IMPACT OF CLIMATE VARIABILITY ON COFFEE YIELD AND ADAPTATION STRATEGIES IN GOMMA DISTRICT, JIMMA ZONE OF OROMIA NATIONAL REGION, ETHIOPIA

MSc. THESIS

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I hereby certify that I have read and evaluated this Thesis entitled 'Impact of Climate Variability on Coffee Yield and Adaptation Strategies in Gomma District, Jimma Zone of Oromia National Region, Ethiopia' prepared under my guidance by Zinash Nigussie Tsega. I recommend that it can be submitted as fulfilling the Thesis requirement.

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DEDICATION

This thesis is dedicated to my mother Ms. Dinkinesh Midaksa for her dedicated partnership in the success of my life by carrying my duty as her duty without any payment and for her infinite love.

STATEMENT OF AUTHOR

I the undersigned, hereby declare that the thesis- *Impact of climate variability on coffee yield and adaptation strategies in Gomma district, Jimma zone of Oromia national region, Ethiopia* is the outcome of my original work and all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for an MSc. degree at Haramaya University and is deposited at the University Library to be made available to borrowers under the rules of the library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author Zinash Nigussie Tsega was born on April 20, 1993, in Ada'a Woreda, East Shewa Zone of Oromia Region, Ethiopia. She attended her elementary and secondary education at Oda Nabe High School in Dukam town and preparatory education at Dukam Preparatory School. She joined Arba Minch University in 2013 and obtained her BSc Degree in Meteorology and Hydrology in 2016. Then she has served at the Ethiopian Institute of Agricultural Research at Jimma Agricultural Research Center in Agro meteorology positions. Finally, she joined the Post Graduate Program Directorate of Haramaya University in 2019 to pursue her MSc. degree in Agro Meteorology and Natural Risk Management.

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ACRONYMS AND ABBREVIATIONS

CBB	Coffee Berry Borer
CSA	Central Statistical Agency
DA	Development Agent
DOY	Day of Year
EIAR	Ethiopian Institute of Agricultural Research
ETCCDMI	Expert Team on Climate Change Detection Monitoring and Indices
EMA	Ethiopian Mapping Authority
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
GHG	Greenhouse Gases
IMPS	Improving Productivity and Market Success
ITCZ	Inter Tropical Convergence Zone
IPCC	Intergovernmental Panel on Climate Change
MLR	Multiple Linear Regression
NMA	National Meteorological Agency
SNNPR	Southern Nations, Nationalities, and Peoples' Region
SSA	Sub-Saharan Africa
UNIDO	United Nations Industrial Development Organization

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Impact of Climate Variability on Coffee Yield and Adaptation Strategies in Gomma District, Jimma Zone of Oromia National Region, Ethiopia

ABSTRACT

Changes in frequency and severity of extreme climate events is having significant impacts on human natural systems including coffee production, but this impact and adaptation strategies have not been well explored at local scale.. This study was therefore; conducted to assess the impact of climate variability on coffee yield and farmer's adaptation strategies in Gomma District. A multistage sampling technique was employed to select the sample households for this study. A total of 262 respondents were selected from four kebeles. Data were collected using household survey, Key informant interviews, focus group discussion and field observation. Meteorological data from 1988 to 2019 and time series data of coffee yield from 2007 to 2019 were collected from the National meteorological agency of Ethiopia and district's Agriculture and Natural Resource office respectively. INSTAT+ v.3.36, SPSS version 25 and XLSTAT 2014 were employed for data analysis. The result observed that annual rainfall amount showed statistically non-significant increasing trend by a factor of 2.68 mm/year. The annual mean maximum and mean minimum temperatures at study area significantly increased by a factor of 0.4 ^{0}C and 0.2 ^{0}C per decade, respectively. Pearson correlation showed that, temperatures, start of rainy season and end of season had negative correlation with coffee yield, whereas length of growing period, kiremt season and belg Season rain had positive correlation. Climate factors such as, start of rainy season, end of season, kiremt and belg season, maximum and minimum temperature, contributed about 74% for the variation of coffee yield during the study period. Adaptation strategies pursued by farmers to minimize detrimental effect of climate variability include using shade tree, improved varieties and agroforestry and crop diversification. The study concludes that climate variability and its effect on coffee production are evident in the study area. However, further studies on the impacts of climate variability on coffee production at agro ecological zones is necessary to design and apply more effective climate adaptation strategies for various growing condition and cultivation practices.

***Keywords*:** Adaptation, Coffee, Dry spell, Gomma, Onset

1. INTRODUCTION

Our planet is getting warmer and warmer as a result of an increase in the Earth's average temperature associated with anthropogenic activities (Bozzano, 2014). The change in temperature and rainfall have been dubbed the most significant environmental threats of the 21st century, and the potential long-term impact on crop production is a topical issue worldwide (IPCC, 2014). Depending on the geographical location, changes in variability, seasonality, changes in mean precipitation and availability of water, and the emergence of new pathogens and diseases affect the agricultural sector (Lal, 2021). Crop production can adversely be affected by rising temperature and fluctuating rainfall patterns (Daba, 2018). Exposure of the crop to temperatures above a specific threshold at critical growth stages, i.e. flowering, pollination, or grain-filling affects the quality and quantity of economic yield (Vara *et al*., 2003).

Moreover, the effect of climate change and variability on agriculture is stronger in poor countries that have rainfall-dependent economies. Agriculture contributes 41% of GDP, 80% of the employment, and the majority of foreign exchange earnings of Ethiopia (Gebreegziabher *et al*., 2011). However, this climate-sensitive sector is highly challenged by rising temperature and erratic rainfall. Seasonal crops are sensitive to their growing conditions, especially rainfall and temperature, which are usually sown with the beginning of the first rains during the advent of the south-west monsoon season, and they are harvested at the end of monsoon season (October–November). These crops are dependent on the quantity of rainwater as well as its timing.

Among the perennial crop produced in Ethiopia, coffee farming supports over 15 million farmers in Ethiopia and serves as the mainstay of the country's foreign earnings (Moat *et al*., 2017) Ethiopia is the biological and cultural home of coffee and is Africa's largest coffee producer and the world's fifth-largest exporter of Arabica coffee. In 2021/22, Ethiopia exported around 300,000 metric tons of coffee at a value of over 1.4 bill USD (Ethiopian Coffee and Tea Authority-Unpublished). In Ethiopia, coffee is produced within specific agro-ecological zones, over numerous boundaries. Most coffee is grown in areas of humid (moist) ever-green forest. The main coffee growing areas are found within the Oromia region and Southern Nation Nationalities, and people region (SNNPR), with modest production in Amhara Region and minor in Benishangul-Gumuz Region (Sisay, 2018). Coffee production has always been highly sensitive to climatic variability in which its growth is governed by the interplay between rainfall, temperature, and seasonality in which the stress increase as the air temperature increases and soil moisture decreases (due to lack of rainfall) and vice versa. Variation in both rainfall and temperature interfere with crop phenology, and consequently in productivity and quality. The Arabica coffee plant responds sensitively to increasing temperatures, specifically during blossoming and fructification(Haggar & Schepp, 2012). Increasing drought stress and rising temperature have both direct and indirect impacts on the physiology of the coffee plant and can adversely affect the plant by making it more vulnerable to plant pathogens and pests. For instance, due to rising temperature, changing rainfall, changing seasonality, and extreme events (regarding the onset of the wet season, as well as a prolonged dry season) coffee crops are exposed to shifting rainfall patterns and drought with the consequence of, abortion of flowers, reduce flower bud formation and cherry production, creation of favorable environment for the Coffee Berry Borer (CBB) (Iscaro, 2014).

Moreover, the changing character of rainfall and temperature are causes for the low yield and emergence of disease and pests. Studies by various investigators indicated that severe climate change could impose a lot of impacts on coffee production. Some of these impacts may include losses of genetic diversity of the indigenous Arabica coffee gene pools from their original places, physiological disorders in mature coffee plants (drying and non-bearing) due mainly to fluctuating weather patterns that trigger continuous flowering and heavy crop loads, development of new insect pests and diseases, declining soil fertility status, and many other associated problems. These climate change impacts on coffee production are highly considerable and may call for immediate action in developing appropriate climate-smart practices and various mitigation and risk management options for use by the smallholder farmers (Coffee Research strategy, 2016).

Jimma zone is one of the areas in the Oromia region where coffee is produced in large quantities. A substantial proportion of the farming community depends on coffee production as a source of livelihood in the area. Better understanding of climate change impact on coffee yield and local adaptation strategies will facilitate development of better adaptation strategies against adverse impacts of climate variability. Although a little study have been conducted to assess the impact of climate variability and change on coffee in Ethiopia (Haile, 2018), there is no as such organized study conducted in Gomma district about the impact of climate variability on coffee production and its adaptation strategies. Therefore, this study was conducted to fill this information gap regarding the impact of climate variability on coffee production and farmers' adaptation strategies in the study area.

Objectives of the study

The general objective of the study was to characterize climate variability and assess its impact on coffee yield and adaptation strategies in Gomma district with the following specific objectives:

- To characterize long-term (1988-2019) rainfall and temperature record of Gomma district
- To assess the impact of climate variability on coffee yield in the study area
- To assess adaptation strategies practiced in the study area

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2. LITERATURE REVIEW

Climate is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans, and other bodies of water and living things which are determined by the balance between the earth's intercepted solar energy and it's re-radiating from the earth. Climate is the weather condition prevailing in a place over 30 years. It is measured by assessing the patterns of variation in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particles, and other meteorological variables in a given region over an extended period. During the preindustrial period, there might be modest climate change, but it changed dramatically after the industrial revolution because climate dynamics now have a new element in the form of anthropogenic inputs (Uprety *et al*., 2019).

Climate is changing naturally at its own place, since the beginning of the evolution of the earth, 4–5 billion years ago, but presently, it has gained momentum due to inadvertent anthropogenic disturbances. These changes may culminate in an adverse impact on human health and the biosphere on which we depend. The multi-faceted interactions among the humans, microbes, and the rest of the biosphere, have started reflecting an increase in the concentration of greenhouse gases (GHGs) i.e. CO_2, CH_4, and N_2O causing warming across the globe along with other cascading consequences in the form of a shift in rainfall pattern, melting of ice, rise in sea level, etc. The above multifarious interactions among atmospheric composition, climate change, and human, plant, and animal health need to be scrutinized and probable solutions to the undesirable changes may be sought (Singh, 2009).

Climate change is defined as a change in the statistical characteristics of the climate system that can be detected by changes in the mean and/or variability of those properties over time, usually decades or more (IPCC, 2014). Climate change is a key environmental concern in today's globe, posing serious challenges to ecosystems, food security, water resources, and general economic stability, resulting in regionally dependent increases or decreases in rainfall, increased cloud cover, and rising sea levels. Extreme events like as greater maximum temperatures, more intense precipitation events, increased drought risk and duration, and enhanced peak wind intensities of cyclones will all rise in severity and frequency (Reynolds, 2010).

According to the decision of Intergovernmental Panel on Climate Change (IPCC) climate change is already happening with multifaceted effects on humans and the environment (IPCC 2007). This has been confirmed by analysis of past climate records and future trends over different parts of the world. For example, analysis of past climate data in Ethiopia indicated an increase of annual minimum temperature by 0.37 °C per decade since 1951 (NMA, 2007) and annual mean temperature by 1.3 °C between 1960 and 2006. Moreover, the average number of hot days and hot nights per year had increased by 20 and 37.5 % between 1960 and 2006, respectively, while the average number of cold days and nights declined by 5.8 and 11.2 %, respectively (Hadgu *et al*., 2015).

Climate variability refers to the Spatio-temporal fluctuation of climatic conditions (Christensen *et al*., 2007). Climate variability is also defined by Houghton *et al*. (2001) as fluctuations in the mean state and other statistical descriptions of severe climatic conditions on all temporal and geographical scales beyond individual weather occurrences. Climate variability, according to Houghton *et al*. (2001), is defined as a climatic parameter of an area that deviates from its long-term mean. The importance of Spatio-temporal scales of meteorological occurrences is also emphasized once more. The IPCC's (2007) definition of climatic variability is similar to that of Houghton *et al*. (2001), with a focus on the variability dimensions.

2.1. Climate of Ethiopia

The statistical interpretation of rainfall and temperature data accumulated over a lengthy period for a certain region or place is frequently used to characterize climate. As a result, the mean annual rainfall distribution across the nation exhibits significant geographic variance, ranging from nearly 2000 mm in certain pocket regions in the Southwest to less than 250 mm in the Afar and Ogaden lowlands (NMSA, 2001).

Rainfall happens at several seasons throughout the year. In contrast to much of the tropics, where two seasons are prevalent (one wet season and one dry season), Ethiopia has three seasons: *bega* (dry season) from October to January, *belg* (short rain season) from February to May, and *biremt* (long rainy season) from June to September (Sigele and Lamb, 2005). The country's diverse altitude also has a significant impact on temperatures. Because of its geography, the nation has mild temperatures for its tropical latitude. The average annual temperature in the nation ranges from around 10 0C in the northwest, central, and southeast highlands to about 35 0C in the north-eastern lowlands.

Ethiopia is one of Africa's biggest countries, with a diverse range of landscapes, strong topographical differences, and elevations ranging from about 155 meters below sea level at Assale Lake in the Danakil valley to roughly 4,533 meters above sea level at Mount Ras Dashin (EMA 1988). Because of these factors, as well as its physical location near the equator and the Indian Ocean, the country experiences significant temperature and precipitation changes across the country.

Ethiopia's climate is largely influenced by the seasonal migration of the Intertropical Convergence Zone (ITCZ) and related atmospheric circulations, as well as the country's varied geography (Korecha and Barnston, 2007). Landscapes with varying physiography and elevation, such as the highlands and lowlands, experience a range of climates, ranging from desert climates to tropical mountain climates. In a country whose economy is primarily dependent on rain-fed agriculture, climate has many evident repercussions on landforms and its dynamic evolution of natural landscapes, as well as on the living situations of local people. (Gebre, H *et al*., 2013).

2.1.1. Rainfall and agriculture

Because water is such an important component of agricultural production, changes in water availability may have an influence on agricultural productivity and income. According to climate research, most of these oscillations are now caused by intra-year, rather than inter-annual, alterations in rainfall timing and intensity (Pale and Naude, 2015). Because all plants require at least some water to thrive, agriculture relies heavily on rain (which is the most efficient method of watering). While a consistent rain pattern is beneficial to plants, too much or too little rain can be detrimental to crops. Aside from illness, rainfall may influence how quickly a crop grows from seed, as well as when it is ready to harvest. A good combination of rain and irrigation can result in faster-growing plants, reducing germination time and the period between sowing and harvest (Torres *et al*., 2019).

2.1.2. Temperature and agriculture

The balance of the planet's system's incoming and outgoing energy influences the earth's temperature. Large swings in climate and weather can be caused by little changes in the Earth's average temperature. As a result, agriculture, as a highly climate-sensitive industry, is especially vulnerable to temperature variations. Warmer temperatures speed up the growth of some crops, whereas quicker growth shortens the time it takes for seeds to grow and mature, reducing harvests. Increased weeds, pests, and fungus, which flourish in warmer temperatures, as well as a rise in extreme weather events like floods and drought, can have an impact on crops and diminish yields (Bozzano *et al*, 2014). Increased plant temperature accelerates growth by reducing the window of opportunity for photosynthesis because the life cycle is shortened, whereas heat and drought stress may also restrict growth directly at the metabolic level.

