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Original Research

Effect of Climatic Variability Parameters on Maize Yields in Central and Eastern Ethiopia

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Abstract

This study uses long-term observed and future data to assess how climatic conditions affect maize output throughout Ethiopia's four agro-ecological zones and the relationship between climate variables and maize yield. In both lowland and highland zones, trend analyses showed increasing maximum and minimum temperatures and decreasing precipitation, rainy-season duration, wet-day frequency, and seasonal rainfall. The results of regression and correlation studies indicate that factors linked to rainfall account for 61.64% of the variability in maize yield, emphasizing precipitation as a key factor influencing productivity. Rainfall variability was identified as the most important determinant of maize yield, particularly in lowland and moisture-stressed areas, where delayed onset, early cessation, and uneven distribution of rainfall substantially reduced crop productivity. However, highland and midland areas were more sensitive to increasing temperatures, which accelerated crop development, shortened the grain-filling period, and ultimately reduced grain yield. The combined effects of increasing temperatures and irregular rainfall intensified water stress during critical growth stages, resulting in considerable yield reductions across all agro-ecological zones. Findings emphasize the necessity of location-specific agronomic adaptations and policy interventions, such as drought-tolerant varieties, adjusted planting dates, and water-conserving practices, to sustain maize production under changing climatic conditions.

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INTRODUCTION

Climate change will affect almost every region of the planet. However, low-income countries, such as Ethiopia, are particularly vulnerable because a large share of the population relies on agriculture. According to Seleiman et al. (2017) and Dustgeer et al. (2021), maize is a significant food crop that is essential to maintaining food security. The productivity of important staple food crops such as maize will be significantly affected by climate change (Jones & Thornton, 2003; Bassu et al., 2014). This is because crops primarily depend on sunlight, temperature, and water for growth and development (Chen et al., 2013). By creating coping and mitigating strategies, Ethiopia has not sufficiently addressed the effects of climate change. Global warming and altering rainfall patterns have progressively affected agricultural yields, ultimately leading to food insecurity for a growing global population (IPCC 2001). Unfortunately, massive greenhouse gas emissions continue to raise the average annual global temperature. According to the IPCC Fifth Assessment Report, average annual temperatures in much of Africa would rise by more than 2 °C by the middle of the twenty-first century. According to the research, the average temperature increase by the end of the twenty-first century might be 2°C under low-emission scenarios. On the other hand, in areas with strong emissions, it might reach 6°C. Over 60% of the workforce and more than 30% of GDP are employed in agriculture, which remains the primary source of income for rural Africans (Nhemachena, 2007).

Statement of the Problem

Ethiopian agriculture is expected to be the sector most impacted by climate variability because of its strong reliance on climatic elements, including temperature, humidity, and precipitation. Despite this possibility, 97% of the agricultural land in sub-Saharan Africa is rainfed, leaving it susceptible to the negative consequences of climate change and volatility (Rockstrom, 2014). The selected district, a major Ethiopian region that produces maize, is the research area. However, the previously conducted research did not focus much on how local farmers' operations are affected by environmental change. Locals' daily observations in the research area, such as rising temperatures and erratic rainfall patterns, indicate distinct climatic conditions. Higher maximum temperatures, more dry days during the rainy season, and a later start to the rainy season are all signs of climate variability in the area. Less rainfall occurs during warmer seasons, and droughts and other extreme weather events become more frequent and severe. Research by Shahidur et al. (2010) found that maize is Ethiopia's most significant crop in terms of both output and the number of farmers that cultivate it. However, smallholder farmers who make up about 80% of Ethiopia's population are the country's main producers and consumers of maize (Dawit et al., 2008). However, it has been shown that climatic variability causes anomalies at the beginning and end, which impact farmers' cropping cycles in the studied areas. It is necessary to examine how variability in climatic parameters affects maize production and to offer recommendations for increasing maize production in the research region. Hence, the objective of the research is to evaluate the impact of temperature and precipitation on maize yields. By highlighting the necessity of climate-resilient farming methods and climate-informed policymaking to maintain food security, this greatly enhances the few studies on the subject.

Research Questions

1. Has climatic variability changed?
2. What are the impacts of climate variability on the maize yield?
3. What is the relationship between the study area's maize production and climatic factors?

MATERIALS AND METHODS

Description of the study area

Ambo, Bako, Haramaya, and Melkassa, depicted in Figure 1 and representing the Ambo (highland), Bako (midland), Melkassa (lowland), and Haramaya (semi-arid) regions, were the four locations in central and eastern Ethiopia that covered portions of Oromia where the study was conducted.

Data Sources

The Ethiopian National Meteorological Institute (NMI) supplied the temperature and rainfall data based on meteorological satellite readings and weather station records. Future climate data sets for the years 2040–2069 and 2070–2099 were created using the identical RCM-GCM combinations that were retrieved from MarkSimGCM, a weather-generating program created by CCAFS. Information from 17 climate models used in the IPCC's Fifth Assessment Report is incorporated into these estimates. The RCPs 4.5 and 8.5 were used for the future scenarios of the research regions.

