

**VARIABILITY AND CHANGE OF RAINFALL,
TEMPERATURE, AND RAINFALL TELECONNECTION
WITH PACIFIC OCEAN SEA SURFACE TEMPERATURE IN
EASTERN HARARGHE**

M.Sc. THESIS

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**Variability and Change of Rainfall, Temperature, and Rainfall
Teleconnection with Pacific Ocean Sea Surface Temperature in
Eastern Hararghe**

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**In Partial Fulfillment of the Requirements for the Degree of
MASTER OF SCIENCE IN PHYSICS (ENVIRONMENTAL
PHYSICS)**

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DEDICATION

I dedicate this Thesis to my mother Zara Habibe Ahmed and my brother Abdi Mohammed Yusuf.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this Thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis, and compilation of the Thesis. Any scholarly matter that is included in the Thesis has been given recognition through citation.

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BIOGRAPHICAL SKETCH

The author Abdurezak Mohammed Yusuf was born in September 1981 from his father Mohammed Yusuf and his mother Zara Habibe in Gorogutu District, Bika Kebele, East Hararghe Zone, Oromia National Regional State, Ethiopia. He completed his primary School at Gorogutu Primary School and at Kara mile Secondary School, respectively. After his successful completion, he joined Asalla College of Teachers Education in 1998 and graduated with a TTC in Mathematics and Physical Science at the end of 2000. He joined Jimma University in 2002 through a summer program and graduated with a **BSc in Physics** in 2006.

Since graduation, he worked in East Hararghe; Fadis District Education Office He joined the Postgraduate Program Directorate of Haramaya University in 2019 to pursue a study leading to a Master of Science Degree in Environmental Physics.

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ACRONYMS AND ABBREVIATIONS

Arc GIS	Aeronautical Reconnaissance Coverage Geographical Information System
CFSR	Climate Forecast System Reanalysis
CSA	Central Statistical Agency
CV	Coefficient of Variation
EALLJ	East African Low –Level Jet
FAO	Food and Agriculture organization
FDAO	Frequency Difference of arrival
FDRE	Federal Democratic Republic of Ethiopia
GDP	Growth Domestic Production
GHGs	Green House Gasses
IFAD	International Food and Agricultural development
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Converging Zone
MK	Mann-Kendall
MS	Microsoft Excel
NMA	National Meteorological Agency
NMS	National Meteorological Service
NMSA	National Meteorological Services Agency
NOAA	National oceanic and Atmospheric Administration
NSE	Nash-Sutcliff Efficiency
PBIAS	Percentage of Bias
SAI	Standardized Anomaly Index
SST	Sea Surface Temperature
TEJ	Tropical Easterly Jet
UNEP	United Nations for Environmental Protection
UNFCCC	United Nations Framework Convention on Climate Change

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VARIABILITY AND CHANGES OF RAINFALL, TEMPERATURE, AND RAINFALL TELECONNECTION WITH PACIFIC OCEAN SEA SURFACE TEMPERATURE IN EASTERN HARARGHE

ABSTRACT

For thousands of years, the world's climate has been changing, and it is real, with serious consequences, notably in the water sector, which is essentially vulnerable. Climate variability is erratic, shifting unpredictably at the global, regional, and local levels. Knowledge of past climatic variability at local and regional scales can help build adaptation methods. As a result, a study was carried out and developed to examine changes, variability of rainfall, temperature, and its teleconnection with Pacific Ocean Sea surface temperature in Eastern Hararghe, Ethiopia using the CFSR dataset. The study is based on gridded CFSR rainfall and temperature data from 1983 to 2021 and 1983 to 2020 respectively. The spatial trend, variability, and distribution of rainfall and temperature were examined using ArcGIS 10.5 software. Mann-Kendall (MK) and Sen's slope estimator trend tests were also employed to analyze rainfall and temperature trends of change and anomaly. Correlation analysis was used to examine the relationship between seasonal rainfall with Pacific Ocean Sea surface temperature. The findings in the Eastern Hararghe zone show that the dry season (Bega) has higher seasonal fluctuation and the short rainy season (Belg) has higher variability. Rainfall trends declined significantly in most areas except the northernmost tip, but increased in Bega, particularly in the central region. NINO 3.4 SST had a decreasing effect on Kiremt season rainfall, while equatorial Pacific Ocean SST decreased rainfall. Droughts were generally connected with ENSO episodes in the study area. The study also found that the eastern half of the Eastern Hararghe experienced a significant increase in seasonal maximum temperatures, with the eastern section experiencing the largest increase. This raises concerns about potential drought and the need for increased attention to identify temperature extremes. The study also found that the typical seasonal maximum temperature has been higher than its minimum temperature over the last 38 years. Overall, the unpredictable rainfall, rising temperatures, and the biggest regional variance seen in the zone indicate that the area's agricultural sector is vulnerable and that all actors must work together to save agriculture output in Ethiopia's Eastern Hararghe Zone. To create an effective climate change adaptation strategy, it is vital to first analyze the current effects of climate on economic growth as well as extreme events. The study suggests further research on future climatic variability, temperature extremes, and human intervention in the Zone using various data sources, including CFSR grid data.

Keywords: Eastern Hararghe,; climate; Pacific Ocean Sea surface temperature; variability

1. INTRODUCTION

1.1. Background of the Study

The world's climate has been changing for thousands of years, and it is real, with severe implications, particularly in the water sector, which is fundamentally vulnerable (IPCC, 2014). Temperatures are anticipated to rise by 0.3 c° to 4.8 c° by the end of the twenty-first century, making extreme events (such as drought, flood, and heat extremes) more severe and common (IPCC, 2014). Furthermore, proper water availability and accessibility for various uses have become a global concern, particularly in poor nations (IPCC, 2014; Asfaw et al., 2018). Weather and climate extremes alter in frequency, intensity, regional extent, duration, and timing as the climate changes (IPCC, 2007).

Global average temperature change is still a critical issue that threatens the earth and mankind in numerous ways. Between 1880 and 2012, land and ocean surface temperatures increased by 0.85°C on average (IPCC, 2013). This is an indication of the variability of temperature and rainfall change around the globe (Pachauri et al., 2014). The unfavorable worldwide high temperature has accumulated since the 1850s, owing mostly to the accumulation of greenhouse gases (GHGs) in the atmosphere (IPCC, 2013). The burning of natural fuel, such as coal or gas, formed in the geological past from the remains of living organisms to meet increasing energy demand, and the expansion of demanding agriculture to meet increasing food demand, which is often accompanied by the state of being clear of trees, are the main causes of GHGS. According to the FAO (2009) assessment, this trend of global warming shows no indications of abating and is predicted to result in long-term changes in meteorological conditions.

The twentieth century's rise in surface high temperature in the northern hemisphere is reflected more than any other century in the last 1000 years. According to several studies, the global mean surface temperature increased by 0.602°C, the number of

hot days per year increased in many places, while the number of cold days dropped in practically all land areas (IPCC, 2001).

Climate change has already been affecting rainfall and temperature variability for a long time. Understanding the nature of the different climatic systems and their impact on society and the environment requires awareness of climate variability throughout helpful records and further away on distinct temporal and spatial scales. Climate change is also causing food shortages, changing rainfall patterns, and other severe climate actions and the negative consequences are widespread, rapid, and increasing (Mbow et al., 2019). Starvation is much higher in nations that are most vulnerable to the rainfall and high-temperature extremes associated with climate change, compared to all populations in agriculture-dependent economies (FAO, 2009).

The global climate has rapidly changed, with the global mean temperature rising by 0.7°C over the last century (IPCC 2007). Nonetheless, variation rates vary greatly among locations (IPCC 2007). This is mostly due to the climate effects of different types of land surfaces with changing surface albedo, evapo-transpiration, and carbon cycle effects (Snyder et al. 2004).

Many African countries are vulnerable to climate change because their economies rely significantly on climate-sensitive agricultural production systems that are vulnerable to a range of extreme weather events, and their lower adaptive capacity has aggravated the situation (Lemi and Hailu, 2019). Rain-fed agriculture employs more than 85% of the population in various African nations (Mulugeta et al. 2019). As a result, they are extremely vulnerable to unusually high and/or low rainfall amounts (IPCC 2014). Sub-Saharan Africa is one of the world's warmest and driest regions, plagued by a lack of rainfall and vulnerable to food insecurity due to its current reliance on cereal imports, rapid population growth, a lack of technology, and stagnant agricultural productivity (Van Ittersum et al., 2016).

Rainfall variability in East Africa has contributed to catastrophic droughts and food shortages, affecting the livelihoods of many people (Mekasha et al., 2014; Tierney et al., 2015). This condition increases the number of persons in need of emergency shelter and food. Ethiopia is noted for its great variability in rainfall across area and time due to its geographical location and topographic complexity (Worku 2015). Agriculture is the principal source of income for the majority of Ethiopia's rural population and is critical to the national economy. It accounts for over 52% of GDP, generates more than 85% of foreign exchange revenues, and employs roughly 80% of the workforce (CSA, 2005). However, the agriculture sector is more vulnerable to the effects of climate change and variability than other sectors because it is rain-fed, which is very sensitive to climate change and variability.

Due to its geographical location and topographic complexity, Ethiopia is noted for its significant rainfall variability over place and time (Gemechu 1988; Mengistu et al. 2014; Worku 2015). In Ethiopia, seasonal changes in rainfall, volume, onset and cessation timings, and growing season length can be used to characterize regional variances (Segele and Lamb 2005). Furthermore, the direction and size of rainfall patterns over areas and seasons can vary over time, from days to decades (Jury and Funk 2013; Viste and Sorteberg 2013; Worku et al. 2019). Reliable and adequate seasonal rainfall trend analysis and rainfall forecasts are critical for disaster mitigation (Diro et al. 2011).

