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Research Article

Analysis of Temporal Variability and Trends of Rainfall and Temperature Over Western Amhara Region, Ethiopia

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Abstract—This study examined the temporal trends and variability of rainfall and temperature in seasonal and annual time series over western Amhara, Ethiopia. The 75 weather stations of daily precipitation and the 49 stations of daily maximum and minimum temperature were collected from the Western Amhara Meteorological Service Center from 1989 to 2018. Then, after quality checking, the daily data was arranged in a Microsoft Excel spreadsheet and analyzed using statistical analysis software (XLSTAT), Arc GIS 10.3 software, and the R program. The results indicated that western Amhara receives its rainfall mostly in *Bega*, *Belg*, and *Kiremt* and annually receives 100–300 mm, 120–350 mm, 800-1600 mm, and 1100-2000 mm, respectively. The statistics reveal that the maximum and minimum temperatures of the region increased annually by 0.0905°C and 0.0886°C, respectively. Similarly, the rainfall trend slightly increases in the *Belg* season, *Kiremt* season, and annually, but not during the *Bega* season. The rainfall variability was high, with a coefficient of variation (CV = 48.42% and CV = 37.2%) in the *Bega* and *Belg* seasons, respectively. However, the rainfall variability was moderate on *Kiremt* and annually (CV = 29.02% and CV = 27.79%). The results further indicated that the Awi zone has the best rainfall distribution, mostly more than 1600 mm. Some parts of this zone, like Enjibara and Tilili, receive more than 2200 mm of rainfall annually. West Gondar zone received the lowest rainfall amount in the region.

Keywords— rainfall, temperature, temporal variation, Mann-Kendall test, western Amhara

1. Introduction

Sustainable development heavily depends on the climate, but social, economic, and ecological systems are disrupted by independent climate cycles brought on by natural climate variability [1], [2]. The primary causes of global climate change are prolonged high population growth, a greater reliance on transportation, industry, and technology based on the combustion of fossil fuels, as well as land-use changes including urbanization, agriculture, raising livestock, and deforestation [2], [3], [4]. Regional, subregional, and global climate trends are influenced by such human activities [5], [6], [7]. Even though climate change is a worldwide phenomenon, prospective variations and changes are not anticipated to be uniform, and there may be significant regional differences [8]. Although climate change has always been seen as an environmental issue, it affects many sectors, including infrastructure, transportation, agriculture and food security, and health [9]**.** The most extreme and potentially catastrophic consequences of climate variability and change in East Africa include variations in temperature and the intensity, frequency, and predictability of precipitation [10], [11]. Changes in regional precipitation eventually impact the spatiotemporal distribution of water resources [12], [13]. These may result in widespread food shortages, decreased agricultural productivity, and increased food insecurity. Ethiopia is the finest example of a nation impacted by climate change and variability; within the last ten years, the country has had multiple food crises [11]. Ethiopia is vulnerable to long-term variations and fluctuations of climatic elements such as temperature and precipitation in frequency and severity, climate change [14], [15], and rain-fed agriculture. The second reason is that Ethiopia lacks the resources necessary to adapt to natural disasters such as floods and droughts, which have a negative impact on food security by reducing agricultural productivity and output [16], [17], [18], irrigation [19], and hydroelectric power [20]. Ethiopian rural families are negatively impacted by climate-related risks, especially in the Amhara regional state, where a large portion of agriculture and animal output are dependent on weather-sensitive systems [11], [21], [22]. The distribution of rainfall at various time scales is a significant finding of this study that will be useful to water resource planners, professionals in the design of urban drainage systems, bridges, and dams, as well as agricultural and urban planners.

2. Related Work

The climate has a significant impact on agricultural production and productivity in low-income nations like

Ethiopia [11]. Ethiopia has few resources to adapt to climate change and depends primarily on rain-fed agriculture. Prolonged changes in temperature and precipitation have a negative impact on food security [23], [24], [25]. The net revenue from agricultural production is negatively impacted by these changes as well. Rainfall patterns and temperature have an impact on the amount of water available for irrigation and other agricultural uses [26].

