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Research Article

Analysis of Climate Variability and Trends for Climate-Resilient Maize Farming System in Major Agroecology Zones of Ethiopia

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Maize is one of the most important cereal food crops, and it can be grown all year in various agroecological zones. However, its vegetative growth and yield are susceptible to rainfall and temperature variability. As a result, the analysis of rainfall and temperature variability and trend was urgently needed in maize-growing agroecology zones to restructure the production system. The aim of the study was to examine rainfall and temperature variability and trends for developing a climate-resilient maize farming system in major agroecology zones in northwest Ethiopia. The study was implemented in low productive agroecology zones (LPZ), medium productive agroecology zones (MPZ), and high productive agroecology zones (HPZ) of northwest Ethiopia using daily time series climate data during the period 1987–2018. The coefficient of variation (CV), precipitation concentration index (PCI), rainfall anomaly index (RAI), and standardized precipitation (SPI) were applied to examine rainfall variability. Mann–Kendall's and Sen's slope estimator trend tests were used to detecting the statistical significance of changes in rainfall and temperature. Statistically significant increasing trends for annual maximum and minimum temperatures were recorded for all maize-producing agroecology zones. The mean annual temperature has exhibited a significant warming trend of 0.12 to 0.54°C per decade. The average annual rainfall has decreased by 38 to 67 mm per decade in all maize agroecology zones. Our research also showed that droughts now happen every one to three years; even consecutive droughts were seen in 2009, 2010, and 2011. For this reason, it could be required to develop a system of climate-resilient maize farming to address the issues of both global warming and the sub-Saharan countries that make up our study area. Climate-resilient maize agronomic activities have been determined by analyzing the onset, length of the growth period (LGP), and cessation date. Accordingly, the lower and upper quartiles of the date of onset of rainfall were in a range of May 9 to June 2, respectively; the length of the growth period (LGP) during the rainy season ranges from 97 to 232 days, and the cessation date of rainfall was November 1. Therefore, the short- to long-maturing maize varieties can be planted from May 9 to June 2 and can begin to be harvested in the first week of November under the current climatic circumstances.

1. Introduction

Maize (Zea mays L.) is one of the world's most important cereal food crops, together with rice and wheat [1]. Moreover, it is widely recognized as the key crop for ensuring food security in many nations, particularly in SSA, East Africa, and all of Ethiopia. In Ethiopia, maize ranks second in area coverage next to Teff [*Eragrostis tef (Zuccagni) Trotter*] and first in terms of productivity among major cereal crops [2]. It can be grown in diverse agroecological zones in all the regions of Ethiopia since it has a high adaptive capacity to climate stress in tropical and subtropical environments [3]. Though maize is cultivated intensively in the low- to medium-altitude agroecological zone, it is now competing for land in the high-altitude agroecological zone with wheat and teff [Eragrostis tef (Zuccagni) Trotter] in Ethiopia due to what might be climate change [4].

The average maize productivity is 3 metric tons ha^{-1} which is low compared to the world average of 5.6 metric tons ha^{-1} [5]. This may be brought on by a number of factors, such as declining soil fertility, limited input use, poor seed quality, insect and disease infestations, ineffective agronomic management techniques, and climate variability. Climate variability, particularly substantial geographical, and temporal variations in rainfall and temperature, has been one of the major causes of maize's low productivity in Ethiopia. The recent studies [6–10] described in different areas would be strong evidence that the temperature and rainfall variability impact on maize production and productivity. Therefore, we choose rainfall and temperature as the major climate variables for this study since they have serious implications for maize vegetative growth and yield [11]. Indeed, some studies [12–17] and [18] have assessed climate trends and variability at different spatial and temporal scales. However, full comprehensive studies of climate variability, trend, onset date, cessation date, length of growing season have been limited at both the spatial and temporal scales levels in our study area. These attributes are extremely relevant for designing climate-resilient farming systems since they greatly influence the agronomic activities to be done in rain-fed agricultural systems [19]. Hence, this paper examined the spatial variability and trends of the temperature and rainfall by using the Enhancing National Climate Services (ENACTS) climate dataset between 1987 and 2018.

Resilience can be understood as the ability or capacity of the farming system to adjust, absorb, or adapt to stress and change following a perturbation [20]. Thus, a "resilient" maize farming system would be capable of providing maize production when challenged by severe temperature and variability in a specific maize production agroecological zone. The major climate-resilient agronomic practices that are covered in these studies are the selection of a maize variety and setting planting and harvest dates for the current climate condition. These practices involve the entire community, whose livelihood is strongly dependent on maize. Therefore, the spatial climate variability and trend analysis on an agroecology basis were an urgent need and highly relevant for restructuring maize farming systems in the maize-growing agroecology zones in our study area.

Agroecological zones indicate major physical conditions that are grouped into relatively homogenous areas having similar altitudes, climates, soil, and agricultural land uses. We choose agroecology as the most appropriate spatial frame for analysis. As such, it is a more meaningful unit than an administrative boundary or river basin when considering climate-resilient agronomic adaptation in rain-fed subsistence agriculture. Therefore, we followed the climate variability and trend analysis based on a specific crop-agroecological zonation approach, which is innovative in sub-Saharan Africa in general and Ethiopia in particular. Therefore, the aim of this study was to analyze rainfall and temperature variability and trends across the maize-productive agroecology zones in northwest Ethiopia.

2. Materials and Methods

2.1. Description of the Study Site. This study has been conducted in the maize production belt of Mecha areas in northwestern Ethiopia's agroecology zones (Figure 1). The geographic location of these areas extends from 11.30°N latitude to 37.20°E longitude. The altitude varies from 1000 to 3131 meters above sea level. The average annual rainfall is 1397.37 mm, and the average annual temperature is 24.17°C. Based on the traditional agroecological classifications of Ethiopia, the study area is categorized into three zones. Low-productive agroecology zones (highland), high-productive agroecology zones (midland), and medium-productive agroecology zones (lowland) [4] constitute 32%, 51%, and 17% of the total land of Mecha areas. A mixed subsistence farming system that involves crop production and animal husbandry is the main economic sector on which the majority of the population in the study area primarily depends [21].