2.2. Impacts of Climate Change and Variability on Agriculture

Climate change, according to the IPCC (2014), impairs agricultural productivity, posing a significant danger of global food insecurity. Africa is one of the world's most susceptible areas to climate change. Due to factors such as widespread poverty, repeated droughts, inequitable land distribution, and over reliance on rain-fed agriculture, previous assessments by Lema and Majule (2009) concluded that Africa is particularly vulnerable to the impacts of climate change due to temperature and rainfall changes and extreme events. Climate change and unpredictability, according to Rickards *et al.*, (2012), restrict agricultural growth and influence crop species and cultivar selection, as well as farm management decisions. Climate change's impact on agricultural systems raises significant doubts regarding crop yield and appropriateness in the future, particularly in locations prone to extreme environmental change (Orlandi *et al.*, 2020). Agriculture is vulnerable to short-term weather fluctuations as well as seasonal, yearly, and longer-term climatic variations. Agriculture can sustain minor deviations in the climatic mean for long-term changes. Variations in meteorological factors are more transient, yet they have a significant impact on agricultural systems. Crop production and animal agriculture will be affected by changes in temperature, solar radiation, and precipitation. Climate change will have an economic influence on agriculture, affecting farm profitability, pricing, supply and demand, trade, and regional comparative advantages, among other things. The size and distribution of such climate-induced changes may have an impact on our capacity to grow food production (Singh *et al*., 2009).

The agricultural industry contributes significantly to greenhouse gas emissions, and climate change has the potential to irreparably harm the natural resource base upon which agriculture relies, as well as negatively impact agricultural output in general. In the mid-to-high latitudes, mild temperature rises can have a slight beneficial influence on crop yields; but, in the low latitudes, even moderate temperature increases are likely to have a detrimental effect on yields. Water scarcity and availability will become increasingly constrained, necessitating a rethinking of water storage to deal with more intense precipitation events, higher intra- and inter-seasonal variability (floods and droughts), and higher evapotranspiration. Invasive species, pests, and disease vectors are already harming agricultural output and are predicted to worsen as a result of climate change (Reynolds, 2010)

2.2.1. Climate variability and crop production

Worldwide climate changes have raised worries about prospective changes to food yields and crop production systems, according to the IPCC's 2007 report. Increased atmospheric concentrations of greenhouse gases might lead to regional and worldwide changes in temperature and precipitation, according to studies undertaken to examine the impact of climate change on agriculture. These changes are expected to have an influence on agricultural production systems, according to new IPCC (2007) estimates. Global warming, according to Schreck and Semazzi (2004), has increased the intensity of heat and decreased the dependability of rainfall in East Africa, resulting in droughts and floods that have been observed to cause crop loss and damage. Rosenzweig (2002) found the same thing in his research. Similarly, according to Rosenzweig (2002), changes in rainfall patterns and levels have resulted in agricultural losses in several regions of Africa. In general, variations in rainfall and temperature are expected to lower agricultural production. Changes in rainfall patterns may raise the chances of crop failure in the short term while decreasing productivity in the long term.

Despite significant advances in specific crops in some parts of the world, climate change is anticipated to have a negative overall influence on food productivity (Rosenzweig *et al*., 2002). Increases in average temperature can prolong the growing season in areas where the spring and autumn are generally mild, while also harming crops in areas where July heat already limits yield (Lobell, 2009). Furthermore, rising temperatures result in increased respiration rates, shorter seed development times, and, as a result, poorer biomass output (Battisti and Naylor, 2009). Additionally, warmer temperatures cause a shorter grain filling time, smaller and lighter grains, and so poorer crop yields and perhaps inferior grain quality (Waggoner, 1983). For some plants, a temperature increase of less than 1°C can increase transpiration rate by up to 30% (Kimball, 1983). Temperature rises may also influence water supply by changing runoff and groundwater recharge rates, as well as capital and technology needs such as surface water storage and irrigation systems (Oki *et al*., 2006). Climate change will most likely result in a major spatial shift and extension of croplands, according to Olsen and Bindi (2002), because it will create a favorable or restricted environment for crop growth across different regions, and because climate is a primary determinant of agricultural productivity, any significant changes in climate now and in the future will influence crop productivity.

2.2.2. Climate change and variability & coffee production

Coffee productivity and quality, according to Haggar & Schepp (2012), is highly reliant on temperature and rainfall conditions, and is particularly vulnerable to drought, excessive wetness, and wind damage. Tucker *et al*. (2010) found that the blooming and fructification of Arabica coffee, in particular, need a precise pattern of dry and rainy seasonal alternation. Steps in coffee production and possible implications from severe effects of climate change and variability according to Haggar & Schepp, (2012) and ICC,(2015). According to ICC, (2015), increasing temperatures and erratic rainfall patterns are projected to have severe repercussions for coffee production in terms of quality, yield, and pests and illnesses, even if future climatic variations between areas remain unclear. Camargo conducted a study (2009), climate change and unpredictability are posing a danger to coffee output in every major coffee-growing location on the planet.

Climate change has resulted in higher temperatures, longer droughts interrupted by severe rains, and more resilient pests and plant diseases, all of which have impacted coffee output in the majority of cases. Temperature and rainfall are thought to be crucial elements in deciding whether or not coffee can be grown. According to research done by Marengo and Antonio

(2009), mean temperatures above 23°C inhibit coffee growth, and persistent exposure to daily temperatures as high as 30°C might result in lower yield. Nonetheless, as scientific studies and participatory evaluations have shown, many of today's coffee-growing locations are already experiencing climate change and unpredictability, and are extremely likely to be influenced in the near and long term. According to (TACRI, 2009), a quality issue may occur as a result of the rapid plant growth, which will result in inferior coffee fruit quality.

Furthermore, during the summer months, high maximum temperatures may produce excessive fruit ripening, which is detrimental to fruit quality. Although coffee trees are resistant to high temperatures and drought, the occurrence of more extreme circumstances can lead to physiological stress, such as a decrease in photosynthetic efficiency. Flowering and maturation in connection to the anticipation of bud potential break are the recognized crucial stages that may be impacted, according to Muya (2008). Furthermore, during the reproductive period, high temperatures and dry conditions might be crucial for optimal coffee yield and quality. The establishment of appropriate air temperature restrictions for coffee is critical for its distribution and commercial utilization. Coffee output will be negatively affected when temperatures climb in the highlands.

2.2.3. Climate variability and trend in Ethiopia

Global trends of temperature and rainfall point to the fact the climate is changing. Mean annual temperatures have been increasing and places in Sub-Saharan Africa and Asia continue to experience weather extremes like flood and drought respectively. With global warming, not a hiding secret whether caused by natural variability or anthropogenically induced (IPCC, 2007), it is important to be informed and regularly updated on observed regional temperature and precipitation trends at both regional and local levels. The IPCC (2014) has projected that, if measures are not taken to reduce the generation of GHG emissions, the future temperature will continue to increase as well as extreme weather conditions such as drought in most parts of the world especially, countries in Sub-Saharan Africa.

Climate variability is short-term fluctuations in average weather patterns which has an impact on agriculture. Climate variability, on the one hand, has an impact on agroecological, agricultural, and livestock growth conditions. A delicate balance between agricultural output and food security is created by high climate variability (e.g., low and irregular rainfall distribution). According to studies, changes in agriculturally important climatic factors (e.g., rising temperatures and diminishing rainfall amounts and distribution) are anticipated to affect maize, rice, wheat, and other food crop yields in semi-arid parts of the world (Lobell *et al*., 2009). Many additional characteristics of agricultural productivity among smallholder farmers in Sub-Saharan Africa (SSA) are influenced by rainfall, including farm sizes, crop enterprises, cropping calendars, and the occurrence and growth of weeds, crop pests, and illnesses (Yengoh *et al*., 2010).

2.2.4. Rainfall variability and trend in Ethiopia

Ethiopia has one of the most unpredictable rainfall patterns, which is a natural aspect of agriculture (MoA, 2000). The country is sensitive to rainfall unpredictability due to its geographic position and terrain. Long-term trends in the nation are difficult to identify due to the high inter-annual and inter-decadal variability in rainfall. Between 1960 and 2006, there was no statistically significant trend in recorded mean rainfall in any season. Significant interannual variations between 2.2 and 3.8-year periodicity were found in reconstructed rainfall since 1811, with significant decadal and multidecadal variations during 1855–1900 and 1960–1990; the duration of negative and positive rainfall anomalies varied between 1–7 years and 1–8 years (Mokria *et al*., 2017).

For farmers who rely on agricultural production, rainfall fluctuation is the most significant source of risk. In Ethiopia, there are two major rain seasons: '*kiremt*' and '*belge*.' The *kiremt* rains start in the south west in March and May and move northwards from July to September, impacting the majority of the nation. The *kiremt* rain accounts for over 90% of the agricultural produce gathered between October and December (CSA, 2011). Extreme weather variability has always been a problem in the United States. Droughts and floods wreaked havoc over the land, resulting in catastrophic famines and floods (World Bank, 2006).

Intraseasonal rainfall variability in terms of start of the season, end of the season, length of the growing season, number of rainy days, length of the dry spell within the growing period, and trend is more important for agricultural purposes in dry land areas than annual and seasonal totals, according to a study of the past and future (Hadgu *et al*, 2013). The first occurrence of at least a specified mm of rainfall totaled over certain consecutive days is considered the commencement of the rainy season. Segele and Lamb (2005) defined onset date as any date when 20 mm of rain is accumulated over three consecutive days and there are not more than eight dry (0.1 mm) days in the next 30 days. Tesfaye and Walker (2004) utilized 20mm rainfall over three days and no dry periods longer than seven days in the next 30 days to define onset. On the other hand, Mesay (2006) defined onset date as the time when precipitation equals half of the reference evapotranspiration at the start of the growing season.

Segele and Lamb (2005) also define the end of the rainy season as the first day following the commencement of a dry spell (0.1mm rainfall per day) lasting at least 20 days, while Tesfaye and Walker (2004) define the end date as the day when the soil water level reaches zero after September 1. The Length of Growing Period is the difference between the onset date and the termination date (cessation), which is a critical component in determining the maturity of cultivars to be cultivated in different rainfall regimes (Getaneh, 2015).When a certain amount of precipitation is recorded the day is the rainy day which means when more than 0.85mm precipitation is accumulated and a dry day is a day with less than 0.85mm precipitation or no precipitation is recorded (Love *et al*., 2008).

2.2.5. Temperature variability and trend in Ethiopia

Global average surface temperatures have been increasing since the mid-nineteenth century, according to climate trends and climatic extreme indices developed from empirical, observed data, with the largest pace of change documented since the mid-1970s (IPCC, 2014). This is due to the ongoing production of greenhouse gases as a result of human activity. Anthropogenic forces remain a key contributor of recent global warming, according to the IPCC's latest assessment. Because of the increased concentration of greenhouse gases in the atmosphere, the temperature continues to rise due to the greenhouse effect, which may have led to changes in rainfall patterns throughout the world. According to recent climatological studies, worldwide surface air temperature increased by 0.76°C from 1850 to 2005 (Bakri and Abou-Shleel, 2013).

Ethiopia's climate is inherently both diverse and unpredictable, and the country has seen both climatic fluctuation and change.

However, in recent years, the climate has shifted considerably (Mokria *et al*., 2017). The temperature (maximum, minimum, and mean) is rising, but the rainfall has no discernible pattern–it is highly variable (NMSA, 2007; McSweeney *et al*., 2008; Eshetu, 2011; Mokria *et al*., 2017). According to studies, there has been a significant temperature variance and trend shift throughout time. The annual lowest temperature, represented as temperature deviations from the mean and averaged across 40 sites from 1951 to 2005, exhibited a significant degree of fluctuation (NMA, 2007). Over those 55 years, the country saw both warm and chilly years, with recent years being the warmest compared to earlier decades. Furthermore, between 1951 and 2005, there was a rising tendency in the annual lowest temperature. Every ten years, it has risen by roughly 0.370°C (NMA, 2007).

2.2.6. Climate change and crop production in Ethiopia

In many parts of the world, climate change is one of the biggest risk factors impacting the agricultural system's performance and management. Climate change worsens the living conditions for many who are already vulnerable, particularly in developing countries because of the lack of assets and adequate insurance coverage. Climate change is projected to the overall decrease in the yields of cereal crops in Africa through shortening growing season length, amplifying water stress, and increasing the incidence of diseases, pests, and weeds outbreaks (Niang *et al*., 2014). Among the various environmental changes brought by climate change that limits crop yields, heat and water stresses are considered the most important (Prasad *et al*. 2008). The major impacts of climate change are predicted to be harsh in sub-Sahara Africa because of the region’s characteristic of high heat stress and low precipitation (World Bank, 2006; IFPRI, 2007; Thornton *et al*., 2008).

Africa is most vulnerable to climate change and climate variability and the situation is aggravated by the interaction of multiple stresses occurring at various levels and low adaptive capacity. Agricultural production and food security (including access to food) in many African countries and regions are likely to be severely compromised by climate change and climate variability (IPCC, 2014). Some countries in Africa already face semi-arid conditions that make agriculture challenging, and climate change will be likely to reduce the length of the growing season as well as force large regions of marginal agriculture out of production.

Agriculture, which is the mainstay of the Ethiopian economy, is highly exposed to the impacts of climate change which threatens sustained economic growth that will lead to extended poverty. However, like the rest of Sub-Saharan Africa, Ethiopia's agriculture is mainly rain-fed and therefore highly vulnerable to climate change. Rain-fed crop production is the basis of all subsistence farming in most parts of Ethiopia and accounts for more than 95% of the land area cultivated annually. A typical farming household in the semi-arid areas owns just a small portion of land (generally less than one hectare) on which crops are produced and which also partly supports variable numbers of cattle, goats, donkeys, and sheep (Deressa, 2007). According to Deressa (2007) climate change, especially increasing temperature has a damaging impact on Ethiopian agriculture.

In Ethiopia, models indicate that the average daily rainfall amount will decline to around 1.97 mm from 2070 to 2099. The decrease in rainfall amount will be aggravated by increased evapotranspiration rates caused by likely mounting temperatures and aridity. The mean annual temperature will rise to 26.9^{o}C during 2070-2099 (Cline, 2007: cited by MoA, 2011). On the other hand, the National Metrological Agency (1986) revealed that in Ethiopia climate variability and change in the country are mainly manifested through the variability and a decreasing trend in rainfall and increasing trend in temperature. Besides, rainfall and temperature patterns show large regional differences (NMA, 2007).

2.2.7. Coffee production and its importance in Ethiopia

Coffee is growing in more than 60 tropical countries among which Ethiopia is one, and its production is a significant contributor to agricultural GDP. Coffee (Coffee *arabica L.*) is an economically important crop, which is contributing the highest of all export revenues in Ethiopia accounting for about 27-34 % of the value of all exports (USDA, 2020). It is a cornerstone in the export economy of the country and it supports directly or indirectly for about 25 mill livelihood of people. As it is well known, Ethiopia is the only center of origin and diversity of Arabica coffee (Vavilov, 1951); it is produced in four production systems, namely: forest, semi-forest, garden, and plantation coffee in the Western, Southern, and Southwestern parts of the country (CFC, 2004). Of the Southwestern parts of the country, Jimma Zone is one of the coffee-growing zones by small-scale farmers' holdings as well as state and private-owned plantations. The

Garden coffee production system is predominantly implemented by small–scale farmers' holdings.

