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

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Abstract

The frequency and severity of extreme climate events have a significant impact on agricultural systems, including coffee production, yet local exploration of these impacts and adaptation strategies has been lacking. This study was therefore conducted to assess the impact of climate variability on coffee yield in Gomma district. Meteorological data from 1988 to 2019 and time series data on coffee yield from 2007 to 2019 were collected from the Ethiopian Meteorological Institute and the district's Agriculture and Natural Resources offices, respectively. Data analysis was carried out using INSTAT+ v.3.36, SPSS version 25, and XLSTAT 2014. The mean annual rainfall of the study area during the study period was 1474.8 mm, with a standard deviation of 128.2 mm and a coefficient of variation (CV) of 9%. The results revealed that the annual rainfall amount showed a statistically non-significant increasing trend by a factor of 2.68 mm/year. The annual mean maximum and mean minimum temperatures in the study area were significantly increased by a factor of 0.40 °C and 0.20 °C per decade, respectively. Pearson correlation showed that maximum and minimum temperatures, the start of the rainy season, and the end of the season had a negative correlation with coffee yield, whereas length of growing period, the kiremt season, and the belg season rain had a positive correlation. 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 in agro-ecological zones are necessary to increase coffee production and productivity.

Keywords: Adaptation; Coffee; Climate variability; Dry spell; Gomma district

Introduction

Our planet is getting warmer and warmer as a result of an increase in the Earth's average temperature associated with anthropogenic activities. The change in temperature and rainfall have been dubbed the most significant environmental threats of the 21st century, and their potential long-term impact on crop production is a topical issue worldwide. Crop production can be adversely affected by rising temperatures and fluctuating rainfall patterns. 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 [1]. The impact of variability on agriculture is stronger in poor countries that have rainfall-dependent economies. Agriculture contributes 41% of the gross domestic product (GDP), 80% of employment, and the majority of foreign exchange earnings in Ethiopia. However, this climate-sensitive sector is highly challenged by rising temperatures and erratic rainfall. Among the perennial crops produced in Ethiopia, coffee farming supports over 15 million farmers and serves as the mainstay of the country's foreign earnings. Coffee originated in Ethiopia, both biologically and culturally and is largest coffee producer in Africa and the fifth-largest exporter of Arabica coffee in world. In 2021/22, Ethiopia exported around 300,000 metric tons of coffee at a worth of over 1.4 billion USD (Ethiopian Coffee and Tea Authority, unpublished).

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 stress increases as the air temperature increases and soil moisture decreases (due to a lack of rainfall) and vice versa. Variations in both rainfall and temperature interfere with crop phenology and, consequently, productivity and quality. Temperature increases have a sensitive effect on Arabica coffee plants, especially during blooming and fructification. Increasing drought stress and rising temperatures 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 [2].

For instance, due to rising temperatures, 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, reduced flower bud formation, and cherry production, creating a favorable environment for the Coffee Berry Borer (CBB).

Moreover, the changing character of rainfall and temperature are causes for the low yield and emergence of disease and pests. Studies by various researchers 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, the development of new insect pests and diseases, declining soil

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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 smallholder farmers.

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. Although a few studies have been conducted to assess the impact of climate variability on coffee production in Ethiopia [3], there is no such organized study conducted in Gomma district that assessed the impact of climate variability on coffee production. Therefore, this study was conducted to characterize climate variability and assess its impact on coffee yield in Gomma district of Jimma Zone.

Materials and Methods

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

Data Sources and Data Quality Control

Source of data: Secondary data sources were used to generate the data for this study. Time-series data (secondary data), including climate data (rainfall and temperature data) from 1988–2019 and crop data from 2007–2019, were collected from the Ethiopian Meteorology Institute, and coffee yield data was from the Agriculture and Natural Resources Office. Both climate and crop data were used to present the trend analysis over time variation in weather variables and crop yield.