Many studies have been conducted to assess the spatiotemporal patterns of precipitation and temperature in various regions of Ethiopia. However, the findings of these studies are sometimes contradictory and inconsistent. For instance, studies [27], [28], [29], [30], [31] concluded that there isn't a discernible pattern in the yearly rainfall across the nation's different areas. On the other hand, the southwestern, northern, and central parts of Ethiopia had a notable decrease in precipitation from June to September [27], [32], [33]. Seleshi [31] was unable to locate such a tendency in Ethiopia's central, northern, or northwest regions. They found that in eastern, southern, and southwest Ethiopia, annual rainfall and precipitation from June to September had decreased. The findings of Seleshi [31] about the decrease in annual rainfall in southwest and eastern Ethiopia were corroborated by Jury [34] and Verdin [35]. Other studies showed statistically non-significant increasing trends for yearly rainfall, such as Mengistu [36] in the Upper Blue Nile basin in Ethiopia and Alemayehu [37] in the central highlands of Ethiopia. Similar findings were made by Alemayehu [37] who carried out a relatively recent study in Ethiopia's central highlands. He discovered that while rainfall from March to May (*Belg*) showed a significant decreasing trend, rainfall from June to September (*Kiremt*) showed statistically non-significant increasing trends. However, [38] in the Omo-Ghibe Basin, Ethiopia, noted a notable upward trend in the average annual rainfall for the basin as a whole. Comparable research conducted in the Amhara region by [39], [40] revealed the variability of rainfall on monthly, seasonal, and annual time scales, with non-significant negative trends (in the remaining months) and a significant increasing trend (in the majority of the region) from May to September. Furthermore, a notable rise in annual and *Kiremt* rainfall in the western Amhara region was documented by [2]. On the other hand, [41] demonstrated that the Lake Tana sub-basin's yearly precipitation was generally decreasing. In the Amhara region and the Tekeze River basin, other studies [1] similarly showed the spatial distribution of seasonal and monthly rainfall as well as a combination of non-significant positive and negative trends. Comparably, the mean annual and seasonal rainfall trends in Enebsie Sar Midir, south Gondar, Mecha district, and south Wollo, respectively, exhibit statistically non-significant increasing tendencies [11], [14], [42], [43]. Similarly, [44] discovered that, in the Zarima subbasin, the annual rainfall trended upward statistically in certain areas and upward statistically in most other areas.

Many of the discrepancies in the earlier findings on rainfall patterns in Ethiopia and the Amhara region, according to Seleshi [31], can be attributed to the arbitrary segmentation of the study area caused by different station density, time length, and quality of the climate data, as well as diverse topography. Because of this, there is no discernible pattern in the intricate geographical and temporal variability of climate parameters throughout the nation and in western Amhara. The majority of investigations employed scant data from meteorological stations, particularly in the Amhara region [39], [40], [45]. Thus, using those stations to make generalizations about the entire Amhara region is challenging. In a similar vein, [2] uses five meteorological stations to characterize the climate system of western Amhara. The authors also display the distribution of seasonal and yearly rainfall. Additionally, utilizing those stations to generalize to the entire western Amhara region is challenging. This study closes this gap by presenting a more thorough examination of temperature and precipitation with respect to annual and seasonal fluctuations and trends, utilizing denser station data and more rigorous methodology analysis. Thus, the study is designed in western Amhara to address this issue. Thus, the study is designed in western Amhara to address this issue. In order to close this gap, this study uses a dense station to do a more thorough evaluation of the temporal patterns and trends of annual and seasonal rainfall and temperature over western Amhara from 1989 to 2018. Therefore, understanding the climatology of temperature and rainfall in a particular area, offering simple seasonal climate forecasts for various industries like agriculture, health, investment, etc., and validating or evaluating the long-term climate in a particular area at a particular time all depend on scientific investigations into temperature and rainfall data analysis.

3. Description of the study area and weather systems in Ethiopia

3.1. Description of the study area

The study was carried out in western Amhara (Figure 1), which is situated between 35°30′ and 38°70′ East and 9°80′ to 14°0′ North. The limits of the study area are shared by Oromiya in the south, Wolo in the east, Sudan in the west, and Tigray in the north. The topography of the area is extremely varied, encompassing chains of plateaus that stretch from less than 700 meters above sea level to 4,620 meters at Ras-Dashen, Ethiopia's highest peak, as well as lowland, midland, and highland plains, mountains, and rough terrain [2]. The region's fluctuating rainfall has been influenced by several variables, including its diverse topographic features [46]. Taye [2] states that the Amhara region's climate can be divided into three categories based on altitude: Kola (hot zone) below 1500 masl, which makes up 31% of the region; Woyina Dega (warm zone) between 1500 and 2500 masl, which makes up 44% of the region; and Dega (cold zone) between 2500 and 4620 masl, which makes up 25% of the region. The region of the annual mean temperature ranges from 15 to 21 °C, although it can get as high as 27 °C in valleys and marginal areas [39].