2.2. Data Type and Source. The daily precipitation and the minimum and maximum temperature data for the study areas in the period from 1987 to 2018 were obtained from the Enhancing National Climate Services (ENACTS) dataset. ENACTS is the first high-resolution gridded (4 × 4 km) surface meteorological dataset developed specifically for studies of surface climate processes in Ethiopia [22]. ENACTS data sources for 30 locations in the northwest Ethiopia were obtained from the Ethiopian National Meteorological Agency. In recent years, ENACTS data have been used for climate analysis because of the following basic reasons: 1. conventional measurements of climate parameters did not represent all the study sites due to a limited number of stations [23]. 2. The distribution of the ground stations is quite irregular, and thus, the distance between stations could be quite big, sometimes more than 50 km. 3. Most stations did not provide long seasonal data records for trend analysis due to recently established [13, 22, 23]. 4. Station datasets have many missing values [13].

2.3. Data Analysis

2.3.1. Variability Analysis. The equations for the following climate variability indicators were computed using R-software and Excel for the investigation of variability.

The coefficient of variation (CV) is a relative measure of variability that indicates the size of a standard deviation in relation to its mean. Accordingly, the variability of annual and seasonal was determined by calculating the coefficient of variation (CV):

$$CV\,(\%) = \frac{\sigma}{\mu} X\,100, \tag{1}$$

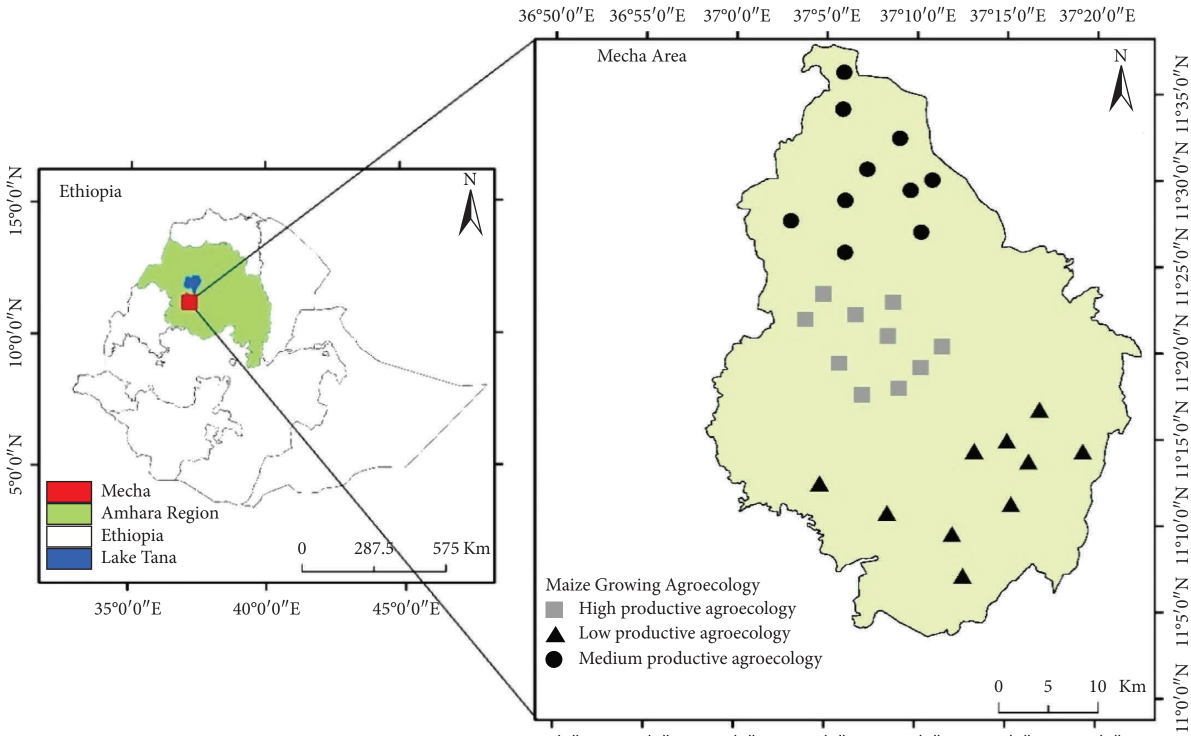


Figure 1: Location map of the study area.

where CV is the coefficient of variation, σ is the standard deviation, and μ is the mean precipitation of the recording period. According to Hare [24], the degree of rainfall variability is categorized as follows: CV < 20%, indicates less variable, CV = 20% to 30%, indicates moderately variable, and CV = 30%, indicates highly variable.

Precipitation concentration index (PCI) is the major tool that is the indicator of uniform or nonuniform rainfall patterns over the region. Accordingly, precipitation concentration index (PCI) was applied to evaluate the heterogeneity of intra-annual rainfall amount (PCI) [25].

$$\mathrm{PCI}_{\mathrm{annual}} = \frac{\sum_{i=1}^{12} Pi^2}{\left(\sum_{i=1}^{12} Pi\right)^2} \mathrm{X}\,100. \quad (2)$$

PCI values were categorized as uniform (<10), moderate (11–15), irregular (16–20), and strongly irregular (>20) in monthly rainfall distributions [25].

Rainfall anomaly index (RAI) is used as a single hydroclimatic index for estimating climatic change wetness and dryness conditions. Therefore, annual variability of rainfall was evaluated using rainfall anomaly index (RAI) used by Tilahun [26] and is calculated as follows for positive anomalies:

$$\mathrm{RAI} = +3\left(\frac{RF - \mathrm{MRF}}{\mathrm{M\ meanH10} - \mathrm{MeanRF}}\right). \quad (3)$$

And for negative anomalies

$$\mathrm{RAI} = -3\left(\frac{RF - \mathrm{MRF}}{\mathrm{MeanL10} - \mathrm{MRF}}\right), \quad (4)$$

where RAI = rainfall anomaly index, RF = the actual rainfall for a given year, MRF = mean annual rainfall over the full record of analysis, MH10 = the mean of the 10 highest values of annual rainfall on record, and ML10 = the mean of the 10 lowest values of annual rainfall on record. Years with positive and negative anomalies indicate years of high and low rainfall, respectively, compared to the mean climatology. Annual temperature anomaly was computed as the difference between a year's average temperature and the long-term mean.

2.3.2. Trend Analysis. All rainfall and temperature time series data were tested to examine the autocorrelation problem before applying the Mann–Kendall test by calculating the acf() function in R-software at a 5% significance level. Trend analysis was carried out using Mann–Kendall (MK) trend tests (nonparametric trend tests) and Sens's slope estimator in R-package modified MK. The MK trend test is the most appropriate and preferred nonparametric test for finding trends in time series climate data [27]. This method is less influenced by missing values and uneven data distribution, and it is less sensitive to outliers because it considers the ranks of the observations rather than their actual values [28–30].