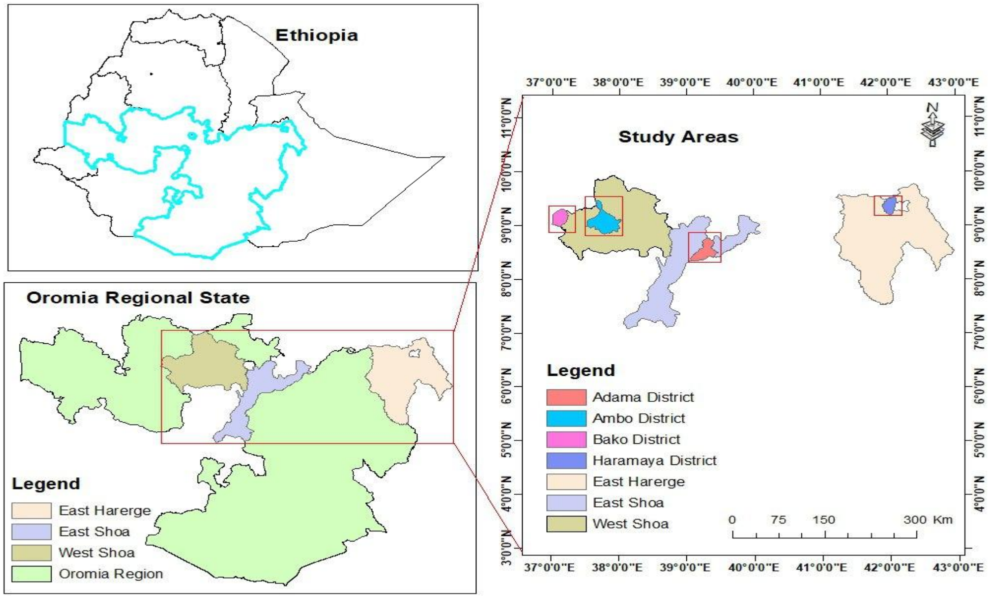

Figure 1. *Map of the study*

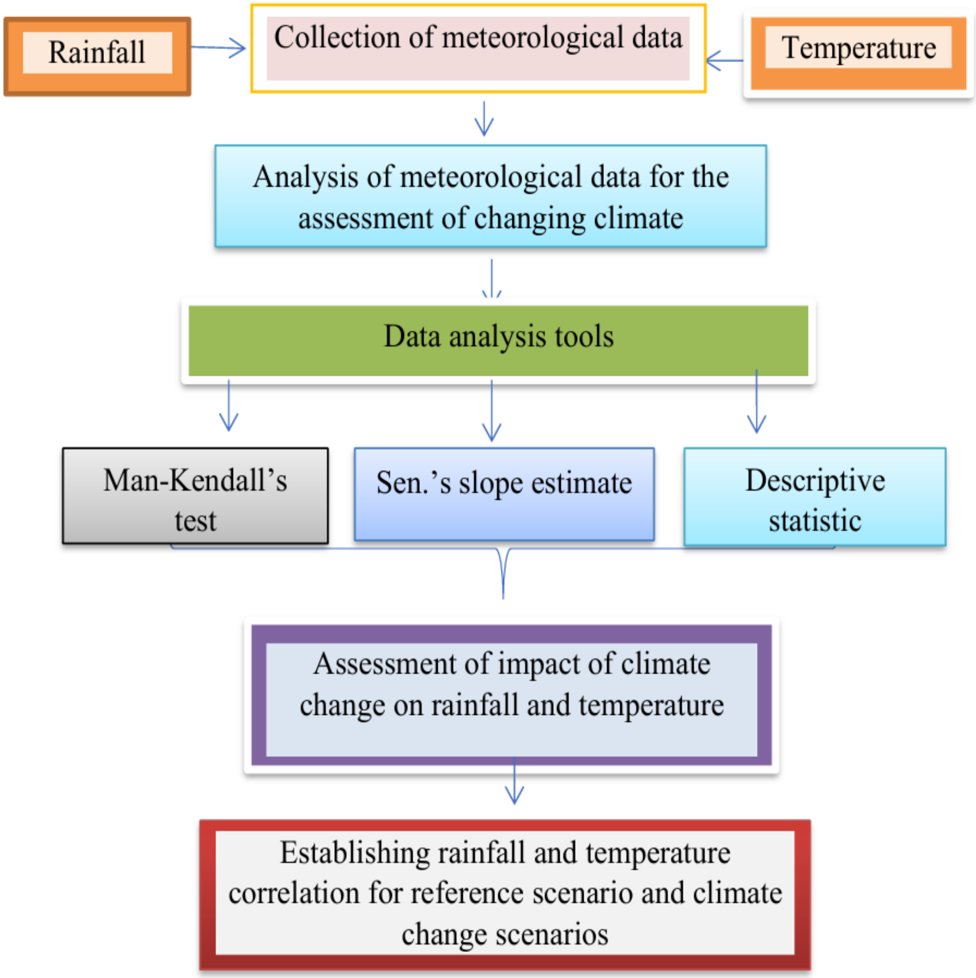

Figure 2. *Flow chart of the study*

Processing and Analyzing Data

The data was evaluated by calculating the mean, yearly minimum, and maximum temperatures. We also calculated the seasonal rainfall means, maximums, and minimums. The provided grain yields were utilized. Further data checks were carried out to identify the duration of the data period that included weather and agricultural yields. The study employed 30 years of trustworthy data on weather and agricultural yield, except for missing data on both variables (Figure 2).

Analysis of trends and variations in temperature and rainfall

Microsoft Excel and time-series plots were used to assess rainfall and seasonal temperature variations (minimum and maximum). This was done in order to look at how the seasonal distributions of precipitation and temperature changed over the research period. The amplitude and statistical significance of the trend are examined in time series trend analysis. The range of explanatory variables was evaluated using the average, standard deviation, and coefficient of variation. This formula has been used in scientific calculations.

$$CV = \frac{\sigma}{\mu} x100\%$$

where σ is the standard deviation, μ is the mean rainfall, and CV is the coefficient of variation. The CV is used to categorize rainfall event variability into three groups: low ($CV < 20\%$), moderate ($20\% < CV < 30\%$), and high ($CV > 30\%$). Oliver (1980) created the precipitation concentration index to characterize the rainfall distribution on a monthly basis.

Analysis of Future Climate Change

Average monthly rainfall and maximum and minimum ambient temperature data for the baseline period 1981–2010 were used to compare observational and historical data. Absolute variations in yearly average temperature and precipitation were also used to depict future climate changes relative to the base period.

Variation in the Association Between Climate Change and Maize Yield

Initially, the kind and intensity of the association between maize and climatic indicators were evaluated using correlation in SPSS to determine whether there was a relationship between crop yields and seasonal temperature and rainfall, i.e., whether an increase in one would cause a drop in the other. It must be stated whether the changes in the independent variable and the corresponding changes in the dependent variable exhibit a substantial correlation. The extent to which seasonal precipitation and temperature (maximum and minimum) may be linked to variations in maize production was then assessed using multiple regression analysis. The R^2 determination coefficient was used to calculate the percentage change in maize yield caused by seasonal temperature and rainfall. This method, which offers the most linear and objective estimation of all estimators, has been used by a number of writers to study how climatic variability affects agricultural productivity (Chabala et al., 2014; Adamgbe & Ujoh, 2010). The general regression equation was:

$$Y = a + b1X1 + b2 + X2 \ldots bnXn + \epsilon$$

where b1 is the regression coefficient, a is the constant value, and X1, X2, X3, and Y are the result variables (in this case, maize yield). The explanatory variables (e) are X1 and Xn, while the error term is denoted by the symbol ϵ. The descriptive variables are seasonal precipitation, mean annual high temperature, and mean annual low temperature.

RESULTS AND DISCUSSION

Results

Annual and seasonal rainfall and variability

Ambo station receives 1490 mm of mean annual rainfall, while Haramaya receives 726 mm. Haramaya and Melkasa had an average yearly rainfall of less than 1000 mm during the survey. All places received the most rainfall on average each year in Kiremt.

Table 1

Annual and Seasonal Rainfall during the period 1981-2020

Station	Parameters	Max (%)	Min (%)	Mean (%)	Contribution to Annual (%)	CV (%)
Ambo (Highland)	Annual	2063.5	755.2	1490.5	-	15.2
	Belg (FMAM)	433.3	92.1	230.2	23.2%	35.2
	Kiremt (JJAS)	992.7	507.2	693.4	70.0%	16.2
Bako (Midland)	Annual	1786.3	685.5	1143.3	-	20.4
	Belg (FMAM)	577.8	53.5	245.6	21.5%	43.8
	Kiremt (JJAS)	1345.5	560.9	803.4	70.3%	23.7
Haramaya (dry highland)	Annual	1554.1	344.0	726.0	-	17.5
	Belg (FMAM)	1205.4	113.9	279.2	38.6%	68.5
	Kiremt (JJAS)	687.4	148.0	365.6	50.5%	35.5
Melkassa (Lowland)	Annual	1024.9	430.2	752.6	-	31.5
	Belg (FMAM)	354.1	27.2	170.9	22.7%	45.9
	Kiremt (JJAS)	769.7	266.3	522.3	69.4%	23.1

FMAM (February, March, April, and May) JJAS (June, July, August, and September); Min. = minimum; Max. = maximum; CV = coefficient of variation.