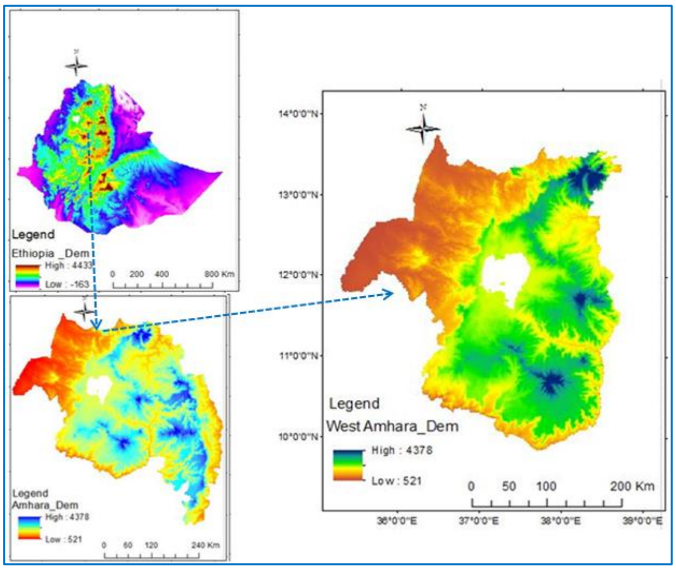


Figure 1. Amhara region and study Area

3.2. Seasons in Ethiopia

The NMSA states that there are three primary seasons in Ethiopia: (i) the *Kiremt*, or main and wet season, which runs from June to September; (ii) the *Belg*, or short wet season, which runs from February to May; and (iii) the *Bega*, or dry season, which runs from October to January. Except for the south and southeast, *Kiremt* rainfall accounts for the majority of the nation's yearly rainfall [47], [48], [49], [50], [51]. During *Kiremt*, air movement is dominated by a zone of convergence in the low-pressure systems of the Inter-Tropical Convergence Zone (ITCZ), which stretches from West Africa via Ethiopia and towards India [52]. *Belg* rainfall is caused by moist, easterly, and southeasterly winds; it is the primary rainy season in the southern and southeastern regions of the country, but it is only a brief period of rainy weather in many other areas [48]. Nonetheless, the Saharan anticyclone and northeasterly warm and chilly breezes from Asia have the greatest impact on *Bega* [31].

3.3. Weather systems producing seasonal rainfall over Ethiopia

There are two dry and one rainy season in the majority of northwest Ethiopia [47], [48], [53]. Locally, June to September is referred to as *Kiremt*, the wet season. In Ethiopia, the dry months that span the remainder of the year (October to January) are referred to as the *Bega* and *Belg* rainfall regimes (mid-February to May) [47].

Bega, or the dry season, starts from October to January. The *Bega* season is primarily defined by hot, dry days and cool nights, according to [47], [48]. In these conditions, frosty early mornings are a typical occurrence in most mountainous regions. The ITCZ, the northern Atlantic and Mediterranean Seas; high-pressure cells over the Northern Indian Ocean and the neighboring Arabian Sea; the ENSO phenomenon; the IOD anomaly; and tropical cyclones are the worldwide regulatory systems that impact *Bega* seasons [53], [54]. Except for lowland areas south and southeast, most of Ethiopia has experienced minimal rainfall throughout the *Belg* season [55]. These speak about February through to May. High maximum temperature are typical, and seasonal precipitation varies widely in both time and space [48]. The months of March, April, and May are warmer than the *Bega* seasons. Mid-latitude frontal systems from the Mediterranean Sea, moisture inflow from the northern Indian Ocean and the nearby Arabian Sea, seasonal oscillation of the ITCZ, ENSO phenomena, IOD phenomena, and the formation and propagation of tropical cyclones across the southern Indian Ocean are the global governing systems that impact *Belg* seasons [53].

Ethiopia produces between 85% and 95% of its food during the major rainy season, known as *Kiremt* [49]. It is associated with regular downpours and uniform temperatures, mostly in July and August but with significant fluctuations in June and September. *Kiremt* rainfall is significantly higher in several parts of the nation than it is during other seasons [55]. Global governing systems during the *Kiremt* season include the ITCZ's northward migration in response to the sun's movement, the growth of the tropical Easterly jet and the Somali jet, high-pressure systems over the Atlantic and Indian oceans, Mascarene and St. Helena, the well-established Congo Air Boundary, and ENSO (El-Nino/Southern oscillation) [48], [52]. During *Kiremt* (JJAS), the ITCZ's northward propagation and its formation of heat lows over the Arabian and Saharan landmasses are prominent features. The ITCZ peaked at 15N and 15S, respectively, between July and January [56]. A convergence zone of cyclonic areas dominates air circulation, and an oscillating ITCZ stretches from West Africa via Ethiopia and India [52]. The formation of subtropical high-pressure systems over the Azores, St. Helena, and Mascarene, as well as the position and strength of these systems particularly over St. Helena and Mascarene high pressure influence rainfall and moisture flux over Ethiopia [57].

4. Research Design, Data and Methodology

The type of study is quantitative. The data were described and summarized quantitatively and were collected from the Western Amhara Meteorological Service Centre (WAMSC), Bahir Dar. Seventy-five meteorological stations were purposely selected among a total of a lot of stations from 1989 to 2018. In addition, forty-nine meteorological stations were purposely selected based on the availability of monthly rainfall, maximum and minimum temperature, and a fair distribution of the stations in the study area from 1989 to 2018. Missing data is one of the main problems often encountered in meteorological analysis, which may be due to the absence of observers or the malfunction of instruments during a certain period. When data is missing, it may be appropriate to complete these data sets using CHIRPS data.