2.2.8. Climate change and coffee production in Ethiopia

Coffee crops need favorable conditions throughout their vegetative and reproductive cycle that is the way most of their oscillation is mainly associated with climatic factors(Tavares *et al*., 2018). The climatic variability is the main factor responsible for the oscillations and variation of the coffee grain yield in the world. The relationships between the climatic parameters and the agricultural production are quite complex because environmental factors affect the growth and the development of the plants under different forms during the phenological phases of the coffee crop. Temperature and rainfall conditions are considered to be important factors in defining potential coffee yield. Both factors interfere in the crop phenology, and consequently in productivity and quality. The Arabica coffee plant responds sensitively to increasing temperatures, specifically during blossoming and fructification. Mean temperatures above 23°C hinder the development and ripening of cherries and continuous exposure to daily temperatures as high as 30°C could result in reduced growth or even in yellowing and loss of leaves. The FAO Eco Crop model gives information on optimal and absolute temperatures for coffee Arabica, ranging from 14°C to 28°C and 10°C to 30°C, respectively. Besides the direct impacts of high temperatures on the coffee crop, the increase of pests and diseases is supposed to be a consequence of increasing temperatures (Haggar & Schepp, 2012).

2.3. Adaptation to Climate Change

Isa (1995) defines adaptation as "the entire adjustment made or self-made within natural and human systems as a therapeutic or preventative reaction to present or future climatic stimuli or their consequences in order to limit harm or take benefit of it at the appropriate moment." Adaptation, according to Tarleton *et al*. (2008), is a change in ecological, social, and economic systems in response to actual or anticipated climatic stimuli and their consequences or implications. As a result, these are changes in processes, practices, and structures to reduce potential damage or take advantage of opportunities associated with climate change. It is defined as a change in procedures, practices, and structures aimed at limiting or eliminating potential damages or taking advantage of opportunities created by variability and climate change.

2.3.1. Adaptation to climate variability and change

Making decisions about how to adapt to the consequences of climate change coffee yiald. The impact of numerous climate variables on agricultural yields needs to be isolated and measured in order to execute such techniques. A different adaptation approach, for example, will be needed in response to a change in temperature than a change in rainfall (Ainsworth, 2008). In order to study adaptation strategies that can be utilized to increase food productivity under climate change in Cameroon, Tingem *et al*. (2009) combined climate and crop models. The study's findings suggest that using new crop cultivars—late-maturing and heat-tolerant cultivars—can significantly lessen the negative effects of climate change on food supply in Cameroon.

There are two different types of production system adjustments involved in agricultural adaptation. The first is more diversification, which entails engaging in production activities that can withstand temperature stressors and/or droughts as well as activities that effectively utilize and fully exploit the current water and temperature circumstances, among other considerations. Given that different crops are impacted by climate events differently, crop diversification can act as insurance against rainfall variability (Orindi and Eriksen, 2005).

The second technique focuses on crop management procedures designed to prevent crucial crop growth stages from coinciding with extremely unfavorable weather circumstances, such as dry periods in the middle of the growing season. Changes in planting and harvesting dates, as well as lengthening the growing season, are all possible crop management techniques (Orindi and Eriksen, 2005). Testing possibilities for adaptation in-depth seemed to be hindered by a number of factors. Prioritizing among crop management modifications that could be adaptive is the main challenge, particularly for interacting practices like planting dates, fertilizer levels, cultivar selection, and irrigation management.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location of the study area

This study was conducted in Gomma District of the Jimma Zone, Oromia National Regional State of Ethiopia (Figure 1). It is situated at 390 km southwest of Addis Ababa, the capital city of Ethiopia, and about 45km west of Jimma town. The District is located between $7^0$39'43"N to $8^0$41'7"N and $36^0$28'54"to 36^0 39'00" E and bordered by Seka-Chekorsa, Mana, Gera, Gumay, Kersa, Limu-Kosa Districts, and by the Buno Bedele Zone.

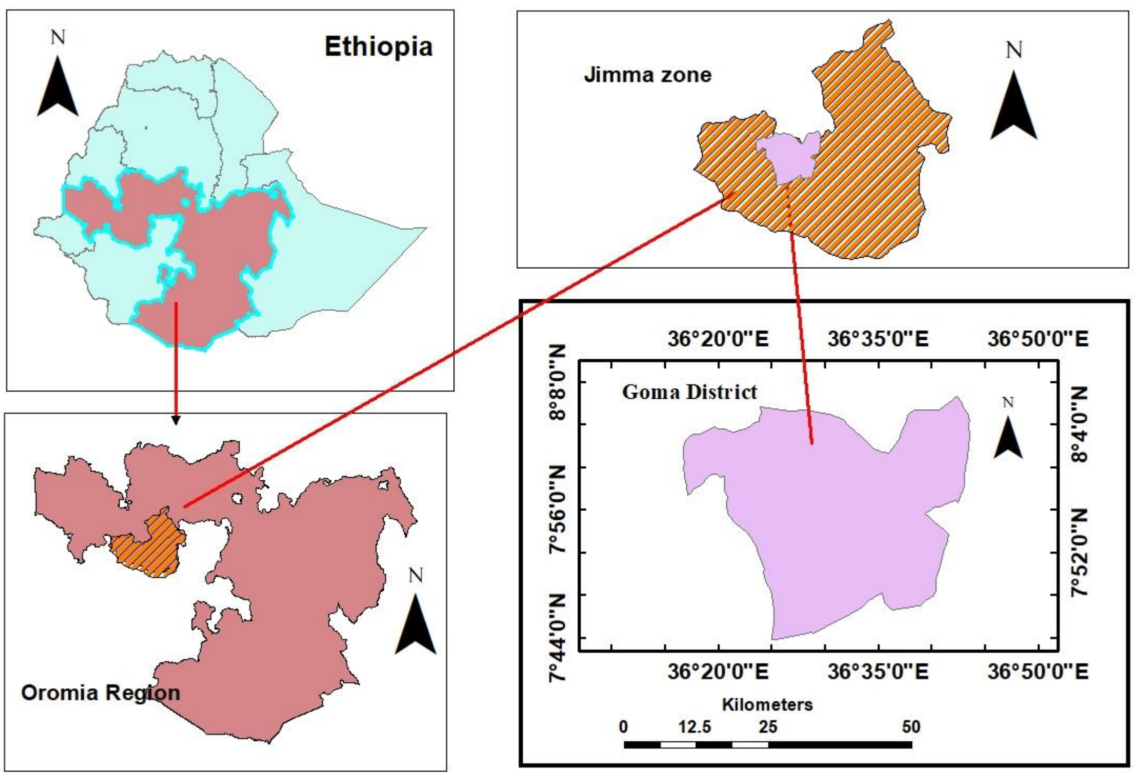

Figure 1. Location map of the study area

3.1.2. Climate, topography and soil

Gomma District has an average annual rainfall of 1524 mm which has bi-modal rainfall distribution. The small rainy season falls from March to April and the main rainy season extends from June to October (IMPS, 2007). Gomma District enjoys well-distributed annual rainfall and agro ecologically it is classified as wet midland 96% and lowland 4%.

The topography of the study area ranges from gently sloping to hilly land with ridges and valleys in between (Elias, 2005).The altitude of the district ranges from 1387 to 2870 meters above sea level. The most abundant soil type of the district is Nitosoil and covers about 90% of the area of the district. The pH of the soil in Gomma ranges between 4.5 and 5.5 (IPMS, 2007).

3.1.3. Population and farming system

The total population of the Gomma District was 216,662 (CSA, 2008). It has a total area of 96,361.72ha (96.4 km^2) including the two coffee state farms which cover an area of 2704 ha. In the district, there are 36 rural *kebeles* and 3 urban *kebeles*. Gomma District has 45,567 agricultural households from which 35,533 are male-headed and 10,034 are female-headed. Thirty-two *kebeles* with more than 92% of the people in Gomma are categorized under the coffee and livestock farming system. The major cash crops in the district include coffee, chat, tropical and subtropical fruit (mango, avocado, papaya, banana, orange, pineapple), and spice (ginger and Ethiopian cardamom). Among cereal crops, maize, *teff* and barley are grown in the area. Livestock reared include; cattle, small ruminant (sheep and goat) apiculture, poultry, and equines (IPMS, 2007).

3.2. Research Design

In this study a cross-sectional research design was used to acquire the required data. Gomma District was selected purposively based on the fact that it is one of the major coffee-growing areas in the southwestern part of Ethiopia. The choices of the *kebeles* were based on prevalence of coffee production. Out of thirty-two *kebeles* four *kebeles*; Bulbulo, Genji Ilbu, Omo Beqo, and Omo Gurude were selected for this study. Household heads of the selected *kebeles* were selected from a list provided by *kebele* administration using lottery method.

3.2.1. Sampling procedures and sample size determination

Multistage sampling procedure was applied to select the sample households or respondents for this study. In the first stage, Gomma District was selected purposively due to its coffee production potential. In the second stage, among the 32 *kebeles* in the district, 18 *kebeles* were selected purposively because of coffee production in the area; then four *kebeles* (Bulbulo,Genji Ilbu, Omo Beko and Omo Gurude) were selected by simple random sampling technique. Finally, a total of 262 HHs were selected from the four *kebeles* using simple random sampling techniques. The sample size was determined using a simplified formula provided by Yemane, (1967) at 95% confidence level, 6% degree of variability, or 0.06 level of precision.

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

Where n is the sample size; N= is the number of coffee producer household in the study area; e= the level of precision (in this case, e= 6%) and e^2 is the variance of an attribute in the coffee producers. Then, the sample size (n) was calculated as follows:

$$n = \frac{\mathbf{4665}}{\mathbf{1+4665(0.06)^2}} = 262$$

Table 1. Total number of coffee producers and sample household heads

Kebeles	Total number of coffee producer household	Proportion of sampled households %	Sample household
Bulbulo	941	20	53
Ganji Ilbu	689	15	39
Omo Beko	1535	33	86
Omo Gurude	1500	32	84
Total	4665	100	262

3.2.2. Data source and data collection methods

Both primary and secondary data sources were used to generate the data for this study. Primary data about the effect of climate change on coffee yield, farmers' adaptation practices were gathered using a structured questionnaire, key informant interviews (village leaders, agricultural extension worker), focus group discussions, and personal observations. Time-series data (secondary data) including climate data (which is rainfall and temperature data for over the past 30 years) 1988-2019 and crop data from 2007 to 2019 years was collected.

Climate data which is a set of secondary data was collected from the National Meteorology Agency of Ethiopia and coffee yield data was from the Agriculture and Natural resource office. Both climate and crop data were used to present the trend analysis over time variation in weather variables and crop yield.

3.2.2.1. Household survey questionnaire

Semi-structured open and closed-ended questions pertinent to the research objective were prepared in English language and translated to local language; Afan Oromo for easy communication with the interviewees. The questionnaire was used as the main data collection tool to provide information that may identify adaptation practices and impact of climate change on coffee production and productivity in the study area. During the survey, the interviewer was a household head or his partner.

3.2.2.2. Key informant interview

Key informant interviews was carried out with knowledgeable and experience rich-experts from the district agricultural office and development agents (DA). A number of knowledgeable individuals in the study district were interviewed to acquire insight about climate and coffee production. Individual considered are DA and extension workers. This was done to extract sufficient information on climate change and climate variability on coffee production and adaptation practices of the farmers.

3.2.2.3. Focus group discussions (FGD)

FGDs were organized at a community level. A group of smallholder farmers was selected randomly to discuss the existing and persistent impacts of climate change and climate variability on coffee yield and adaptation measures used as a response to extreme weather events.

3.3. Method of Data Analysis

Survey data was verified, compiled, summarized, and analyzed using statistical package for social science (SPSS). The quantitative data was summarized and presented using descriptive statistics such as mean, standard deviation, frequencies, percentile, histograms, etc.

3.3.1. Climate data analysis

3.3.1.1. Estimating missing climate values

In climate studies before starting analysis or working with data estimation of missing rainfall value is a more important task and it is common to check the gaps in the time series or datasets before filling the missed data. In this study, a simple mathematical equation was applied to quantify the total %age of missed values from the total data series as follows.

$$\% \text{ of missed data} = \left[\frac{X_1}{X_2}\right]*100$$

Where X_1 is the count of missed data

X_2 is the whole data set

Accordingly, the %age missed values less than 10% out of the total data series is considered for inclusion of the data set for analyses (Baddour and Kontongomde, 2007). There is a various deterministic method of estimating missing value. In this study, two methods were applied to fill the missing values: i.e spatial interpolation for temperature and first-order Markov chain simulation of INSTAT for rainfall (Stern *et al.*, 2006). INSTAT fits a model to the past data and then generates similar time series for any number of desired years.

3.3.1.2. Data quality control

In most cases, the data we used are subjected to disturbance of different kinds especially error and uncertainties over data storage and we have to take data quality control before proceeding to analysis(Einfalt and Michaelides, 2008). For this study the procedure in RclimDex 1.0 software.

The main benefit of this software in quality control is to identify errors usually caused by data processing, such as errors when keying manually (computational error). The quality control procedure was also detecting outliers in daily data series. Additionally, by using the Turkey fence we screened the outlier's which is recommended for non-normally distributed data like rainfall (Ngongondo *et al*., 2011).

$$Q_1 - 1.5*IQR,\ Q_3 + 1.5*IQR \qquad \text{(EQ 1)}$$

Where Q1 and Q3 are lower and upper limit quartiles respectively, 1.5 represent standard deviations from the mean, and IQR represents the in quartile range. A value outside the turkey fence was considered as outliers. Outliers were set to a limit value corresponding to ±1.5×IQR.

Data homogeneity test is a means of removing changes, not due to the climate itself' but it is due to non-climatic factors. Next to the change detected due to non-climatic factors, raw climate records also contain non-climatic jumps and change for example due to relocation/change in instrumentation. For this study, Buishand's method was used to check data homogeneity which is conducted by using a cumulative deviation test. The cumulative deviation test is based on the adjusted partial sum or cumulative deviation from the mean(T.A. BUISHAND, 1982).

$$S_k^* = \sum_{t=1}^{k} (xt - \bar{x}), \quad k=1, 2, 3, 4\ldots n \qquad \text{(EQ 2)}$$

Where $\mathbf{S_k^*}$ are the cumulative deviations $\mathbf{x_t}$ is the observed value**,** $\bar{\boldsymbol{x}}$ is the sample mean, and n is the number of records in the time series.

The cumulative deviations test statistic (Q) is estimated as:

$$\mathrm{Q} = \max|\mathrm{Sk}*|, 0 \le \mathrm{k} \le \mathrm{n}. \qquad \text{(EQ3)}$$

The maximum value of Q indicates non-homogeneity.

To assess the impact of climate change on coffee yield, weather variables described were annual rainfall, maximum and minimum temperatures (time series data) was achieved using descriptive statistics such as means, %ages, and the standard deviation of the series.

3.3.1.3. Onset, cessation, and length of growing season

A day with an accumulated rainfall amount of 20 mm in three consecutive days with no consecutive dry spells extended beyond 10 days within 30 days from planting is defined as the onset date (Stern *et al*., 2006). The end of the rainy season is defined as any day when the soil water reaches zero with the assumption of fixed average evapotranspiration of 5mm per day and 80 mm/meter of soil water holding capacity (Stern *et al*., 2006) to be reached, by taking a given day; e.g. first of September, after which the end of rain is highly probable. The length of the growing period (LGP) is determined by taking the difference between the end date and the onset.