S-Statists: S-statists was applied to check increasing or decreasing, or no trend on the hydrometeorological data series in each of the selected weather station data in the MK test statistic is given as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(Xj - Xk), \tag{5}$$

where n = number of data points, Xk and Xj = data values in time series k and j ($j > k$), and sgn($xj - xk$) is defined as follows:

$$\operatorname{Sgn}(Xj - Xk) = \left\{ \begin{array}{c} 1 \text{ if } Xj - Xk > 0 \\ 0 \text{ if } Xj - Xk = 0 \\ -1 \text{ if } 1\, if\ Xj - Xk < 0 \end{array} \right\}, \tag{6}$$

$$\text{The variance of } S \text{ is computed as } \mathrm{VAR}(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{m} tp(tp-1)(2tp+5))}{18},$$

where n is the number of data, m is the number of tied groups, and tp is the number of data points in the i^{th} group. Z-statistics test: the test statistics Z was used as a measure of the significance of the trend. If the value of Z is positive, it indicates increasing trends, while negative values of Z show decreasing trends. The values of S and VAR(S) are used to compute the test static Zs as follows:

$$Zs = \left\{ \begin{array}{c} \dfrac{S-1}{\sqrt{\mathrm{VAR}(S)}} \text{ if } S > 0 \\ 0 \text{ if } S = 0 \\ \dfrac{S-1}{\sqrt{\mathrm{VAR}(S)}} \text{ if } S < 0 \end{array} \right\}, \tag{7}$$

$Z0$ is a null hypothesis that signifies the trend is not significant and is recognized if Z-statistics are insignificant statistically ($Z\alpha/2 < Z < Z\alpha/2$), where $Z\alpha/2$ is the standardized normal deviation (Modarres & da Silva, 2007). Hence, for the purpose of this study, 1, 5, and 10% significance levels were considered. Sen's slope estimator and percentage change: the magnitude of the trend was estimated through Sen's slope estimator in a nonparametric procedure. Both the slope (i.e., linear rate of change) and intercepts were computed according to Sen's method [31]. Likewise, the linear model can be calculated as follows:

$$f(x) = Qx + B, \tag{8}$$

where Q is the slope, B is constant, and a set of linear slopes is calculated as follows:

$$Qi = \frac{Xj - Xk}{J - K} \text{ for } i = 1, 2, 3, \tag{9}$$

where Q is the slope, X denotes the variable, n is the number of data, and j, k are indices where $j > k$. The slope is estimated for each observation, and the corresponding intercept is also the median of all intercepts. Median is computed from N observations of the slope to estimate Sen's slope estimator:

$$N = \frac{n(n-1)}{2}, \tag{10}$$

where n is the number of time periods. The N values of Qi were ranked from smallest to largest, and the median of slope or Sen's estimator was computed as follows:

$$Q = \left\{ \begin{array}{cc} Q\dfrac{N+1}{2} & \text{if } N \text{ is odd} \\ \dfrac{1}{2}\left(Q\dfrac{N}{2} + Q\dfrac{N+1}{2}\right) & \text{if } N \text{ is even} \end{array} \right\}. \tag{11}$$

Positive/negative values of Qi indicate an increasing/decreasing trend, respectively.

2.4. Analysis of Onset, Cessation Date, and Length of Growing Period. For this study, determining the onset, cessation date, and length of growing period (LGP) was performed by adapting the definition from [32]. Instat software version 3.36 was used to analyze and estimate the onset, cessation date, and length of the growing period (LGP). Accordingly, the day with accumulated rainfall of 20 mm over three consecutive days that were not followed by greater than 9 days of dry spell length within 30 days from planting day was said to be the onset date. The condition of having no dry spell lasting more than 9 days after the start of the growing season eliminates the possibility of a false start to the season whereas the stored soil water and its availability to the crop after the rain stops were a very useful criterion for determining the end of the growing season or rainy season [32]. The cessation date of the rainy season adopted in this case was defined as any day after the first of September or October, when the soil water balance reaches zero [32]. As a result, the planting and harvest dates for the current climate condition were determined using the onset and session dates of rainfall, respectively. The length of growing period (LGP) refers to the average amount of time that rainfall from the onset to the cessation date. The spatial distribution of crops and farming systems in any region is determined by the LGP. The maturation duration based on the rainfall regime is important to consider when choosing the cultivars to be produced. Hence, the LGP was calculated between the start and end of the growing season using meteorological data (1987–2018) to recommend climate-resilient maize varieties suitable for each of the three main agroecological zones.

3. Results and Discussion

3.1. Rainfall

3.1.1. Coefficient of the Variability of Rainfall. The results of the coefficient of variation (CV) of rainfall at the three maize-growing agroecology zones using annual daily time series climatic data from 1987 to 2018 are presented in Table 1. In comparison among agroecological zones, the annual rainfall variability was higher in the LPZ (CV = 16.4%) than in the HPZ (CV = 14.6%) and MPZ (CV = 14.1%). These indicated that the LPZ tends to show a slightly higher coefficient of variation than the MPZ and HPZ study area (Table 1). This may be due to the fact that the LPZ is found at a higher elevation than the MPZ and HPZ.

3.1.2. Precipitation Concertation Index. The proportions average value of PCI in the LPZ, MPZ, and HPZ maize-growing agroecology zone were 22.2%, 19.06%, and 19.56%, respectively (Table 2). According to De Luis et al. [25] PCI classification of rainfall variability, LPZ is classified as significantly irregular, whilst MPZ and HPZ are part of the strong irregular rainfall distribution category (Table 2). These results in particular showed also that the annual rainfall variability was higher in the LPZ (highland agroecology zone) than in the MPZ (lowland) or HPZ (midland agroecology zone). The findings are directly comparable to those of Dawit et al. [33] who discovered a significant irregularity in precipitation distribution during the kiremt seasons in the Guna Tana Mountain watershed, Upper Blue Nile Basin, Ethiopia.