The seasonal Kiremt rain (June–September) accounts for a large portion of the annual rainfall total, though Belg rainfall (March–May) also plays a great role (Table 1). The area's annual precipitation variation rate (CV) ranges from 15.2 in Ambo to 31.5 in Melkasa.

Annual Minimum and Maximum Temperature Variability

Table 2 shows that Melkasa Station had the highest average annual temperature among other stations (30.50 °C). A relatively low annual temperature was recorded at the Ambo station (24.7 °C). On the other hand, the Ambo and Melkasa districts in the area recorded low annual minimum temperatures of 10.4 and 14.5 °C, respectively. With a coefficient of difference fluctuating from 2.5 in Ambo to 5.1 in Bako, the annual average temperature in this region shows a low degree of variation. The coefficient of variation for the annual minimum temperature, which ranged from 6.7 to 14.6, also showed a small variation. Except for Bako, all other stations have a higher CV for the annual low temperature than for the annual high temperature. This indicates low interannual variation in the region's maximum and minimum temperatures.

Rainfall and maize yield variability

Figure 3 illustrates the relationship between annual rainfall and maize yield from 2003 to 2022. Overall, the two variables exhibit a similar pattern over time, suggesting that annual rainfall has a strong influence on maize yield. Years with higher rainfall generally correspond to higher maize yields, while years with lower rainfall are associated with reduced maize production. Between 2003 and 2006, both rainfall and maize yield declined gradually, reaching one of the lowest levels in 2006. This indicates that insufficient rainfall may have limited soil moisture availability, leading to reduced crop growth and lower yields. A noticeable recovery occurred from 2007 to 2011, during which rainfall increased, and maize yield also improved. This positive trend suggests that favorable rainfall conditions enhanced crop establishment, vegetative growth, and grain filling. In 2012, both rainfall and maize yield experienced a sharp decline. The highest maize yields were recorded in 2016 and 2018, coinciding with years of relatively high annual rainfall. These results indicate that adequate rainfall during the growing season provided favorable conditions for maize development. However, the Figure 3 also shows that increased rainfall does not always produce proportionally higher yields. For example, 2017 received substantial rainfall, yet maize yield was slightly lower than in 2016. Likewise, in 2019, rainfall remained relatively high, but maize yield declined. These observations suggest that factors other than total annual rainfall, such as rainfall distribution during the growing season, temperature variability, soil fertility, fertilizer use, improved seed varieties, pest and disease pressure, and agronomic management, also influence maize productivity.

Table 2

Descriptive statistics and trend analysis of the maximum and minimum temperature period 1981-2010

Station	Season	Maximum temperature				Minimum temperature			
		Max (%)	Min (%)	Mean (%)	CV%	Max (%)	Min (%)	Mean (%)	CV %
Ambo	Annual	27.3	24.4	24.7	2.5	13.0	9.9	10.4	7.6
	Belg (FMAM)	29.4	25.7	27.3	3.2	15.7	10.6	12.1	9.0
	Kiremt (JJAS)	26.2	22.4	24.0	3.7	13.6	10.5	12.1	7.7
Bako	Annual	31.6	25.1	28.4	5.1	15.6	10.7	13.4	6.7
	Belg (FMAM)	34.8	25.0	31.7	7.1	16.2	11.6	14.0	8.2
	Kiremt (JJAS)	29.6	23.4	26.5	5.0	16.0	12.0	14.2	6.9
Haramaya	Annual	27.0	24.1	25.2	2.7	14.4	9.7	12.0	14.6
	Belg (FMAM)	28.0	24.3	26.0	3.5	15.7	10.3	12.5	7.8
	Kiremt (JJAS)	27.8	23.4	24.8	3.6	14.9	11.8	12.9	4.6
Melkasa	Annual	31.7	27.9	30.5	2.9	15.8	11.6	14.0	7.8
	Belg (FMAM)	32.6	29.0	30.6	3.2	17.0	10.7	14.9	8.2
	Kiremt (JJAS)	32.1	26.9	28.3	4.8	17.1	10.3	15.6	8.4

FMAM (February, March, April, and May), JJAS (June, July, August, and September); Min. = minimum; Max. = maximum; CV = coefficient of variation.

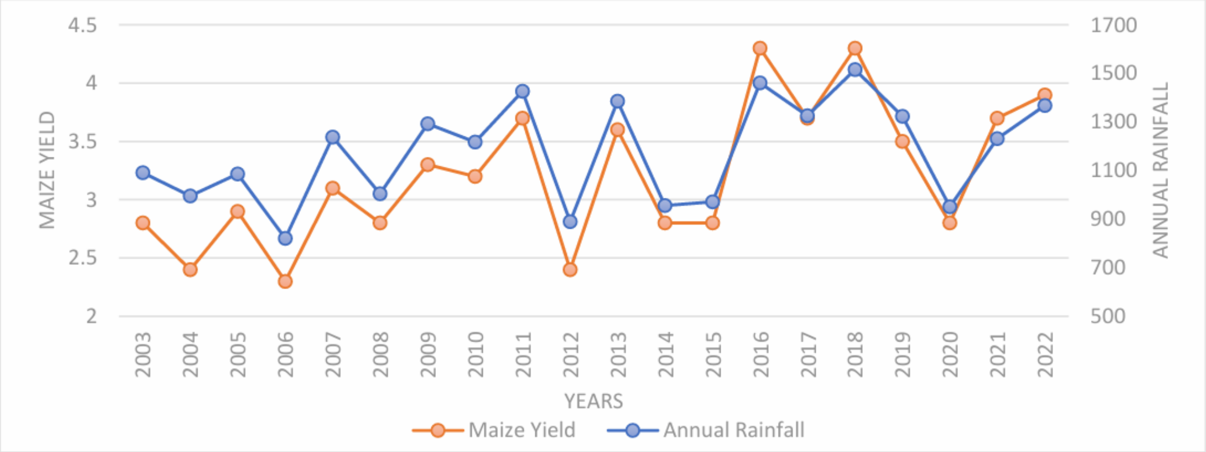

Figure 3. *Annual rainfall and maize yield production*

Onset, cessation, and Length of Growing Season (LGS)

A study of long-term rainfall data shows that Ambo and Haramaya stations have quite distinct rainy season starts, with a CV value of 30.5%. Whereas the least variable stations were Bako and Melkassa stations, as shown in Table 3. There are noticeable variations in the variation coefficients at all sites. Melkassa records the last start date in July of the preceding year, while Ambo records the first start date on May 18th, based on the average start date. The Days of the Year (DOY) for Ambo, Bako, Melkassa, and Haramaya are 120, 162, 174, and 123 on these dates.