Dry spell length was also be determined as consecutive days with rainfall less than 1 mm per day exceeding 7, 9, 10, and 15 days and analyzed by Markov Chain analysis as indicated in Stern *et al*.,(2006) and (Stern & Cooper, 2011) using INSTAT v3.36. Likewise, the maximum one-day precipitation was determined as the highest precipitation amount received in one day, and the number of very heavy precipitation days is determined by counting the annual number of days in the season having precipitation greater or equal to twenty mm, and the simple daily intensity index is also was computed as total precipitation of rainy days in the season divided by the number of rainy days with precipitation ≥1mm as outlined in (Mekasha *et al*, 2014)and (Degefu *et al*, 2014).

3.3.1.4. Variability analysis

Variability in rainfall and temperature variables/parameters was analyzed using descriptive statistics (frequency, mean), coefficient of variability, standardized anomaly index, and standard deviations. The SAI was calculated as the difference between the total of a particular year and the long term average records divided by the standard deviation of the long term data as follows:

$$\mathrm{SAI(Z)} = \left(\frac{\mathrm{X}-\mu}{\delta}\right) \qquad \text{(EQ4)}$$

Where, Z is the standardized rainfall or temperature or crop anomaly; x is the crop growing seasonal rainfall total or mean crop growing season temperature of a particular year; μ is the mean crop growing season rainfall throughout observation and δ is the standard deviation of crop growing season rainfall throughout the observation.

The coefficient of variation (CV) is also calculated to evaluate the variability of all parameters/variables in this study and its characteristics by dividing the standard deviation of the event by its mean. The coefficient of variation was computed as:

$$CV=\left(\frac{\delta}{\bar{X}}\right)100 \qquad \text{(EQ5)}$$

Where CV is the coefficient of variation; X is the average long-term rainfall or temperature over the given decade and δ is the standard deviation.

According to Reddy (1990), a CV< 20% shows less variability, a CV from 20-30% is moderately variable and a CV > 30% is highly variable. Moreover, based on values of standard deviation (SD), it was classified as less stable for SD > 40, as moderate for SD 20-40, as highly sable for SD 10-20, and very high stability for SD <10.

Further, rainfall variability analyses were done using the precipitation concentration index (PCI) for decadal variability of rainfall. PCI was calculated by Oliver (1980) and modified by De Luis *et al*. (1997). It is computed as follows:

$$\text{PCI} = \sum_{i=1}^{12} P^2{}_i \Big/ \left(\sum_{i=1}^{12} P_i\right)^2 * 100 \qquad \text{(EQ6)}$$

Where, Pi is the rainfall amount of the i^{th} month. PCI values of less than 10 indicate the uniform monthly distribution of rainfall, PCI values between 11 and 20 show high concentration, and values more than 21 show a very high concentration in the distribution of rainfall (*De Luis, M., et al*, 2000)

3.3.1.5. Trend analysis

Mann-Kendall test is one of the most widely used non-parametric tests for detecting a trend in climatic time series of the annual value of rainfall and maximum and minimum temperature and is preferred for trend analysis when more than one station is tested in a single study (Refat Nasher and Uddin, 2013). Also, this non-parametric test is less sensitive to outliers and test for a trend in a time series without specifying whether the trend is linear or non-linear ((Partal & Kahya, 2006; Yenigün *et al*., 2008).

The Mann-Kendall trend test is a rank-based test that has been very commonly used to test for randomness against monotonic trends in the field of climatological studies (Deasy Nalley, 2012). It is very suitable in cases where the data with skewed variables, non-normally distributed, data with outliers, and data showing the non-linear trend. The MK test examines the null hypothesis of no trend (independent observations and they are ordered randomly) against the alternative hypothesis of positive or negative monotonic trends over time that is present in the dataset being analyzed (Mohsin, T., & Gough, 2010). MK test compares the relative magnitude of a data value with all subsequent data values in the ordered time series. The initial value of the MK test statistics S is assumed to be zero, implying no trend. If a data value from a later period is found to be greater than the data value from an earlier period, then S is incremented by one unit. On the other hand, if the data value from the later period is lower than that of the earlier period, the MK test statistics S is reduced by one. The overall result of all increments and decrements provides the final S value which lies between -1 and +1. The Mann-Kendall test statistics are given as follows (Longobardi & Villani, 2010):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(X_j - X_k)$$

(EQ7)

Where, S is the Mann-Kendal's test statistics which is any integer between $-n(\frac{n-2}{2})$ and $n\ (\frac{n-1}{2})$, X_j and X_k are the sequential data values of the time series in the years *i* and *j*
(j > *i)* and *N* is the length of the time series. A positive *S* value indicates an increasing trend and a negative value indicates a decreasing trend in the data series.

The sign function is given as

$$sgn(X_j - X_k) = \begin{cases} 1\ if\ \ (X_j - X_k) > 0 \\ 0\ if\ \ (X_j - X_k) = 0 \\ -1\ if\ \ (X_j - X_k) < 0 \end{cases} \quad \text{(EQ8)}$$

If the sample size is (n) < 10, the value of |S| is compared directly to the theoretical distribution of S derived by Mann and Kendall (Gilbert, 1988)the two-tailed tests are used. At a 95 % probability level, H_0 was rejected in favor of H_1 if the absolute value of S equaled or exceeded a specified value Sα/2, where Sα/2 is the smallest S which has a probability less than α/2 to appear in case of no trend. A positive (negative) value of S indicates an upward (downward) trend (Rahman *et al*., 2017).

For n > = 10, the statistic S is approximately normally distributed with the mean and variance as follows:

$$E(S)=0 \tag{EQ9}$$

$$VAR(S) = \frac{\left[n(n-1)(2n+5) - \sum_{p=1^t}^{q} P(tp-1)(2tp+5)\right]}{18} \tag{EQ10}$$

Where q is the number of tied group's tp is the number of data values in the pth group. In this case, the standard test statistics Z is computed as follows (Douglas *et al*., 2000)

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & for\, S > 0 \\ 0 \quad , & for\, S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & for\, S < 0 \end{cases} \tag{EQ11}$$

The presence of a statistically significant trend is evaluated using the Z value. A positive value of Z indicates an upward and a negative value of Z indicates a downward trend. To test for either an upward or downward monotone trend (a two-tailed test) at the level of significance, H_0 is rejected if the |Z| > Z1-α/2, where Z1-α/2 is obtained from the standard normal cumulative distribution Tables.

3.3.1.6. Regression and Correlation Analysis of Climate Variability with Coffee Yield

This study employed two different models respective to its objectives. Multiple linear regression models were used to assess the impacts of climate change on coffee yield, and correlation analysis was used to establish the relationship between climatic variables and coffee yield.

Correlation and multiple regression methods were computed to establish the relation, case and effects of rainfall and temperature on coffee yields. The equation is provided in the form of thefollowing:

$Y=a+b_1x_1+b_2x_2+b_3x_3....b_nx_n+e$ (Eq 12)

Where; Y= the value of the dependent variable (coffee yield in qt or qt/ha);

a= Y intercept and $b_1,b_2,b_3......$

b_n= regression coefficients

$x_1,x_2,x_3....x_n$= the independent variables,

e= the error of estimate or residuals of the regression..

Pearson Product Moment Correlation Coefficient (r) is used in exploring individual climatic variables' relationships with coffee yields for the entire growing period to identify those variables that influenced a significant portion of the observed yield variance. Where the value of (r) ranges between -1 to +1, a correlation coefficient close to +1 indicates a strong positive correlation, a correlation coefficient close to -1 indicates strong negative correlation similarly a correlation coefficient of 0 indicates no correlation. Mathematically

$$r = \sum(\mathbf{x} - \bar{\mathbf{x}})\,(\mathbf{y} - \bar{\mathbf{y}}) \qquad \text{(EQ13)}$$

Where: r= coefficient of Pearson correlation, x is climate feature and y is yield

4. RESULTS AND DISCUSSION

4.1. Demographic Characteristics of Respondents

The socioeconomic characteristics of the household head were presented in Table 2. Over whelming majority of the respondents, 96% were male households and the remaining 4 % were female household heads. The age structure of the sample household showed that about 18 % of the household were found in the age group of 25 to 40 years, 62 % of households were found in the age of 40 to 60, and 20 % of households were found at age of above 61. The age range of 41 to 60 makes up the greatest portion of the population sample, which showed that the respondents were very engaged and knowledgeable about the effects of the current climate on agriculture and other socioeconomic activities in the research area.

In the study area, the educational status of the respondent was classified as no school, primary, secondary, and preparatory for of population. From the result, 70% of the household head had formal education; whereas about 9 % of the household heads did not have formal education. The educational status is very important to easily capture and understand the information of climate variability to adjust adaptive capacity to climate change.

Table 2. Demographic characteristics of the study household in Gomma District

		Kebele of respondent							
		Bulbulo		Genji Ilbu		Omo Gurude		Omo Beko	
		F	%	F	%	F	%	F	%
Sex	Male	53	100	29	74	86	100	84	100
	Female	0	0	10	26	0	0	0	0
Age	25- 40	17	32	20	51	10	12	0	0
	41 – 60	27	51	17	44	52	60	66	79
	Above 61	9	17	2	5	24	28	18	21
Formal education of farmer	No school	10	19	13	33	0	0	0	0
	Primary)	34	64	16	41	63	73	60	71
	Secondary	6	11	10	26	23	27	24	29
	Preparatory	3	6	0	0	0	0	0	0

4.2. Farmer's Adaptation Strategies to Climate Variability

The main adaptation strategies identified in study area are using shade tree, good agricultural practice and using improved coffee varieties. According to this survey study, 5.3, 57.3 and 2.3% of respondents were practicing good agricultural management, plant shade trees and agroforestry and crop diversification, respectively as an adaptation strategy (Table 3). This indicated that the majority of the respondents were aware of the use of shade trees for coffee production. 35.1% of respondents were applying changing crop varieties as an adaptation strategy. This finding agree with Gebreyesus *et al,* 2017 and Ansha, 2019 who reported that shade trees, improved crop varieties; and agroforestry and crop diversification as a main farmer's adaptation strategy for climate change. None of the respondents are practicing the irrigation as climate change strategy. This may be due to lack of accessible infrastructure of irrigation facility around the study area. Adaptation strategies can also serve as insurance against climate variability (Mongi *et al* 2009). Farmers' respond to climate change stimuli by undertaking activities that help them cope with adverse consequences, reduce vulnerability and potential damages from climate change, and help them to adjust to climate change and variability (IPCC 2001).

Regarding the effectiveness of the adaptation practice, about 34, 57 and 9% of the respondents were said that their adaptation practices were very effective, moderately effective and were not effective, respectively. The effectiveness of the adaptation practice is actually depends on the type and mechanism of the adaptation strategy. 31% of the household do not have knowledge about climate change variability and adaptation practice, 22% of households facing constraints to expand farm size due to limited land, 2% of households facing high cost of agricultural input and 45% of households do not have access to climate data.

Table 3. Adaptation strategies of farmers to climate variability in Gomma district.

		Frequency	Percent
On farm management practice to adopt failure in crop due to climate variability	Good agricultural practice	14	5.3
	Plant shade trees	150	57.3
	Take up agroforestry and crop diversification	6	2.3
	Changing crop varieties	92	35.1
	Irrigation	0	0
Degree of effectiveness of adaptation practice	Very effective	89	34
	Moderately effective	149	57
	Not effective	24	9
which factor affect your ability to adapt varying climate	Lack of knowledge on the situation	81	31
	constraints to expanding farm size due to limited land	58	22
	high cost of agricultural input	5	2
	lack of access to climate data	118	45

4.3. Characterization of Climate Variability of Gomma District

4.3.1. Characterization of rainfall features

4.3.1.1. Annual and monthly rainfall

The mean annual rainfall of the area during the study period was 1474.8mm with a standard deviation of 128.2mm and a coefficient of variation (CV) of 9% (Table 4). The coefficient of variation implies that rainfall in the district had low inter-annual variability during the study period. As it is indicated in Figure 2, the recorded annual rainfall amount in the years of 1989, 1991, 1994, 1995, 1999, 2002, 2003, 2004, 2007, 2009, 2013, 2017 and 2018 was below an average. In this study, the maximum and minimum annual rainfall observed during the study period were 1726.8mm in1996) and 1232.3 mm in 2002. The result of statistical analysis at a 95% confidence level for annual rainfall data using the Mann-Kendall test showed statistically non-significant increasing trend by a factor of 2.68 mm/year during the study period.

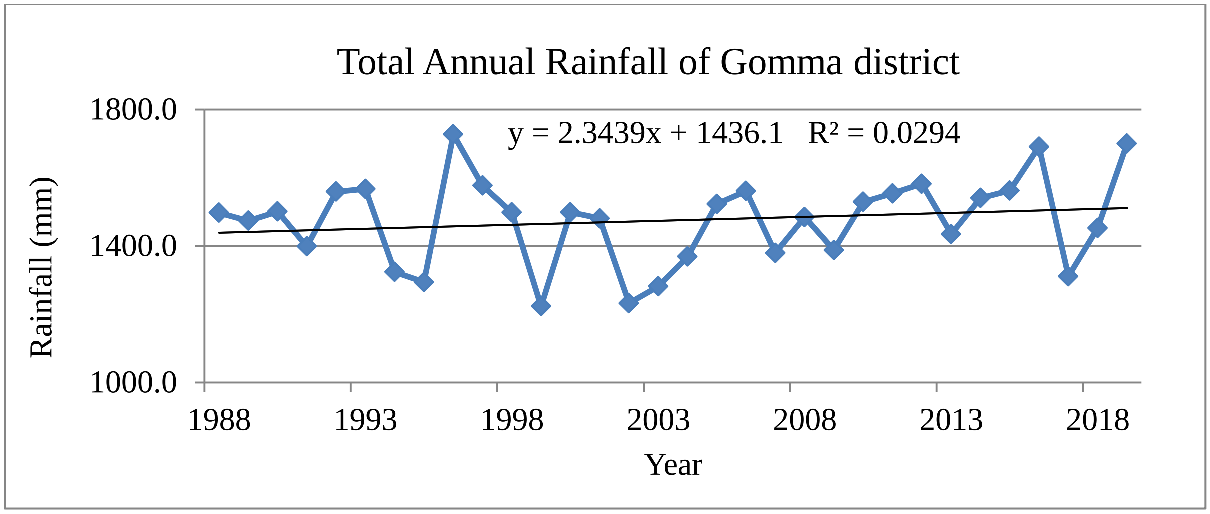

Figure 2. Annual rainfall of Gomma district for the period of 1988 to 2019

The computed descriptive statistics of monthly rainfall in the study area were presented in Table 4. In the study area, the monthly CV lies between 14% in July and 87% in December and the result shows there is high rainfall variability from month to month in the district. The three month with highest maximum monthly rainfall were June (207.9 mm), July (239.6mm) and August (239.2 mm) contributing 14.1%, 16.2% and 16.2% to total rainfall respectively.

The Mann-Kendall test for monthly rainfall at 95% confidence showed both increasing and decreasing trends. It shows decreasing trend during January, February, March, June, July, and September whereas increasing trend during April, May, August, October, November, and December. The positive Sen's slope for monthly rainfall analysis indicates there is an upward or increasing rainfall trend during that month and the negative Sen's slope value indicates a downward or decreasing trend during that month that in line with the finding of Sa'adi *et al* (2019), Mondal *et al* (2012) and Kumar *et al* (2017) who found increasing and decreasing trend of rainfall in certain months, but it is varying across all months.