3.1.3. Rainfalls Anomaly Index. Figure 2 and Table 3 display the results of the RAI distribution pattern for the main maize-growing agroecology zones in northwest Ethiopia. Out of the studied period (1987–2018), there were 5, 3, and 5 years that were extremely wet and 4, 5, and 3 years that were extremely dry under LPZ, MPZ, and HPZ, respectively (Table 3). The LPZ (−3.22) had the greatest average negative RAI values as compared to the MPZ (−2.23) and HPZ (−1.48). MPZ and HPZ were rated as being very dry and LPZ as being extremely dry as per De Luis et al. [25] PCI classification (Table 2). This result implies that dry events were high at LPZ followed by MPZ and HPZ. In the LPZ, the year of 1990, 1991, 2005, 2009, 2010, 2011, and 2012 was very dry to extremely dry years, with average RAI values ranging from −2.00 to −5.571; in the MPZ, the year of 1992, 1995, 2009, 2015, and 2018 was very dry to extremely dry years, with RAI values ranging from −2.00 to −4.83, and in HPZ, the year of 1989, 1990, 1991, 2005, 2009, 2010, 2011, and 2012 was very dry to extremely dry years with average RAI values ranging from −2.00 to −4.47 (Table 3). Most of the years of negative rainfall anomalies in the study region coincided with El Niño events. For instance, the year 2009 experienced the highest negative anomaly due to the occurrence of El Niño which affected the main livelihood of the rural people in different parts of Ethiopia [34]. Therefore, this variability can be attributed to the seasonal movement of the intertropical convergent zone (ITCZ) as well as warm and cold ENSO events (El Nio and La Nia) [35].

According to RAI intensity levels between 1987 and 2000, there was evidence of wetness in all maize-growing agroecology zone of northwest parts of the country. However, after 2000, the intensity has shifted to dry compared to 1987–2000 (Figure 2). These indicated that the highest wet and dry years were observed in the 1990s and 2000s, respectively (Figure 2). Currently, the implications of the results indicated that a negative anomaly (dryness) was now more prominent in the research area. Therefore, these conditions might result in erratic and unexpected rainfall patterns, which would have an impact on the production of maize and encourage the installation of climate-resilient adaptation measures in each zone.

3.1.4. Comparison between Rainfall Anomaly Index and Standardize Precipitation Index. The characteristics of the meteorological drought were also derived from SPI in the study area. The analyzed SPI value in the study area was evaluated based on McKee and others' [36] classification system. Accordingly, an SPI value ranging from −1 to −2 categories indicates moderately to extremely dry drought events, whereas +1 to +2 showed moderately to extremely wet.

The analysis of results revealed that SPI −1 to −2 categories in the LPZ indicate that moderate to extremely dry drought events occurred in 2007, 2009, 2010, 2011, 2015, and 2018; categories in the MPZ indicate that these events occurred in 2003, 2007, 2009, 2010, 2011, and 2018, and in the HPZ, they occurred in 2003, 2004, 2005, 2007, 2009, 2010, and 2012, respectively (Figure 3). Accordingly, our research shows that droughts now happen every one to three years in every agroecological zone in northwest Ethiopia that grows maize; even consecutive droughts were seen in 2009, 2010, and 2011. Because of this, it could be required to develop a system of climate-resilient maize farming to address the issues of both global warming and the sub-Saharan nations that make up our study area.

A comparison of RAI and SPI analysis was done as part of this study to look at precise and realistic data on the occurrences of meteorological drought episodes in the study area. The procedure of comparison analysis was performed by overlapping the drought index from the RAI with the SPI in the same year. Figure 3 shows a comparison between SPI and RAI using the annual climate data from 1987 to 2018. According to the chart, distributions of SPI showed a similar tendency of increasing drought after 2000 in each of the maize-growing agroecological zones as revealed by RAI. So, the RAI and SPI displayed a pattern that was comparable, suggesting strong agreement between the two drought indexes. The results from SPI were mostly similar to those from RAI when they were brought into common discourse in the index.

Table 1: Annual and seasonal rainfall (mm) and coefficient of variation (1987–2018).

Prod. area	Mean	CV
LPZ	1456	16.4
HPZ	1396	14.1
MPZ	1344	14.6

LPZ = low productive agroecology zone, HPZ = high productive agroecology zone, MPZ = medium productive agroecology zone, CV = coefficient of variation; source: own study.

Table 2: Precipitation concentration index of 10 point data at each agroecology zones and number of years (1987–2018) [25].

Agroecology zones	PCI range	Class of PCI				
		PCI average value	Uniform (<10%)	Irregular (11–15%)	Strong (16–20%)	Significantly irregular (PCI ≥ 20)
LPZ	15.24–9.20	22.22	0	6	13	13
MPZ	13.1–19.03	16.06	0	8	13	11
HPZ	11.8–27.33	19.56	0	8	14	10

LPZ = low productive agroecology zone, HPZ = high productive agroecology zone, MPZ = medium productive agroecology zone, PCI = precipitation concentration index; source: own study.