1.2. Statement of the Problem

Globally, the frequency of temperature and rainfall variance has increased over time (Chibinga et al., 2012). Ethiopia is experiencing the direct effects of climate change, such as rising average temperatures and altered rainfall patterns (FDRE, 2011). The seasonal migrations of the Inter-Tropical Converging Zone (ITCZ), complicated topography, and global atmospheric circulation teleconnection all have a significant impact on Ethiopia's climate. The El Nino southern oscillation (ENSO), for example, was the final cause of Ethiopia's greatest drought years, particularly in 2015 (Funk 2012).

Understanding the spatial-seasonal changes in rainfall and their relationship with SST is currently critical for producing trustworthy weather and climate forecasts for users (Degefu et al. 2017). Previous research has shown that El Niño/Southern Oscillation (ENSO) has a significant impact on inter-annual rainfall variability in Ethiopia (Seneshaw and Yitea 2015; Alhamshry et al. 2020). Precipitation in equatorial east Africa may be altered positively or negatively by easterly (westerly) wind anomalies during El Niño (La Nina) (Ratnam et al. 2014). ENSO is the inter-annual oscillation of the equatorial Pacific atmosphere-ocean system, and it has three phases: warm (El Niño), cold (La Nina), and neutral (Jajcay et al. 2018; FAO 2019). When neither El Niño nor La Nina exists, the climate is said to be neutral (FAO 2019). El Niño is a recurring global atmospheric oceanic phenomenon characterized by a rise in sea surface temperature (SST) in the central tropical Pacific Ocean. It increases the risk of heavy rain and flooding in some parts of the world, as well as the risk of drought in others (FAO 2019). The tropical Pacific SST varies both geographically and temporally (Philip 2018), and there is a strong link between precipitation and SST (Wu et al. 2008; Chen et al. 2014).

Several studies (Mohammed et al. 2018; Weldegerima et al. 2018; Abegaz and Mekoya 2020; Geremew et al. 2020, Anose et al., 2021) have been conducted on the spatiotemporal variability and trends of rainfall in Ethiopia. However, there are limits in the East Hararghe Zone. Most of the early, studies were organized and carried out based on meteorological stations' rainfall data in eastern Ethiopia. In contrast, meteorological rainfall and temperature data and satellite-based estimates were used in the present study.

This study was assessing also the applicability of CFSR climate to the re-analysis data to Eastern Hararghe. From the above study, the rainfall and maximum and minimum temperature of the globe are varied due to many factors of the climate of the Globe and these factors can influence societies in our country where unpredictable rainfall has occurred.

There is a lack of data and a high rate of missing in the study area. The study used Climate Forecast System Reanalysis (CFSR) re-analysis data to solve this problem. As a result, understanding trends in micro scale temporal and spatial climatic variables, as well as distribution behavior, is crucial in this field. As a result, the objective of this study was to look at the spatial variability and trends of rainfall and temperature in Eastern Hararghe, Ethiopia, using CFSR satellite data. This study also looked at the seasonal rainfall and its teleconnection with Pacific Ocean Sea surface temperature. The overall findings of this study will be used to design future adaptation and mitigation efforts.

1.3. Objectives of the Study

1.3.1. General objective

The general objective of this study is to investigate the changes and variability of Rainfall, Temperature, and its teleconnection with Pacific Ocean Sea surface temperature in Eastern Hararghe, Ethiopia using CFSR Dataset.

1.3.2. Specific objectives

The specific objectives of the study are:

- To assess the rainfall and temperature trend in Eastern Hararghe
- To investigate seasonal variability of rainfall and temperature in the Eastern Hararghe.
- To investigate the linkage of seasonal and annual anomaly of rainfall with Pacific Ocean Sea surface temperature (SST).

1.4. Research Questions

1. What are the historical trends in rainfall and temperature?
2. What is the extent and magnitude of climate variability to account for climate change?
3. To what extent is Pacific Ocean Sea surface temperature connected with the changes in rainfall anomalies seasonally and annually?

1.5. Scope of the Study

The scope of this study was restricted to change, climate variability, and trends, as well as its teleconnection with selected global driving forces in East Hararghe, which is part of Eastern Ethiopia, utilizing ArcGIS software and Excel. The Trend, spatial variability, and anomaly of the area were examined using ArcGIS. The supplied data included meteorological and spatial information obtained from CFSR which will serve as alternative data sources.

1.6. Significance of the Study

The study's findings will be persuasive for planning and development measures aimed at reducing global warming through appropriate actions such as reforestation, drought control and protection, monitoring, and early warning systems. The works stated or expressed as we mentioned above are very important elements of climatic change. There order to increase the resilience of farmers around eastern Ethiopia have to be trained in the prevention of drought and famine and the wide-ranging aim of the study is to assess the overall spatiotemporal variation of rainfall and temperature using CFSR grid data set in Eastern Hararghe. Moreover, the CFSR will also serve as an alternative climate data source as there is climate station scarcity in the area.

2. LITERATURE REVIEW

2.1. Definition of Key Words

The next section outlines significant topics employed in this thesis in brief. IPCC (2001) and Nakicenovic et al. (2000) provide more thorough explanations.

Weather: it is the fluctuating state of the atmosphere around us. Weather is what you feel, for instance, you may feel hot or cold when you arrive in Haramaya from Dire Dawa that is weather.

Climate: Climate is often characterized in terms of 30-year averages and higher-order moments about those means, implying that a given climate condition is stationary. The climate is what you expect; for example, if you expect Kiremt to be dry in the future, it is climate.

Climate variability: Variation in the mean condition and other statistics of climate (such as standard deviations, occurrence of extremes, and so on) on temporal and spatial scales larger than individual weather occurrences. Variability can be caused by either natural processes within the climate system or by artificial forces (external variability).

Climate change: A shift in the condition of the climate that may be characterized by changes in the mean and/or variability of its attributes and that lasts for a long time, generally decades. Climate change can occur as a result of natural internal processes, external forces, or persistent anthropogenic changes in the composition of the atmosphere or land use patterns.

2.2. Seasonal and Annual Trend of Rainfall Variability in Ethiopia

Various studies have been undertaken during the last decades to investigate rainfall changes in Ethiopia (Bewket and Conway, 2007; Seleshi and Camberlin, 2008; Hadgu et al., 2013). The NMSA (2001) recorded a large decrease in yearly rainfall in the north and southwest, but an increase in the middle section of the country. However, Bewket and Conway (2007) discovered conflicting patterns in annual, Kiremt, and Belg rainfall across the country. Kiremt and yearly rainfall exhibited a substantial growing tendency at Dessie and Labella from 1975 to 2003, but a significant decreasing trend at Debre Tabor,

according to Bewket and Conway (2007). Meze-Hausken (2004), Seleshi and Camberlin (2006), and Cheung et al. (2008) found no significant trend in the country's northern and north-eastern regions. Hadgu et al. (2013) found a decreasing trend in annual and seasonal rainfall levels in northern Ethiopia, however, the trends were insignificant at the majority of the stations he surveyed. According to Hadgu et al. (2013), the start date of the growing season increased while the end date and length of the growing season decreased in northern Ethiopia.

2.3. Climate Change and Variability

The idea of climate change has been around for quite some time, with the earliest indications dating back to the nineteenth century. Swedish physicist Svante Arrhenius was the first to investigate the effect of CO₂ on climate. Climate change is defined by the Intergovernmental Panel on Climate Change (IPCC) as "a change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or variability of its properties and that persists for an extended period, typically, decades or longer." Climate change may be caused by natural internal processes, external forcing, or anthropogenic changes in atmospheric composition or land use" (IPCC, 2001).

Climate variability refers to how the climate changes yearly above or below a long-term average value, whereas climate change refers to the long-term continuous change (increase or decrease) in average weather conditions or the variety of meteorological circumstances. As depicted in Yitea's (2012) work. Climate is defined as the variability of relevant atmospheric variables such as high temperature, rainfall, wind, precipitation, humidity, and clouds, including extreme or sporadic events, over a long period of time in a certain place.

In Africa, climate change is a reality (Besada and Sewankambo, 2009). Temperatures in Africa are likely to climb by 2 to 6°C over the next century, with increased rainfall variability, and this warming will be more severe than in other regions (Gemedu and Sima, 2015). According to the IPCC's Regional Climate Projections report from 2007, average temperatures in Africa are anticipated to rise by 1.5 to 3 C⁰ by 2050, resulting in more frequent flooding (Hulme et al., 2001). Because of the terrifying consequences of

climate change, research has selected Africa as the most susceptible region. Africa, for example, is recognized as one of the geographical areas in the world most vulnerable to the consequences of climate change due to its high exposure and poor capacity for adaptation. Africa is one of the continents where the effects of climate change are most acute (Clements, 2009).

Ethiopia is particularly vulnerable to the effects of climate change due to a variety of variables, including its location and social and economic mix. Significant rainfall and temporal and regional temperature changes characterize Ethiopia's climate (NMA, 2007). This is due to variations in latitude, elevation, wind, and humidity. Between 1960 and 2006, Ethiopia saw a 1.3°C temperature increase, averaging 0.28°C each decade (Echeverra and Terton, 2016).

The climate is defined as the average state of meteorological conditions in a region over a lengthy period of time. As a result, we can think of climate change as the manifestation of anomalous patterns or changes in atmospheric circumstances. Climate change is defined by the Intergovernmental Panel on Climate Change (IPCC) as "the state of the climate that can be identified statistically by changes in the mean and/or variability of its properties, and that persists for an extended period, typically decades or longer." Its composition may change due to natural internal processes, external forcing, or chronic anthropogenic changes (IPCC, 2007).