Table 4. Monthly and annual rainfall variability and Mann-kendall trend analysis of Gomma District

Variable	Mean(mm)	SD(mm)	ZMK	P-value	Q	CV (%)	Contribu Tions	Trend
Jan	26.3	16.4	-0.16	0.19	-0.40	62	1.8	D
Feb	31.7	23.0	-0.07	0.58	-0.30	73	2.2	D
Mar	75.3	31.6	-0.02	0.87	-0.06	42	5.1	D
Apr	106.3	41.9	0.04	0.75	0.25	39	7.2	I
May	169.0	55.1	0.36	0.00	1.89	33	11.5	I
Jun	207.9	56.1	-0.02	0.87	-0.21	27	14.1	D
Jul	239.6	33.2	-0.10	0.45	-0.37	14	16.2	D
Aug	239.2	38.2	-0.01	0.96	0.00	16	16.2	D
Sep	184.2	40.1	-0.05	0.71	-0.22	22	12.5	D
Oct	110.5	53.9	0.03	0.82	0.44	49	7.5	I
Nov	55.2	45.4	0.22	0.08	0.98	82	3.7	I
Dec	29.7	25.7	0.00	1.00	0.00	87	2	I
Annual	1474.8	128.2	0.15	0.25	2.68	9	100	I

Where, CV= Coefficient of variation, SD= Standard deviation, ZMK= Mann-Kendall trend test, Q= Sen's slope estimation '+' significant at 0.05 significance level D= decrease, I= increase.

4.3.1.2. Analysis of seasonal rainfall

Seasonal rainfall analysis of Gomma district was depicted in Figure 3 and Table 5. Seasonal rainfall analysis showed less variability during *kiremt* season with CV of 10% and moderate variability for *belg* (CV=21%), while *bega* had high variability with CV of 30%. This result is line with the finding of Yilma and Zanke (2004), Aklilu (2006), Rosell and Holmer (2007), Cheung *et al*. (2008), Viste *et al*. (2013) and Arragaw and Woldeamlak (2017), who reported that, in most part of Ethiopia, there is more variability in *belg* rainfall than *kiremt* rainfall. The estimated contribution of the season to the total annual rainfall showed that *kiremt* and *belg* accounted for 59% and 26%, while *bega* contributed a smaller proportion (15%) of the total rainfall (Table 5). The average rainfall received during *kiremt* season was 870.9 mm while *belg* and *bega* received 382.2mm and 221.7mm, respectively. This result is aligned with Bekele, *et al* (2016) who reported similar amount of maximum and minimum amount of rainfall during *kiremt* and *bega* seasons at different location of the country.

Table 5. Seasonal rainfall variability and Mann-Kendall trend analysis of Gomma District for the period of 1988 to 2019

Variable	Mean	SD	Minimum	Maximum	ZMK	P-value	Q	Contributions (%)	CV (%)
Belg	382.2	79.1	231.3	617.1	0.20	0.12	1.98	26	21
Kiremt	870.9	90.3	667.9	1023.1	-0.07	0.57	-0.94	59	10
Bega	221.7	67.1	112.1	414.8	0.09	0.47	0.96	15	30

Where, CV= Coefficient of variation, SD= Standard deviation, ZMK= Mann-Kendall trend test, Q= Sen's slope estimation '+' significant at 0.05 significance level.

The optimum amount of rainfall during *kiremt* season favors better bean growth as it is critical stage for bean filling and berry expansion and consequently contributes for better yield. The shortage of the rain during the *belg* might have adverse effect on bean filling ultimately resulting in higher number of undesirable coffee bean which is so called floater beans (Yonas *et al*., 2014). However, the average amount of rainfall (382.2mm) observed during *belg* season seems to be adequate for berry growth and expansion. The Mann-Kendall trend analysis showed that there was a statically non-significant increasing trend for the *bega* (0.496mm/year) and *belg* (2.24mm/year) rainfall, whereas the *kiremt* seasonal rainfall showed a non-significant decreasing trend by -0.392mm/year (Figure 3).

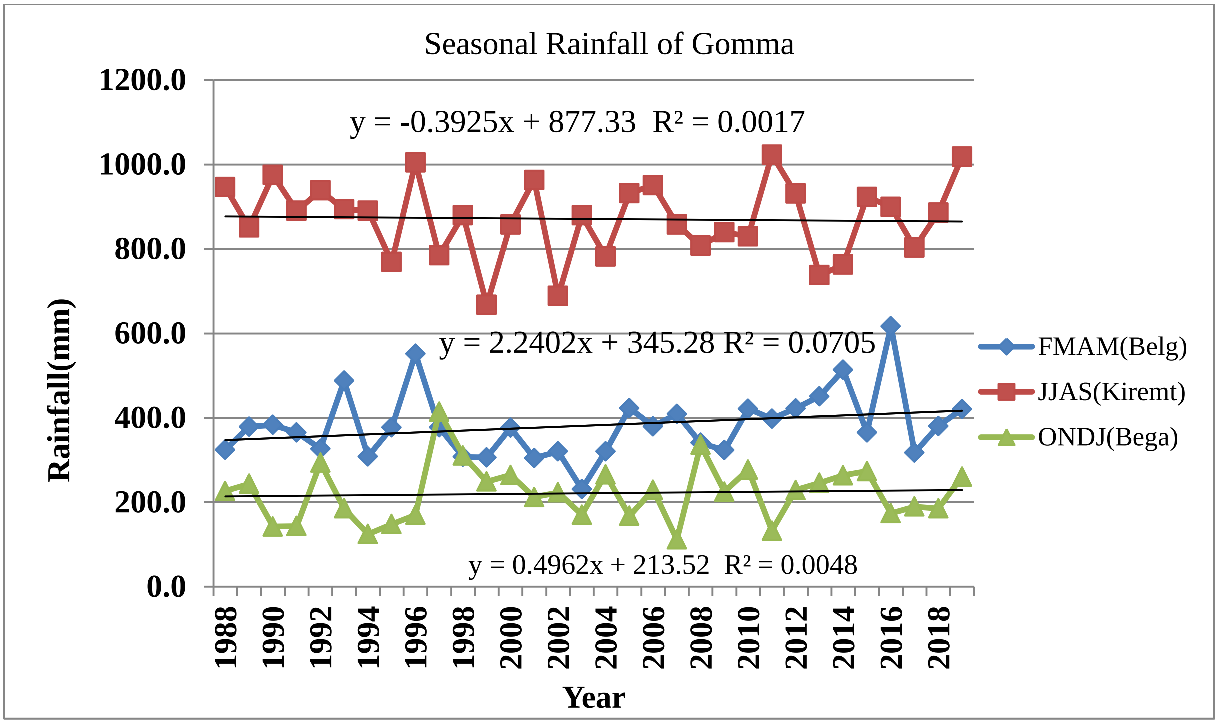

Figure 3. Seasonal rainfall of Gomma District for the period of 1988 to 2019

4.3.1.3. Onset, cessation, and length of growing period

In the Gomma District, the rainy season began at its earliest point in the second decade of March (75 DOY) and at its latest point in the fourth decade of April (120 DOY) (Figure 4 and 5). The onset date has a CV of 13% and an SD of 11 days, indicating that the area's rainfall began with reduced variability and a high degree of stability during the study period. The results agree with those of Segele *et al*. (2005), who discovered that rains begin in early to mid-March over southwestern Ethiopia and move northward to reach the western half of the nation by mid-June.

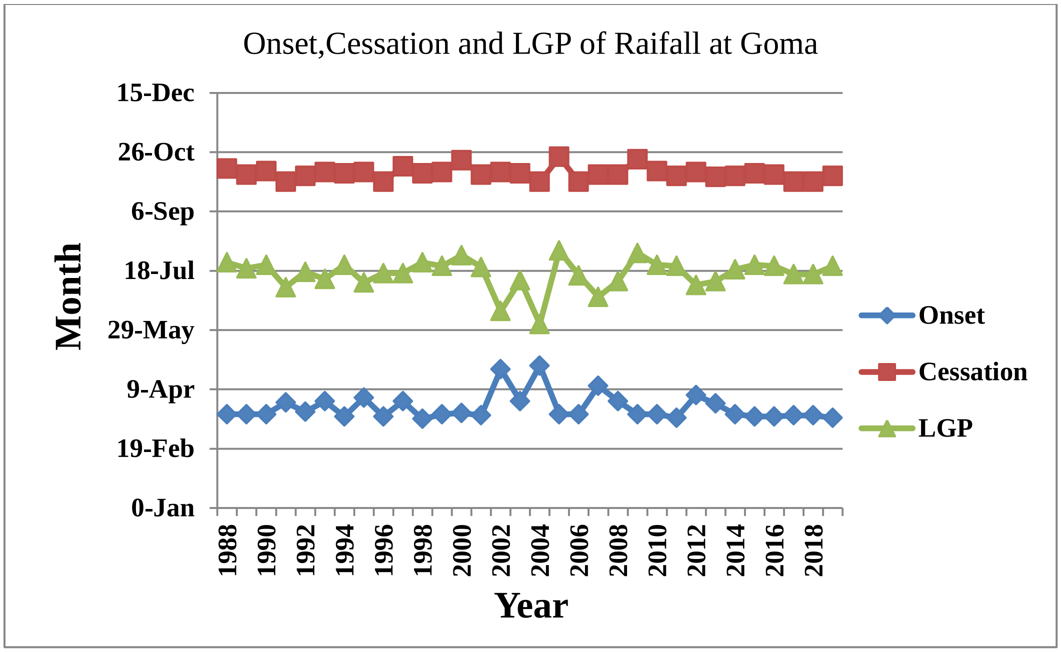

Figure 4. Onset, cessation, and LGP of rainfall at Gomma district for the Period of (1988 to 2019)

The start of the rainy season was on March 18 (78 DOY), which happens once every four years (25%), while the SOS was on March 19 (79 DOY), which happens twice every four years (50%) and three times every four years (75%) on March 30 (90 DOY) over the study period (Table 6).

Table 6. Descriptive statistics of seasonal rainfall of Gomma district

Season	Mean	SD	Min.	Quartile1 (25%)	Median (50)	Quartile3 (75%)	Max.	CV (%)
SOS	85	11	75	78	79	90	120	13
EOS	282	5	275	280	282	283	296	1.8
LGP	197	13	155	192	200	205	217	6.4

Where, SOS = start of season, EOS = end of season, LGS = length of growing season, DOY = day of year, Min. = minimum, Max. = maximum, SD= standard deviation, CV= coefficient of variation

Rainfall in the studied area stopped from the first decade of October (275 DOY) until the third decade of OCT (DOY 296), with an SD and CV of 5 days and 1.8%, respectively. This suggests that there were fewer variables over the study period and that the end date of the study area was highly stable. Although EOS occurred in the first week of October only once every four years

(25%), the primary rainy season concluded three out of four years (75%) in the second decade of October (283 DOY) and twice in four years (50%) in the second week of October (282 DOY). This result is consistent with that of Mamo (2005), who found that in the Central Rift Valley of Ethiopia, the primary rainy season ends in the second week of October three out of four years.

The length of the growing period ranged June to August first (155 to 217 DOY) with mean of 197 days. The LGP of the area begins in the second decade of June (192 DOY) once every four years and at fourth decade of June (205 DOY) occurs three times every four years. During the study period the length of growing period was less variable(CV= 6.4) and highly stable (SD= 13 days).Depending on the onset, cessation, and length of the growing period, one can adjust the crop production Schedule and which type of crop can grow at which month.

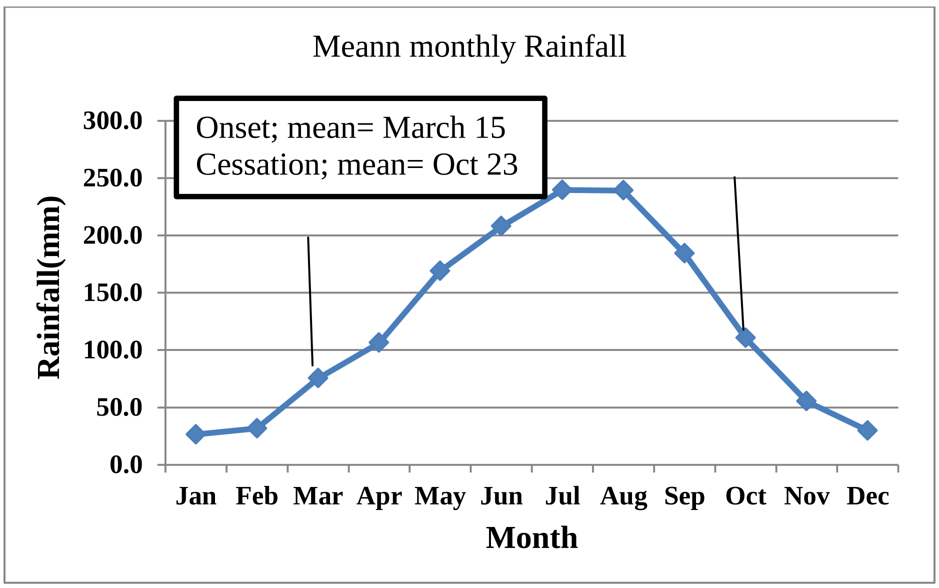

Figure 5. Mean Monthly Rainfall of Gomma district for the period of 1988 to 2019

4.3.1.4. Dry spell

For Gomma District, the likelihood of dry spells lasting longer than 5, 7, 10, and 15 days during 1988 to 2019 (Figure 6). This provides information on the dangers associated with various dry spell lengths during the whole rainy season. Additionally, the inclusion of dry spell length circumstances into the later months of the growing season serves to complete the picture of the distribution of dry spell length of different magnitudes throughout the course of the full growing season and to assess the risk in the research region.

For instance, the probability of dry spells longer than 15 days within the first 30 days following planting is explained by the curves in Figure 6. At Gomma District, there is no chance of dry spells lasting more than 15 days between the beginning of June and the middle of October. Between the beginning of June and the second decade of August during the rainy season, there is less than 10% chance of a dry period lasting more than 10 days. The same graph also shows that from the first of June through the second decade of October, the chance of 5 and 7-day dry period curve remains at a value of greater than 20%.

For various group of farmers that operate under various capabilities or resource endowments, knowledge of the likelihood of such a range of dry period lengths is useful. For instance, one farmer might choose to plant during the earliest and riskiest months of the growing season if he has access to irrigation water. In this manner, one might increase output while assuming risks related to such a protracted dry season. On the other hand, a farmer with fewer resources who is risk adverse must wait until enough soil water has accumulated before managing any danger of a dry spell lasting more than five or seven days. The predicted yield level would not be comparable for the two farmer groups since the two farmer groups do not utilize resources at the same level (time of planting, timeliness of operation, choice of crops and/or cultivars). In any event, late onset is the least desirable scenario, since it reduces the length of the crop growth season that is available and the possibility of meeting the crop's water needs. Because high water demand periods can be anticipated, information on the length of dry spells could be used as a reference for arranging extra irrigation. A planting date and cultivar selection can be chosen based on the length of dry spells. For instance, in this location, the likelihood of dry spells lasting more than 15 days is extremely low. However, if dry spell probabilities are calculated after effective (successful) planting dates, judgments can be made more effectively.

