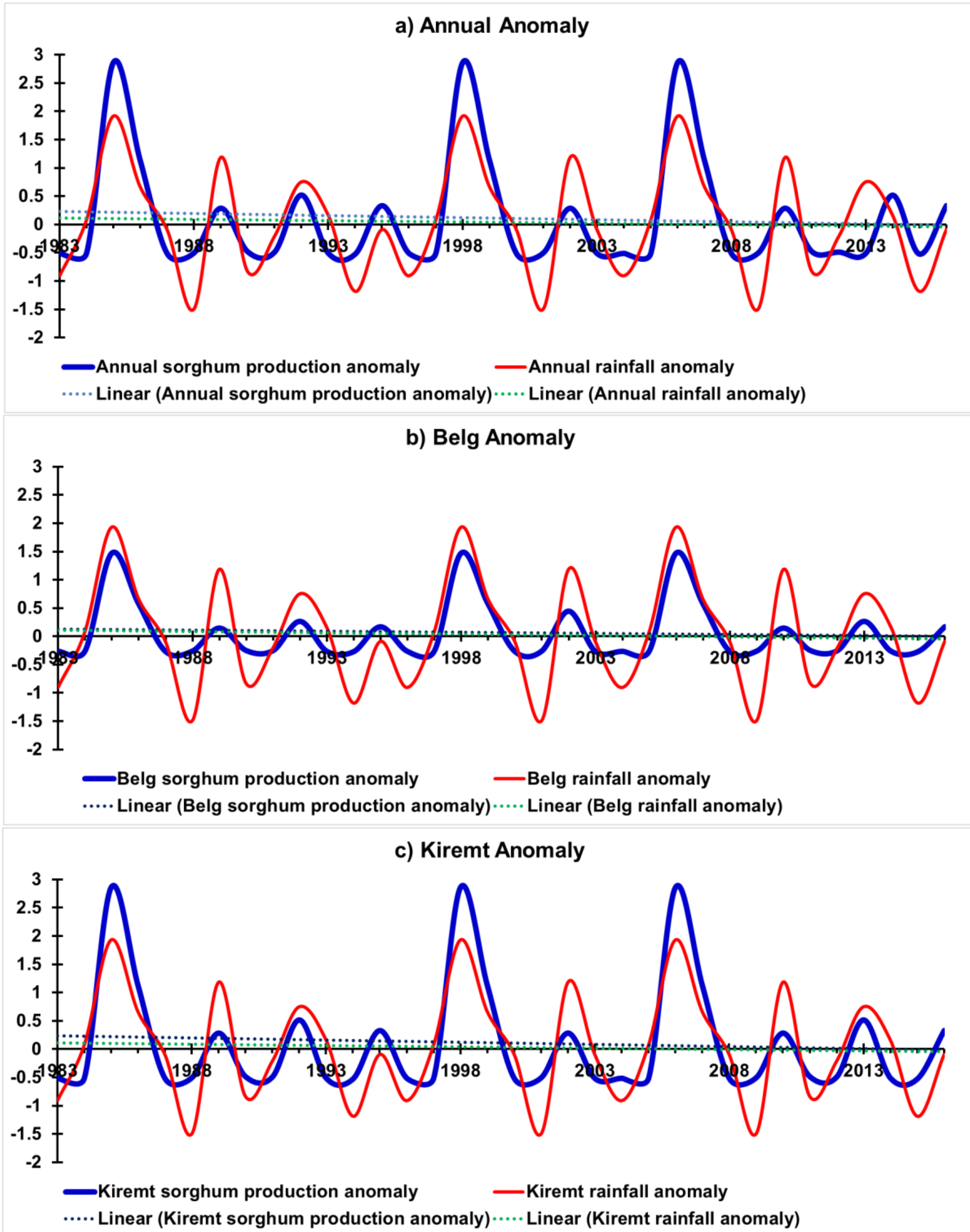

Figure 1 Trends of sorghum production and rainfall anomalies (1983–2016)