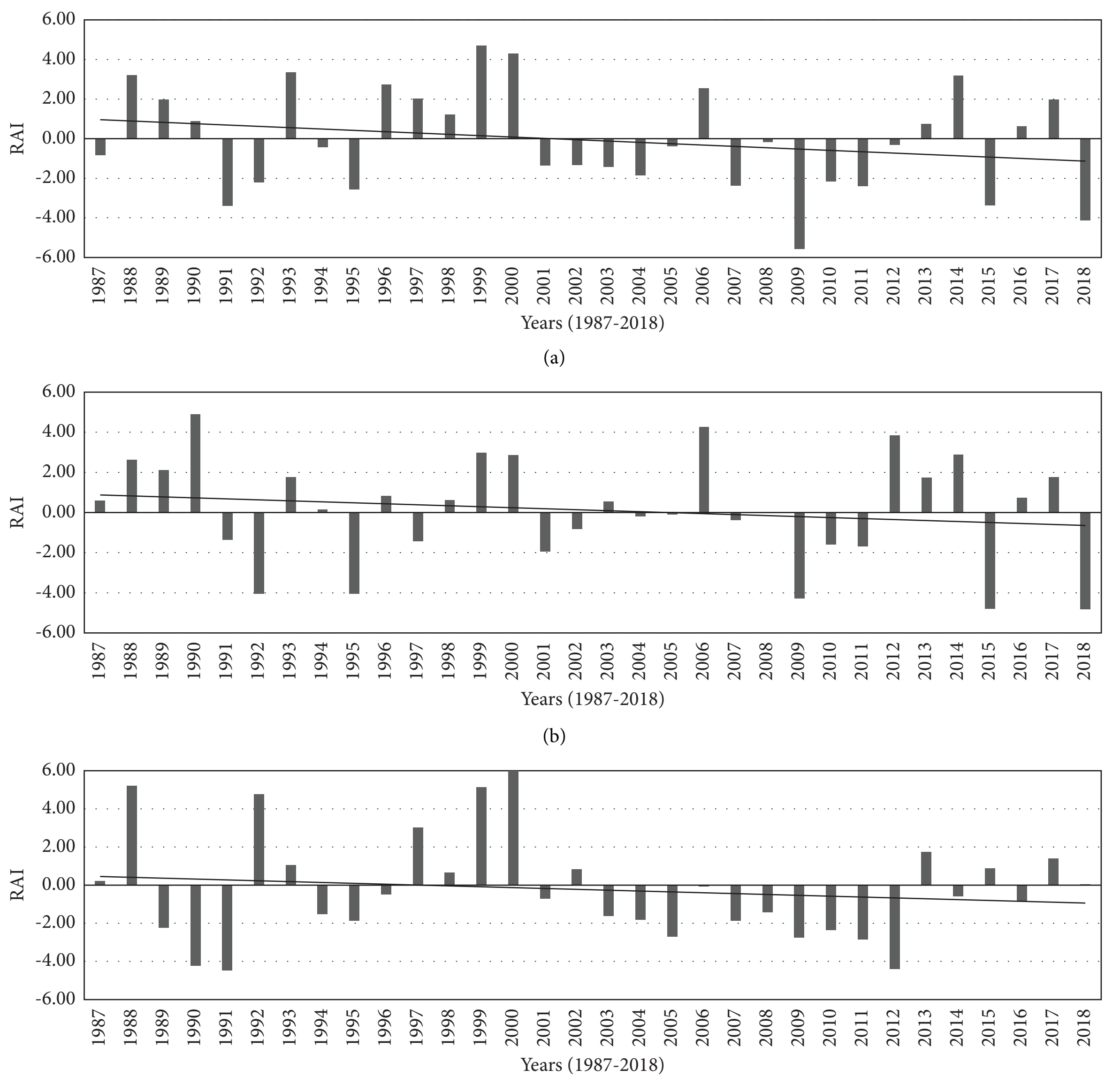
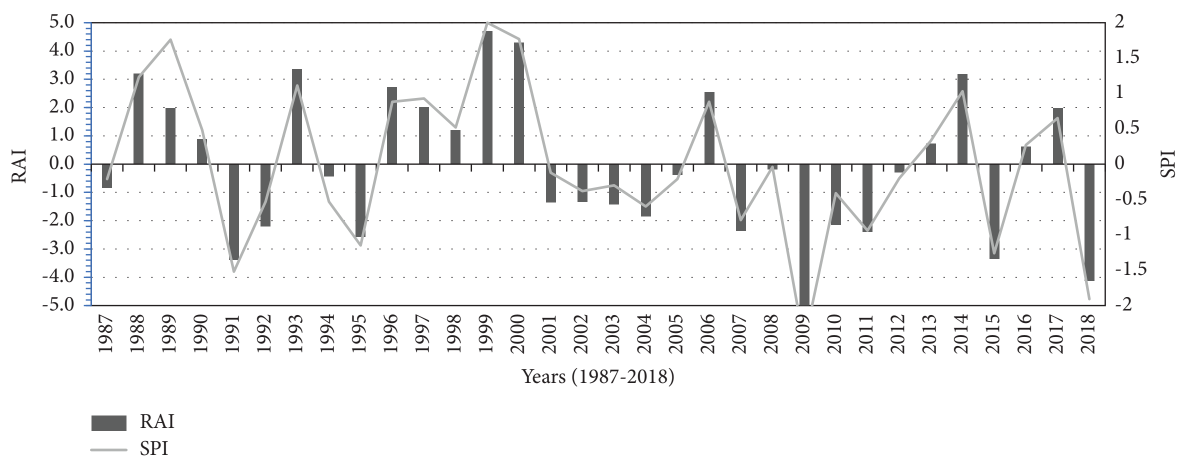


Figure 2: Rainfall anomalies in the northwest Ethiopia maize-growing agroecology zones (1987–2018) source: own study. (a) LPZ. (b) MPZ. (c) HPZ.

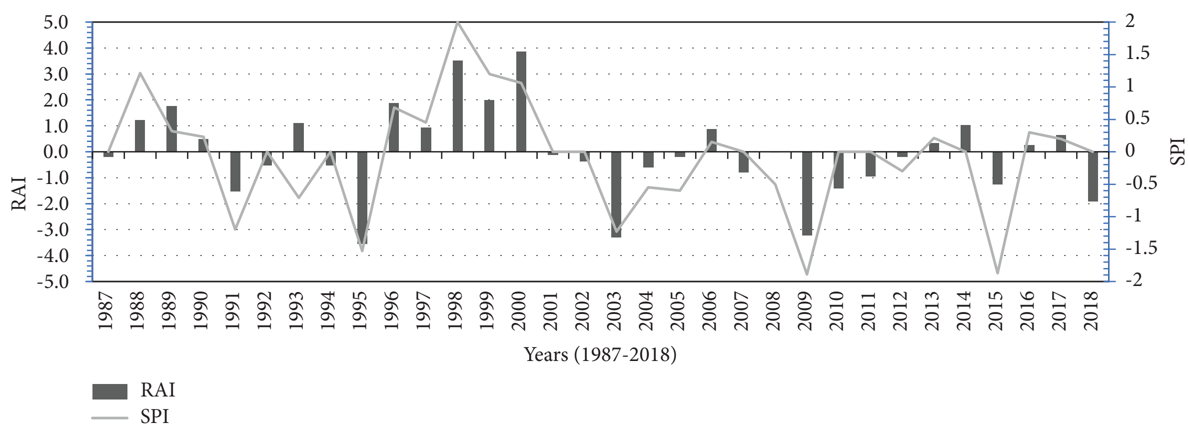
Table 3: Rainfall anomaly index of 10-point data at each agroecology zones and number of years (1987–2018).

Agro.eo. zones	RAI range	RAI average value	RAI class: Extreme wet	Very wet	Moderately wet	Slightly wet	Near normal	Slightly dry	Modernly dry	Very dry	Extremely dry
			≥3.00	2.00 to 2.99	1.00 to 1.99	0.5 to 0.99	0.49 to −0.49	−0.5 to −0.99	−1.00 to −1.99	−2.00 to −2.99	≤ −3.00
LPZ	−5.57 to 4.71	−3.215	5	3	3	3	4	1	4	5	4
MPZ	−4.83 to 5.21	−2.225	3	5	3	5	5	1	5	0	5
HPZ	−4.47 to 5.99	−1.475	5	0	3	3	7	3	3	5	3

Agro.eo. = Agroecology, LPZ = low productive agroecology zone, HPZ = high productive agroecology zone, MPZ = medium maize productive agroecology zone, RAI = rainfall anomaly index.