Data quality control assessment: RclimDex 1.0 software was used for data quality control, and detected outliers were removed using the Turkey Fence approach. Buishand's method was used to check data homogeneity, which is conducted by using a cumulative deviation test. In this study, to fill the missing values, a first-order Markov chain simulation of INSTAT was applied. INSTAT fits a model to the past data and then generates similar time series for any number of desired years [4].

Methodology : In this study, we employed INSTAT, XLSTAT, R (RStudio), and MS Excel spreadsheet tools to analyze our data set. Graphs were mapped using ArcGIS software; inverse distance weighting was used for spatial interpolation.

Analysis of rainfall variability: Variability in rainfall and temperature variables/parameters was analyzed using descriptive statistics (frequency, mean), coefficient of variability, standardized anomaly index, and precipitation concentration index (PCI), and standard deviations. The contribution of seasonal rainfall to the total annual rainfall in percent (CT) for each station is also computed.

Analysis of rainfall trend: To estimate the sum and slope of long-term rainfall and temperature, the Mann-Kendall test and Sen's slope estimation method were used. The presence of a statistically significant trend is evaluated using the ZMK value. In a two-sided trend test, the null hypothesis **H**o should be accepted if | | 1 / 2 **MK Z Z** α < −at a given level of significance. Z1-α/2 is the critical value of ZMK from the standard normal table. E.g., for a 5% significant level, the value of Z1-α/2 is 1.96. In this study, a 5% significant level is used [5].

Results and Discussion

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 1). The coefficient of variation implies that rainfall in the district had low inter-annual variability during the study period. As indicated in Figure 2, the recorded annual rainfall amount in the years 1989, 1991, 1994, 1995, 1999, 2002, 2003, 2004, 2007, 2009, 2013, 2017 and 2018 was below average. In this study, the maximum and minimum annual rainfall observed during the study period were 1726.8mm in 1996 and 1232.3 mm in 2002. The Mann-Kendall test for annual rainfall showed a statistically non-significantly increasing trend (p = 0.05) by a factor of 2.68 mm/year during the study period.

The computed descriptive statistics of monthly rainfall in the study area are presented in Table 1. In the study area, the monthly CV lies between 14% in July and 87% in December, and the result shows there was high rainfall variability from month to month in the

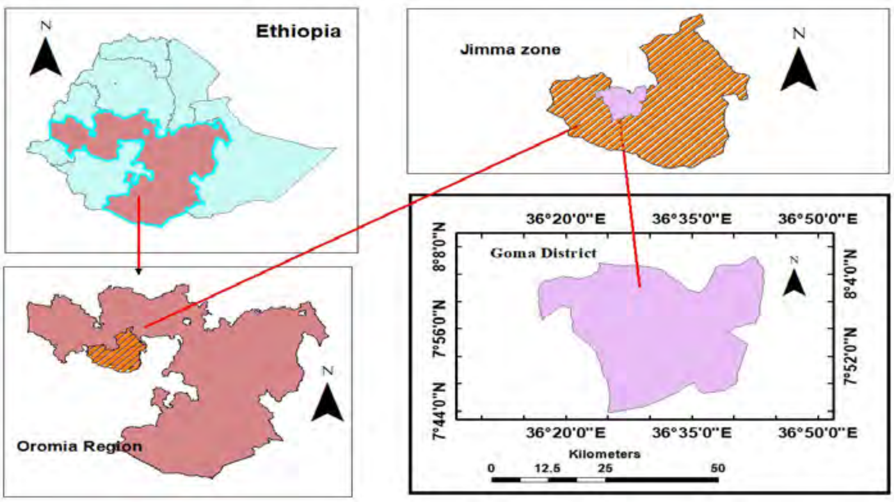

Figure 1: Location map of the study area.

Table 1: Monthly and annual rainfall variability and Mann-Kendall trend analysis of Gomma District.