Climate is an interactive system made up of five key components: the atmosphere, hydrosphere, cryosphere, land surface, and biosphere, all of which are forced or impacted by various external forcing mechanisms, the most important of which is the sun. An external force is the direct effect of human activities on the climate system. The atmosphere is the most volatile and constantly changing component of the system. Its composition, which has evolved with the earth's evolution, is critical. The dry atmosphere of the Earth is mostly composed of nitrogen (N₂, 78.1% volume mixing ratio), oxygen (20.9% volume mixing ratio), and argon (Ar, 0.93% volume mixing ratio). However, there are a number of trace gases, such as carbon dioxide (CO₂), methane (CH₄), Nitrous oxide (N₂O), and ozone (O₃), which absorb and emit infrared radiation. These so-called greenhouse gases (GHGs), with a total volume mixing ratio in the dry air of less than

0.1%, play an essential role in the earth's energy budget. Moreover, the atmosphere contains water vapor (H_2O), which is also a natural greenhouse gas. So, the atmosphere has important components of water, in its various phases such as vapor, cloud droplets, and ice crystals.

The most powerful greenhouse gas is CO_2 . Water vapor is crucial to the climate, its fluctuation, and change for these reasons, as well as the fact that the transition between the various phases absorbs and releases a lot of energy. Those last absorb infrared radiation emitted by the Earth and radiate infrared radiation up and down, raising the temperature near the Earth's surface (IPCC, 2001).

2.4. Climate Extreme Events

Ethiopian is characterized by a history of climate extremes, such as drought and flood, and increasing temperature and decreasing precipitation trends (NMS, 2007). The history of climate extremes, especially drought, is not a new phenomenon in Ethiopia; moreover, the frequency of drought has increased, especially in the lowlands.

Furthermore, the annual minimum temperature has been rising, and the average annual rainfall has recently demonstrated a high amount of unpredictability (NMS, 2007). As a result, the livelihood of households, particularly pastoralists, is now threatened by frequent dangers of climate failure. The risks of climate change are certainly increasing. Drought cycles have decreased from 5-10 years to 3-5 years, according to traditional evidence from Borana pastoralists (Mar kakis, 2004).

2.5. Climate change and Global Driving Forces

Together climate variability and climate change are causal to the modern climate. Consequently, climate variability is "put on top" of climate change's long-term evolution and makes the exposure of its impacts over a short time period difficult (IPCC, 2013).

Rainfall and temperature are the two most prominent variable influences the climate of a of the region, Precipitation is the general term for rainfall, snowfall and other forms of frozen or liquid water falling from clouds. A changing climate can directly influence precipitation amount, intensity, and type. Large natural variability and strong geographic variations in these Parameters are evident, substantially affected by atmospheric circulation patterns such as the El Niño Southern Oscillation.

Greater than before warming accelerates evaporation and increases the amount of water vapor in the atmosphere, resulting in certain areas getting wetter and others getting drier. Widespread increases in heavy precipitation events have occurred even in places where total amounts have decreased (IPCC, 2007). Temperature is a measure of the intensity of heat energy produced by solar radiation. Temperature influences plant growth as it affects physiological processes such as photosynthesis, transpiration, respiration, germination, and flowering (<https://extension.oregonstate.edu/gardening/techniques/environmental-factors-affecting-plant-growth>).

2.6. Climate Variability and its Teleconnection with Global Driving Forces

Ethiopia has a variety of rainy seasons, which are impacted by geography and rain-carrying systems (Dawit, 2010). The amount of rain received over the mountains is said to be greater than that received over the lowlands, with the southwest receiving the most and the southeast receiving the least. Regional and global elements that influence kiremt rain include the ITCZ, TEJ, anticyclones in the South Atlantic and West Indian Oceans, the EALLJ or Somali Jet, and ENSO. The ITCZ, SWJ stream, Arabian High, frequency of tropical cyclones over the Southwest Indian Ocean, and ENSO all influence Belgian rainfall. Climate variability and changing climate knowledge, as well as the underlying climate pattern of the given location, assist policymakers in anticipating how weather and climate may influence every part of the inhabitants and their socioeconomic development.

The weather and climate of numerous areas and countries around the world are affected by diverse coupled ocean-atmosphere phenomena. El Nino and La Nina are periodic variations from expected SSTs in the equatorial Pacific Ocean, known as the ENSO. These higher or lower-than-normal ocean temperatures can have an impact on weather patterns all around the world by changing high- and low-pressure systems, winds, and precipitation. (NOAA, <http://www.esrl.noaa.gov/psd/enso/index.html>) ENSO can supply much-needed moisture to some areas while generating extremes of too much or too little water in others.

2.7. Climate of Ethiopia

Understanding the nature of the Ethiopian climate is important for any food security policy in Ethiopia. The Ethiopian National Meteorological Services Agency (NMSA) divides Ethiopia into four climatic zones based on the pattern of rainfall (NMSA 1996). These are:

1. The two-season type: this includes the western half of Ethiopia, which is divided into distinct wet and dry seasons.
2. Bi-two season type: the south and southeastern part of Ethiopia is characterized by double wet seasons. It occurs between March-May and September-November with two dry seasons in between (NMSA 1996).
3. The undefined season mostly has sporadic rainfall between July and February without any defined season. It occurs in the dry northern part of the Ethiopian Rift Valley.
4. The three-season type: these areas include central and southwestern Ethiopia.

The average annual rainfall in the highlands of Ethiopia is above 1000 mm a year and it rises to 2000mm, and 3000 mm in the wet southwestern parts of Ethiopia (NMSA 1996).

2.8. Rainfall and Temperature in Ethiopia

Like in most other parts of Africa, human-induced greenhouse gas emissions would bring further change in Ethiopia's climate over the next century. Although the level of change and associated impacts depend on the extent of emission scenarios and the climatic

models used to predict future scenarios, there are high levels of confidence that unlike temperature and rainfall is highly variable and uncertain (Sleshi and Zanke, 2004).

2.9. Climate Variability in Ethiopia

Human-caused greenhouse gas emissions would induce further changes in Ethiopia's climate over the next century, as they have in most other parts of Africa (Conway and Schipper, 2011). Although the extent of change and associated impacts are dependent on emission scenarios and the climatic models used to predict future scenarios, there is a high degree of certainty that, unlike temperature and rainfall, climate change is highly variable and uncertain (Sleshi and Zanke, 2004; Conway and Schipper, 2011; Ayalew et al., 2011).

In Ethiopia, Arndt et al. (2011) found that rainfall in the Kiremt and Belg seasons would be reduced by 20% and 5-6%, respectively, by the 2080s. According to the same study, by Ayalew et al. (2012), the amount of yearly rainfall and number of wet days in Ethiopia's ANRS will decline by the 2080s. Furthermore, future rainfall projections indicate a forward shift for the Kiremt season and a decrease for Belg rainfall in several areas of northern 14 Ethiopia (Hadgu et al., 2014). According to the authors, rainfall in Belgium is expected to shift from its current range of February to May to April to June in some areas. However, the pattern of its distribution, timing, and severity across the country is ambiguous (NMA 2007; Ayalew et al., 2012). Climate change is also expected to alter agriculturally relevant rainfall events, affecting the livelihoods of farming communities (Cooper et al. 2009; Sarr 2012; Kassie et al., 2014).

2.10. Climate Change, Variability, and Agriculture

Average temperature change is probably one of the most significant challenges facing African countries, mainly due to their geographic revelation, low profits, greater dependence on climate-sensitive sectors such as farming, and weak capacity to acclimatize to the variable environment. Even still climate change and climate inconsistency influence all economic sectors, farming activities are most exposed to average temperature fluctuations (Anwar and Liu, 2013).

These reflect in changes in high temperature and precipitation, which affect the land and water regime and eventually affect agricultural production (Anwar and Liu, 2013). A small increase in temperature decreases agricultural production (IPCC, 2007). Several studies have revealed the importance of climate variability in explaining crop production fluctuations at different spatial scales. At the global level, estimates are that climate variability accounts for roughly a third of observed crop yield variability. At the continental level, climate variability is widely recognized to be a major driver of crop production fluctuations, particularly in Africa, where agriculture is predominantly small-scale and rain-fed (IPCC, 2014).

For instance, Rowhani (2011) reported that intra-annual and inter-annual changeability of rainfall and temperature had significant impacts on crop production and thereby food security of communities in Tanzania.

As indicated in the IPCC (2007) report, climate variability impacts on water demand are predicted to be highly significant in Africa, this is likely to have severe impacts on crop yields, as the majority of the African population (over 85 percent in the case of Ethiopia) depends on rain-fed agriculture (IPCC, 2007). Climate variability will aggravate the water stress currently faced by some countries, while some countries that currently do not experience water stress will become at risk of water stress (IPCC, 2007).

Currently, climate change and variability have imposed significant challenges on Ethiopia by affecting food security, water and energy supply, health, poverty reduction, and sustainable development efforts. Furthermore, extreme weather events, such as droughts, floods, or landslides, may cause death to domestic animals.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

This research was carried out in the Eastern Hararghe Zone, which is located in the eastern part of Oromia, Ethiopia. Its geographical coordinates are 7.5 and 9.75 N latitude and 41.16 to 42.83 E longitude, with an elevation ranging from 492 to 3401 meters above sea level. The Shebelle River separates it from Bale on the southwest, West Hararghe on the west, Dire Dawa on the north, and the Somali Region on the north and east. This Zone contains the Harari Region, which is an enclave.