Table 3

Descriptive statistics and trends of weather events

Rainfall Features	Min	Max	Mean	25%	50%	75%	SD	CV
			Ambo					
SOS (DOY)	92	180	120.85	105	131.5	155	36.89	30.5%
EOS (DOY)	273	309	274.83	273	275	274	6.702	2.4%
LGP (days)	93	231	144.98	122.75	141.5	168.75	27.571	19.0%
			Bako					
SOS (DOY)	95	194	162.95	119	128	149	20.657	12.6%
EOS (DOY)	266	339	282.15	266	266	297.75	23.234	8.2%
LGP (days)	96	214	149.2	122.75	146	171	32.162	21.6%
			Melkassa					
SOS (DOY)	99	221	174.25	165.5	183	191.75	22.02	12.6%
EOS (DOY)	266	306	267.75	266	266	266	7.8078	2.9%
LGP (days)	65	201	93.5	74.25	83	110	31.994	34.2%
			Haramaya					
SOS (DOY)	92	226	123.03	97	106.5	136.5	37.504	30.5%
EOS (DOY)	267	318	269.77	267	267	267	9.3136	3.5%
LGP (days)	79	227	146.75	135.25	162	171	36.257	24.7%

SOS-start of season, EOS-end of season, and LGP-length of growing period

Rainfall Anomaly Index (RAI)

In Ethiopia's agro-ecological zones, Figure 4 presents the rainfall anomaly index (RAI) for seasonal and annual periods. In all agro-ecological settings, negative rainfall anomalies were frequently seen during the Belg/FMAM season; in recent years, these anomalies have become more frequent, especially in mountainous regions. Furthermore, in certain years, all four locations experienced below-normal rainfall during the busiest time of year. At each location, the Kiremt/JJAS season was marked by annual variations in rainfall anomalies, with the highland regions experiencing below-average Kiremt/JJAS rainfall in subsequent years.

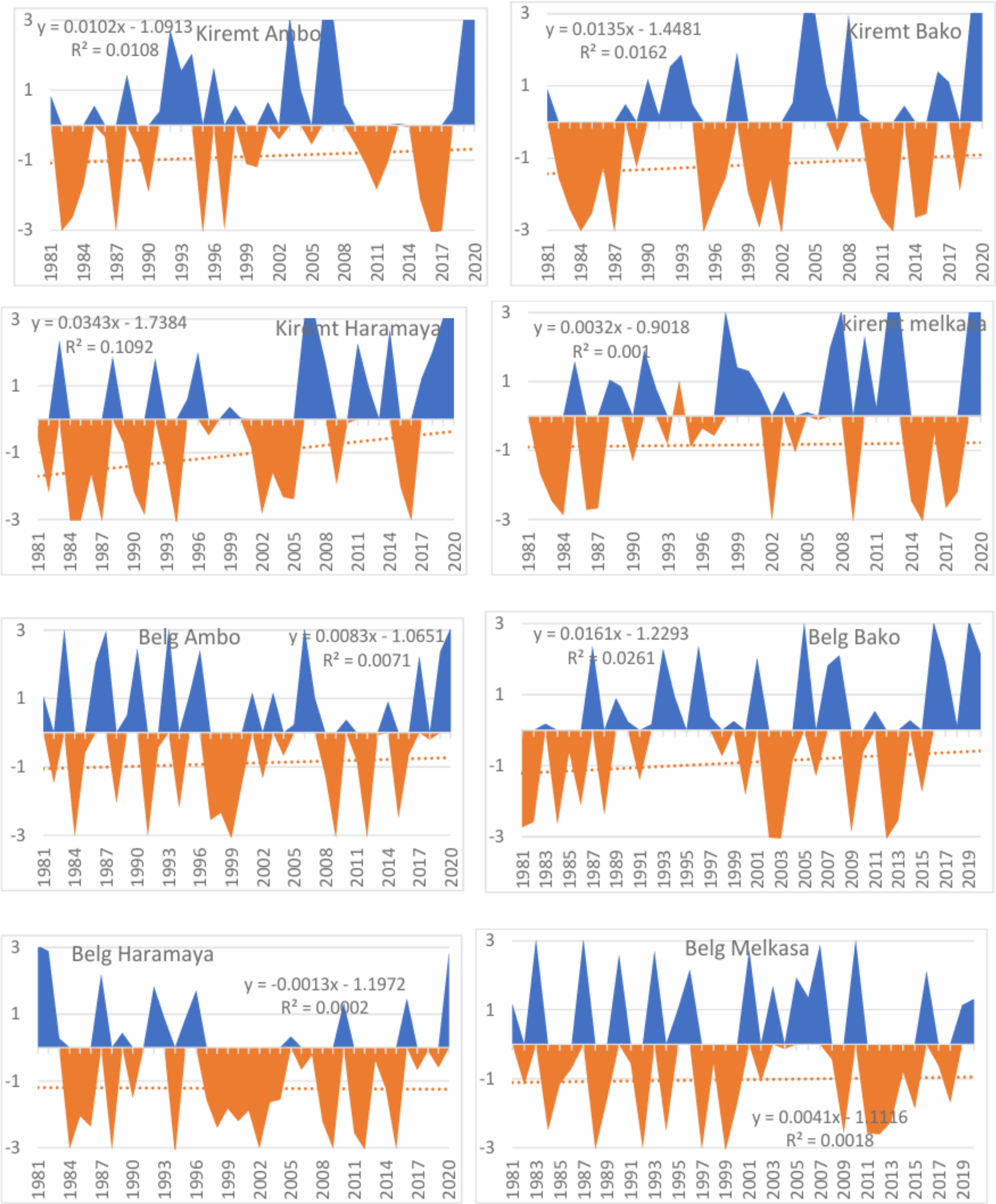

Figure 4. *Annual and seasonal rainfall anomaly index of the study area*

Average Monthly Future Rainfall Distribution

Projected changes in monthly precipitation are evaluated by calculating a percentage of precipitation from the base period. Additionally, projections were made for the Far Future (2070–2099) and Middle Future (2040–2069). Precipitation fluctuations are predicted and shown in Figure 5. In all time periods, March, April, and May (summer) exhibit a pattern of decreasing predicted changes. August usually has the fastest rate of rainfall rise across all RCP scenarios. Precipitation changes under RCP4.5 tend to be less than those under RCP8.5.