4.1. Data analysis

The appropriate 75 stations for monthly rainfall and 49 stations for monthly temperature (max and min) data were captured into a Microsoft Excel 2010 spreadsheet following the entry format and saved in CSV format. Data quality control was done by careful inspection of the completeness and spatial and temporal consistency of the rainfall and temperature records in the study areas. All records are analyzed using statistical methods (mean, range, standard deviation, standardized anomaly, and coefficient variation), Arc GIS 10.3.1 software, and the R program. The sample estimate of population parameters is given in the following equations:

$$\bar{x} = x_1 + x_2 + ... + x_n = \sum_{i=1}^{n} \frac{x_i}{n} \quad (1)$$

Where n is the number of observations in a single observation for i = 1, 2, 3,.. n, and $\bar{x}$ is the sample mean. A number list's arithmetic mean is calculated by dividing its total by the number of entries in the list. Finding a data set's general trend or getting a fast overview of your data can both be aided by the mean. The fact that averages are quick and simple to compute is another benefit. The variance (S^2) and standard deviation ($\sqrt{S^2}$) respectively, are given as;

$$S^2 = \frac{\sum\left(x-\bar{x}\right)^2}{n-1} \quad (2)$$

$$\sqrt{S^2} = \frac{\sqrt{\sum\left(x-\bar{x}\right)^2}}{n-1} \quad (3)$$

$$SA = \frac{x-\bar{x}}{\delta} \quad (4)$$

SA refers to a standardized anomaly. The standard deviation, often represented by the Greek letter sigma, is the measure of the spread of data around the mean. A high standard deviation means that the data are far from the mean, and a low standard deviation means that more data are in line with the mean. Among a variety of data analysis techniques, the standard deviation helps quickly determine the spread of data points.

The coefficient of variation is used to evaluate the seasonal and yearly rainfall data's variability. Increased CV values are linked to increased variability in the time-series data of rainfall.The coefficient of variation (CV) is calculated as the ratio of the standard deviation (SD) to the mean over a given time series and is used to quantify the amount of variation, expressed as a percentage. According to Belay [58], CV values are classified as follows: if $CV < 20\%$, it shows low variability; if $20\% < CV < 30\%$, it represents moderate variability; if $CV > 30\%$, it is strong variability.

The non-parametric Mann-Kendall test statistics were used to analyze the climate trend. According to Harka [59], the non-parametric test is utilized for non-normally distributed, outlier, and missing data in hydrological time series data. was employed to ascertain whether the temperature and precipitation data exhibited any noteworthy trends. Because it is less prone to outliers, Mann-Kendall statistics (S) is the most often employed non-parametric test for identifying climatic trends [41]. The Mann-Kendall statistic (S) of the series x is given by the test [60], [61]:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \quad (5)$$

Whereas S is the Mann-Kendall's statistical test: x_i and x_j are consecutive data values for the time series data of length.

$$\operatorname{sgn}(x_j - x_k) = \begin{cases} +1, if\,(x_j - x_k) > 0 \\ 0, if\,(x_j - x_k) = 0 \\ -1, if\,(x_j - x_k) < 0 \end{cases} \quad (6)$$

A positive Zs value indicates an upward trend, a negative Zs value indicates a downward trend, and 0 values indicate no trend [58]. To statistically quantify the importance of a trend, we need to compute the probability associated with S and the sample size n.

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{m} t_k(t_k-1)(2t_k+5)}{18} \quad (7)$$

Where t k is the number of data points in group k, and m is the number of tied groups. In cases where the sample size *n* > 10, the test statistic Z(S) is calculated using [60], [61].

$$z_s = \begin{cases} \frac{S-1}{\sqrt{\operatorname{var}(S)}}, & \text{if S >0} \\ 0, & \text{if S =0} \\ \frac{S+1}{\sqrt{\operatorname{var}(S)}}, & \text{if S <0} \end{cases} \quad (8)$$

The trend is seen to be declining if Z is negative and its absolute value is higher than the significance level; conversely, if Z is positive and its value is higher than the significance level, the trend is deemed to be increasing. The fact that the current studies frequently use various methods, geographies, periods, and observational data for evaluation poses a substantial obstacle to a thorough evaluation of regional downscaling. So, significant tests were done using the R program at 5% significant level.

5. Result and Discussion

5.1. Climatology of Rainfall (mm)

During the *Bega* season, rainfall ranged from 45 to 120 mm in many parts of western Amhara to 200–300 mm in other portions of West Gojjam and Awi zone (Figure 2 (A)). While the region had a rise in rainfall distribution during the *Belg* season, with most of western Amhara receiving between 73 and 160 mm, most of Awi, South Gondar, West, and East Gojjam received between 200 and 300 mm (Figure 2 (B)). Similarly, less than 600 mm of rain had fallen in Areb Gebeya and the adjacent areas throughout the *Kiremt* season. During the *Kiremt* season, rainfall in several parts of western Amhara has been recorded between 900 and 1400 mm. Rainfall in areas such as D/Elias, Awi zone, and West Gojjam has been between 1400 and 1600 mm. Lastly, throughout the *Kiremt* season, Adiarikay, Tikelidingay, Dingayber, and Gundel received more than 1600 mm of rain (Figure 2 (C)). The majority of western Amhara receives more than 1100 mm of rain annually. Looking at each zone, the majority of the Awi zone has seen yearly rainfall between 1600 and 2000 mm. On the other hand, the majority of East and South Gojjam receive between 1200 and 1400 mm of rain annually. Lastly, the yearly rainfall in the majority of North Gondar and select areas of West Gojjam is 1100–1200 mm and 1600–2000 mm, respectively. Over 2000 mm of rainfall annually occurs in some areas of the Awi zone, including Enjibara, Tillil, and Adiarkay, Tikildingay, Gundel (Figure 2 (D)).