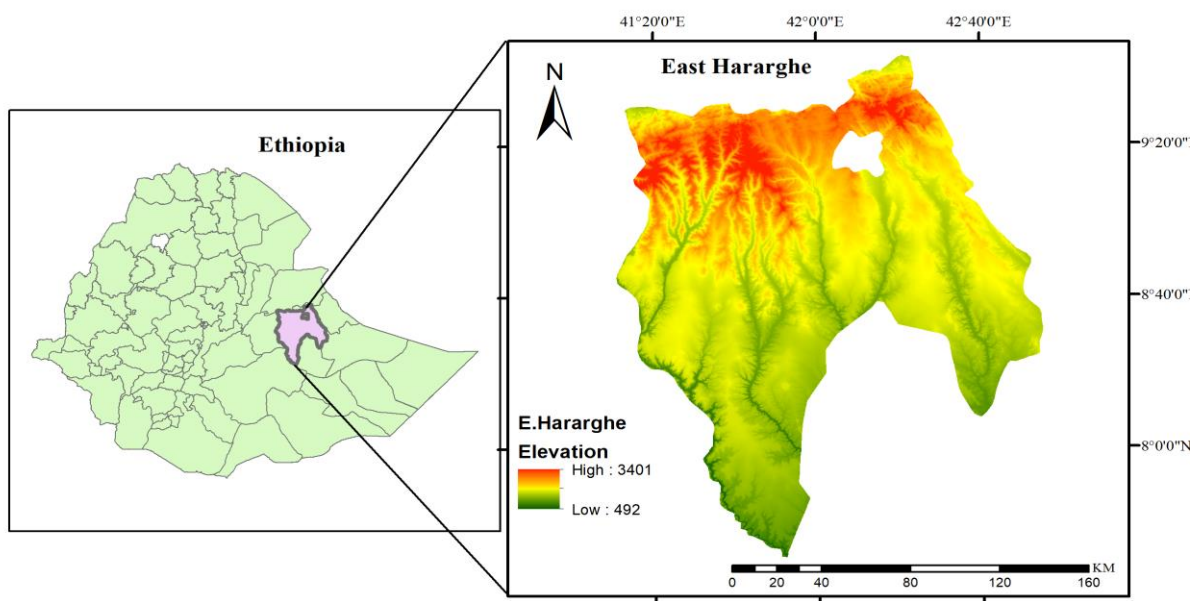


Figure 3.1. Map of Study Area

3.2. Data and Sources

Daily rainfall and temperature data for the period 1983–2021 for Rainfall and 1983–2020 for temperature for stations located data within the study area boundary would have been collected from the National Meteorological Agency (NMA) of Ethiopia and the National Centers for Environmental Prediction Climate Forecast System Reanalysis (CFSR). Therefore, these data would be summarized into monthly, seasonal, and annual means and totals and then used to analyze the variability and trends of rainfall at multiple timescales. Observed station data would be collected from the National Meteorological Agency (NMA) of Ethiopia for validation purposes.

3.3. Data Analysis Tools and Methods

In this study, data was processed and analyzed using ArcGIS and MS Excel software. Differences in maximum and minimum temperatures, as well as maximum and minimum rainfall, were analyzed to determine the diurnal temperature range, which serves as an index of global climate change and provides more information about temperature and rainfall variability of an area than using mean temperature alone (Braganza et al., 2004). Temperature and rainfall changes and trends were studied using statistical descriptors such as mean standard deviation, percentage, and regression analysis.

The study employed both descriptive and inferential statistics to analyze the data. Descriptive statistics such as mean, maximum, minimum, and standard deviation were used to characterize the nature of the data. Various statistical analyses were employed to measure the variability and trend analysis of rainfall data.

These include a coefficient of variation (CV), and Linear Regression was employed to extract seasonal and annual rainfall trends from the data.

3.3.1 Correlation Analysis

The use of correlation and regression techniques is critical in demonstrating the relationship between climatic parameters and global climate indices.

3.3.2 Mann–Kendall test

In this investigation, the Mann-Kendall (MK) test was applied. The Mann-Kendall (MK) test is a non-parametric test that is often used to determine the presence of trends in meteorological variables (Mann, 1945; Kendall, 1975). It is effective when dealing with non-normally distributed data since it is determined by time series ranks and sequences rather than the original values (Dong et al. 2019). The Mann-Kendall statistic S of the series x is given by test (Mann, 1945; Kendall, 1975):

$$S = \sum_{K=1}^{n-1} \sum_{J=K+1}^n \text{sgn}(X_J - x_i) \quad (3.1)$$

Where X_j and X_i are the annual values in years j and $i, k > i$, respectively, and Considering $X_j - X_i = \theta$,

$$\text{sgn}(\theta) = \begin{cases} 1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases} \quad (3.2)$$

A positive value of S means an "upward trend or increasing trends", while a negative value of S indicates a "downward trend or decreasing trends". To statistically quantify the significance of the trend, the probability associated with S and the sample size, n , must be computed. S 's variance is calculated as follows (Mann 1945; Kendall 1975):

$$\text{var}(s) = \frac{n(n-1)(2n+5) - \sum_{i=1}^m t_i(t_i-1)(2t_i+5)}{18} \quad (3.3)$$

Where m represents the number of linked groups and k represents the number of data points in group k . When the sample size n is greater than 10, the test statistic $Z(S)$ is calculated as follows (Mann 1945, Kendall 1975):

$$Z = \frac{S - 1}{\sqrt{\text{Var}(S)}} \text{ if } S > 0 \quad (3.4)$$

$$Z=0 \text{ if } S=0$$

$$Z = \frac{S + 1}{\sqrt{\text{Var}(S)}} \text{ if } S < 0$$

If Z is negative and the absolute value is greater than the level of significance, the trend is said to be decreasing; if Z is positive and the absolute value is greater than the level of significance, the trend is said to be increasing. There is no trend if the absolute value of Z is less than the level of significance. In this study, the desired value was set at 0.05 (Birhan, 2017). Sen's Slope will be used to detect the magnitude of change in the climate (Salmi, 2002).

3.3.3 Coefficient of variation (CV)

The coefficient of variation (CV) degree of variability is classified as (CV <20) for low variability, (20 <CV <30) for moderate variability, and (CV >30) for high variability.

The formula used is:

$$CV = \frac{\sigma}{\mu} \times 100\% \quad (3.5)$$

Where σ is the standard deviation and μ is the mean climatic variable.

3.3.4 Standardized Anomaly Index (SAI)

The negative and positive anomalies of rainfall and temperature fluctuation in the area were computed using the standardized Anomaly Index (SAI). It is calculated as follows:

$$SAI = \frac{(X - \mu)}{\sigma} \quad (3.6)$$

Where x is rainfall or temperature data, μ is the mean, and σ is the standard deviation of the data.

3.4. Performance and Correlation Indicators

The model performance metrics were calculated using Goodness-of-Fit Functions (GOF) (Zambrano-Bigiarini 2020). During the correlation of the observed and gridded data, the performance of the time series was verified using the coefficient of determination (R^2), Pearson's correlation coefficient (r), Nash-Sutcliff Efficiency (NSE), which are defined by Gupta et al. (2009); Moriasi et al. (1983); Nash & Sutcliff (1970) for NSE, and Gupta et al. (2009) for PBIAS. The formula of R^2 , NSE, and PBIAS one by one is as follows.

R^2 is expressed as by Zehtabian et al. (2016)

$$R^2 = \left[\frac{[\sum_{i=1}^n (x_i^{\text{sim}} - \bar{x}_{\text{sim}}) * (x_i^{\text{obs}} - \bar{x}_{\text{obs}})]^2}{\sum_{i=1}^n (x_i^{\text{sim}} - \bar{x}_{\text{sim}})^2 \sum_{i=1}^n (x_i^{\text{obs}} - \bar{x}_{\text{obs}})^2} \right]; \quad 0 \leq R^2 \leq 1 \quad (3.7)$$

In the equation, n is the number of observations in the period under consideration, x_i^{obs} is the i^{th} observation of the constituent being evaluated, x_i^{sim} is the i^{th} simulated value for the constituent being evaluated, and $\bar{x}_{\text{sim}}$ and $\bar{x}_{\text{obs}}$ are the mean of simulated and observed data, respectively.

Pearson Correlation Coefficient is as follows

$$r = \frac{\sum (x_i - \bar{x}) (y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}} \quad (3.8)$$

r = correlation coefficient,

x_i = values of the X variable in a sample

$\bar{x}$ = mean of the values of x variable and

$\bar{y}$ = mean of the values of the Y variable respective.

The equation for NSE is given (Gupta et al., 2009; Moriasi et al., 1983; and Nash & Sutcliffe, 1970):

$$\text{NSE} = 1 - \left[\frac{\sum_{i=1}^n (x_i^{\text{obs}} - x_i^{\text{sim}})^2}{\sum_{i=1}^n (x_i^{\text{obs}} - \bar{x})^2} \right] \quad (3.9)$$

The $\bar{x}$ is the mean of observed data for the evaluated constituent and the others, as defined in Eq. (3.7).

PBIAS is calculated by Gupta et al. (2009) as follows:

$$\text{PBIAS} = \left[\frac{\sum_{i=1}^n (x_i^{\text{obs}} - x_i^{\text{sim}}) \times 100}{\sum_{i=1}^n x_i^{\text{obs}}} \right] \quad (3.10)$$

Again the variables are as defined in Eq. (3.7).

4. RESULTS AND DISCUSSIONS

4.1. Validation of CFSR Climate Data

Table 4.1 shows the statistical performance climate data for the Eastern Hararghe between observed rainfall, Tmax, and Tmin and their counterparts from CFSR data. Table 4.1 shows that the r and R^2 for rainfall and Tmax obtained from the correlation were nearly perfect for the three stations (Haramaya, and Gursum). Tmin in the Gursum climate station had the lowest correlation (0.79 and 0.62) for r and R^2 between observed and CFSR data. Overall, the results demonstrated an outstanding match between observed and CFSR gridded rainfall and temperature data. For all three factors, positive correlations were found between observed and gridded rainfall.