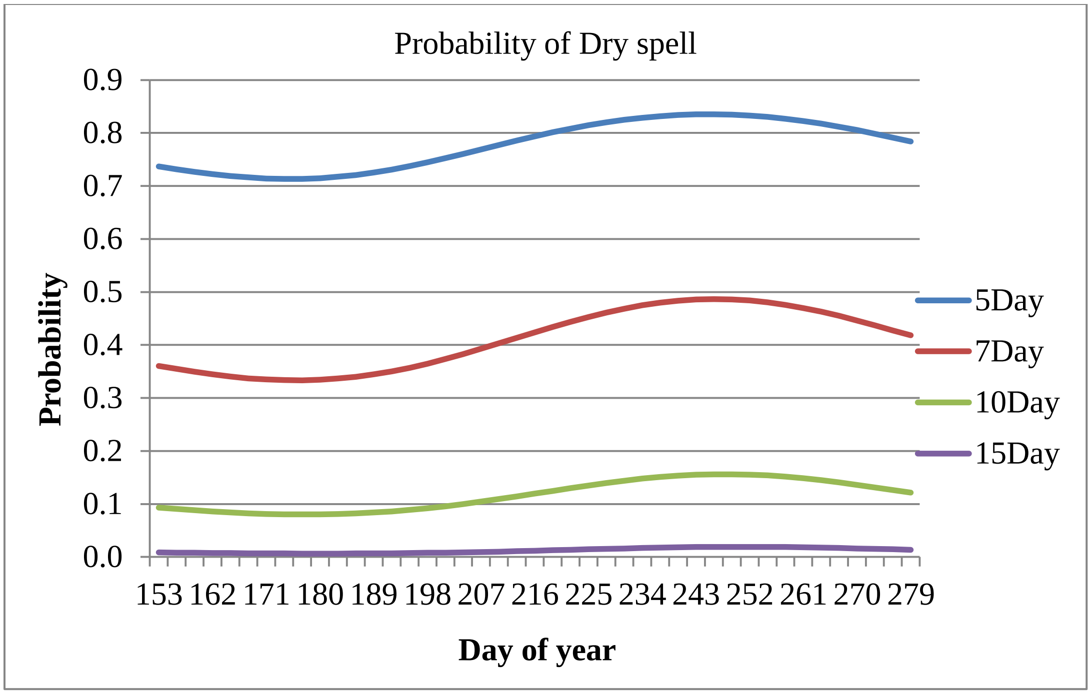

Figure 6. Probability of dry spells longer than 5,7,10 and 15s day at Gomma district (1988-2019)

4.3.1.5. The standardized anomaly of annual rainfall (SAI)

Analysis of the Standardized anomaly index for the study area is presented in Figure 7. SAI were used to demonstrate the intensity and frequency of drought and inter-annual variability at various times in the area. The negative anomalies in Gomma District were 37.5% during 1991, 1994, 1995, 1999, 2002, 2003, 2004, 2007, 2009, 2013, 2017, and 2018. And the rest 62.5% is positive anomalies. The differences between the frequencies of occurrence of the dry and wet years were small. Negative anomaly index (dry) was observed for years 1983, 1984, 1994, 2002, and 2003 in the district (Figure 7). In line with this, Quinn and Neal (1987), and Webb and Braun (1994) cited in NAM (2007) reported that Ethiopia experienced drought years from 1983 to 1984, 1987 to 1988, 1990 to 1992, 2000, and 2002 to 2003.

This study indicated that the standard anomaly value of (-2 or less) categorized as extreme drought occurred in the 1999 year in Gomma District. This result showed that 1999 was the driest year in Gomma District. Severe drought periods (SAI value -1.5 to -1.99) were observed in the 2003 and 2004 years. On the other hand, severe wet (SAI value of +1.5 to +1.99) years occurred in 1996, 2016, and 2019 in Gomma District. These agree with the finding of NMA (2007) who reported that there was increase in dry year frequency in Ethiopia. The rainfall pattern in the study area showed the characteristic of the dry year is followed by two or three dry years and vis-à-vis the wet year's (Figure 7).

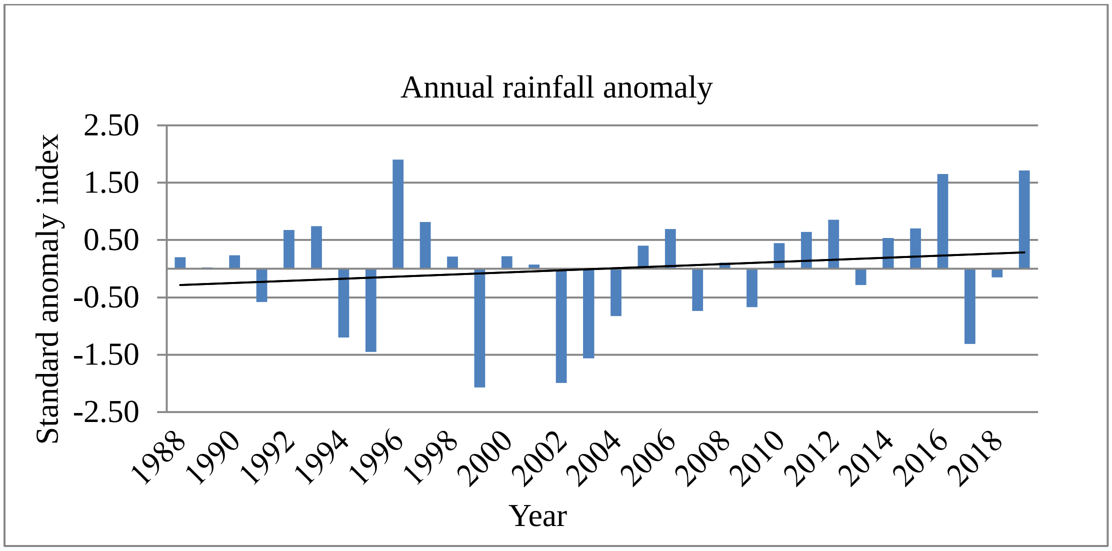

Figure 7. Standard anomaly index of rainfall of Gomma district throughout 1988 to 2019

The present study revealed that the rainfall fluctuation occurred in annual variability (Table 7). Such inter-annual variability in rainfall would negatively affect the ability of farmers to cope with climate change and variability (Ayalew *et al.*, 2012). Similarly, in the next few decades and the second half of the 21st century and beyond, there will be a risk of food insecurity and the breakdown of food systems linked to warming, drought, flooding, and precipitation variability and extremes, particularly for poorer populations in urban and rural settings IPCC (2014). The drought phenomenon will create a more vulnerable environment for the subsistence farming sector.

Table 7. Descriptive statistics of standardized rainfall anomaly from 1988 to 2019 in Gomma

Drought category	Standard anomaly index Value range	%age and frequency of occurrence (Years) Gomma	
		Frequency	%
Extreme drought	-2.0 or Less	1	3.13
Severe drought	-1.5 to -1.99	2	6.25
Moderate drought	-1.0 to -1.49	3	9.38
Mild drought	-0.99 to 0	6	18.75
Normal	+ 0.01 to + 1.49	17	53.13
Severe wet	+1.5 to +1.99	3	9.38
Extreme wet	+2.0 or more	0	0.00

The precipitation concentration index (PCI) value for the annual rainfall result indicated that the value is ranged from 11- 16 throughout the study year showing a high concentration of rainfall in the area. PCI values of less than 10 indicated uniform monthly distribution of rainfall, PCI between 11 and 20 indicate high concentration, and PCI above 21 indicate very high concentration (Oliver, 1980). This gives information on the normal amount of rainfall expected in the study area per annual. It can also help to obtain an idea of the departure of the annual rainfall from the normal or to compare one region with others

4.3.2. Analysis of temperature variability and trends in the study area

4.3.2.1. Maximum temperature

The result of annual and monthly maximum temperature variability and trend of temperature in the study area from 1988 to 2019 was given in (Table 8). Temperature in some years varied greatly among year as illustrated in Figure 8. The annual average of the maximum temperature at Gomma over the study period was 25^{o}C with a standard deviation of 0.51 and a coefficient of variation of 2% (Table 8).

Table 8. Maximum temperature variability and trend of Gomma district

Variable	Mean(°C)	SD(°C)	MK	P-value	Q	CV
Jan	26.2	1.00	0.34	0.016	0.046	0.04
Feb	27.2	1.51	0.34	0.006	0.075	0.06
Mar	27.4	0.98	0.32	0.011	0.05	0.04
Apr	27.1	0.96	0.28	0.027	0.045	0.04
May	25.7	0.84	0.25	0.05	0.036	0.03
Jun	23.9	0.75	0.23	0.072	0.029	0.03
Jul	22.4	0.73	0.36	0.004	0.036	0.03
Aug	22.4	0.66	0.20	0.119	0.017	0.03
Sep	23.4	0.63	0.38	0.003	0.029	0.03
Oct	24.6	0.76	0.28	0.028	0.032	0.03
Nov	24.9	0.72	0.07	0.615	0.012	0.03
Dec	25.2	0.94	0.15	0.255	0.021	0.04
Average Annual	25.0	0.51	0.42	0.001	0.033	0.02

The mean monthly maximum temperature in the study area ranged from 22.4°C in July and August to 27.4°C in February with a coefficient of variation of 3% and 4%, respectively. The monthly CV of maximum temperature lied between 3% and 6% indicating monthly variability of temperature in the study area for the study period. This indicated that more or less the maximum temperature show stability over time with less variability. For all of the months, the trend for maximum temperature showed significant increasing trend, where it is statistically significant at 95% level of confidence except for June, August, November and December.

The raising temperature might affect the production and productivity of the crop and the growing of coffee plants can be affected by climate variability. The mean annual temperatures of the study area increased at different rates. The result illustrated a significant ($p < 0.05$) increases. This result is compatible with a national study which found broadly consistent warming trend or rising minimum and maximum temperatures over the past fifty years. The empirical analysis of temperature trends of metrological data station is in line with the Perceptions of farmers with respect to changes in temperature. The direction of the perceived changes in temperature level by the farmers in the study area indicates that about 100% of the respondents except Bulbulo, which were 94.9% of the respondents perceived an increment in the level of temperature. Using a linear regression model, the rate of change is defined by the slope of regression line (Figure 8). In this case, is the annual temperature will increase by 0.4 ^{o}C per decade for mean maximum temperature during the study period.

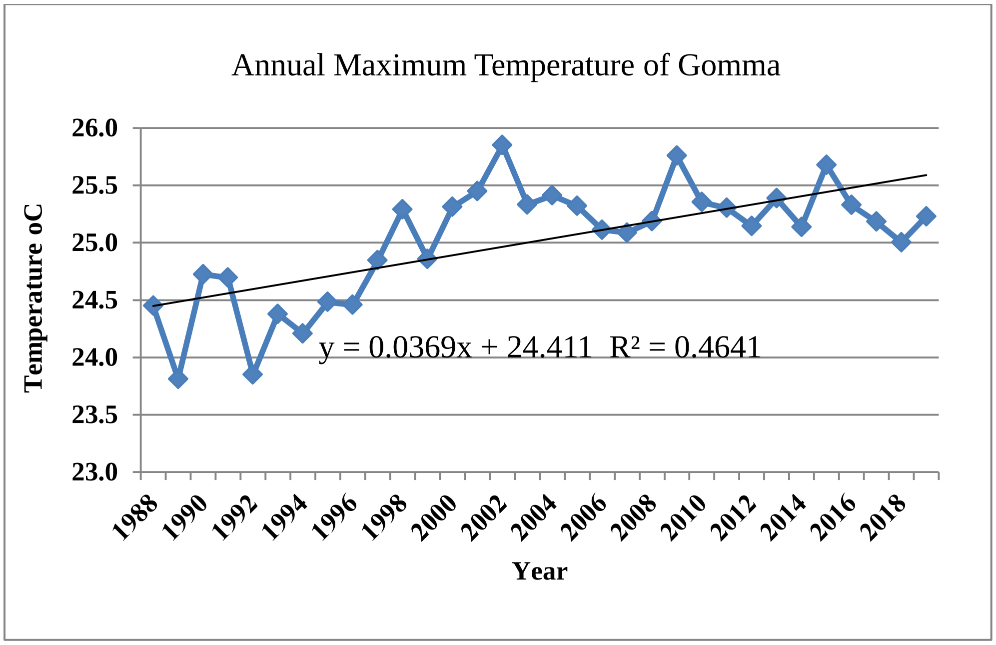

Figure 8. Annual maximum temperature of Gomma District for the period of (1988-2019)

4.3.2.2. Seasonal maximum temperature

The long-term seasonal trend of maximum temperature of Gomma was presented in Figure 9. Regarding the seasonal maximum temperature, the maximum temperature (27.8^{o}C) was recorded in 2015 during *belg* (FMAM) while, the minimum value of maximum temperature (22.0^{o}C) was observed in 1994 during *kiremt* (JJAS). Therefore, *belg* and *kiremt* seasons were known for their extreme temperatures in Gomma District during the study period. Using linear regression model seasonal maximum temperature was increased by 0.5, 0.4 and 0.3 ^{o}C per decade respectively in *belg*, *bega* and *kiremt* at Gomma. It found that *belg* season maximum temperature increased faster than *bega* and *kiremt* seasons.

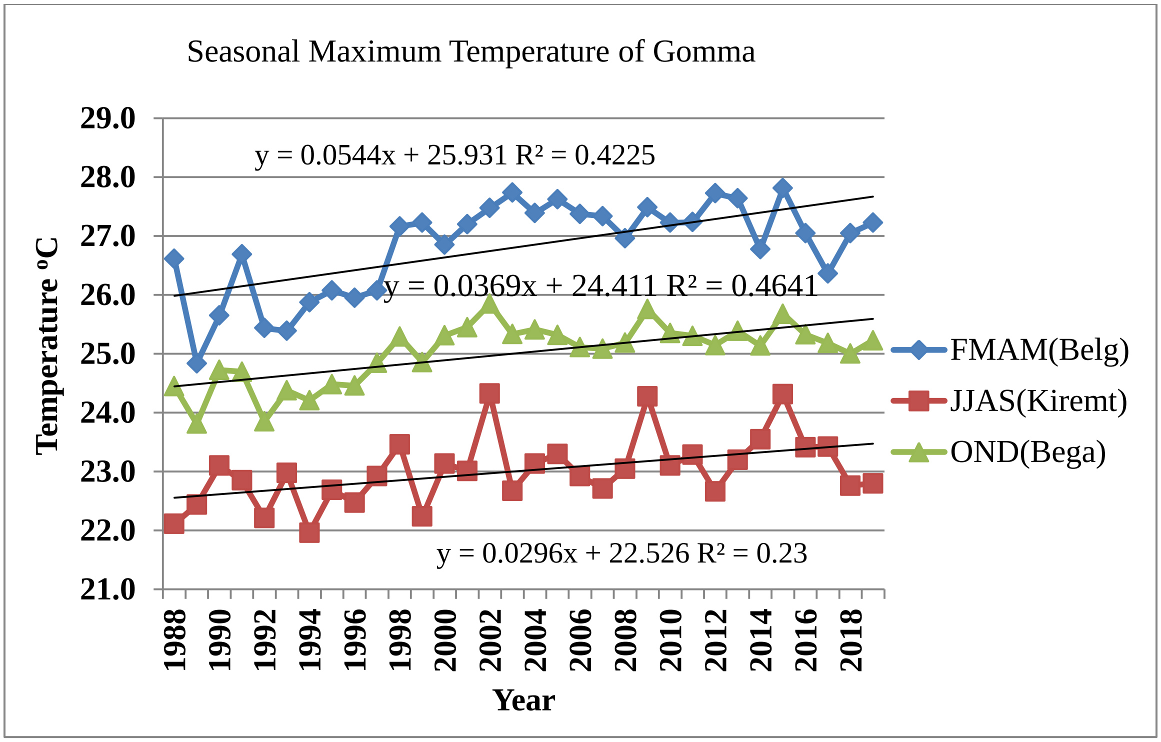

Figure 9. Seasonal maximum temperature of Gomma District for the period of (1988-2019)

There was significant increasing trend of the maximum temperature at all season during the study period. The trend of *belg* season mean maximum temperature was 26.8 with standard deviation and coefficient of variation of 0.78 and 3%, respectively (Table 9).