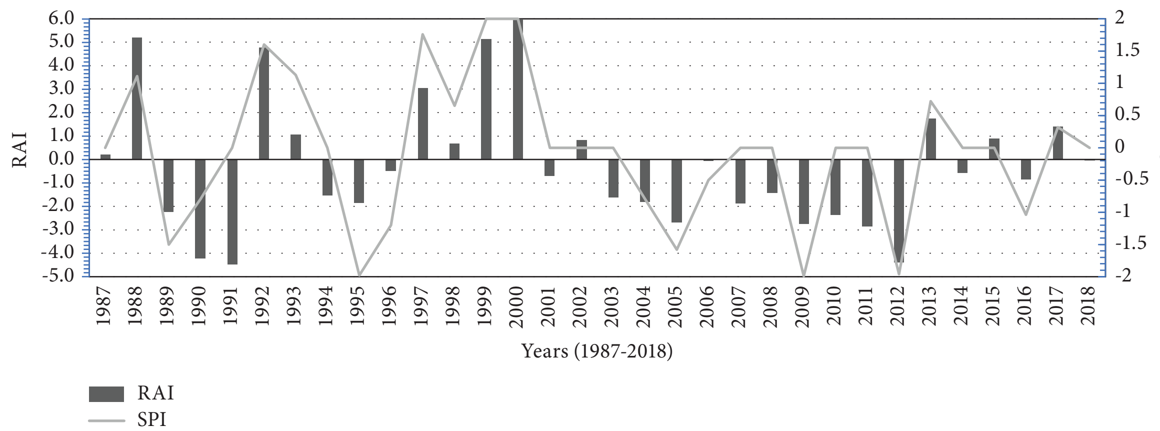


(a)



(b)

Figure 3: Continued.



(c)

Figure 3: Normality plot of annual drought index of standardized precipitation index (SPI) and rainfall anomaly index (RAI); source: own study. (a) LPZ. (b) MPZ. (c) HPZ.

3.1.5. Rainfall Trends. The trend of rainfall has declined in all the maize-producing agroecology zones, with different magnitudes (Table 4). The trends of the change rate vary widely at spatial levels. The result showed that annual rainfall has decreased by 6.7, 3.8, and 4.1 mm per annum in the LPZ (highland agroecology zone), HPZ (midland agroecology zone), and MPZ (lowland agroecology zone), respectively. Hence, higher decreasing trends of rainfall were observed in the LPZ (67.1 mm) and MPZ (43 mm). Similar to this result, the declining trend was found in the Woleka sub-basin, northcentral Ethiopia [13]. As a result, less water-required maize varieties may be needed for this agroecology zone in the future climate period.

3.2. Temperature

3.2.1. Temperature Variability. Figures 4 and 5 display the results of an analysis of the mean annual minimum and maximum temperatures in the research area. The annual anomalies of maximum temperature showed a little bit of variation across maize production agroecology zones. In general, increasing trends for annual maximum temperature anomalies were recorded for all maize-growing agroecology in the study area (Figure 4). As a result, the 2000s were warmer than the previous decade. In terms of minimum temperature, the 2000s were also the warmest decade compared to the 1990s (Figure 5). This indicated that the general trends of the annual anomalies in the minimum temperature had similar patterns to those of the maximum temperature.

3.2.2. Temperature Trends. Trends of minimum and maximum temperatures resulting from the Mann–Kendall test for three maize-productive agroecology zones are presented in Tables5 and 6. Based on S or *Z* values, statistically significant increasing trends for annual maximum and minimum temperatures were recorded from all study areas over the last 32 years (1987–2018) (Tables 5 and 6). All agroecology zones showed a highly significant upward trend in the maximum temperature at $P < 0.01$ and $P < 0.001$ (Table 5). Relativity the highest warming trend was observed from LPZ while the lowest warming trend was on display from HPZ all over the study area and period. This could explain why maize is being grown in a low-maize productive agroecology zone.

Similarly, there is a highly significant rising trend in the minimum temperature, with values of $P < 0.001$ and $P < 0.01$ (Table 6). The result of this study agrees with previous studies that indicated the annual maximum and minimum temperatures are currently trending upward in different stations in Ethiopia [14, 37] and [38].

3.3. Analysis of the Onset, Cessation Date, and Length of Growing Period. The lower and upper quartiles of the date of onset of rainfall are in a range of 131 (May 9)–154 (June 2) day of the year (DOY), respectively (Table 7). Therefore, planting maize crops earlier than May 9 is possible in a study area once in five years' time for long-maturing varieties. On the other hand, planting earlier than June 2 (154 DOY) is possible in four out of every 5 years' time. In general, the median onset date of 140 DOY (18 May) could be taken as a dependable planting date at and around in study area. Furthermore, on average, the long rainy season (*Kiremt*) starts on DOY 144 (May 22) for northwest Ethiopia with CV of 11.9% (Table 7).

Thus, May 22 was picked as a potential planting date for the long-maturing main-season maize crop for the Mecha district. The result of the analysis showed that in Table 7, the rainy season terminates in the third dekad of October (298 DOY) once in 5 years time and earlier than the second dekad of November (319 DOY) in four out of five years (Table 7). Accordingly, on average, the rainy season ends in the first dekad of November (310 DOY) in the study area with a CV of 5.3% (Table 4). Harvesting, transporting, storing, and marketing of maize crop could thus be more easily accomplished in the study area after the first dekad of November (310 DOY). The probability that the length of the

Table 4: Trends of rainfall in the northwest Ethiopia agroecology zone (1987–2018).

Maize-growing agroecology zones	Mean	Z	S
LPZ	1451.7	−1.9	−6.7
HPZ	1396.3	−1.4	−3.8
MPZ	1344.1	−1.1	−4.1

LPZ = low productive agroecology zones, HPZ = high productive agroecology zones, MPZ = medium productive agroecology zones, Z = Mann Kendal test, S = Sen slope; source: own study.