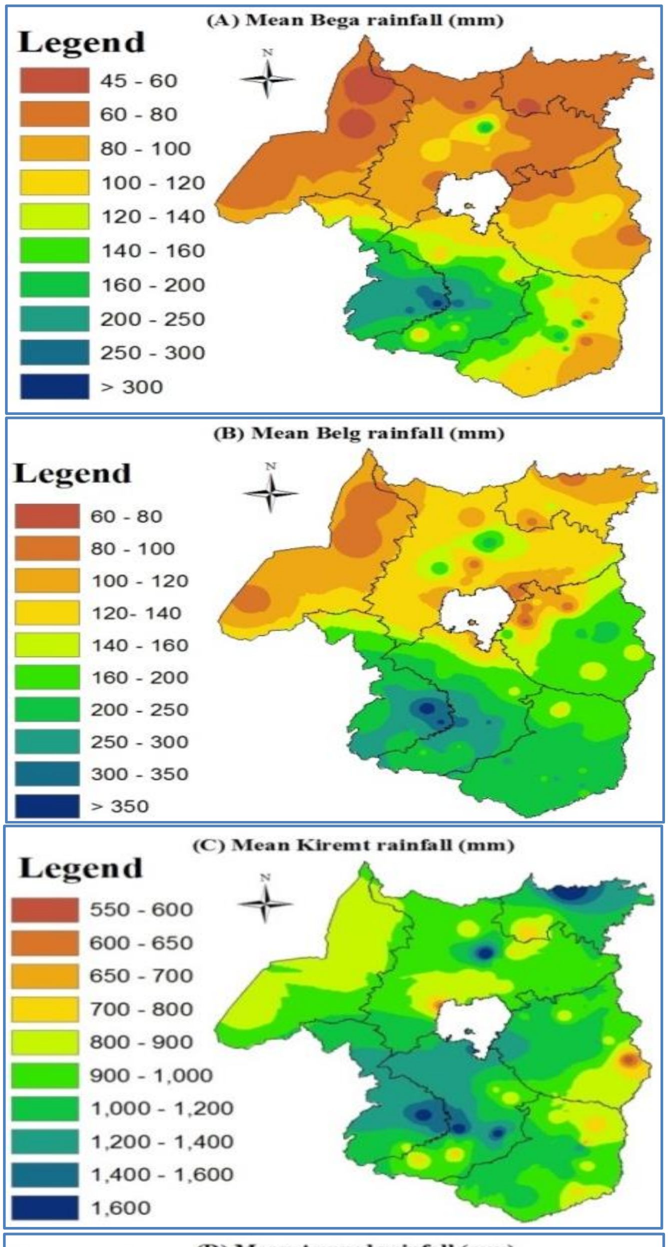


Figure 2. Climatology of rainfall over western Amhara during *Bega (A)*, *Belg (B)*, *Kiremt (C)*, and Annual (D)

5.1.1. Descriptive statistics of rainfall

Table 1. Descriptive statistics of rainfall over western Amhara (areal) form 1989-2018 years

Season	Ext. max	Ext. min	Range	Mean	SDV	CV%
Bega	327.4	45.5	281.9	119.5	57.85	48.42
Belg	383.1	73.3	309.8	184.4	68.59	37.2
Kiremt	1999.6	572.3	1427.3	1047.9	304.1	29.02
Annually	2468.1	778.3	1689.8	1355.9	376.94	27.79

Over the last 30 years, the variability (in terms of area) of precipitation for all stations in the *Belg* season has been high (37.2%) (Table 1). Similarly, over the past 30 years, there has been a considerable fluctuation in rainfall at all stations (areal) during the *Bega* season (48.42%) (Table 1). While the area-based variability of precipitation over the past 30 years for all stations throughout the *Kiremt* season has been moderate (29.02%) (Table 1). The extreme maximum (Ext max) and extreme minimum (Ext min) *Kiremt* total rainfall measurements were 1999.6 mm and 572.3 mm, respectively, in Tikildingay and Arebgebya. The extreme annual rainfall measurements (Ext max and Ext min) for Gundel and Delgi, respectively, show that they are 2468.1 mm and 778.3 mm. The average annual rainfall in the region (western Amhara) is 1355.9 (Table 1). This result is almost similar to that of [39], in which the long-term mean annual rainfall of the region is 1165.2 mm.