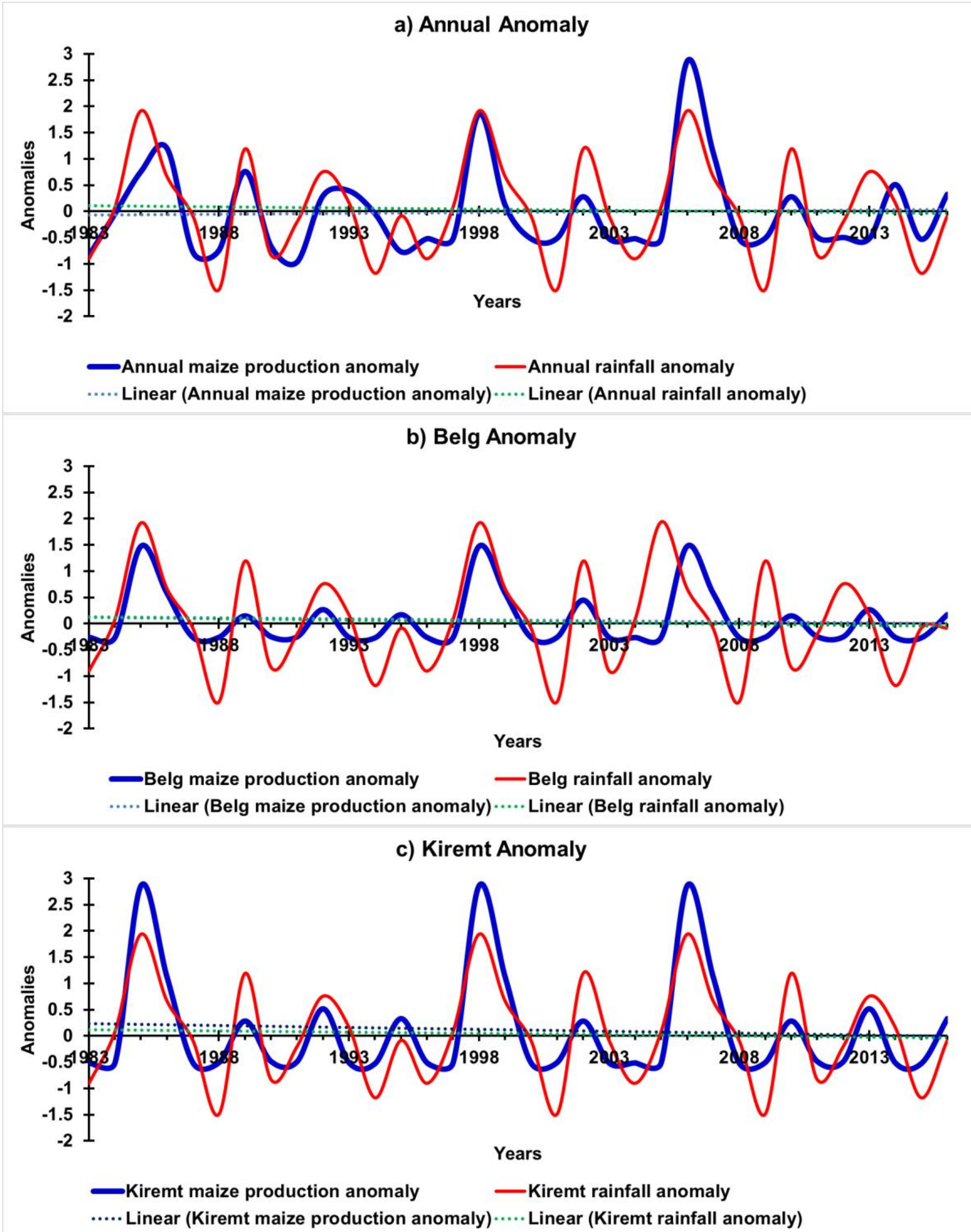

Figure 2 Trends of maize production and rainfall anomalies (1983–2016)