Table 4.1: Correlation of observed and CFSR gridded climate data

Parameter	Stations	r	R ²	NSE
Rainfall	Haramaya	0.92	0.84	0.75
	(Alemaya)			
T_{max}	Gursum	0.90	0.81	0.72
	Haramaya	0.88	0.77	0.71
	(Alemaya)			
	Dire Dawa	0.91	0.83	0.73
T_{min}	Gursum	0.87	0.76	0.70
	Haramaya	0.91	0.83	0.73
	(Alemaya)			
	Gursum	0.79	0.62	0.66

4.2. Seasonal Spatial Rainfall and Temperature Trends

4.2.1. Seasonal Rainfall Trends

Figure 4.1 depicts the results of the seasonal rainfall MK trend-test analysis for the research area. Figure 4.1 illustrates the results of the spatial seasonal rainfall pattern and distribution generated from CFSR data for Eastern Hararghe during the last 38 years. According to the data in Figure 4.1, the red and green-shaded areas showed the strongest positive and negative seasonal rainfall trends ($p < 0.05$). According to this data, a significantly increasing trend of seasonal rainfall was recorded in Kiremt (JJAS) in the northern and extended to the middle portions of the territory, in contrast a decreasing trend was observed in the southern sections of the area (Figure 4.1a). Figure 4.1b displays a decreasing trend in seasonal rainfall near the point of Northern and much of the central part of Bega. Rainfall in the Belg season has increased dramatically in the last 38 years in the eastern portion of the country, extending to the middle part, including Haramaya Woreda. The CFSR data revealed a statistically significant ($p < 0.05$) decrease in Belg

season rainfall by 0.81 mm/year, whereas a statistically significant ($p < 0.05$) increase in Kiremt season rainfall was recorded in the Northern half of the research region by 1.14mm/year (Figure 4.1a).

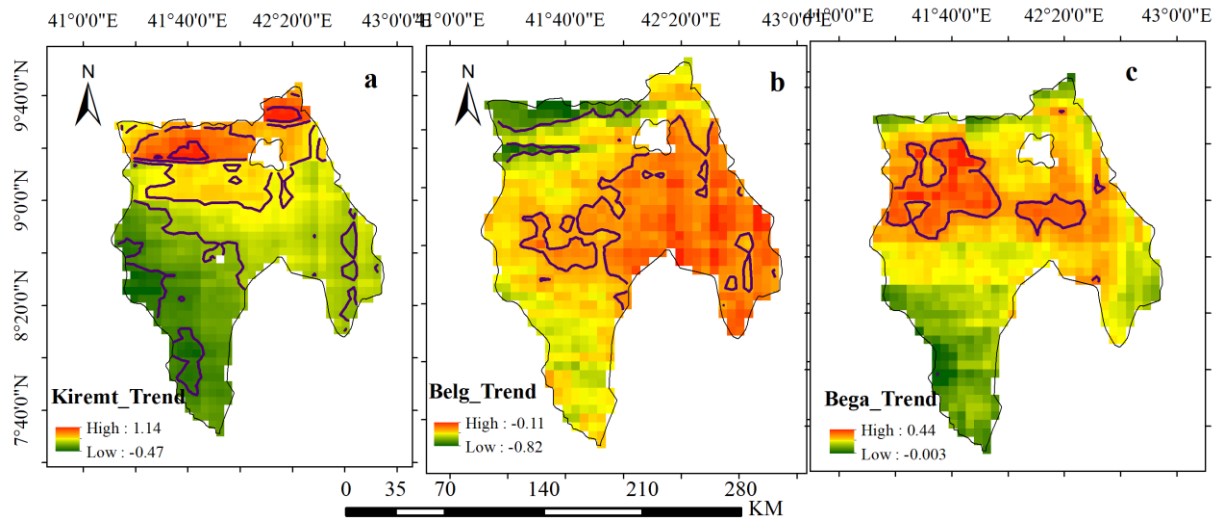


Figure 4.1 Spatial analysis of the seasonal rainfall trend a) Kiremt, b) Belg and c) Bega

According to a statistical study of the CFSR rainfall information, rainfall magnitude was statistically higher in the northeast region of the area throughout the primary crop season, at the same time it was lower in the rest of the territory. There is concern in the area as the majority of the territory is seeing decreased rainfall, with the highest in the southwest. According to the CFSR statistics, the seasonal rainfall trend ranged from low to high. This means that the Zone is seeing significant decreases in rainfall. This heavy rain could create drought and flooding in the area, necessitating additional monitoring and categorization to identify climate extremes in the Eastern Hararghe.

4.2.2. Seasonal Temperature Trend

Figure 4.2 illustrates the results of the geographical seasonal maximum temperature trend and distribution behavior generated from CFSR data for Eastern Hararghe during the last 38 years. The data in Figure 4.2 reveal that the red and green-shaded areas exhibited the strongest seasonal maximum temperature (T_{max}) rise and drop trends ($p < 0.05$). This data shows a significantly increasing tendency of seasonal T_{max} in all seasons, with a

maximum in Kiremt (JJAS) in the eastern portion, Belg Northern and eastern expanded to the central and western part of Bega season. Tmax has increased dramatically in the eastern portion of Babile during the Kiremt season over the last 40 years. In the western section of the study area, the CFSR data revealed a statistically significant ($p < 0.05$) increase in Bega season Tmax of $0.22^{\circ}\text{C}/\text{year}$. Furthermore, a statistically significant increase of $0.051^{\circ}\text{C}/\text{year}$ was seen in the eastern half of the research region during the Kiremt season (Figure 4.2a).

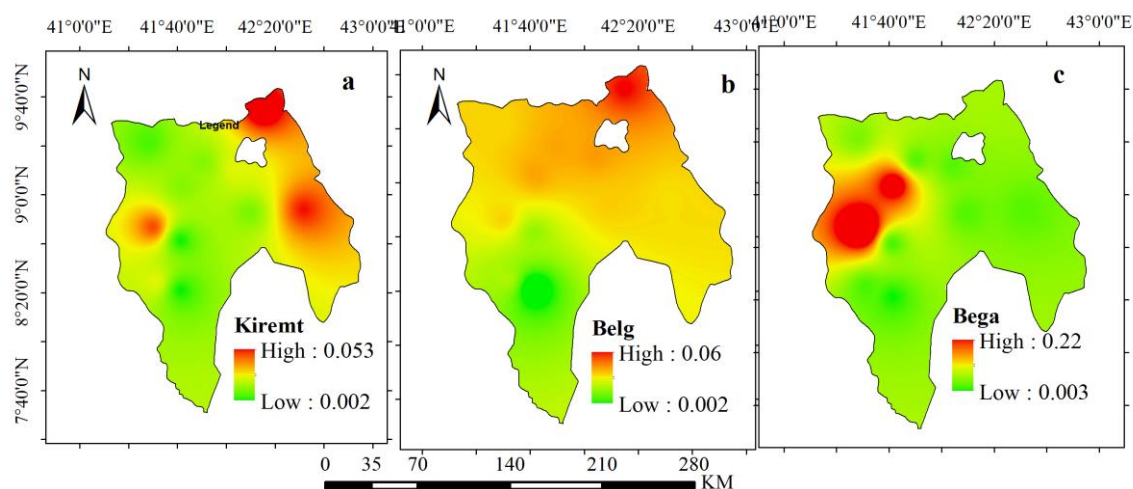


Figure 4.2 Spatial analysis of the seasonal maximum temperature trend a) Kiremt, b) Belg, and c) Bega during 1983_2020

Tmax magnitude was statistically bigger in the eastern half of the area, according to the statistical analysis of the CFSR Tmax dataset, whereas the remainder of the area had a low increase throughout the main crop season. There is concern in the area as all parts are experiencing increases, with the highest in the eastern section of the area. According to the CFSR data, the seasonal Tmax trend ranged from low to high.

The data in Figure 4.3 demonstrate that the red and green-shaded areas exhibited the strongest seasonal maximum temperature (Tmin) rise and drop trends ($p < 0.05$). This data shows a significantly increasing tendency of seasonal Tmin in all seasons, with a maximum in Kiremt (JJAS) in the eastern portion, Belg Northern and eastern expanded to the central and western part of Bega season. Tmax in the Kiremt season has dramatically grown in the previous 40 years in the eastern section, including Babile, and certain parts

of the western. The CSFR data demonstrated a statistically significant ($p < 0.05$) increase in BelgTmin of $0.044^{\circ}\text{C}/\text{year}$ across the study area's northern and eastern parts (Fig. 4.3b). Furthermore, a statistically significant increase of $0.032^{\circ}\text{C}/\text{year}$ in the last 40 years was seen in the eastern half of the research zone during the Kiremt season (Figure 4.3a).

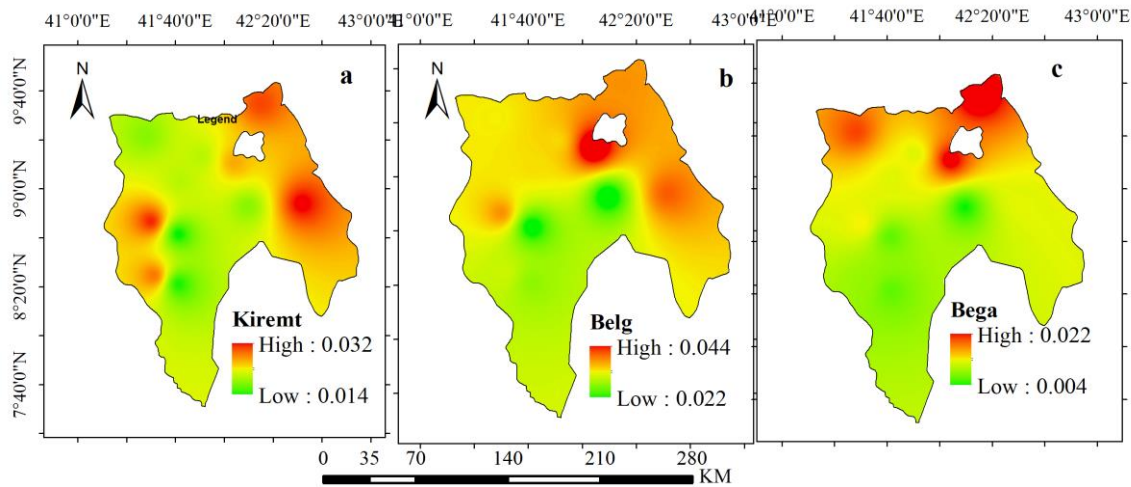


Figure 4.3 Spatial analysis of the seasonal Tmin trend a) Kiremt, b) Belg, and c) Bega

This implies that increasing temperature has a significant effect on the Zone. This severe temperature has the potential to induce drought in the area, necessitating more attention and categorization to identify temperature extremes in the Eastern Hararghe.