Table 9. Seasonal maximum temperature variability and trend of Gomma district

Variable	Mean	SD	MK	S-value	P- value	Sen's slope	CV (%)
Belg	26.8	0.78	0.43	211	0.001	0.05	3
Kiremt	23.0	0.58	0.37	182	0.003	0.027	3
Bega	25.0	0.51	0.42	206	0.001	0.033	3

4.3.2.3. Minimam temperature

The analysis of annual and monthly minimum temperature data was undertaken in the study area for the period of 1988 to 2019 is shown in (Table 10). Average annual minimum temperature varied from 10.1^{o}C in 1999 to 12.1^{o}C in 2016. There was significant increasing trend of annual minimum temperature from year to year in the study area. The highest mean monthly minimum temperature was observed was in April (12.79 ^{0}C) followed by July (12.77 ^{0}C) during the study period. In contrary, the lowest minimum temperature (8.35^{0}C) was observed in December representing a relatively cold period. The average minimum monthly temperature of the study area was 11.2 ^{0}C with standard deviation of 0.39 and 0.04 CV. The MK and Sen's slope test results revealed that all months showed an increasing trend where it is statistically significant for March, May,July, September, October and Novemebr at 95% level of significance (P-value < 0.05). The coefficient of variation for mean monthly minimum temperature shows a variation ranging from 3 to 12%. The minimum temperature showed more variation than the maximum. This is aligned with report of Panda and Sahu (2019) that the coefficient of variation in minimum temperature is larger than the coefficient of variation in maximum temperature.

Table 10. Minimum temperature variablity and trend of Gomma District

Variable	Mean	Std. deviation	MK	P-value	Q	CV
Jan	8.754	1.039	0.004	0.987	0	0.12
Feb	10.393	1.141	0.174	0.168	0.026	0.11
Mar	11.946	0.805	0.296	0.019	0.035	0.07
Apr	12.793	0.619	0.099	0.436	0.008	0.05
May	12.589	0.718	0.264	0.036	0.025	0.06
Jun	12.503	0.463	0.098	0.445	0.005	0.04
Jul	12.774	0.359	0.375	0.003	0.023	0.03
Aug	12.639	0.406	0.07	0.591	0.002	0.03
Sep	12.248	0.421	0.333	0.008	0.012	0.03
Oct	10.548	0.689	0.245	0.05	0.033	0.07
Nov	9.250	0.936	0.351	0.005	0.05	0.10
Dec	8.356	1.000	0.214	0.089	0.033	0.12
Enter annual	11.233	0.399	0.359	0.004	0.02	0.04

Using a linear regression model, the rate of change is defined by the slope of regression line (Figure 10) which in this case is about 0.2 ^{o}C per decade for mean minimum temperature during the study period.

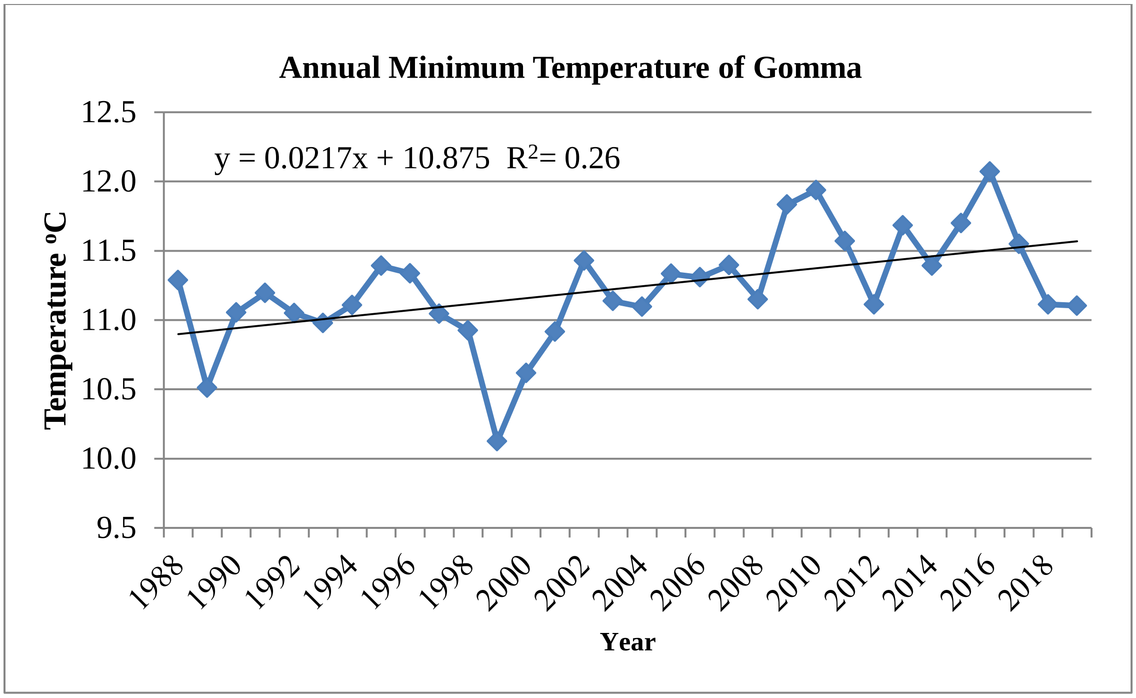

Figure 10. Annual minimum temperature of Gomma District for the period of (1988-2019)

4.3.2.4. Seasonal minimum temperature

The mean minimum temperature of *kiremt* season was 12.5°C with SD and CV of 0.31°C and 0.02%, respectively as shown (Table 11)**.** The mean minimum temperature of *bega* season was 11.23°C with SD and CV of 0.399°C and 0.04%, respectively. And *belg* season had mean minimum temperature of 11.93°C with SD and CV of 0.596°C and 0.05% respectively. Temperature showed increasing trend in all seasons, but statistically significant for *kiremt* and *bega*. In the study area, *bega* season was the coldest season that followed by *belg* season. In 1999 the lowest value of seasonal minimum temperature recorded was 8°C and the highest recorded was 13.3°C in 2010 in *belg* season. During *kiremt* season especially from 2000 to 2010 variability of minimum temperature was low, *bega* and *belg* season minimum temperature were highly variable from year to year.

Table 11. Seasonal minimum temperature variability and trend of Gomma District

Variable	Mean	Std. deviation	MK	P-value	Sen's slope	CV
Belg	11.930	0.596	0.222	0.077	0.02	0.05
Kiremt	12.541	0.310	0.291	0.02	0.014	0.02
Bega	11.233	0.399	0.359	0.004	0.02	0.04

Using a linear regression model, the rate for change of mean minimum temperature is defined by the slope of regression line (Figure 11). In this case, temperature is increased by about 0.1^{o}C, 0.2^{o}C and 0.3^{o}C per decade for *kiremt*, *belg* and *bega* season, respectively during the study period.

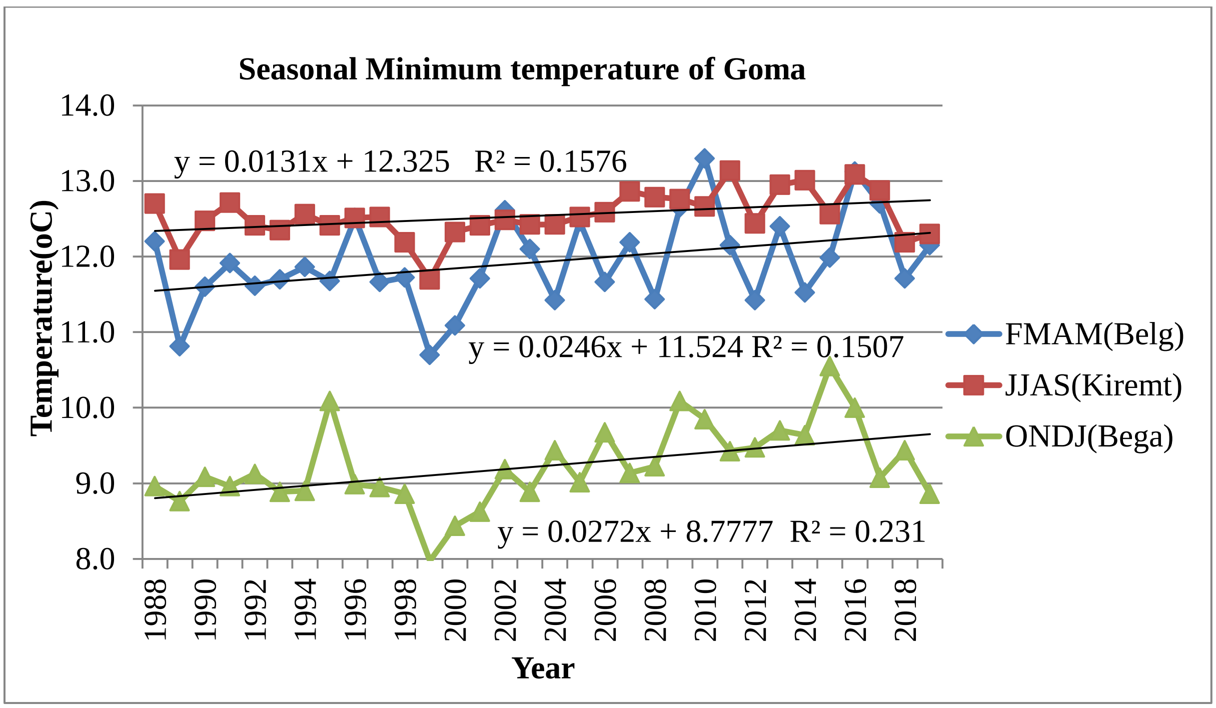

Figure 11. Seasonal minimum temperature of Gomma District for the period of (1988-2019)

4.4. Correlation of Coffee Yields with Rainfall and Temperature

The correlation coefficient computed between coffee yield, rainfall, maximum and minimum temperatures is presented in Table 12. Regarding the rainfall variables, SOS (r=-0.517) and EOS (r=0.571) had negative strong and statically non-significant correlation with coffee yield, whereas the other variables such as Length of growing period (r=0.185), *kiremt* JJAS (r=0.310) and *belg* FMAM (r=0.213) had moderately positive correlation with coffee yield, but also statistically non-significant.

Table 12. Pearson's Correlation matrix of coffee yield and rainfall and temperature features in the study area

	Yield	SOS	EOS	LGP	JJAS	FMAM	TMAX	TMIN
Yield	1							
SOS	-0.517	1						
EOS	-0.571	0.047	1					
LGP	0.185	-0.873	0.445	1				
JJAS	0.310	-0.247	0.006	0.225	1			
FMAM	0.213	-0.071	-0.126	0.002	-0.0004	1		
TMAX	-0.267	-0.335	0.710	0.647	-0.0005	-0.178	1	
TMIN	-0.265	-0.339	0.386	0.492	-0.2025	0.318	0.656	1

Both maximum (r= -0.267) and minimum (r= -0.265) temperatures shows weak negative correlation with coffee yield during the study period indicating that increasing trend of both maximum and minim temperature reduced coffee production in the study area during the study period. Gizaw *et al*.2021, also reported similar results on coffee during his study conducted on Haraghe coffee.

4.5. Regression Analysis of Rainfall and Temperature on Coffee Yields

The start date of the season, the end date of the season, *kiremt* (JJAS), *belg* (FMAM), the maximum temperature and the minimum temperature used as explanatory variables in the regression analysis of this study (Table 13). To predict the effect of the explanatory variable on coffee yield or the dependent variable, the model was built using the dependent variable of coffee yield and the independent variable.

Y=24.784-0.416EOS+0.002JJAS+0.011FMAM+4.529TMAX-4.183TMIN

Where Y is predicted coffee yield qt/ha

Table 13. Coefficient of regression for rainfall and temperature features in the study area

Model	B	Std. Error	t	Sig.
Constant	24.784	81.269	0.305	0.771
SOS	0.000	0.000	-1.475	0.168
EOS	-0.416	0.149	2.532	0.028
JJAS	0.002	0.006	0.305	0.769
FMAM	0.011	0.008	1.865	0.104
TMAX	4.529	4.808	3.380	0.012
TMIN	-4.183	2.591	-2.173	0.066

The end date of the rainfall and the minimum temperature had an effect on coffee yield, according to the results of the regression coefficient analysis. Coffee yield is negatively impacted by the end date of the season (-0.416 qt/ha). The *kiremt* season, the *belg* season, and the maximum temperature was positively affect coffee yield. Coffee yield was negatively impacted by the minimum temperature (-4.183 qt/ha). This indicated that minimum temperature is the major determinant factors for the coffee production and productivity. This indicated that as the minimum temperature rise there will be a significant reduction in coffee yield. This is obviously known that; low or high temperatures are known to disturb plant metabolism; consequently affecting the coffee growth and yield. Similarly, Jaramillo *et al*.(2019) stated that even the smallest increases in temperature could cause extensive damage to coffee production.

Multiple regression analysis of the study data showed that the coefficient of determination (R^2) was 0.732 (Table 14). This indicated that 73.4% of the variance on coffee yield was explained by combination of the starting season, end of the season, *kiremt* and *belg* rainy season, maximum and minimum temperature with others the rest 26.6% non-climatic factor. This shows that bean yield of coffee genotypes was found to be significantly affected by environmental factors.

Table 14. Regression values for predictors

Model	R	R Square	Adjusted R Square	Std. Error
1	0.856	0.734	0.301	1.663

a. Predictors: (Constant), SOS, EOS, JJAS, FMAM, TMIN, TMAX,

Despite the detrimental effects of climate variability, coffee production yield was increased by 0.57 quintals per hectare per year (Figure 12). In order to determine evidence of changes in coffee production, a regression line was constructed; it showed that 95% increase in productivity during the study period. The increased of production and productivity was mostly because of the positive relationship between length of growing period, *kiremt* and *belg* season, use of improved coffee variety and application of good agronomic management practices.