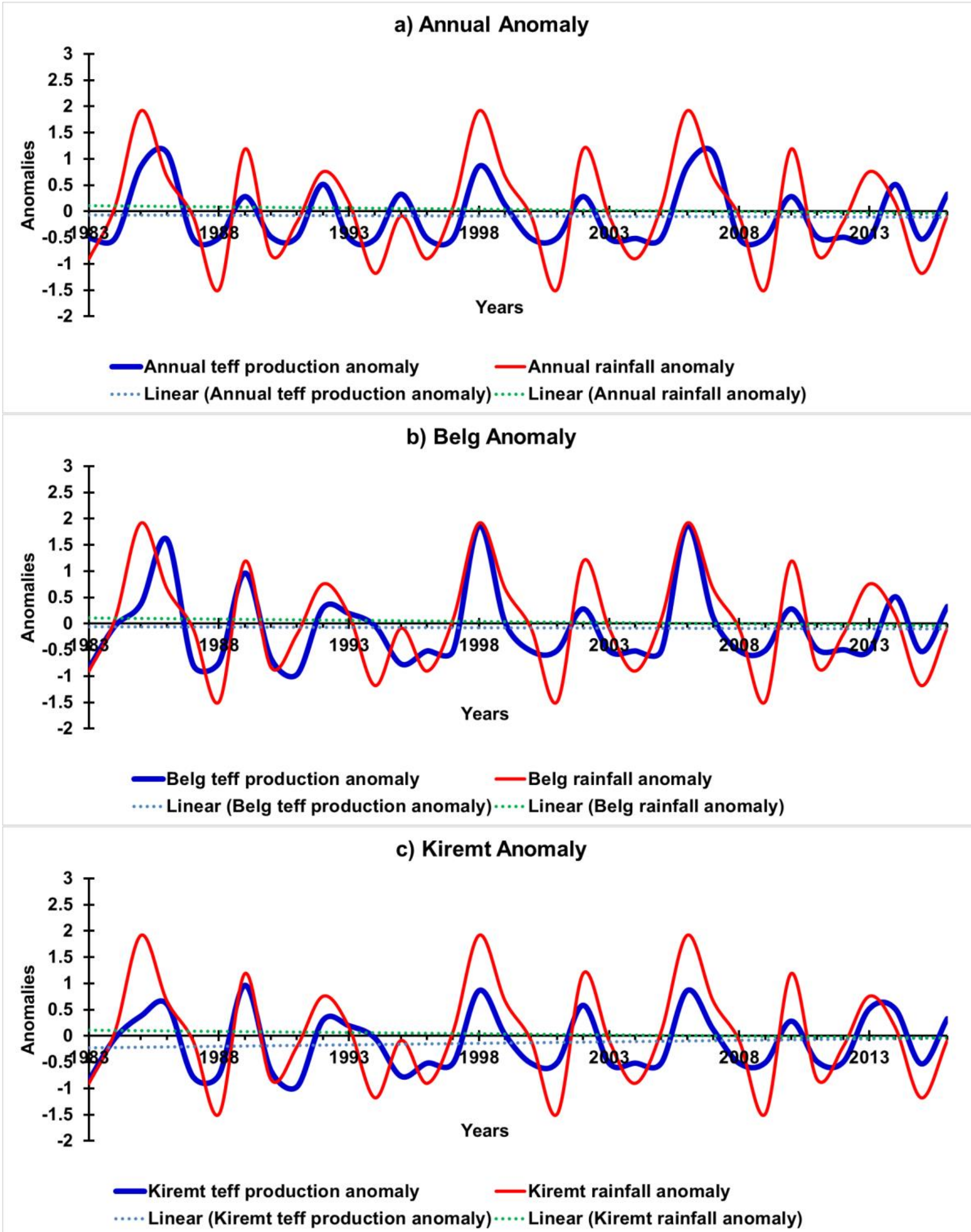

Figure 3 Trends of teff production and rainfall anomalies (1983–2016)