4.3. Seasonal Spatial Rainfall and Temperature Variability

4.3.1. Seasonal Rainfall coefficient of variation

Figure 4.4 displays the seasonal coefficient of variation (CV) of rainfall based on CSFR data. The data, as shown in Figure 4.3, indicate that seasonal rainfall was most variable in the research area's south-east during the major rainy season (Kiremt). Seasonal rainfall was more variable at low altitude at the southwest tip, with $\text{CV} = 32.26\%$, and lowest in the rest of the area, but variability was substantial across the Zone during the Bega season, with the greatest record in the southern tip (71.68%). During the Belg season, there was significant variability in rainfall over the last 38 years in most of the region obtained, as demonstrated by the red-colored ad contour plot. When we compare the two

rainy seasons ($CV > 30\%$) in East Hararghe zones, Ethiopia, the coefficient of variation result of seasonal rainfall showed substantial variability in all seasons, especially in the Bega season. This finding is congruent with the findings of Teshome et al. (2021), who discovered a large coefficient of variation for the annual Belg season ($CV > 30\%$) in East Hararghe zones.

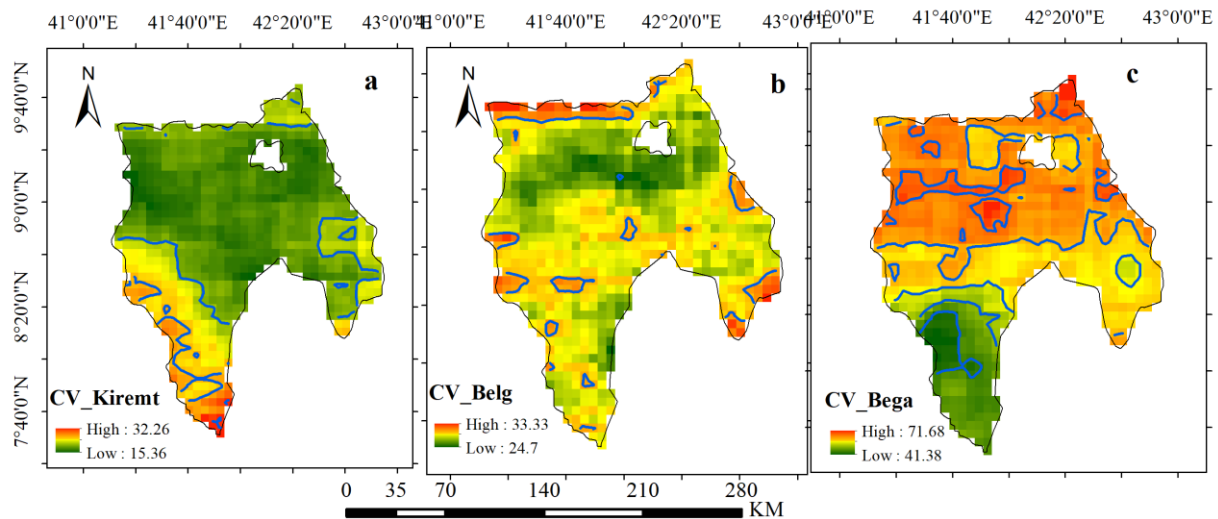


Figure 4.4 Spatial analysis of the annual coefficient of variation (CV) a) Kiremt, b) Belg and c) Bega

According to the statistical analysis of the rainfall dataset, rainfall variability was statistically greater in most of the region except at the southwest point of the zone area in the Kiremt season, whereas the remainder of the area had lower CV values. According to the CFSR data, yearly rainfall variability ranged from low to high. This means that rainfall variability is high in the Zone. This heavy rain could create flooding in the area, necessitating additional monitoring and categorization to identify climate extremes in the Eastern Hararghe.

4.3.2. Seasonal Rainfall Anomaly Trend

Figure 4.5 illustrates the results of the geographic seasonal rainfall anomaly trend and distribution behavior generated from CFSR data for Eastern Hararghe during the last 38 years. According to the data in Figure 4.5, the green and red-shaded areas had the strongest positive and negative seasonal anomaly trends ($p < 0.05$). According to this data,

a significantly increasing seasonal rainfall tendency was identified in Kiremt (JJAS) except in the southwest, and it spread to the center portion of the Zone (Figure 4.5a). Figure 4.5b depicts a decreasing trend of seasonal rainfall anomaly around Kombolcha, which is the northernmost point of the Zone, including the Harari region. Except for a portion of the center section of the study region that has a positive rainfall anomaly during the Bega season, the rest has a negative anomaly (Figure 4.5c). The CFSR data revealed a statistically significant ($p<0.05$) decrease in Kiremt season rainfall by 0.021mm/year, but a statistically significant ($p<0.05$) increase in the research region's southern sector by 0.028mm/year (Figure 4.5a, b, and c).

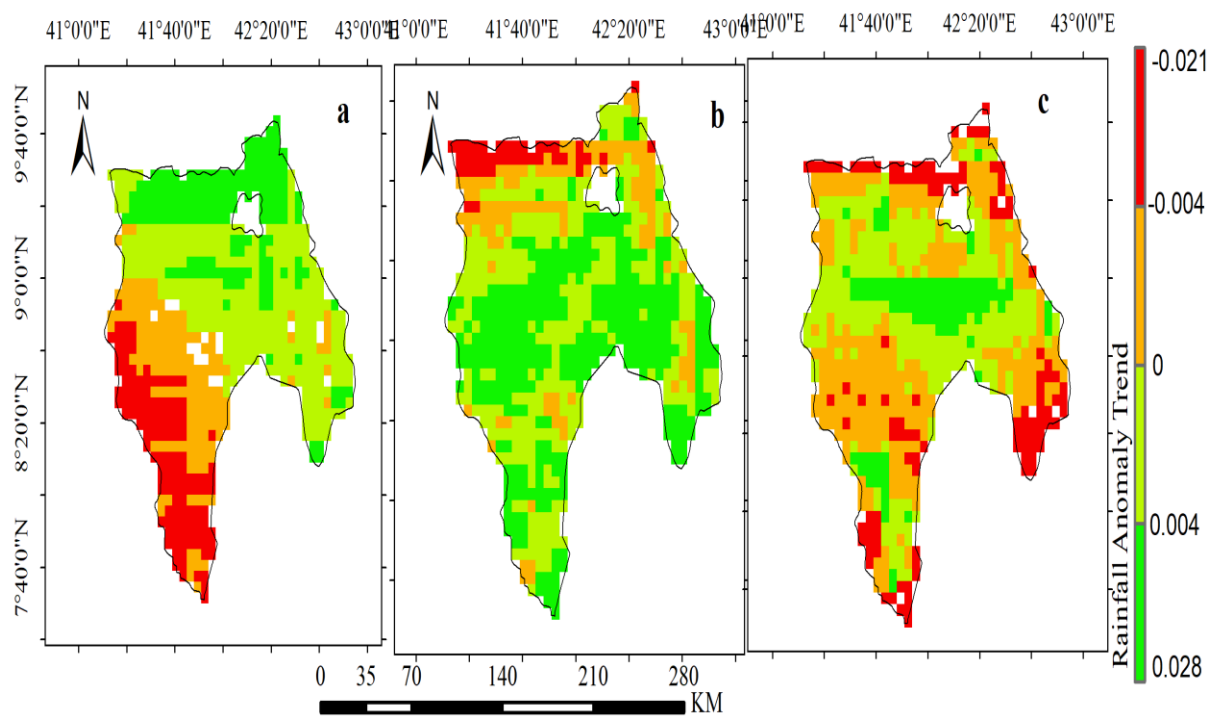


Figure 4.5 Seasonal spatial anomaly trend of rainfall of a) Kiremt b) Bega and C) Belg during 1983-2020

According to Figure 4.5, the growing and decreasing rainfall trends in most areas of the area were unpredictable. For the Belg and Kiremt seasons, about half of the Zone reported below the long-term mean, indicating that the area's agricultural and water resources may be harmed. Rainfall intensity varies over the area, with relatively high intensity seen in the northern and easternmost portions of the Kiremt and decreasing towards the southwest. Except for the northern half of the territory, the Belg season also

suggests high intensity. As the Belg season is also very significant for the area, this suggests that agricultural practices during the Belg season in the northern part of the area around Kombolcha and Deder require additional attention in the future.

4.3.3. Seasonal Temperature coefficient of variation

Figure 4.6 displays the seasonal coefficient of variation (CV) of Tmax based on CFSR data. The findings, as shown in Figure 4.6, indicate that the seasonal CV was most variable in the northeast of the research region, which stretched all the way to the center, in the outskirts of Harar city. Seasonal Tmax was more variable at Aweday, Maya city, and the outermost Harari region, with a maximum CV = 7.14% (Bega), and lowest in the Zone's western and southern parts, with a CV = 3.20% (Bega). The coefficient of variation of seasonal Tmax in the area showed insignificant fluctuation over the last 38 years. The contour plot also shows the highest variability relatively and around Maya City.