Generally, rainfall in the western Amhara region shows moderate inter-annual variability, as shown by the coefficients of variation (Table 1). It demonstrated that the rainfall in *Belg* and *Bega* varies significantly more (>30%) than the rainfall in *Kiremt*, where the coefficient of variation is less than 30% (Table 1). Bewket [29] examined rainfall data from 12 stations in drought-prone areas of Ethiopia's Amhara Region and came to a similar conclusion: *Belg* and *Bega's* rainfall is more variable than *Kiremt's* rainfall.

Table 2. Significant test over western Amhara

Rainfall	Z- value	Sen's slope	P- value
Bega	-0.7	0.04	1.00
Belg	0.6	0.97	0.5
Kiremt	0.34	0.82	0.73
Annual	0.21	-0.25	0.83

The rainfall condition over western Amhara is increasing without significance in the annual, *Belg*, and *Kiremt* periods, but during *Bega* the rainfall condition shows a non-significant decreasing trend in western Amhara (Table 2). Similar to the present study, [29] in drought-prone areas of the Amhara region (Northwestern Ethiopia), [31] in central, northern, and northwestern Ethiopia, and [62] in the central Ethiopian highlands, [63] in south Omo zone, Ethiopia and Conway [28] in the northeastern Ethiopian highlands agreed that there is no significant and clear trend in the annual rainfall pattern. Addisu [41] also demonstrated that annual rainfall amounts showed a general decreasing trend in the Lake Tana Sub-basin. The standardization of rainfall over western Amhara (areal) in the *Bega* season slightly decreased by 0.0116 every year. During the *Belg* Season, the rainfall was almost similar year to year from 1989 to 2018 and incresed by 0.0078 every year (Figure3). Similarly, the standardization of *Kiremt* and annual rainfall over western Amhara (areal) reveals allmost similar pattern from year to year from 1989 to 2018 (Figure 3).

5.1.2. Areal Rainfall Progress (Standardization) over western Amhara

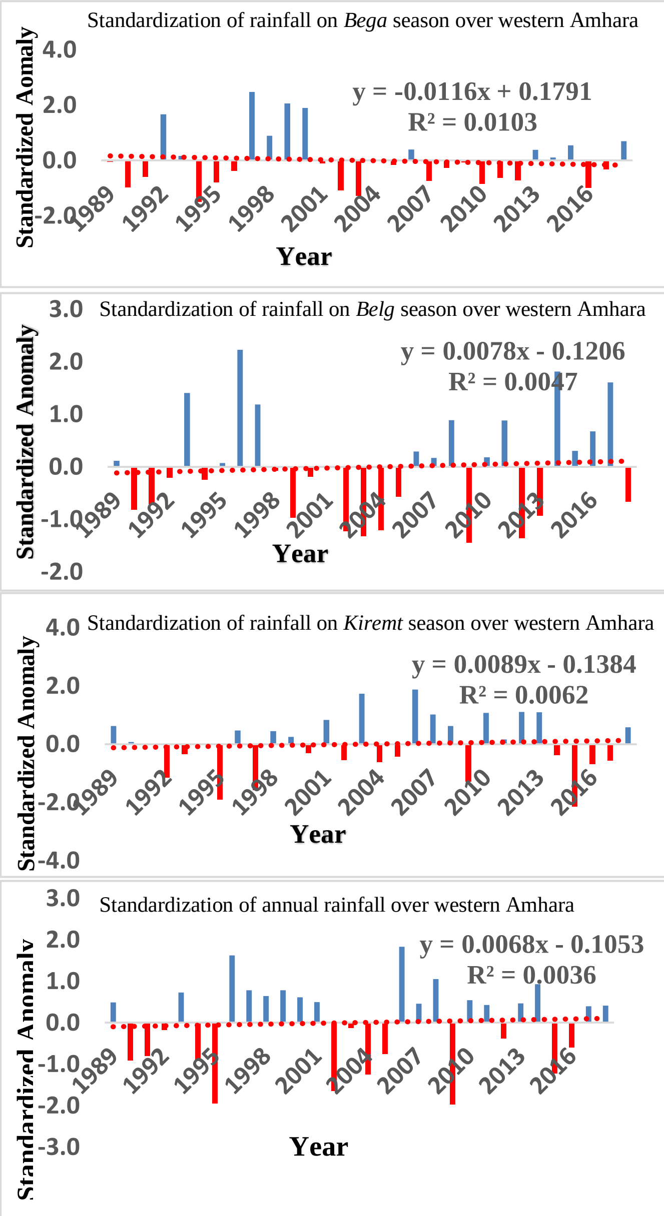
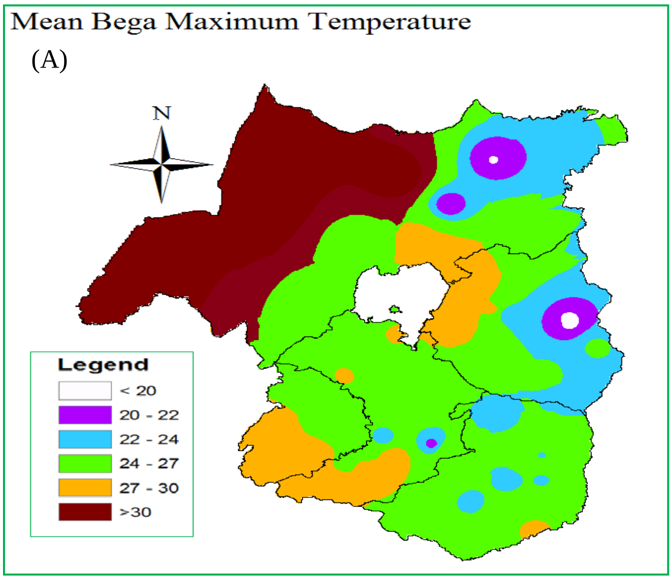