Variable	Mean(mm)	SD(mm)	ZMK	P-value	Q	CV (%)	Contributions	Trend
Jan	26.3	16.4	-0.16	0.19	-0.4	62	1.8	D
Feb	31.7	23	-0.07	0.58	-0.3	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	55.1	0.36	0	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	-0.1	0.45	-0.37	14	16.2	D
Aug	239.2	38.2	-0.01	0.96	0	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	1	0	87	2	I
Annual	1474.8	128.2	0.15	0.25	2.68	9	100	I

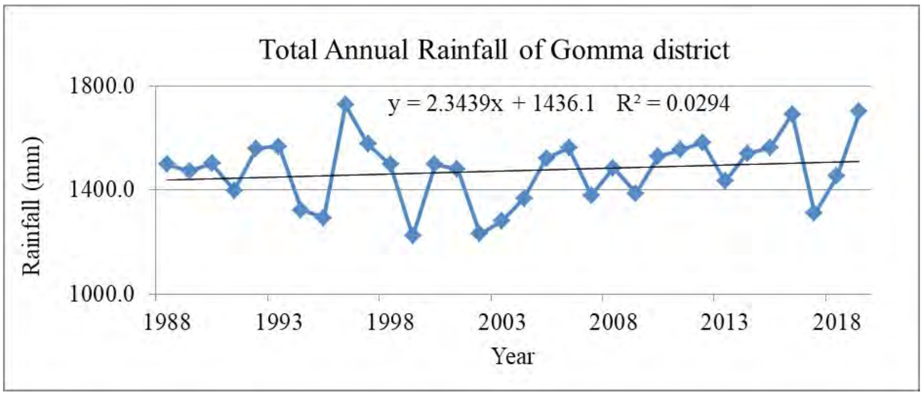

Figure 2: Annual rainfall of Gomma district for the period of 1988 to 2019.

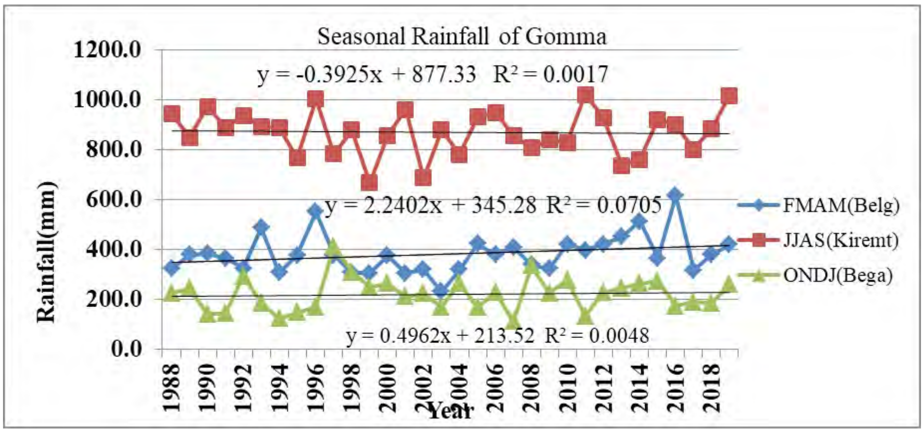

Figure 3: Seasonal rainfall of Gomma District for the period of 1988 to 2019.

district. The three months with the highest maximum monthly rainfall were June (207.9 mm), July (239.6 mm), and August (239.2 mm), contributing 14.1%, 16.2%, and 16.2% to total rainfall, respectively. The Mann-Kendall test for monthly rainfall showed both increasing and decreasing trends. Over the study period, rainfall showed a decreasing trend during the months of January, February, March, June, July, and September, whereas an increasing trend was observed 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 [6].

Analysis of seasonal rainfall: Seasonal rainfall analysis of Gomma district was depicted in Figure 3 and Table 2. Seasonal rainfall analysis showed less variability during the kiremt season with a CV of 10% and moderate variability for belg (CV = 21%), while bega had high variability with a CV of 30%. This result is in line with the findings of who reported greater variability in belg rainfall than kiremt rainfall in most parts of Ethiopia. The estimated contribution of the season to the total annual rainfall showed that kiremt and belg accounted for 59% and 26%, respectively, while bega contributed a smaller proportion (15%) of the total rainfall (Table 2). The average rainfall received during the Kiremt season was 870.9 mm, while Belg and Bega received 382.2mm and 221.7mm, respectively. Reported similar amounts of maximum and minimum rainfall during the kiremt and bega seasons at different locations in the country.