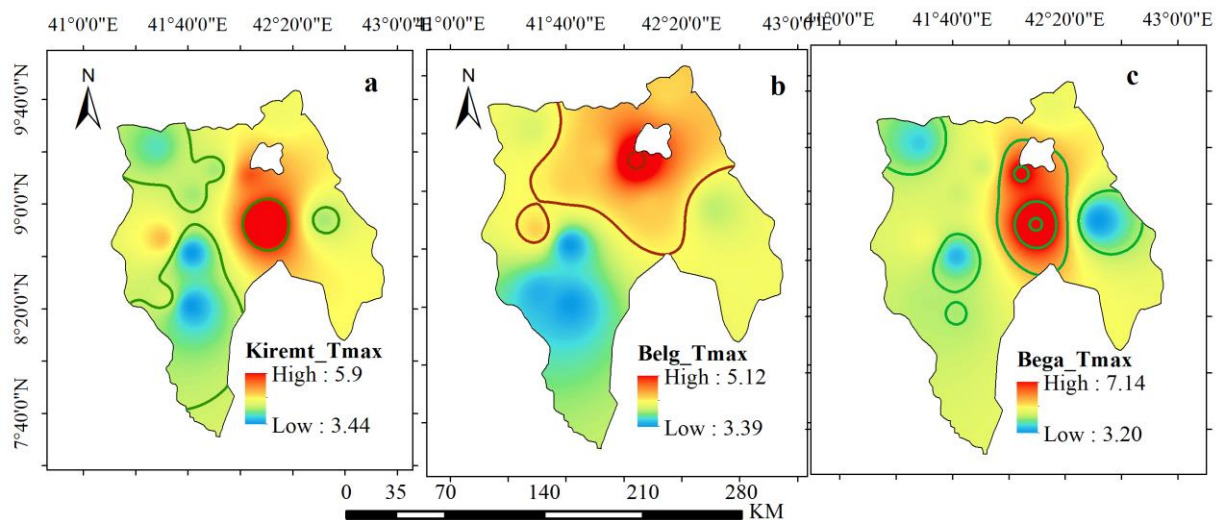


Figure 4.6 Spatial analysis of the seasonal coefficient of variation (CV) a) Kiremt, b) Belg and c) Bega of maximum temperature

Similarly, the investigation of minimum temperature yielded less fluctuation throughout the seasons ($CV < 30\%$). Tmin variability was statistically somewhat higher in the northeast region of the territory, according to the statistical analysis of the CFSR dataset,

whereas the rest of the area has lower CV values. As a result, the maximum and minimum temperatures showed less variability.

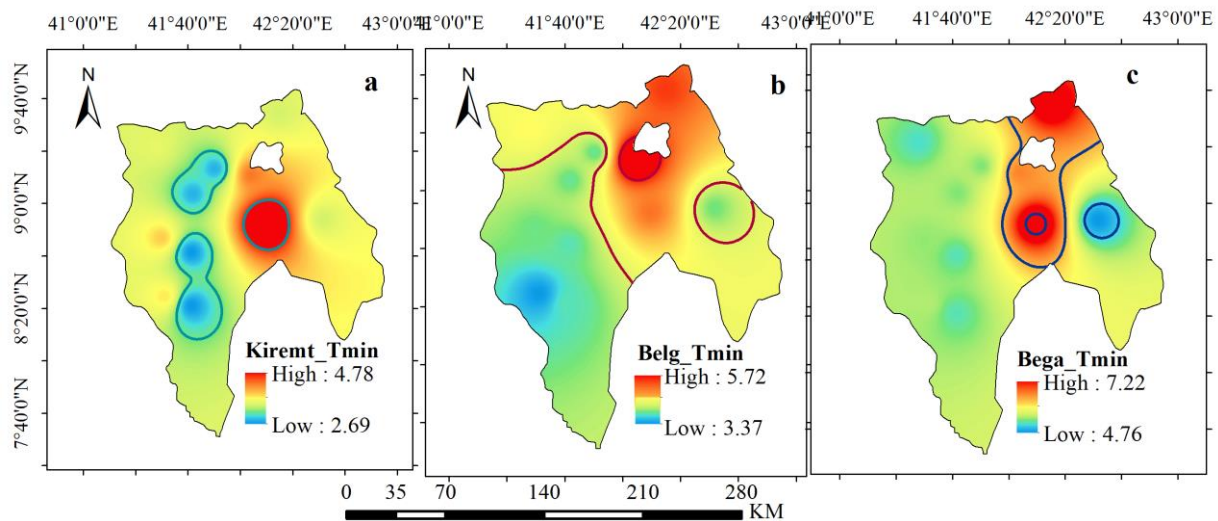


Figure 4.7 Spatial analysis of the seasonal coefficient of variation (CV) a) Kiremt, b) Belg and c) Bega of minimum temperature

The maximum and minimum temperature studies revealed lower variability, with the highest recorded in the northeast sector of the research region extending to the middle and outermost Harar city section at 7.22% (Fig. 4.7c).

4.3.4. Seasonal spatial anomaly trend of temperature

Figures 4.8 and 4.9 show a study of Tmax and Tmin geographical anomaly patterns from 1983 to 2020. Figure 4.8 shows a definite seasonal tendency that was more visible in the Zone's northeast section and extended to the Zone's center during the Belg and Bega seasons, but not in some portions of the west during the Main rain season (Kiremt). The most apparent increase in seasonal data was identified in the Kiremt, Bega, and Belg seasons of Tmax in the northeast half of the territory spread to the center of the area in the Belg and Bega seasons. Overall, these findings reveal that Bega had the highest seasonal maximum temperature increase.

The data demonstrated a considerable increase in seasonal temperature across all seasons, with the maximum temperature increasing by 0.26 degrees Celsius (Figure 4.8) and the minimum temperature increasing by 0.058 degrees Celsius (Figure 4.9). Our findings point to a recent significant increase in seasonal temperature and a warming trend.

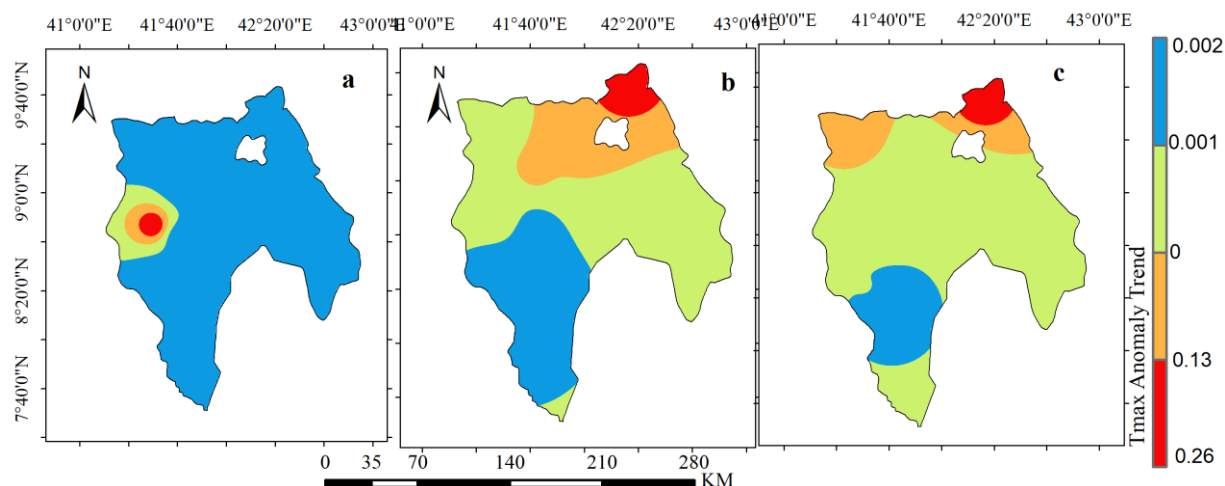


Figure 4.8 Seasonal spatial trend of anomaly of maximum temperature of a) Kiremt b) Bega and C) Belg during 1983-2020

The minimum temperature rose significantly across all three seasons, with the Kiremt and Belg seasons covering the most ground. Because eastern Hararghe has the potential for Chat and Coffee production, greater attention should be given to the area in order to discover the appropriate adaptation and mitigation measures. According to the findings, soil moisture deficit and excessive evapo-transpiration could be the result of a large increase in temperature, which has an impact on water resources, agriculture (e.g. Chat), and fish production in the eastern Hararghe. The total increase in temperature recorded in the study region is a worrisome warning of warming in the Zone, with the maximum temperature increasing more than the minimum. Temperature increases cause a shift from long-duration cultivars to short-maturing cultivars with decreased yield potential (Wylie, 2008).

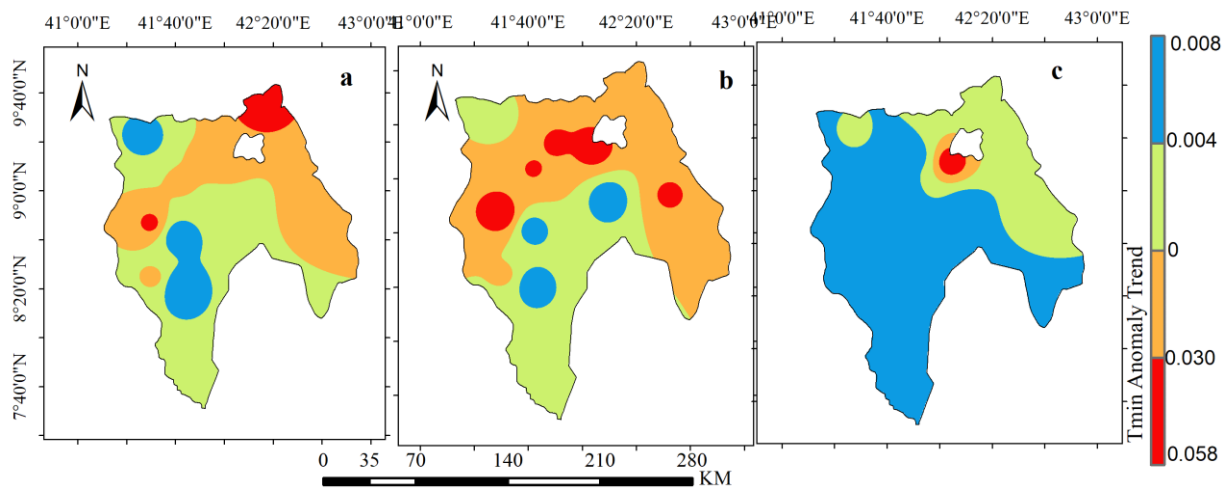


Figure 4.9 Seasonal spatial trend of anomaly of minimum temperature of a) Kiremt b) Bega and C) Belg during 1983-2020

The general rise in temperature recorded in the study area is likewise a worrying symptom of the basin's warming. Previous research (IPCC 2014) on the temperature trend at the local and regional levels corroborates this Eastern Hararghe result.