Figure 3. Areal rainfall standardization during *Bega* (A), *Belg* (B), *Kiremt* (C), and Annual (D) over western Amhara

5.2. Climatology of Maximum Temperature

Bega season temperature below 22°C have been observed in some highland western Amhara regions, including Debark, Ambagiorigis, N/mewucha, and Dingayber (Figure 4). The highest temperature reported during *Bega* season was 24-27°C in the majority of West Gojjam, East Gojjam, and a small portion of the South Gondar zone. There have been reports of 27–30°C in several areas of the Awi zone, including East Gojjam and South Gondar. Conversely, during the *Bega* season, high temperature of over 30 degrees Celsius have been reported in the northwest regions of North Gondar. Similarly, maximum temperature in eastern sections of western Amhara have been reported to range from 24 to 27°C, with the exception of a few pocket regions. While the majority of West Gojjam and Awi, certain areas of North Gondar, South Gondar, and East Gojjam have also reported high temperature between 27 and 30°C. Furthermore, during the *Belg* season, temperature have been recorded above 30 degrees Celsius in the northwestern portion of North Gondar, as well as in certain areas of Awi, West Gojjam, and South Gondar (Figure 4). The majority of western Amhara has recorded high temperature between 20 and 27°C during the *Kiremt* season. However, there have also been reports of lower than 20°C maximum temperature in certain areas. On the other hand, temperatures in northwestern Gondar have been recorded above 30 °C (Figure 4). The maximum temperature for most of western Amhara is measured between 24 and 27°C annually. There have also been reports of yearly maximum temperature of less than 22°C in a few areas, particularly in the eastern region of western Amhara. In addition, temperature between 27 and 30°C have been recorded in a few places in Awi, West Gojjam, South Gondar, and North Gondar, as well as in the northwestern portion of the North Gondar zone (such as Quara, Metema, Metema Yohannes, and Sanja). In the study area the maximum temperature reaches its highest level during *Belg* season (Feb- May) but, decrease again to lowest temperature level in *Kiremt* season (June-September). This results in line with studies Taye [2]. This study has various advantages: such as, to implement climate change adaptation strategies such as climate advisory services, water conservation practices, supplemental and deficit irrigation, and drought-tolerant and early-maturing crops to cope with the risks associated with temperature and rainfall variability.