Table 2: 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	0.2	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

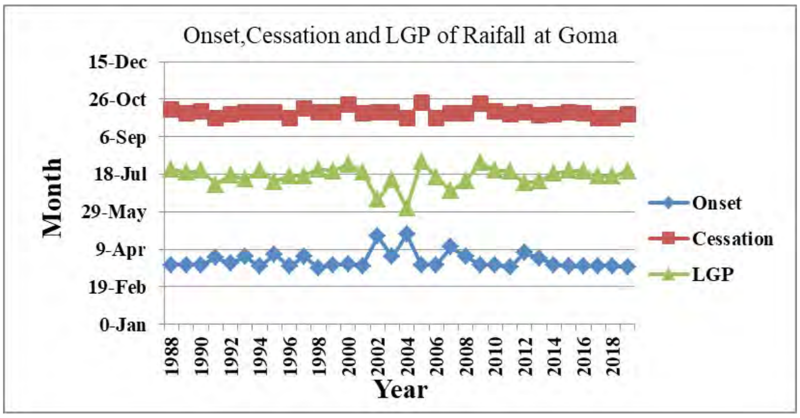

Figure 4: Onset, cessation and LGP of rainfall at Gomma district for the period of (1988 to 2019).

Table 3: 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

The optimum amount of rainfall during the kiremt season favors better bean growth, as it is a critical stage for bean filling and berry expansion and consequently contributes to a better yield. The shortage of rain during the **belg** might have an adverse effect on bean filling, ultimately resulting in a higher number of undesirable coffee beans called floater beans. 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 statistically 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).

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). 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. Congruent with this finding, reported 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.

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 3).

Rainfall in the studied area stopped from the first decade of October (275 DOY) until the third decade of October (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. The major rainy season ended 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), despite the fact that EOS only happened once every four years (25%). 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 from June to August (155 to 217 DOY), with a mean of 197 days. The LGP of the area begins in the second decade of June (192 DOY) once every four years, and in the fourth decade of June (205 DOY), it occurs three times every four years. During the study period, the length of the 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 in which month.

The standardized anomaly of annual rainfall (SAI): An analysis of the standardized anomaly index for the study area is presented in Figure 5. 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%, are positive anomalies. The differences between the frequencies of occurrence in the dry and wet years were small. A negative anomaly index (dry) was observed for the years 1983, 1984, 1994, 2002, and 2003 in the district. In line with this 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 values of -1.5 to -1.99) were

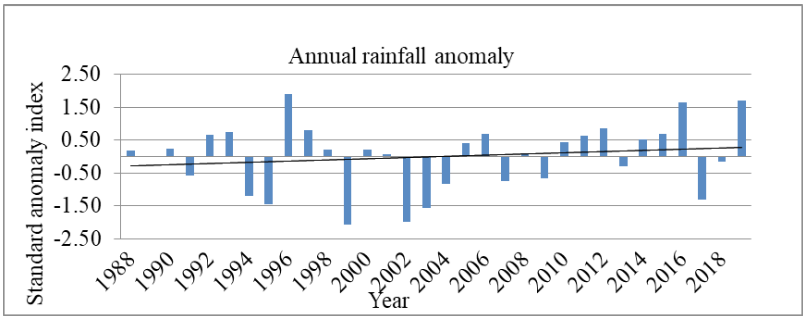

Figure 5: Standard anomaly index of rainfall of Gomma district throughout 1988 to 2019.

Table 4: Descriptive statistics of standardized rainfall anomaly from 1988 to 2019 in Gomma.

%age and frequency of occurrence (Years)			
Drought category	**Standard anomaly index Value range**	**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

Table 5: Maximum temperature variability and trend of Gomma district.