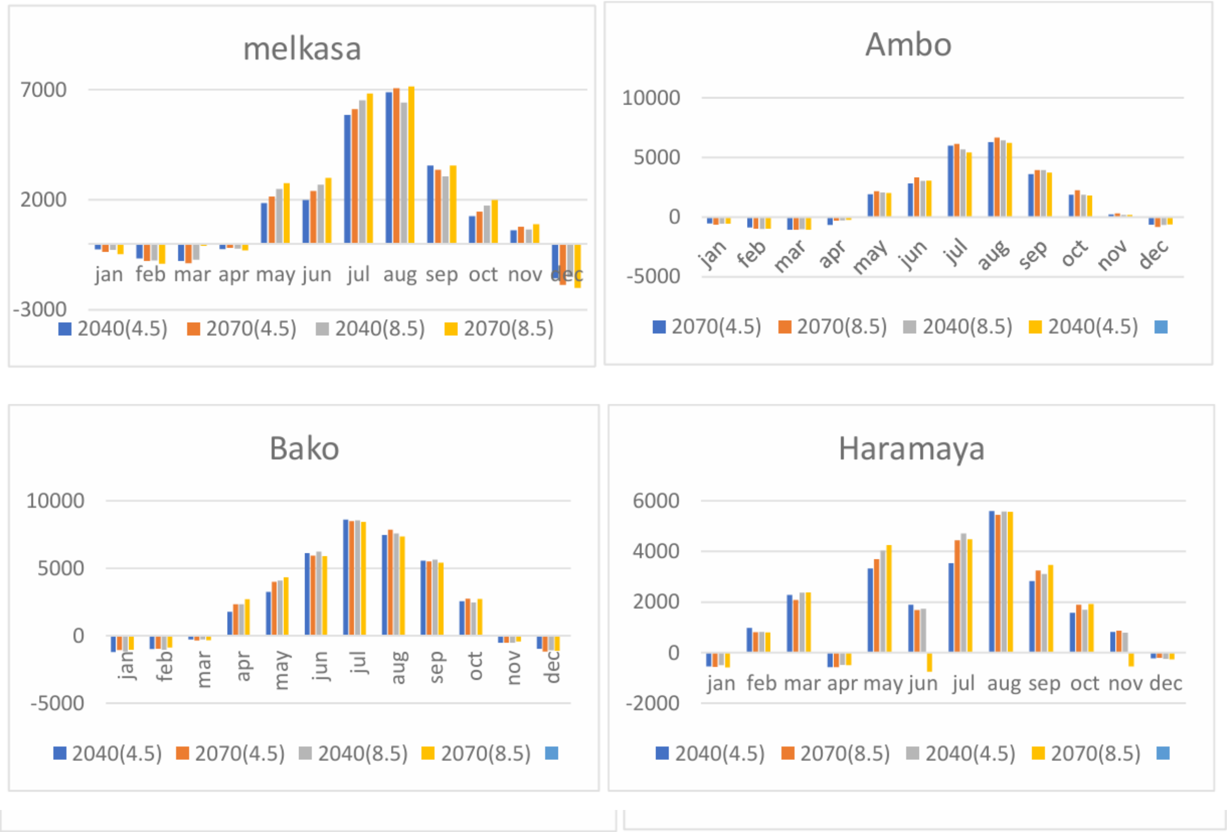

Figure 5. *Average Monthly rainfall distribution over the study areas*

Monthly Average Variations in Maximum and Minimum Temperatures

Figure 6 shows the average monthly temperature increases under two RCP scenarios for the future period (2040-2099) compared to the baseline period (1981-2010). The average temperature is expected to slightly decrease in June and July, while the maximum temperature is expected to rise in January and February. May is the warmest month here, with highs of 2˚C. The average monthly minimum temperature is predicted to increase by 0.45–1.5˚C, 0.7–1.5˚C, and 0.9–1.6˚C under all climate scenarios. All RCP scenarios show increases in average monthly maximum and minimum temperatures in the mid-future, with the exception of RCP4.5, which shows a gain in maximum temperature. Under RCP8.5 and RCP4.5, the average maximum temperature will rise by around 3 °C and 2.5 °C, respectively. Furthermore, in RCP8.5 and RCP4.5, respectively, the average lowest temperature would increase to around 3˚C and 2˚C. The average monthly maximum and minimum temperatures in the long future are shown in Figure 6. RCP8.5 is expected to raise these temperatures by around 3°C to 4°C, whereas RCP4.5 is expected to raise them by about 1.5°C to 2.5°C. All of these figures, with the exception of January and February, indicate that the maximum and minimum temperatures will increase.

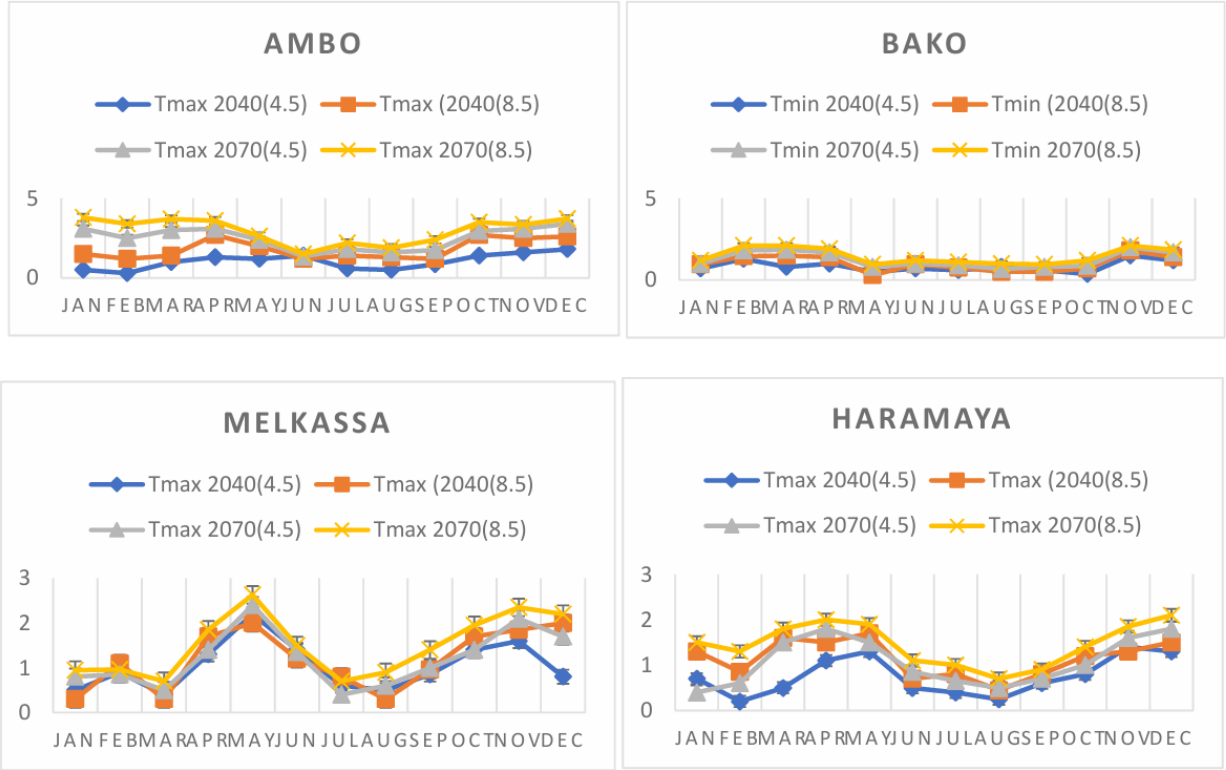

Figure 6. *Average monthly maximum and minimum temperature variations for the future climate*

Rainfall outlook during the Maize growing season

In all climate models under both RCPs, the greatest rainfall for maize occurs in July during the growing season; at all research sites, it peaks in August during the baseline period. This suggests that mean monthly rainfall during the midcentury will show temporal changes relative to the baseline era under high- and medium-concentration scenarios. All research sites, except Melkasa, are expected to see a decrease in mean monthly rainfall in September and October relative to the baseline period. Everywhere but Haramaya will see a drop in the average monthly rainfall in June (Figure 7). Additionally, under both RCPs, all study locations and climate models predict that by the middle of the century, the mean monthly rainfall in July will have increased considerably. The average monthly rainfall in September and October will, however, be lower than it was during the baseline period over the whole study region, according to all models under both scenarios. The research region's maize output may decrease when sufficient rainfall is needed since these two months are critical for blooming and grain filling. This result is in accordance with the prediction made by Cairns et al. (2013) that rainfall throughout the growth season (May–October) will decrease in the 2050s, especially during the critical reproductive period in Ethiopia's highlands.