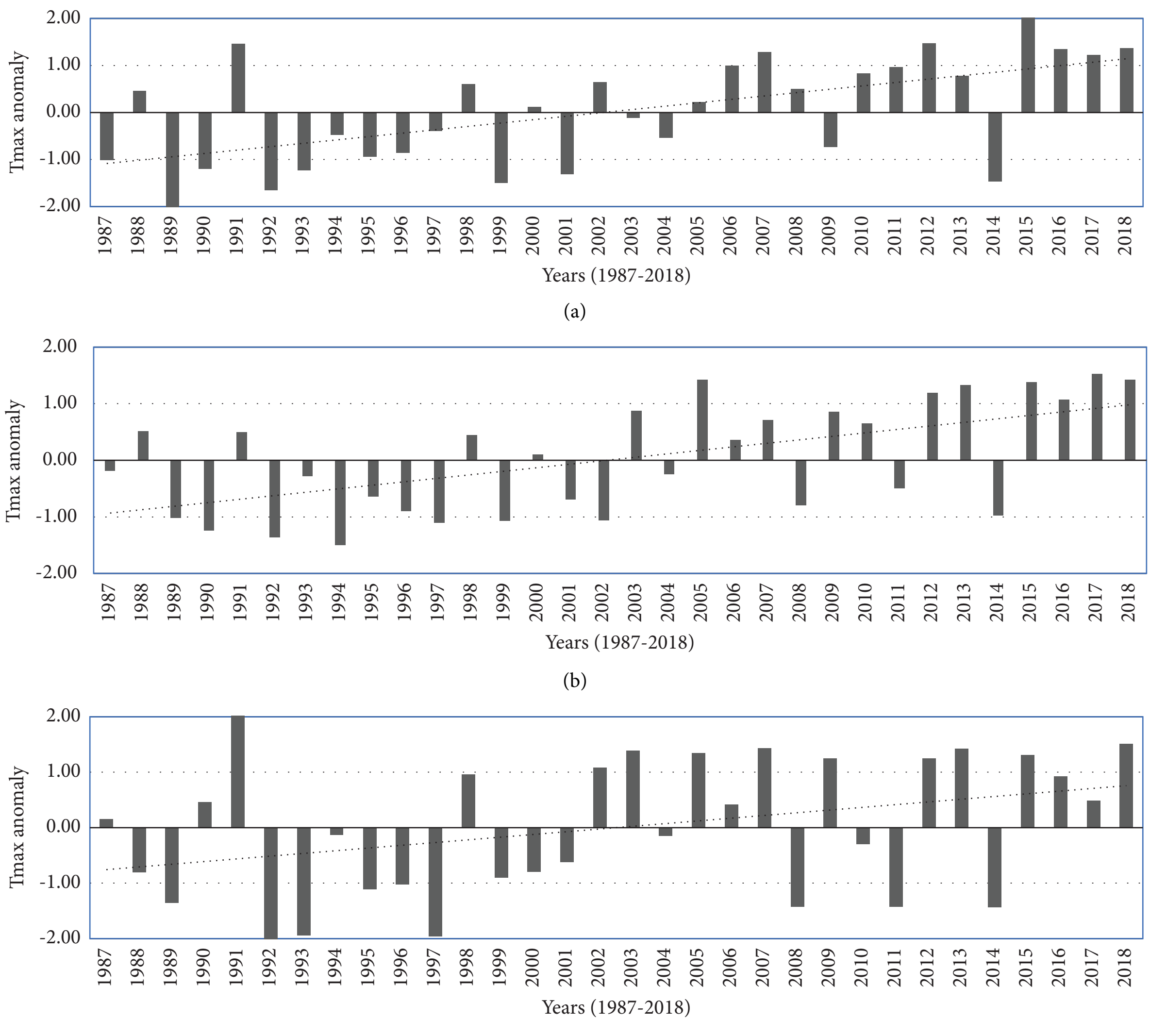


Figure 4: Maximum temperature anomalies in northwest Ethiopia (1987–2018); source: own study. (a) LPZ. (b) MPZ. (c) HPZ.

growing period (LGP) will be shorter than 186 days is 50%, while the probability that it will be longer than 149 days is 25% (Table 7). The analysis of precipitation data revealed that the LGP in the main rainy season (*kiremt*) in the Mecha area ranges from 97 to 232 days with a mean of 180 days, a CV and SD of 9.1% and 32.2 days, respectively. Therefore, if northwest Ethiopia has a 97 to 232-day growing period, researchers need to investigate selecting suitable maturing cultivars of maize for smallholder farmers. For this reason, short, medium, and long-maturing maize cultivars could be