Variable	Mean(°C)	SD(°C)	MK	P-value	Q	CV
Jan	26.2	1	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	0.2	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**	**0.51**	**0.42**	**0.001**	**0.033**	**0.02**

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 findings of NMA (2007), who reported that there was an increase in dry year frequency in Ethiopia (Table 4).

The present study revealed inter-annual variability in rainfall, which would negatively affect crop production, including coffee production, and the livelihoods of farmers. 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. The drought phenomenon will create a more vulnerable environment for the subsistence farming sector.

The precipitation concentration index (PCI) value for the annual rainfall result indicated that the value ranged from 11 to 16 throughout the study year, showing a high concentration of rainfall in the area. PCI values of less than 10 indicated a uniform monthly distribution of rainfall; PCI between 11 and 20 indicated a high concentration; and PCI above 21 indicated a very high concentration. This gives information on the normal amount of rainfall expected in the study area per year. It can also help to obtain an idea of the departure of the annual rainfall from normal or to compare one region with others [7].

Analysis of temperature variability and trends in the study area

Maximum temperature: The result of annual and monthly maximum temperature variability and the trend of temperature in the study area from 1988 to 2019 is given in Table 5. Temperatures in some years varied greatly from year to year. The annual average of the maximum temperature at Gomma over the study period was 25°C with a standard deviation of 0.51 and a CV of 2% (Table 5).

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 showed stability over time with less variability. For all of the months, the trend for maximum temperature showed a significant increasing trend, which is statistically significant at a 95% level of confidence except for June, August, November, and December.

The rising temperature might affect the production and productivity of the crop and the growth of coffee plants. The mean annual temperatures of the study area increased at different rates. The result illustrated a statistically significant ($p < 0.05$) increase. This result is comparable to a national study that found a broadly consistent warming trend or rising minimum and maximum temperatures over the past fifty years. Using a linear regression model, the rate of change is defined by the slope of the regression line (Figure 6). In this case, the annual temperature will increase by 0.4^{0}C per decade for the mean maximum temperature during the study period.

Seasonal maximum temperature: The long-term seasonal trend of the maximum temperature of Gomma is presented in Figure 7. Regarding the seasonal maximum temperature, the maximum temperature (27.8^{o}C) was recorded in 2015 during Belg (FMAM), while the minimum value of the 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 the linear regression model, the 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.

There was a significant increase in the maximum temperature at all seasons during the study period. The trend of Belg season mean maximum temperature was 26.8 with a standard deviation and coefficient of variation of 0.78 and 3%, respectively. The season mean maximum temperature was 23°C, he bega was 25°C, with a standard deviation and coefficient of variation of 0.51 and 3%, respectively (Table 6).

Minimam temperature: The analysis of annual and monthly minimum temperature data undertaken in the study area for the period of 1988 to 2019 is shown in Table 7. The average annual minimum temperature varied from 10.1^{0}C in 1999 to 12.1^{0}C in 2016 during the study period. On the contrary, the lowest minimum temperature (8.350 °CC, with a 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, which is statistically significant for March, May, July, September, October, and November at the 95% level of significance (P-value < 0.05). The coefficient of variation for the mean monthly minimum temperature shows a variation ranging from 3 to 12%. The minimum temperature showed more variation than the maximum. This is similar to the report by Panda and Sahu (2019), which showed larger CV values for the minimum temperature than the maximum temperature.