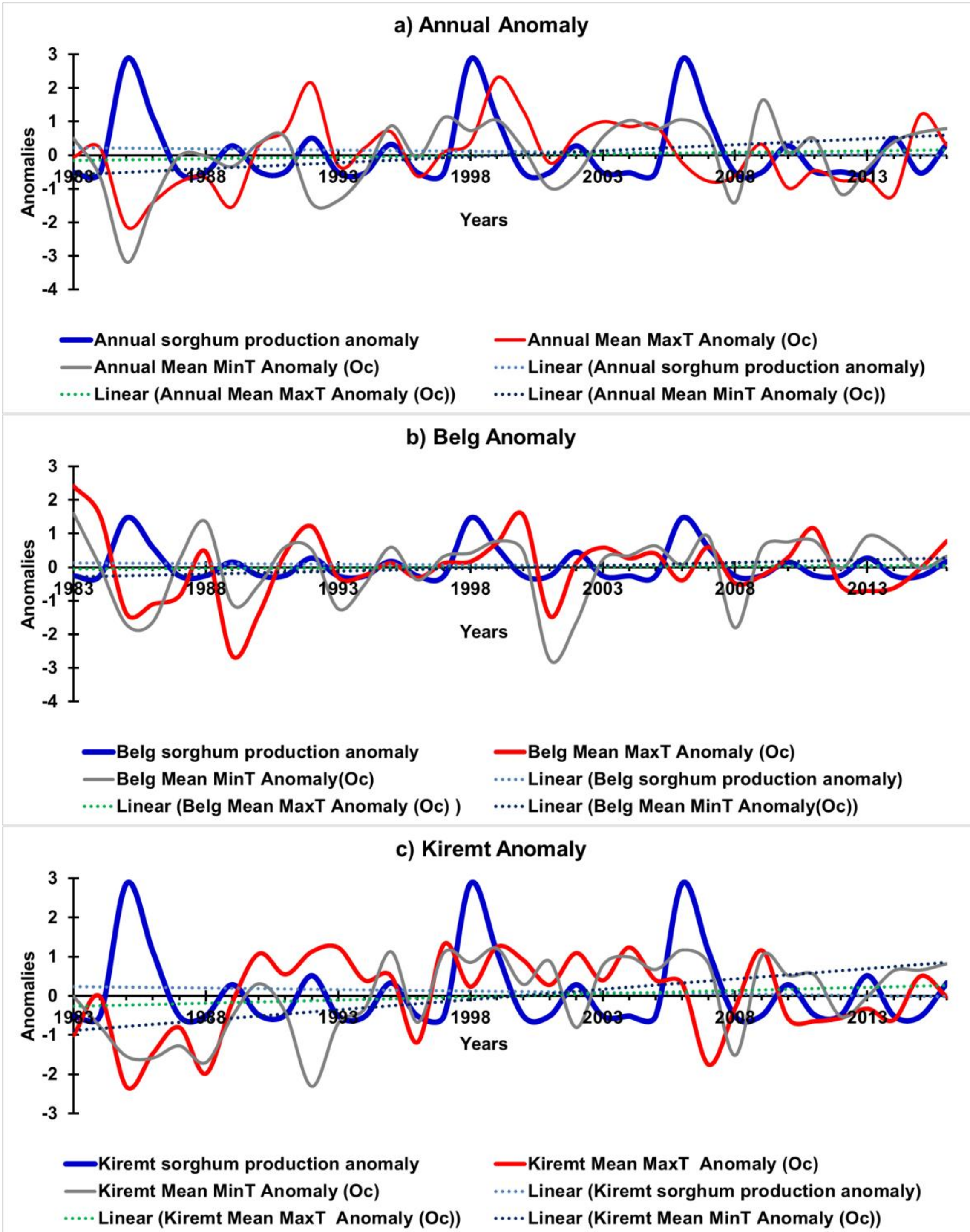

Figure 4 Trends of sorghum production and temperatures anomalies (1983–2016)