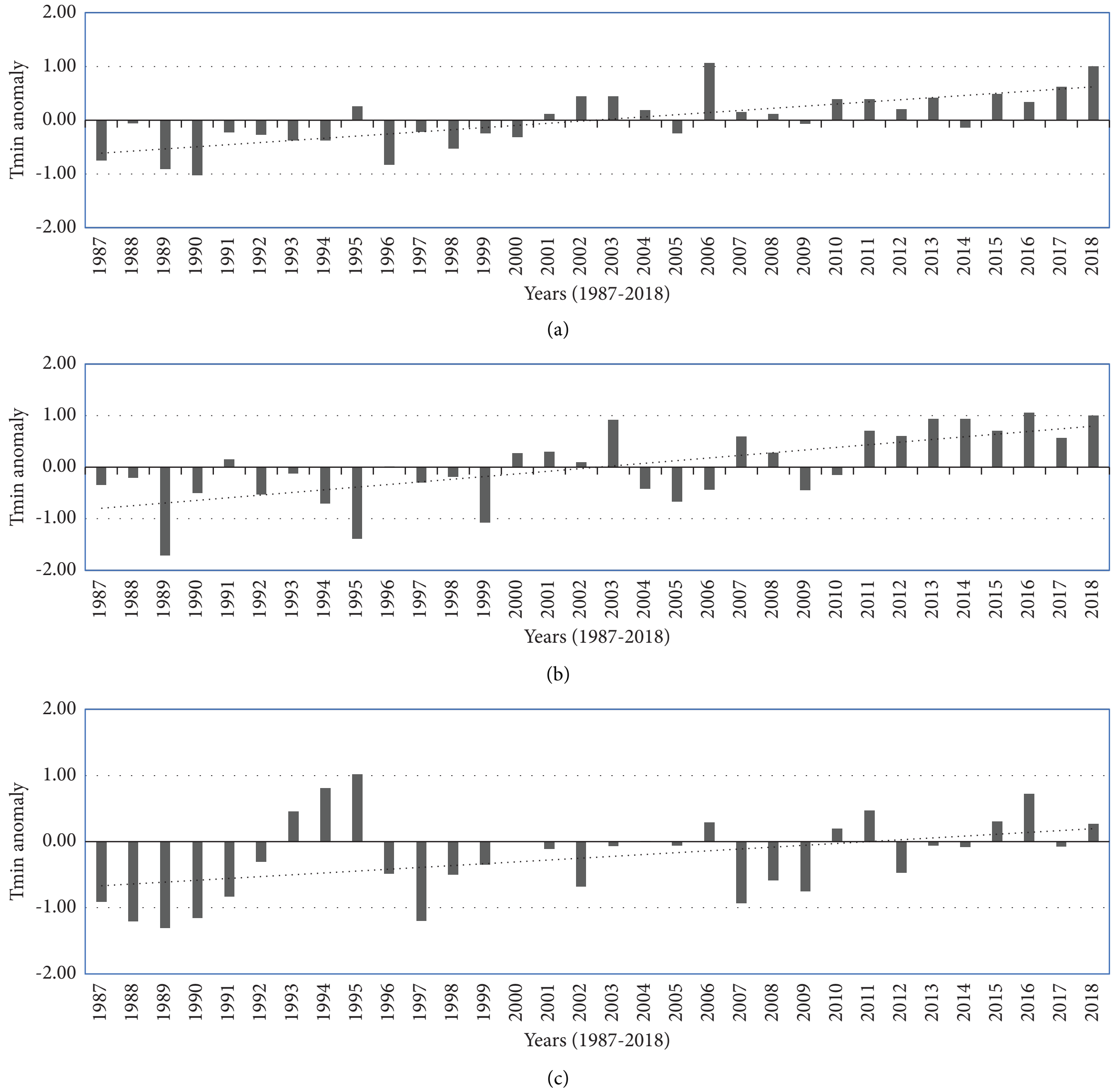


Figure 5: Minimum temperature anomalies in northwest Ethiopia (1987–2018); source: own study. (a) MPZ. (b) HPZ. (c) LPZ.

Table 5: Maximum temperature trends in northwest Ethiopia agroecology zone (1987–2018).

Prod. area	Mean	Z
LPZ	21.5	5.3**
HPZ	25.0	4.1**
MPZ	26.3	4.7**

LPZ = Low productivity agroecology zone, HPZ = high productivity agroecology zone, MPZ = medium productivity agroecology zones, Z = Mann–Kendal test, **significant at 0.001 and 0.01 P level and ns = nonsignificant at $P < 0.05$; source: own study.

Table 6: Minimum temperature trends in northwest Ethiopia agroecology zone (1987–2018).

Prod. area	Mean	Z
LPZ	8.9	4.2***
HPZ	10.4	4.1***
MPZ	11.5	4.3***

LPZ = Low productivity agroecology zone, HPZ = high productivity agroecology zone, MPZ = medium productivity agroecology zones, Z = Mann–Kendal test, ***significant at 0.001 and 0.01 P level and ns = nonsignificant at $P < 0.05$; source: own study.

Table 7: Statistical description of rainfall features in the study areas.

Description	Onset	Cessation	LGP
Min.	122 (April-30)	278 (October-5)	97
Max.	186 (July-4)	344 (December-10)	232
Mean	144 (May-22)	310 (November-6)	180
25.00%	131 (May-9)	298 (October-25)	149
50.00%	140 (May-18)	310 (November-6)	186
75.00%	154 (June-2)	319 (November-15)	206
SD	16.5	16.3	32.2
CV	11.9	5.3	9.1

LGP refers to length growing period: source; own study.

an option for demonstrating, and this will help farmers be able to plant early and produce a crop with less exposure to dry spells.

4. Conclusions

The findings of the spatial research of rainfall from 1987 to 2018 indicate that the LPZ (highland) tends to exhibit slightly larger variation and declining trends than the MPZ (lowland) and HPZ (midland). When RAI intensity levels were taken into consideration, there was evidence of wetness in every agroecological zone that produced maize in the northwest of the country between 1987 and 2000. However, after 2000, the intensity has shifted to dry compared to 1987–2000. These indicated that the highest wet and dry years were observed in the 1990s and 2000s, respectively. Currently, the implications of the results indicated that dryness was now more prominent in the research area. Moreover, our research also shows that droughts now happen every one to three years in every agroecological zone in northwest Ethiopia that grows maize; even consecutive droughts were seen in 2009, 2010, and 2011. Therefore, these conditions might result in erratic and unexpected rainfall patterns, which would have an impact on the production of maize and encourage the installation of climate-resilient adaptation measures in each zone.

In the context of temperature, the annual anomalies of maximum and minimum temperature showed a little bit of variation across maize production agroecology zones, but considerable differences have been observed over the past decade. As a result, the 2000s were warmer than the previous decade. Moreover, statistically significant increasing trends for annual maximum and minimum temperatures were recorded from all study areas over the last 32 years (1987–2018). Particularly, the LPZ (Highland) showed the highest warming trend in maximum temperature.

Onset, cessation date, and LGP are determined by adapting the definition from Stern et al. [32]. The lower and upper quartiles of the date of onset of rainfall are in a range of 131 (May 9)–154 (June 2) day of the year (DOY). Therefore, May 9, May 18, and June 2 were chosen as potential planting dates for long, mid, and short-maturing maize varieties for LPZ, HPZ, and MPZ, respectively. The median onset date of 140 DOY (18 May) could be used as a general guide. In this way, farmers prepare their lands for cropping before the second dekdal of May. In the context of the cessation date, the rainy season typically finishes in the first dekad of November (310 DOY). So, after the first dekad of November, it would be simpler to harvest, move, store, and market the maize crop in the research region. In the research area, the LGP during the primary rainy season (kiremt) ranges from 97 to 232 days, with a mean of 180 days. In light of the 97–232-day growing season in the northwest part of Ethiopia, researchers need to look into the best maturing cultivars of maize for smallholder farmers. As a result, farmers will be able to plant earlier and produce a crop that is less susceptible to dry periods by using short, medium, and long-maturing maize cultivars as a demonstration option.

In conclusion, consistent warming trends and increasingly erratic and concentrated rainfall patterns have been shown in all the northwest Ethiopia agroecology zones. Therefore, we have concluded and recommend that the following climate-resilient agronomic activities should be applied in the study area and similar agroecological zones: maize varieties with a low water requirement and high-temperature tolerance may be required for all agroecological zones in the current climate period; In this manner, lands could be prepared for cropping before the second dekdal of May; first dekdal of May, second dekdal of May and first dekdal of June could be adopted as potential planting dates for long, mid, and short maturing maize varieties for low productive agroecology (highland), mid-productive agroecology (midland), and high productive agroecology (lowland), respectively; Optimal plant density and nitrogen fertilizer doses would be applied to shorten the maturity time for all agroecology zones and harvesting, threshing, and storing the maize crop in the study area could following the first a dekad of November.

Data Availability

The data used to support the findings of this study are included in the results part of the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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