The rate of change is defined by the slope of regression line (Figure 8) which in this case is about 0.2 ^{o}C per decade for mean minimum

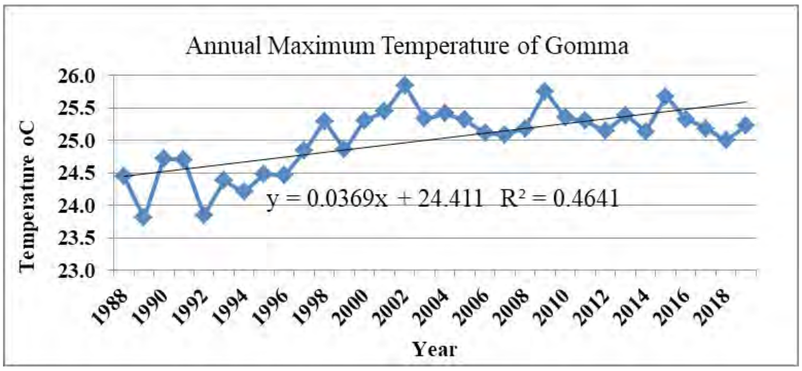

Figure 6: Annual maximum temperature of Gomma District for the period of (1988-2019).

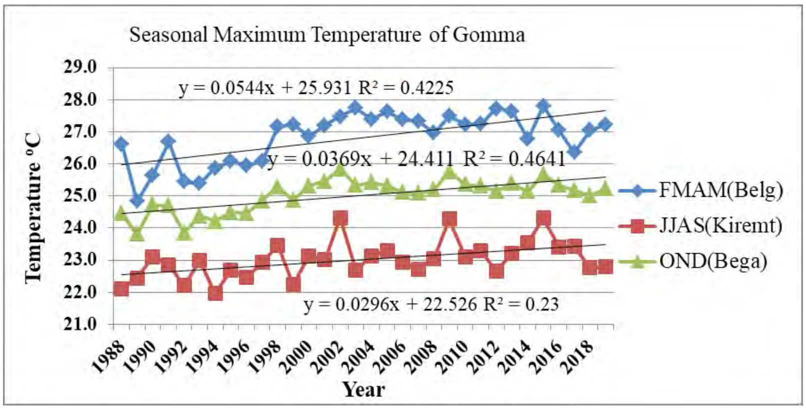

Figure 7: Seasonal maximum temperature of Gomma District for the period of (1988-2019).

Table 6: 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	0.58	0.37	182	0.003	0.027	3
Bega	25	0.51	0.42	206	0.001	0.033	3

Table 7: 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	9.25	0.936	0.351	0.005	0.05	0.1
Dec	8.356	1	0.214	0.089	0.033	0.12
Enter annual	**11.233**	**0.399**	**0.359**	**0.004**	**0.02**	**0.04**

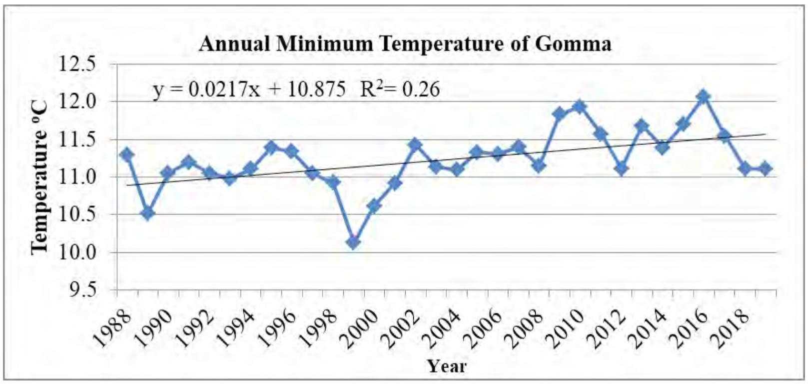

Figure 8: Annual minimum temperature of Gomma District for the period of (1988-2019).

Table 8: Seasonal minimum temperature variability and trend of Gomma District.

Variable	Mean	Std. deviation	MK	P-value	Sen's slope	CV
Belg	11.93	0.596	0.222	0.077	0.02	0.05
Kiremt	12.541	0.31	0.291	0.02	0.014	0.02
Bega	11.233	0.399	0.359	0.004	0.02	0.04

temperature during the study period.