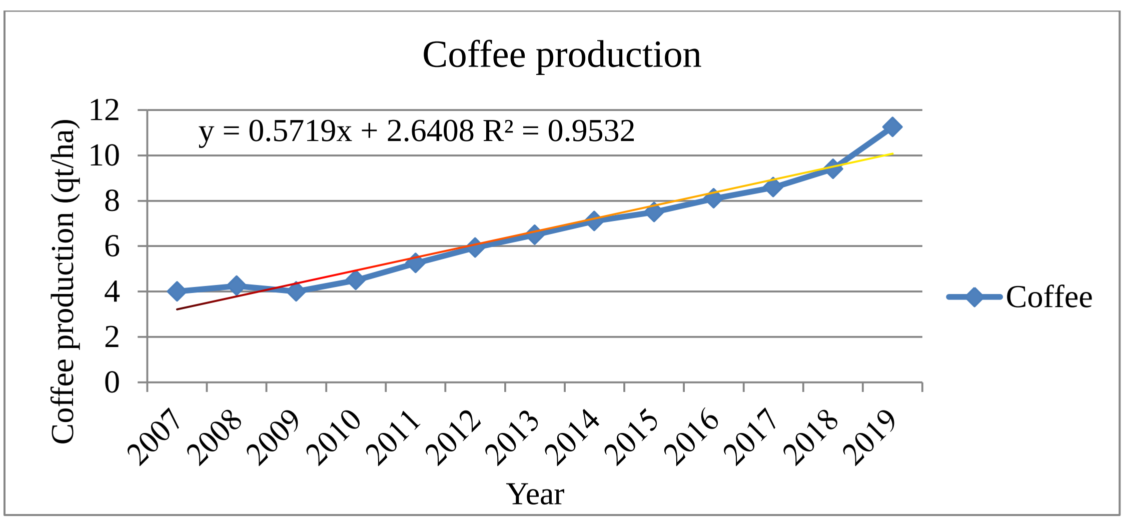

Figure 12. Coffee production trend in Gomma District for the period of 2007 to 2019.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Summary and Conclusion

Climate change and variability is one of the greatest environmental, social and economic threats the world is facing today. Specifically, climatic variability is the main factor responsible for the oscillations of coffee grain yield in the world. This study was conducted to assess the impact of climate variability on coffee yield and farmers' adaptation strategies in Gomma district, Jimma Zone of Oromia National Region, Ethiopia. Household head surveys, focus group discussions, and key informant interviews was conducted to obtain primary data in order to meet the objective. Multistage sampling procedure was applied to select 280 household heads in four *kebeles* of the study area.

Annual and seasonal rainfall revealed statistically non-significant increasing trends except for *kiremt* season. The *kiremt* season on the other hand showed decreasing trend. Whereas, mean monthly rainfall exhibited increasing trend for some month and decreasing trend for other. The result of *belg*, *bega* and annual rainfall total indicated slight increase in rainfall amount by 0.496, 2.24 mm and 2.68 mm/year every year, respectively, whereas the *kiremt* season rainfall showed a decreasing trend by -0.392mm/year. Both seasonal and monthly rainfall was more variable than annual rainfall. *Belg, bega, kiremt* and maximum temperature was increased significantly by 0.5, 0.4, 0.3 and 0.4^{o}C per decade, respectively. Similarly, the minimum temperature increased significantly by 0.1^{o}C, 0.2^{o}C, 0.3^{o}C and 0.2^{o}C for *kiremt, belg*, *bega* season and annual, respectively.

According to the analyzed daily rainfall data rainfall features such as onset season, end of season and length of growing period were less variable and had high stability in the study area. The start of the rainy season was on March 18 (78 DOY), which happened once in every four years, while the SOS is on March 19 (79 DOY), which happened twice in every four years and three times every four years on March 30 (90 DOY). The length of the growing period varied from June to August first (155 to 217 DOY) with mean of 197 days and 6.4 percent coefficient of variation.

Correlation between coffee yield, rainfall, maximum and minimum temperature showed that the start of the season SOS (r=-0.517) was strongly negative correlated with coffee yield while the end of the season EOS (r=0.571) showed positive and strong correlation with coffee yield. Length of growing period revealed a weak; but positive correlation (r=0.185) with coffee yield. On the other hand, *kiremt* JJAS (r=0.310) and *belg* FMAM (r=0.213) had moderately positive correlation with coffee yield but also statistically it was non-significant. Both maximum (r= -0.267) and minimum (r= -0.265) temperature showed weak negative correlation with coffee yield.

Regression analysis also revealed that the end date of the rainfall and the minimum temperature had negative effect on coffee yield. However, other factors like *kiremt* season, *belg* season and the maximum temperature had positive effects on coffee yield. Accordingly, the coefficient of multiple determinations, (R^2) was 0.734%, indicating that climatic factors contributed 74% on coffee yields variance and non-climatic factors contributed the remaining 26% only.

Adaptation strategies such as using and/ or developing improved coffee varieties, shade, and mulching, intercropping and farm diversification are the most commonly practiced adaptation strategies to climate variability by coffee producing households. In this study, it can be concluded that the influence of the climate variability and its effect is on coffee production and productivity is evedent.

5.2. Recommendations

Depending on the finding of this study, coffee has been and is expected to be negatively influenced by climate variability. Therefore, the following recommendations are forwarded to minimize the impacts of the climate variability;

- Development of efficient agro-meteorological tools that can predict, monitors and assess quantitative influence of climatic variables, such as temperature, rainfall and soil water balance on coffee crop phenology and yield for different coffee growing regions in the country.
- Adaptation strategies in rural areas should be done by helping farmers to use their local knowledge in combination with the introduced innovation to enhance local adaptations to climate change and variability.

- ❖ Popularizing and demonstrating of most effective adaptation strategies, such as agronomic practices and development of improved coffee varieties tolerant to current climate change.
- ❖ Further research is recommended to study the interaction between and among various socio-economic factors and other climate variables on coffee production in large areas of coffee producing regions of the country.

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7. APPENDICES

My name is Zinash Nigussie Tsega. I am a master's student in Haramaya University studying Agro meteorology and Natural Risk Management. I am doing my thesis on: Impact of Climate Variability on Coffee Yield and Adaptation Strategies in Gomma District, Jimma Zone of Oromia Region, Ethiopia. Thus, I would like to express my appreciation in advance for your co-operation in giving me your time and being committed for the success of this work.

Altitude ………………………………

Latitude ……………………………………

Longitude …………………………………

Region …………………………………..

Zone …………………………………

District ……………………………

Kebele ……………………………………

Name of Enumerator ………………………………

Date of the interview ………………………….

Identification number ……………….

Section A: Socio-Demographic Characteristics of Coffee Farmers

No	Questions	Response
1	Name of the respondent	
2	Gender	1. Male [ ] 2. Female [ ]
3	Age	
4	Marital status	1. Married [ ] 2. Single [ ] 3. Widow/Widower [ ] 4. Divorced [ ]

5	Have you had formal education?	1. Yes [ ] 2. No [ ]
6	What is your level of education	1. No school 3. Primary 5. primary 2. Illiterate 4. Secondary
7	Number of years lived in the community	
8	Experience in coffee production	
9	Total Farmland owned	
10	Coffee farmland owned	
11	What is your main source of income other than agriculture	
12	Do you get access to the credit facility	1. Yes [ ] 2. No [ ]
13	If yes, who is your source of credit	1. Credit Unions [ ] 2. Cooperative society [ ] 3. Commercial Banks [ ] 4. Rural Banks [ ] 5. Government institutions [ ] Others, specify………………………….

Section B. Effects of Temperature on Coffee Yield

1 4	What type of coffee cultivars do you plant	1. Improved [ ] 2. Local variety [ ] 3. Both [ ]
1 5	How do you rate your coffee land fertility?	High [ ] Medium [ ] Low [ ]
1 6	Have you noticed any long-term changes in the temperature over the past 30 years?	1. Yes [ ] 2. No [ ] 3. No idea [ ]
1 7	Is there any significant effect of low/high temperature on coffee production	1. Yes [ ] 2. No [ ] 3. I don't know [ ]

18	If yes, what type of effect did you observe on coffee production	1. Low yield [ ] 2. Drying [ ] 3. Occurrence of pest and disease 4. Fruit development and ripening 5. Low coffee quality
19	Does high temperature affect coffee yield?	1. Yes [ ] 2. No [ ]
20	If yes, what is the degree of effect?	High Medium Low
21	Which type of variety is highly affected by temperature change?	1. Improved 2. Local 3. Both
22	Does high temperature affect coffee sustainability?	1. Yes [ ] 2. No [ ]
23	To what extent does it affect coffee availability?	High Medium Low

Section C. Effect of Rainfall Variability on Coffee Production

24	Have you noticed any long-term changes in the mean rainfall over the past 30 years?	1. Yes [ ] 2. No [ ]
25	What is the trend of rainfall	How Medium Low
26	Is there any possible relationship between rainfall and coffee production	1. Yes [ ] 2. No [ ]
27	If yes, which type of relationship exists between rainfall and production	1. Positive [ ] 2. Negative [ ]
28	Does rainfall variability affect coffee yield?	1. Yes [ ] 2. No [ ]
29	If yes, what is the degree of effect?	Increased Decrease No effect
30	Which type of variety is highly affected by rainfall variability?	1. Improved 2. Local 3. Both
31	Does rainfall variability affect coffee availability?	1. Yes [ ] 2. No [ ]
32	To what extent does it affect coffee availability?	High Medium Low

Section D. Effect of Extreme Climatic Event on Coffee Production

33	Have you observed any extreme climatic events in your locality for the past decade?	1. Yes [ ] 2. No [ ] 3. Do not know [ ]
34	If yes what kind of climatic event have you observed during this period	1. Flood [ ] 2. Drought [ ] 3. Strong winds [ ] 4. Disease 5. Insect
35	In your opinion, does the extreme climatic event have any effect on coffee production?	1. Yes [ ] 2. No [ ] 3. No idea [ ]
36	If yes at what point of production does it affect	1. Flowering [ ] 2. Fruit setting and development [ ] 3. Ripping period [ ] 4. Harvesting
37	To what extent do floods affect coffee yield	High Medium Low
38	To what extent does drought affect coffee yield	Increase Decrease No effect

Section E. Management Practices To Climate Change and Climate Variability Impact

39	What are agronomic practices do you apply to your coffee production on your farm?	1. weeding/slashing [ ] 2. Pruning [ ] 3. Stumping [ ] 4. Fertilizer application [ ] 5. Shedding [ ] 6. None of the above [ ]
40	What are the most common coffee pest and diseases on your farm?	1. Coffee Leaf Rust (CLR) [ ] 2. Leaf spots [ ] 3.Coffee berry disease [ ] 4. Insect pests [ ] 5. Root rot *disease* [ ]

		Others ……….
41	Do you practice any pests and disease management on your farm?	1. Yes [ ] 2. No [ ] 3. No idea [ ]
42	If yes what type ………	1.Commercial pesticides [ ] 2.Organic pesticides [ ] 3.Cultural methods [ ] Other …………
43	Which of the following on-farm management practices do you adopt in the event of crop failure due to the changing climate?	1. Use good agricultural practices Yes [ ] No [ ] 2. Plant shade trees Yes [ ] No [ ] 3.Take up agroforestry and crop diversification Yes [ ] No [ ] 4. Changing crop varieties Yes [ ] No [ ] 5. Irrigation farming Yes [ ] No [ ] 6. Changes in farm location Yes [ ] No [ ] 7.Non-adaptation Yes [ ] No [ ]
44	What necessitates the selection of your choice of adaptation?	1. Community-based governance system[ ] 2. Age [ ] 3. Availability of resources e.g. finance [ ] 4. Land tenure status [ ] 5. Education [ ] 6. Experience [ ] 7. Extension services [ ] Others, specify………………….
45	What is the degree of effectiveness of the various adaptation practices you employ?	1. Very effective [ ] 2. Moderately effective [ ] 3. Not effective [ ]
46	Do the following affect your ability to	**Factor** Yes no 1 lack of knowledge on the

	adapt to the varying climate?	situation 2. constraints to expanding farm size due to limited land 3.high cost of agricultural inputs 4. lack of access to climate data 5.Lack of access to water 6. financial constraints Other, specify
47	Do you receive support (e.g. extension services, finance, etc.) from the government	1. Yes [ ] 2. No [ ] 3. No idea [ ]
48	Do you receive any form of training from any institution in the district to help your adaptive capacity	1. Yes [ ] 2. No [ ] 3. No idea [ ]
49	If yes, what kind of training do you receive?	
50	What kind of government support do you receive to help you adapt to the varying climate to boost your production	1. Extension services [ ] 2. Finance [ ] 3. Agro-chemicals [ ] 4. Farming tools and equipment [ ] Other, specify……………
51	What is the impact of these support systems on your production?	1. Increase yield [ ] 2. Decrease yield [ ] 3. Constant yield [ ]
52	Apart from the climate, what other challenges affect coffee of the farmers in the *kebele*	

Check List for the Focus Group Discussions (FGDs)

Date of interview ____/____/ 2021

District ___________________________

Sector ____________________________

A. Socio-economic characteristics

1) Do income-generating activities avail to the majority of farmers in this sector? If you agree, what are the most activities done by farmers and the average income per month?

2) How female-headed households differ from male-headed households in terms of agricultural production, vulnerability, and adaptive capacity to climate change and variability?

3) Do farmers with different levels of income affected differently by the effects of climate change and variability?

B. Institutional factors

1) Do government institutions or other local NGOs facilitate rural farmers to have access to climate variability information?

2) How farmers receive weather forecasting information in this region? What are their own predictions techniques mostly used since they noticed the long-term changes in weather?

3) Does government intervene in case of adverse occurrence of climate change events? If you agree, in which ways government intervenes in this area? Please explain.

C. Management measures on climate variability

1) What have been major concerns, related to soil conservation and control, do farmers face in their farming practices; mention them

2) What are the main agricultural techniques (adaptation measures) did farmers adapted to cope with the adverse effects of climate change and variability, describe them (physical, bio-physical, political, economic, etc.)

3) To what extent (effort) did farmers adapt to climate variability Vis a Vis to crop production expectation?

4) Based on climate forecasting, how farmers intend to increase the level of crop production in this area

5) How climate variability affects coffee production; what is the average level of production and portion of land that can be affected at the household level

Check List for the Key Informants Interviews (KIIs)

Date of interview ____/____/ 2021

Interviewer's name: ______________________________

Position: ____

Organization: ____________________________________

A. Crop production and climate change

1) Describe briefly the current level of coffee production in the district. Then compare the situation with the one for the past three decades.

2) What do you see as the foremost factors that involve shifting (increase, decrease, or no shift) of coffee productivity in rural areas?

3) How do you describe matching between agricultural inputs application and increase in crop yield mainly for coffee yield?

4) Are farmers aware of government policies such as the Crop Intensification Program (CIP) which promotes the use of inputs (organic and inorganic fertilizers)?

5) Did farmers adopt fertilizer use needed to increase crop yield; if yes, what is the type's fertilizer they apply for?

6) Did crop production, mainly for coffee (at district level) changed (increasing, decreasing, or no change) since farmers adopted fertilizer application, explain your answer

7) Do farmers have access to input and output market and market price information of their agricultural products in this area?

8) Are there existing infrastructure such as; feeder roads that facilitate the input and output market in rural areas?

B. Adaptation options on climate variability

1) What have been major concerns, related to soil conservation and control, do farmers face in their farming practices; mention them

2) What are the main agricultural techniques (adaptation measures) did farmers adapted to cope with the adverse effects of climate change and variability, describe them (physical, bio-physical, political, economic, etc.)

3) To what extent (effort) did farmers adapt to climate variability vis-a-vis to coffee production expectation?

6) Based on climate forecasting, how farmers intend to increase the level of crop production in rural areas?

7) How climate variability affects coffee production; what is the average level of production and portion of land that can be affected at the household level?

8) Do government institutions and NGOs help poor farmers to increase and improve their adaptive capacity? If yes, what are the options mostly adopted by these institutions in the sample districts?

Thank you for your time and cooperation