4.4. Connection of Seasonal and Annual Rainfall Anomaly with Pacific Ocean Sea Surface temperature (SST)

In this study, the Pearson correlation coefficient (r), coefficient of determination (R^2), and p-value were used to investigate the link between seasonal and annual rainfall and SST. At a 5% significance level, the connection between mean Kiremt rainfall and NINO 3.4 SST was negative and statistically significant (Table 4.2). In the Belg and Bega seasons, however, the connection between mean rainfall values and NINO 3.4 SST was frequently positive (Table 4.2). This implies that SST decreased rainfall in the Kiremt season while increasing rainfall in the Belg and Bega seasons across the study area for the last 38 years (1983-2021). Similarly, the connection between mean annual rainfall and NINO 3.4 SST in the research area was negative. Gissila et al. (2004) discovered a link between Ethiopian rainfall and equatorial Pacific Sea surface temperature. Gebremichael et al. (2023) discovered a negative and positive connection between SST anomalies and rainfall in the Upper Awash basin during the Kiremt and Belg seasons, respectively. In

the Upper Awash basin, a negative relationship between mean annual rainfall and mean annual SST anomaly was also observed.

Table 4.2 Links of seasonal and annual CFSR rainfall and SST (1983–2021) in East Hararghe Zone

	r	R ²	p-value
Kiremt	-0.56	0.31	0.01
Belg	0.30	0.09	0.14
Bega	0.27	0.07	0.16
Annual	-0.18	0.03	0.34

Diro et al. (2010) discovered a negative association between equatorial Pacific SST and rainfall in several locations of Ethiopia during the Kiremt season. Furthermore, Seleshi and Camberlin (2006) discovered that warm ENSO periods (El Niño years) are often related to decreased rainfall and drought years. Cold periods (La Nina years, for example) are connected with increasing rainfall levels.

Severe drought years had the biggest negative rainfall anomaly and the highest positive SST anomaly (Seleshi and Camberlin 2006). Drought years in Ethiopia include 1984, 1987, 1991-1992, 1993-1994, 2002, 2009, 2012, and 2015/16 (Mekonen et al. 2020; Gebremichael et al., 2022), which either coincide with or immediately follow El Niño events (Asfaw et al. 2018). This study's findings corresponded with the above conclusion, with rainfall anomalies for these dry times being very low while SST anomalies were very high. Furthermore, Yasuda et al. (2018) found the impact of Pacific Ocean SST on inter-annual variability of rainfall in East Africa.

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. SUMMARY

Using the CFSR Dataset, a study was performed to explore the changes, variability, and teleconnection of Rainfall, Temperature, and its teleconnection with Pacific Ocean Sea Surface Temperature in Eastern Hararghe, Ethiopia over the previous 38/39 years. (Gridded CFSR data, Mann-Kendall and Sen's slope estimator trend tests, and ArcGIS were employed in the study). The performance of the time series was verified using the coefficient of determination (R^2), Pearson's correlation coefficient (r), and Nash-Sutcliffe Efficiency (NSE), changes in climate variables, and the relationship between seasonal rainfall and Pacific Ocean Sea surface temperature during the correlation of observed and gridded data.

The study used ArcGIS and MS Excel software to analyze data on temperature and rainfall variability. It used descriptive and inferential statistics to characterize the data, measure variability, and analyze trends. Descriptive statistics like mean, maximum, minimum, and standard deviation were used, while Linear Regression was used to extract seasonal and annual rainfall.

Table 4.1 shows a strong correlation between observed rainfall, Tmax, and Tmin in Eastern Hararghe and CFSR data, with perfect correlations for Haramaya and Gursum stations. Gursum had the lowest correlation for Tmin. Overall, positive correlations were found. Figure 4.1 shows the seasonal rainfall MK trend-test analysis for Eastern Hararghe over the last 38 years. The red and green-shaded areas showed the strongest positive and negative rainfall trends, respectively. Kiremt showed a significantly increasing trend in the northern to middle parts of the territory, while southern sections showed a decreasing trend. The Belg season saw a significant increase in eastern parts, including Haramaya Woreda. Figure 4.2 shows the strongest seasonal maximum temperature trends in Eastern Hararghe over the last 38 years, with a significant increase in Kiremt, Belg Northern, and central and western parts of the Bega season. The eastern portion of Babile experienced a dramatic increase in Tmax, while the western section saw a significant increase in Bega season Tmax. The study shows that red and green-shaded areas show the strongest

seasonal maximum temperature rise and drop trends, with a significant increase in all seasons. The Kiremt season has seen a dramatic increase in Tmax, with a statistically significant increase in BelgTmin of $0.044^{\circ}\text{C}/\text{year}$ across the northern and eastern parts.

Figure 4.4 shows the seasonal coefficient of variation (CV) of rainfall in the research area's south-east during the major rainy season (Kiremt). Low altitude at the southwest tip showed more variability, while the Bega season had the greatest variability (71.68%). Significant variability was observed in the Belg season over the last 38 years, consistent with previous research. Figure 4.5 shows the geographic seasonal rainfall anomaly trends and distribution behavior in Eastern Hararghe over the last 38 years. Green and red-shaded areas had the strongest positive and negative trends. A significant increase in seasonal rainfall was identified in Kiremt, except in the southwest, and spread to the center of the Zone. The data revealed a statistically significant decrease in Kiremt season rainfall by $0.021\text{mm}/\text{year}$, but an increase in the southern sector by $0.028\text{mm}/\text{year}$. The seasonal coefficient of variation (CV) of Tmax was the most variable in the northeast of the research region, with a maximum $\text{CV} = 7.14\%$ in Aweday, Maya city, and the outermost Harari region. The study of Tmax and Tmin geographical anomaly patterns from 1983 to 2020 showed a definite seasonal tendency more visible in the northeast section and extended to the Zone's center during the Belg and Bega seasons.

The study investigated the link between seasonal and annual rainfall and Southern Oscillation (SST) in Ethiopia. Results showed a negative and statistically significant connection between mean Kiremt rainfall and NINO 3.4 SST, while positive connections were found in the Belg and Bega seasons. The study also found a negative association between mean annual rainfall and NINO3.4 SST. The findings align with previous research indicating that warm ENSO periods (El Nio years) are associated with decreased rainfall and drought years, while cold periods (La Nia years) are connected with increased rainfall levels.

5.2. CONCLUSION AND RECOMMENDATION

The CFSR dataset was utilized in this work to assess the spatial trend, variability of rainfall, temperature, and its teleconnection with the Pacific Ocean SST in Eastern Hararghe, Ethiopia, during the previous 38 years. In addition, past rainfall, temperature change, and variability have been investigated.

Across the research area, there was a high geographic diversity in rainfall on seasonal time scales. The dry season (Bega) had higher seasonal fluctuation than the other seasons in terms of rainfall. Similarly, rainfall variability in the short rainy season (Belg) was higher than in the main rainy season (Kiremt). During the analyzed years (1983-2021), rainfall trends declined statistically significantly in most of the area except in the northernmost tip. In contrast, the trend of rainfall declined dramatically and insignificantly in all parts of the Zone throughout the Belg season. However, rainfall has increased dramatically in Bega, particularly in the most central region of the country. Furthermore, in terms of area coverage, the trend of rainfall rose in the Bega season rather than in other seasons in the central. However, the rainfall patterns were not significant at the 5% threshold of significance. Furthermore, across the study area, NINO 3.4 SST had a decreasing effect on the quantity of rainfall in the Kiremt season and an increasing effect on the amount of rainfall in the Belg and Bega seasons. Similarly, equatorial Pacific Ocean SST decreased rainfall in the annual time scale (1983-2021). The connection between rainfall and SST in the Pacific Ocean was stronger in the Kiremt season than in the Belg and Bega seasons. Droughts were generally connected with ENSO episodes in the study area, as they were in most other parts of Ethiopia and East Africa.

According to the study's findings, the mean seasonal maximum temperature magnitude was statistically larger in the eastern half of the area, based on a statistical analysis of the CFSR Tmax dataset, but the remainder of the area had a low increase during the main crop season. There is a concern in the area as all portions are experiencing rises, with the eastern section having the largest. This means that rising temperatures have a significant

impact on the Zone. As a result, excessive temperatures have the potential to cause drought in the area, needing increased attention and categorization to identify temperature extremes in the Eastern Hararghe. The results showed a significant increase in seasonal temperature across all seasons, with the maximum temperature rising by 0.26 degrees Celsius (Figure 4.7) and the minimum rising by 0.058 degrees Celsius (Figure 4.8). The area's typical seasonal maximum temperature has been substantially higher than its minimum temperature over the last 38 years, according to the study's findings. However, the seasonal temperature variability from 1983 to 2020 was not statistically significant. Overall, these findings show that Belg experienced the greatest seasonal maximum and minimum temperature increase. Our results indicate a recent considerable increase in seasonal temperature as well as a warming trend.

More research on future climatic variability, future temperature extremes, and human innervation should be undertaken in the Zone utilizing various data sources. This study also indicated that the CFSR grid data sources are one of the country's prospective data sources, owing to their strong correlation with observed station data.

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