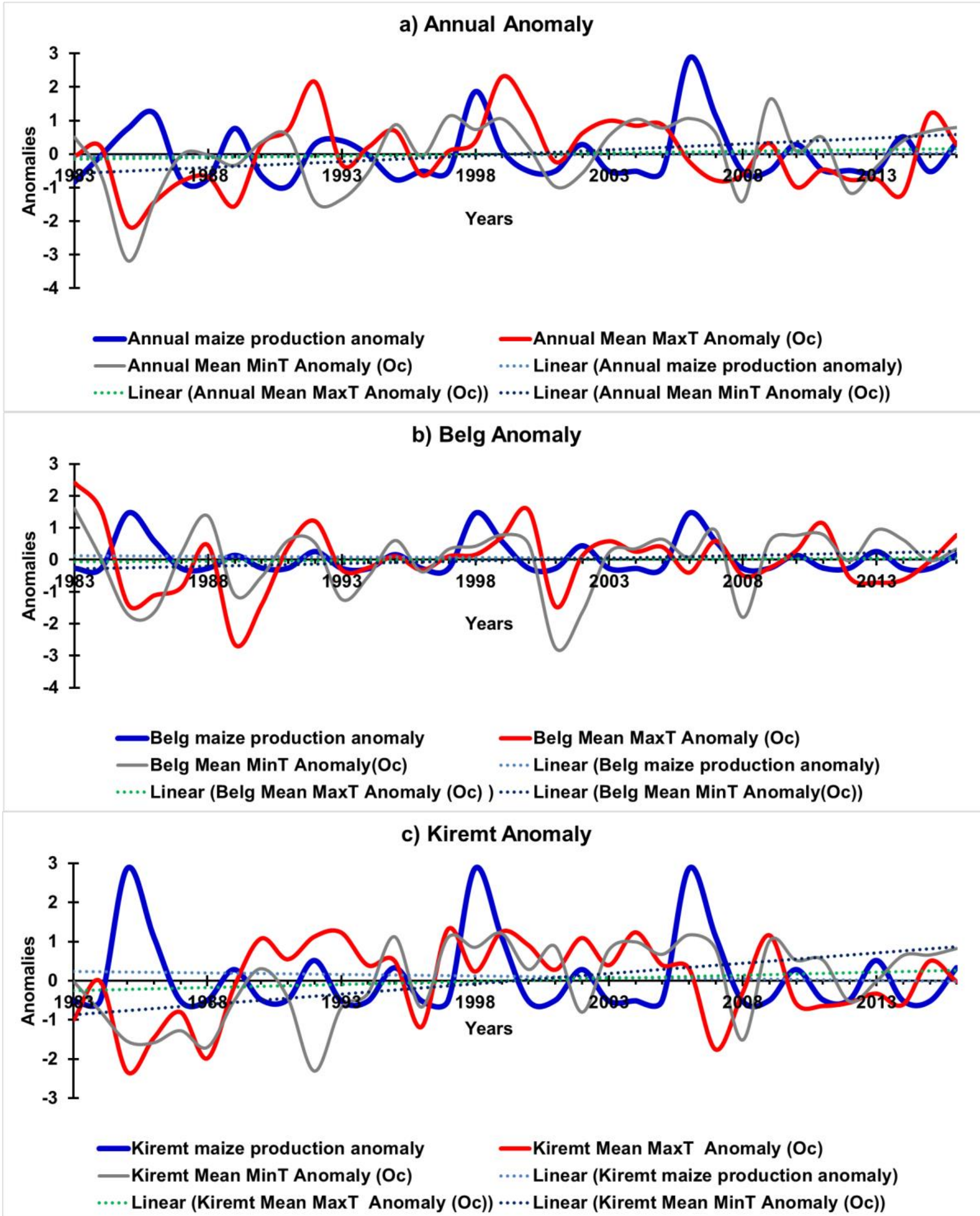

Figure 5 Trends of maize production and temperatures anomalies (1983–2016)