Seasonal minimum temperature: The mean minimum temperature of the kiremt season was 12.5⁰C, with SD and CV of 0.31⁰C and 0.02%, respectively, as shown in Table 8. The mean minimum temperature of the bega season was 11.23⁰C, with SD and CV of 0.399⁰C and 0.04%, respectively. And Belg season had a mean minimum temperature of 11.93⁰C with a SD and CV of 0.596⁰C and 0.05%, respectively. Temperature showed an increasing trend in all seasons, but was statistically significant for kiremt and bega. In the study area, the smallest value of minimum temperature was recorded in the in the bega season, followed by the belg season. In 1999, the lowest recorded seasonal minimum temperature was 8⁰C in Bega, and the highest recorded was 13.30⁰C in 2010 in Bega. During the kiremt season, especially from 2000 to 2010, the variability of the minimum temperature was low. In the bega and belg seasons, the minimum temperature was highly variable from year to year.

Using a linear regression model, the rate of change of the mean minimum temperature is defined by the slope of the regression line (Figure 9). In this case, temperature is increased by about 0.1°C, 0.2oC, and 0.3°C per decade for the kiremt, belg, and bega seasons, respectively, during the study period [8].

Correlation of coffee yields with rainfall and temperature: The correlation coefficient computed between coffee yield, rainfall, and maximum and minimum temperatures is presented in Table 9. Regarding the rainfall variables, SOS (r = -0.517) and EOS (r = 0.571) had a negative, strong, and statistically non-significant correlation with coffee yield, whereas other variables such as length of growing period (r = 0.185), kiremt JJAS (r = 0.310), and belg FMAM (r = 0.213) had a moderately positive correlation with coffee yield but were also statistically non-significant.

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 their study conducted on Haraghe coffee.

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 were used as explanatory variables in the regression analysis of this study (Table 10). 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.

The end date of the rainfall and the minimum temperature had an

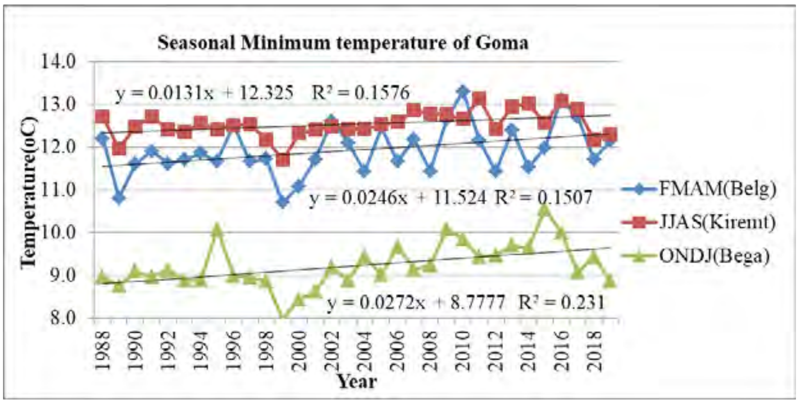

Figure 9: Seasonal minimum temperature of Gomma District for the period of (1988-2019).

Table 9: 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	0.31	-0.247	0.006	0.225	1			
FMAM	0.213	-0.071	-0.126	0.002	-0.0004	1		
TMAX	-0.267	-0.335	0.71	0.647	-0.0005	-0.178	1	
TMIN	-0.265	-0.339	0.386	0.492	-0.2025	0.318	0.656	1

Table 10: 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	0	-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	3.38	0.012
TMIN	-4.183	2.591	-2.173	0.066

Table 11: Regression values for predictors.

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

effect on coffee yield, according to the results of the regression coefficient analysis. Coffee yield was negatively impacted by the end date of the season (-0.416 qt/ha). The **kiremt** season, the **belg** season, and the maximum temperature positively affected coffee yield. The coffee yield was negatively impacted by the minimum temperature (-4.183 qt/ha). This indicated that the minimum temperature is the major determinant factor for coffee production and productivity. This indicated that as the minimum temperature rises, there will be a significant reduction in coffee yield. It is obviously known that low or high temperatures are known to disturb plant metabolism, consequently affecting coffee growth and yield. Similarly 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 0.734 (Table 11). This indicated that 73.4% of the variance in coffee yield was explained by a combination of the starting season, end of the season, **kiremt** and **belg** rainy season, maximum and minimum temperature, and the other 26.6% by non-climatic factors. This shows that the bean yield of coffee genotypes was found to be significantly affected by environmental factors.