One of the main conclusions from studies conducted over several years on maize in Ethiopia's agricultural trials is that the sowing date often has the greatest impact on output. The first two weeks of May, or as soon as possible at the start of the heavy rains, are the best times to sow. Furthermore, the growing time is four to five months, depending on the kind sown. With respect to water shortages during the ripening and vegetative stages, maize appears relatively tolerant. A lack of water during the blooming season is the primary factor limiting grain yield. Reduced yield can also result from a decrease in grain size due to insufficient water during grain production. Water scarcity during the ripening phase, however, has minimal impact on grain production.

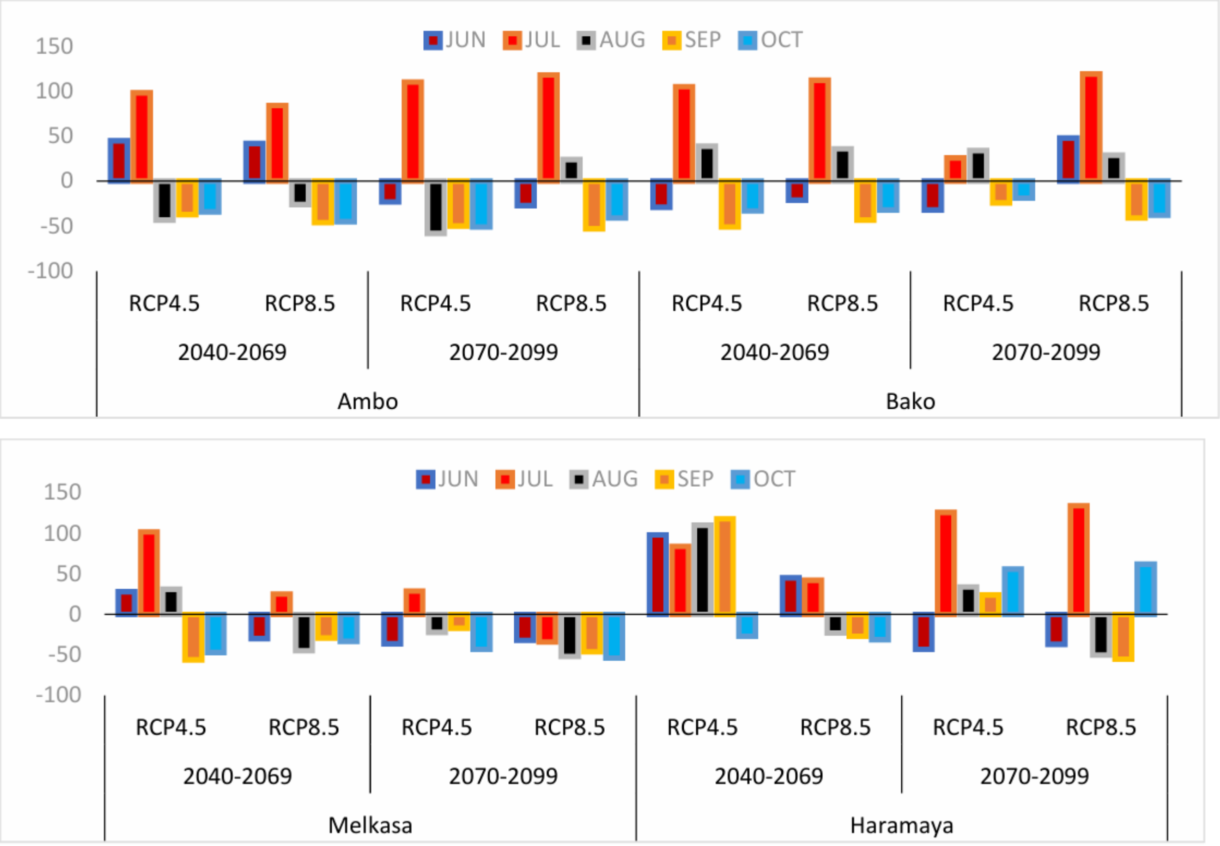

Figure 7. *Mean monthly rainfall distribution changed over the maize-growing months in comparison to the baseline period.*

Temperature outlook during the Maize growing season

In every scenario, the study area's mean monthly temperature will rise during the maize-growing season (Figure 8). June will have the highest temperature during the months when maize is grown at all study locations by the middle of the century. In July and August, the average temperature will increase by 0.13 and 0.11 °C at Ambo, 0.1 and 0.12 °C at Bako, 0.05 and 0.12 °C at Melkasa, and 0.1 and 0.15 °C at Haramaya. Additionally, by the 2050s, the mean average temperature for September and October, when maize is grown, at Bako, Haramaya, Ambo, and Melkasa, increased by 0.14 °C, 0.16 °C, 0.15 °C, and 0.11 °C, respectively. The rates of photosynthesis and evapotranspiration may be impacted by this increase in average temperature, which could have an impact on the productivity of maize in the study area. increasing temperature, particularly maximum temperature during critical growth stages, further reduces productivity by intensifying water stress and shortening the grain-filling period. High temperatures (particularly above 30°C during flowering) can cause pollen sterility, poor kernel formation, and reduced yields. Rising temperatures also increase evapotranspiration, making drought stress more severe.

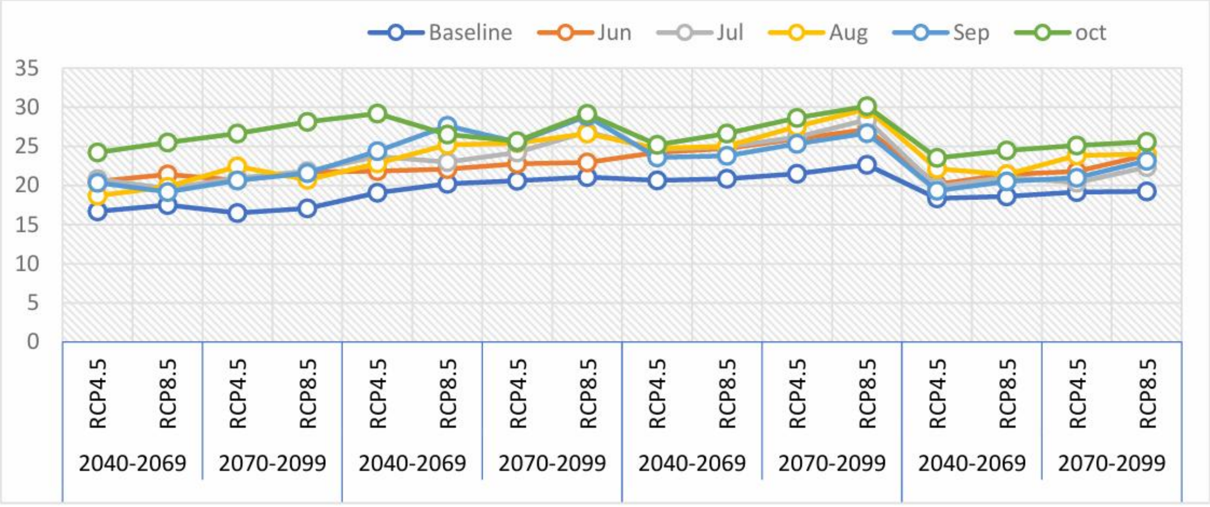

Figure 8. *Baseline and Projected mean average temperature of maize growing months for Ambo, Bako, Melkasa, and Haramaya.*