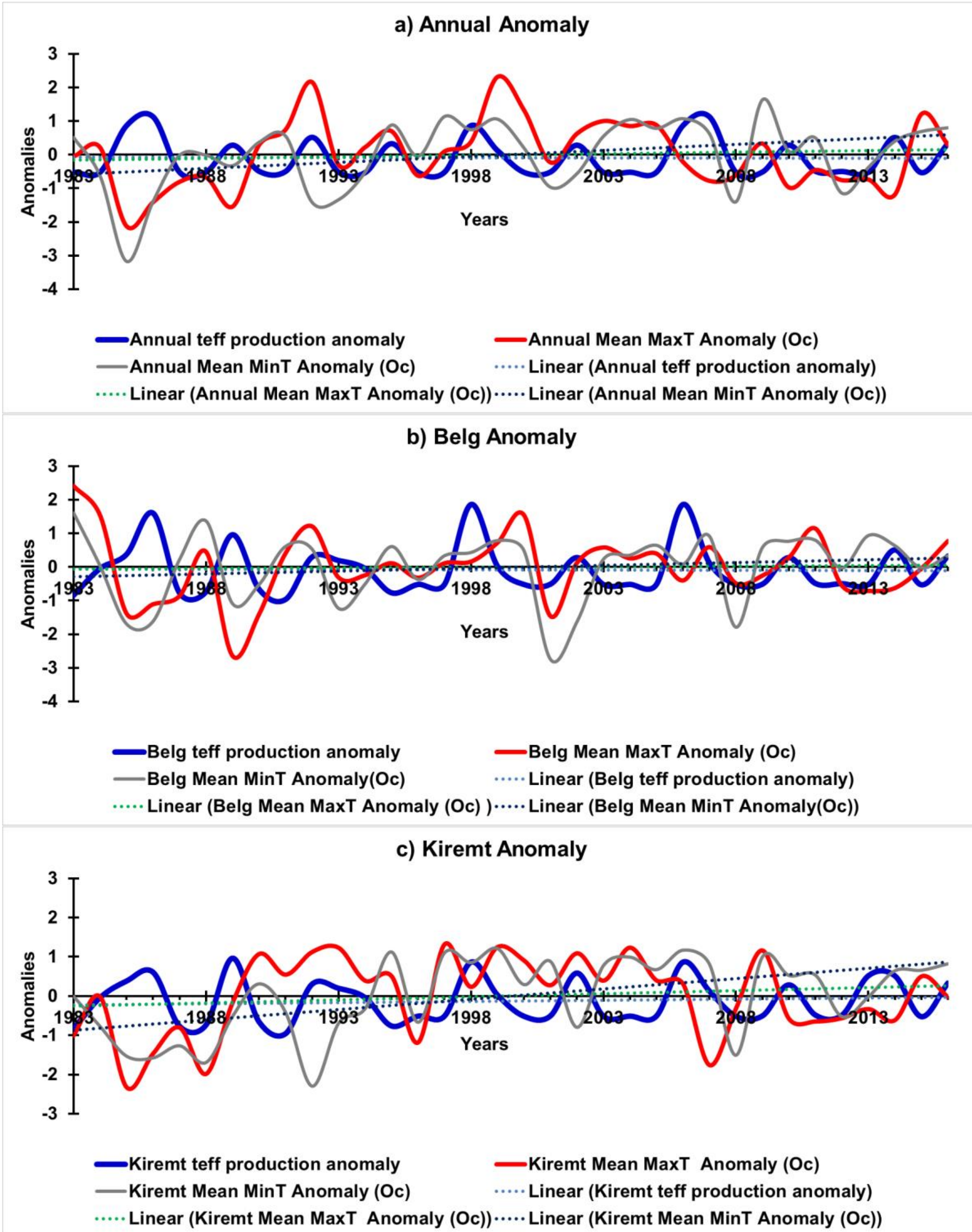

Figure 6 Trends of *teff* production and temperatures anomalies (1983–2016)