Despite the detrimental effects of climate variability, coffee production yield increased by 0.57 quintals per hectare per year (Figure 10). In order to determine evidence of changes in coffee production, a regression line was constructed; it showed a 95% increase in productivity during the study period. The increase in production and productivity was mostly due to the positive relationship between length of growing period, kiremt and belg season, use of improved coffee varieties, and application of good agronomic management practices.

Summary and Conclusion

Climate variability is one of the greatest environmental, social, and economic threats the world is facing today. It is responsible for the oscillations of grain yield, including coffee, and affects the livelihoods of many small-holder coffee farmers. 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 Regional State, Ethiopia. A multistage sampling procedure

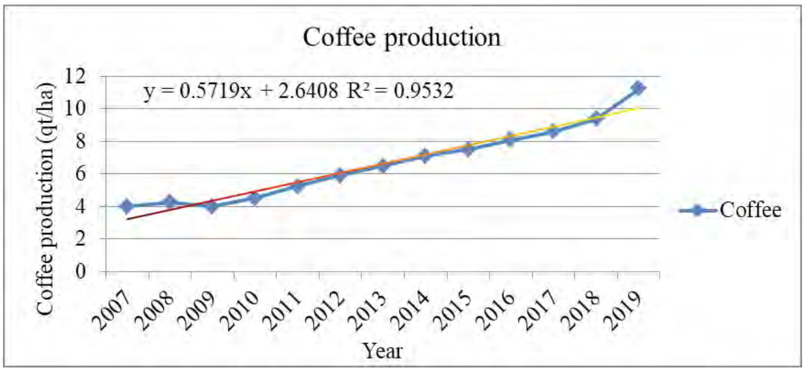

Figure 10: Trend of Coffee production in Gomma District for the period of 2007 to 2019.

was applied to select 260 household heads in four kebeles of the study area. Household surveys, focus group discussions, and key informant interviews were conducted to obtain primary data. Climate data and coffee yield data were collected from the National Meteorological Agency and the Agriculture and Natural Resources Office, respectively.

Annual and seasonal rainfall revealed statistically non-significant increasing trends. The **kindergarten** season, on the other hand, showed a decreasing trend. The mean monthly rainfall exhibited an increasing trend for some months and a decreasing trend for others. The results of **belg, bega,** and annual rainfall total indicated a slight increasing trend in rainfall by 0.496, 2.24 mm, and 2.68 mm/year, respectively, whereas the **kiremt** season rainfall showed a decreasing trend by -0.392 mm/year. Both seasonal and monthly rainfall were more variable than annual rainfall. **Belg, bega, kiremt,** and maximum temperature were increased significantly by 0.5, 0.4, 0.3, and 0.4 oC 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. Onset season, end of season, and length of growing period were less variable and had high stability in the study area.

The correlation between coffee yield, rainfall, and maximum and minimum temperature showed that the start of the season SOS (r = -0.517) was strongly negatively correlated with coffee yield, while the end of the season EOS (r = 0.571) showed a positive and strong correlation with coffee yield. The length of the 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 a moderately positive correlation with coffee yield, but statistically, they were non-significant. Both the maximum (r = -0.267) and minimum (r = -0.265) temperatures showed a weak negative correlation with coffee yield. The end date of the rainfall and the minimum temperature had a negative effect on coffee yield, whereas the kiremt season, the belg season, and the maximum temperature had positive effects. In this study, it can be concluded that the influence of climate variability and its effect on coffee production and productivity is evident. Adaptation strategies such as using and/or developing improved coffee varieties, shade, mulching, intercropping, and farm diversification are the most commonly practiced adaptation strategies to climate variability by coffee-producing households.

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