Potential implications of temperature and rainfall variability on maize yield

Temperature and rainfall variability are among the most important climatic factors influencing maize yield because maize is highly sensitive to weather conditions, particularly during germination, flowering, and grain-filling stages. Variability in these climatic parameters can have significant agronomic, economic, and food security implications. Temperatures above the optimum range (approximately 18–30°C for maize) accelerate crop development, shortening the growing period and reducing biomass accumulation. Temperature and rainfall variability significantly influence maize yield by affecting crop growth, reproductive development, soil moisture availability, and nutrient uptake. Their combined effects lead to reduced maize productivity, greater yield variability, and increased food insecurity, particularly in rain-fed farming systems such as those in Ethiopia. According to Mekonnen and Berlie (2020), the irregular and unpredictable rainfall patterns that take place throughout these seasons discourage farming methods in Ethiopia's highlands and lower output. Farmers' incentive to plant, cultivate, and harvest various crops was impacted by the delayed and early end of rainfall patterns in February and September. The research by Bewket (2009) and Alemayehu and Bewket (2016) emphasizes the significant impacts of climate change and variations on food security and agricultural productivity in the Amhara region and the north-central highlands. Pachauri et al. (2014) state that high temperatures can have a major effect on agricultural productivity.

The correlation between climatic factors and maize yield

Table 4 presents the correlation coefficients between meteorological factors and maize yield for each selected district. The climatic factors and maize yield generally showed a strong to moderate association. In Ambo, for instance, seasonal rainfall, average temperature, and minimum temperature all had strong, significant positive connections (correlation values of 0.784, 0.124, and 0.613, respectively). The correlation was modest, non-significant, and negative at the highest temperature (-0.238). This indicates that maize yields (-0.238 kg/ha) were more sensitive to temperature, indicating that higher temperatures probably result in lower maize yields. Rainfall, on the other hand, increased maize output to 0.784 kg/ha. Seasonal rainfall and maize output in Bako showed a strong and significant positive association (r = 0.469), suggesting that regions with higher rainfall are likely to produce more maize.

Table 4

Climate factors and maize yield correlations

Ambo	Maize	Rainfall	Tmin	Tmax
Maize	1	0.784*	0.613	-0.238
Rainfall		1	124	-0.706*
Tmin			1	0.264
Tmax				1
Bako	Maize	Rainfall	Tmin	Tmax
Maize	1	0.469	-0.045	-0.122
Rainfall		1	0.164	-0.034
Tmin			1	0.043
Tmax				1
Melkassa	Maize	Rainfall	Tmin	Tmax
Maize	1	0.769*	0.421	-0.542
Rainfall		1	0.040	-0.317
Tmin			1	0.769**
Tmax				1
Haramaya	Maize	Rainfall	Tmin	Tmax
Maize	1	0.572	-0.143	0.322
Rainfall		1	0.186	-0.122
Tmin			1	-0.966**
Tmax				1

A substantial negative correlation exists between the yearly average lowest temperature (-0.045) and maximum temperature (-0.122) and the amount of maize produced per acre. This is comparable to the findings of Maital et al. (2019), indicating that increases in the annual average minimum and maximum temperatures will negatively impact the amount of maize produced per acre. Melkassa, however, discovered that minimum temperature, rainfall, and maize production had a small, significant, and non-significant positive connection (0.769 and 0.421, respectively). However, there was a somewhat negative correlation (-0.542) between maximum temperature and maize production. There was a small but not statistically significant positive correlation of 0.572 between seasonal rainfall and maize production in Haramaya.

Maize yield under climate conditions as determined using multiple linear regression.

According to the Ambo station's coefficient regression study, a one-unit change in rainfall has a positive effect on maize yield of 0.589 qt/h. In other words, increased rainfall will result in larger yields throughout the specified years. The yields in the research region increase with rainfall. At the significance level, it is statistically significant. Maximum temperature, the study's other independent variable, had an adverse impact on maize yields. These findings run counter to research on the individual and combined effects of temperature and precipitation change on maize yields in sub-Saharan Africa carried out in the middle to late 21st century by Waha et al. (2013). This study shows that maize yield improves by at least 6% in an environment that supports rising temperatures.

Table 5

Coefficients of regression analyses for rainfall, maximum, and minimum temperature at Ambo.

Item	Regression coefficients	Standard Error	t-value	Sig.
Constant	9.542	3.457	0.239	0.074
Rainfall	0.589	0.265	0.154	0.030
Min. Temp	0.731	1.564	0.064	0.006
Max. Temp	-2.385	0.168	0.082	0.041
Regression model summary for maize yield				
	R	R Square	Adjusted R-Square	Std error
	0.874	0.765	-0.161	26581.780

According to Table 5, the calculated correlation of multiple determinations (R2) is 0.765. Accordingly, Ambo accounts for 76.5% of the variability in maize output per hectare. In other words, rainfall, maximum, and minimum average temperatures account for 76.5% of the yield variance, whereas non-climatic variables (soil, management, input factors, and other approaches) account for 23.5% of the yield variance.

Table 6

Coefficients of regression analyses for rainfall, maximum, and minimum temperature at Bako.

Item	Regression coefficients	Standard Error	t-value	Sig.
Constant	12.833	1.464	1.936	0.077
Rainfall	0.084	0.054	-1.560	0.045
Min. Temp	-0.153	0.014	-0.056	0.001
Max. Temp	-0.462	1.201	-2.130	0.507
		Regression model summary for maize yield		
	R	R Square	Adjusted R-Square	Std error
	0.737	0.544	-0.064	23452.838

Table 6 explains the quantification of explanatory effects on maize, demonstrating that rainfall was a significant variable that positively affected yields. Rainfall in this area will affect maize production by 0.084 qt/ha. It explains why higher rainfall results in higher harvests. However, maize yields were negatively impacted by both maximum and minimum temperatures, which will have an impact of 0.153 qt/ha and 0.462 qt/h, respectively. According to Table 6, the calculated coefficient regression determination value was 0.544, or 54.4%. Conclusion: Other non-climatic causes accounted for 45.6% of the remaining variances. The adjusted R indicated that 25.5% of the variance in maize yield could be described, which was not significant. However, it demonstrated that the yield of maize in Bako rises with the minimum temperature.

Table 7

Coefficients of regression analyses for rainfall, maximum, and minimum temperature at Melkasa

Item	Regression coefficients	Standard Error	t-value	Sig.
Constant	42.833	1.464	1.936	0.107
Rainfall	-0.846	0.054	-1.560	0.045
Min. Temp	0.832	0.086	0.943	0.035
Max. Temp	-1.288	0.045	-3.722	0.001
Regression model summary for maize yield				
	R	R Square	Adjusted R-Square	Std error
	0.918	0.843	-0.051	5728.412

Predicting the amount of maize produced per hectare of land requires estimates of each climate element. The results showed that the greatest temperature was -1.288 and the lowest temperature was 0.832. Therefore, a unit rise in the minimum temperature causes a 0.830-ton increase in maize yield when all other parameters remain the same, while a unit rise in the maximum temperature causes a -1.288-ton decrease in maize production per hectare of land. The rainfall forecast was -0.0846. The data also demonstrated that a comparable decline in maize production was anticipated when seasonal rainfall and maximum temperature rose. This may be because, after temperature was considered, rainfall had less of an effect on Melkassa's grain production (Table 7). It has been demonstrated that in Melkassa, maize production decreases when rainfall and Tmax rise. Furthermore, the yield of maize increases as Tmin does. According to the regression coefficients, seasonal rainfall, maximum temperature, and lowest temperature had the most effects on maize output.

Table 8

Coefficients of regression analyses for rainfall, maximum, and minimum temperature at Haramaya

Item	Regression coefficients	Standard Error	t-value	Sig.
Constant	21.833	3.786	0.294	0.007
Rainfall	0.385	0.054	0.531	0.045
Min. Temp	0.051	1.967	-3.214	0.033
Max. Temp	-0.524	1.831	-3.040	0.092
Regression model summary for maize yield				
	R	R Square	Adjusted R-Square	Std error
	0.832	0.692	0.255	21293.240

Table 8 shows how temperature and seasonal rainfall influenced variations in maize production. According to the model, seasonal rainfall and maximum and minimum temperatures accounted for just 25.5% of the variation in maize output. This might be explained by the farm's ability to anticipate climate change and by implementing extra agronomic practices that alleviate its impact on crop output.

Discussion

The result implies that there is little to moderate interannual variability in the rainfall pattern in the region under study. Belg seasonal rainfall has a much higher coefficient of variation across all stations than Kiremt rainfall, suggesting more rainfall variability. This outcome is in line with Ayalew et al. (2012) investigation, who stated that our results align with previous national research (Bewket & Conway, 2007); Girma et al (2005), who reported between 1960 and 2006, the average yearly temperature increased by 1.3 ^{0}C or 0.28 ^{0}C. Ethiopia experiences its fastest temperature rises (0.32 ^{0}C) in June, August, and September. However, a thorough examination of the comparative data revealed a far stronger correlation between rainfall variability and maize. This interpretation holds that variations in rainfall significantly affected the production of maize. Mekonnen and Berlie (2020) observed that irregular and unpredictable rainfall patterns across these seasons discourage farming and reduce yields in Ethiopia's highlands. When temperatures are higher than usual, crop yields are predicted to decrease; for instance, high temperatures cause grain fill to decrease. (Hatfield et al., 2011).

Although there was a positive correlation between rainfall and maize yield, there was an inverse relationship between rainfall and maize production, meaning that an increase in rainfall did not result in an increase in maize output. This could have been due to other agronomic factors, such as an increase in cultivable land, a potential decrease in pests and diseases, or even a decrease in post-harvest losses. In this case, rainfall might not be enough to guarantee the best possible maize production. This suggests that, in comparison to the other three locations in Ethiopia's center, the Melkassa area has a delay in the start of the growing season. Conversely, the season concluded in Melkassa at the beginning of September 29 and in Bako at the end of November 10. Melkassa's CV value was 2.9% across the research period, while Ambo's termination date variability was 2.4%, with the end date having the lowest variability. Overall, consistent with earlier research conducted in Ethiopia, the start of the rainy season in the study region differs significantly from its conclusion (Diga, 2005). The average growth season length (LGS) at the study site was 93 to 149 days, with Melkassa having the highest variability (CV=34.2%) and Ambo having the lowest variability (CV=19%) during the study period. The research found that both the Midlands and the Highlands saw below-average Kiremt/JJAS rainfall. El Niño and La Niña episodes were shown to be responsible for most rainfall anomalies in an Ethiopian highland agricultural area between 1981 and 2016 (Ademe et al., 2020). Seasonal rainfall patterns, which are marked by irregular and variable rainfall, have a substantial effect on crop and harvest in both the Beg rains/FMAM and the Kiremt/JJAS. The seasonal patterns of rainfall for kiremt/JJAS and the Belg/winter rains, which show irregular, random rainfall that impacts agricultural and livestock output, were accurately reflected by the precipitation anomaly index findings. The research by Bewket (2009) and Alemayehu and Bewket (2016) emphasizes the significant impacts of climate change and variations on agronomic output and food security in the north-central highlands of Ethiopia. Pachauri et al. (2014) argue that high temperatures can significantly affect agricultural productivity. A complete loss of crops due to climate change typically results in famine and the deaths of both humans and animals.

This is mostly due to changes in rainfall patterns and temperature regimes caused by elevated CO_2, which would probably make growing food crops more difficult in these areas. Consequently, this area will unavoidably require adaptation measures. Further studies have demonstrated that temperature fluctuations have a significant impact on a range of crops, including maize (Ogunniyan et al., 2023) and beans (Adeniyi et al., 2022). Dennis (2011) provided evidence that late-onset rainfall causes late plantings, which promotes disease and reduces production. It benefited from the lowest temperature. These findings are consistent with those of Obasi and Uwanekwu (2015), who discovered that greater temperatures and rainfall enhanced maize output. These results are consistent with those of Chabala et al. (2014), who found that a significant amount of the variation in maize yield is attributed to meteorological conditions.

CONCLUSIONS

Ethiopia's sustainable growth, especially with regard to agriculture, depends on an understanding of climate variability. Consistent spatiotemporal variations across sites are evident in a study of temperature and precipitation data, indicating major impacts of climate change. These results improve the province's efforts to monitor climatic variance and change. Temperature extremes and variations in seasonal and annual rainfall indicate that climate-sensitive productions, particularly agriculture and water resource development, are at risk from climate-related hazards. Climate risk management must be incorporated into plans for municipal economic growth. To maintain resilience and sustainability across all agro-ecological zones, which have experienced steady warming and increasingly concentrated rainfall, agricultural methods must account for rising temperatures and unpredictable rainfall. Climate risk management must be integrated into municipal economic planning; agricultural strategies must account for rising temperatures and declining, unpredictable rainfall. The productivity of maize and food security are seriously threatened by rising temperatures and unpredictable rainfall patterns. The results highlight the necessity of enhancing the resilience and sustainability of Ethiopian maize production through climate information decision-making, adjusting planting dates, drought-tolerant varieties, climate-smart agricultural practices, better maize technology, irrigation, and early warning responses are some of the strategies.

Recommendations

To help farmers adapt to climate change, governments must incorporate climate-smart agricultural methods like conservation agriculture and agroforestry, improve soil moisture conservation, and make agriculture resilient to drought. Farmers require advice on the drawbacks of rainfed and traditional agriculture, encouraging them to use more fertilizer, irrigation, water conservation methods, and soil conservation practices. Consistent harvests can also be ensured by using crop varieties that mature early and are resistant to disease and drought, which reduces the hazards related to climatic unpredictability and increases farmers' resilience to current and future climate-related issues.

CRediT Authorship Contribution Statement

Feyera Wakjira: Writing- Original Draft, Software, Formal Analysis, **Nigussie Dechassa:** Validation, Supervision, Conceptualization, **Yibekal Alemayehu:** Methodology, Investigation, Resources, **Feyera Merga**: Data Curation, Visualization, Project administration **Girma Megersa:** Project administration, Writing - Review & Editing

Declaration of Competing Interest

There are no conflicting interests that the authors have disclosed**.**

Ethical Approval

Not applicable

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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