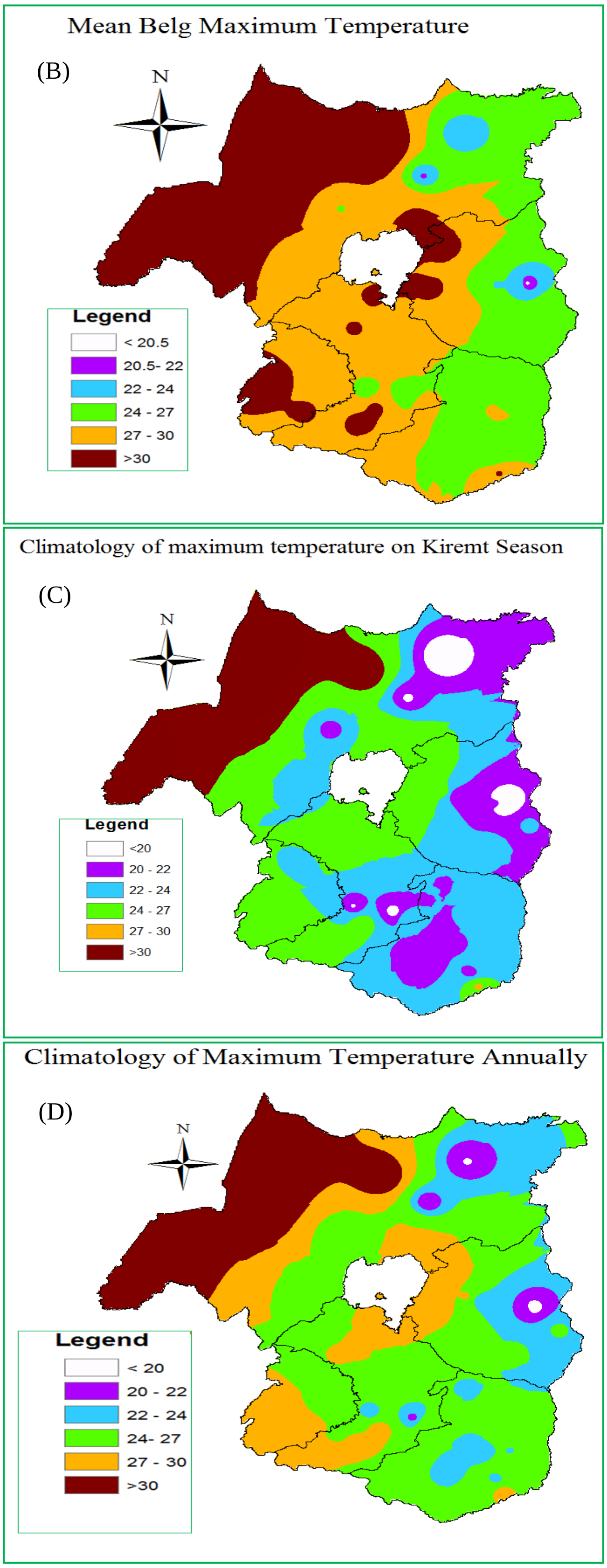


Figure 4. Climatology of western Amhara on maximum temperature during *Bega (A), Belg (B), Kiremt (C),* and Annual

The standardization of maximum temperature over western Amhara (areal) on *Bega* and *Belg* Season increased by 0.0628°c and 0.0815°c, respectively, every year from 1989 to 2018 (Figure 5). Similarly, area maximum temperature standardization during the *Kiremt* (C) season and annual (D) increased by 0.0928°c and 0.0905°c, respectively (Figure 5). So, the maximum temperature over western Amhara has shown a highly increased trend from 1989 to 2018. Maximum temperatures in western Amhara reveal increasing trend.

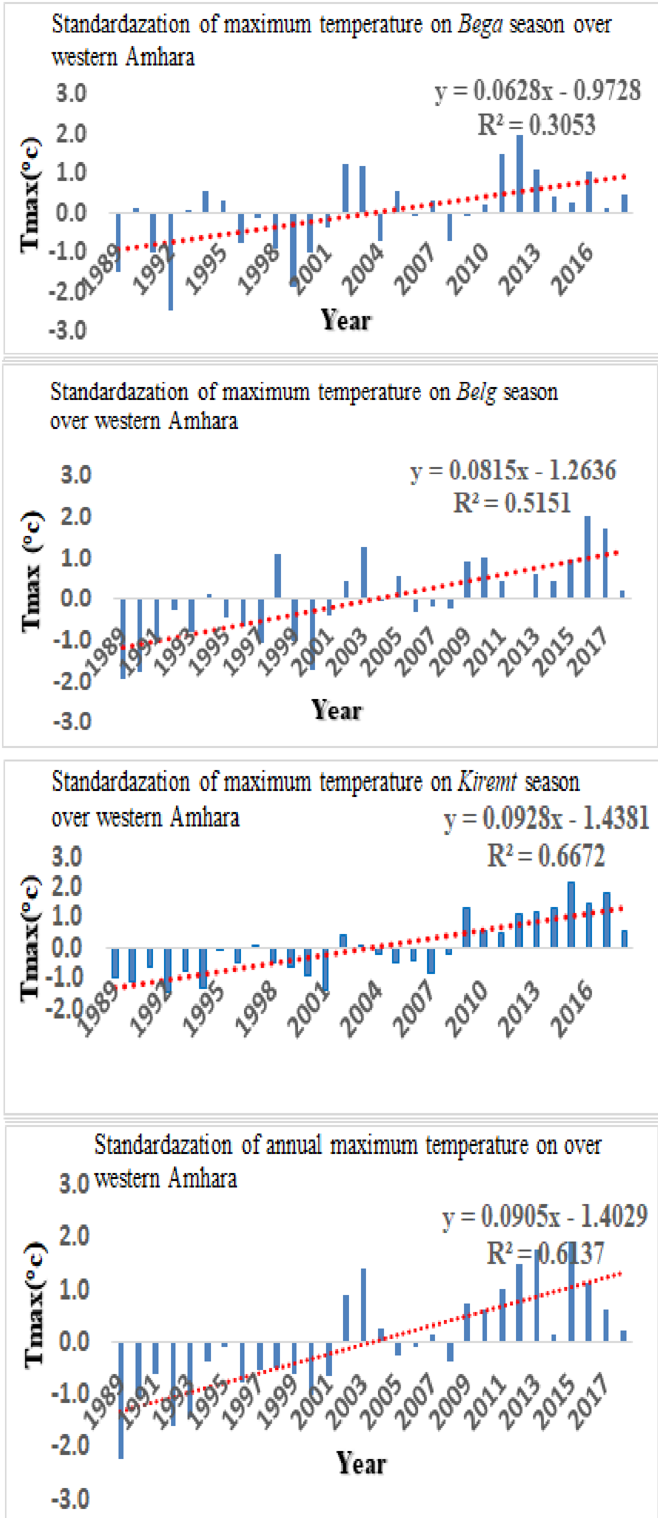
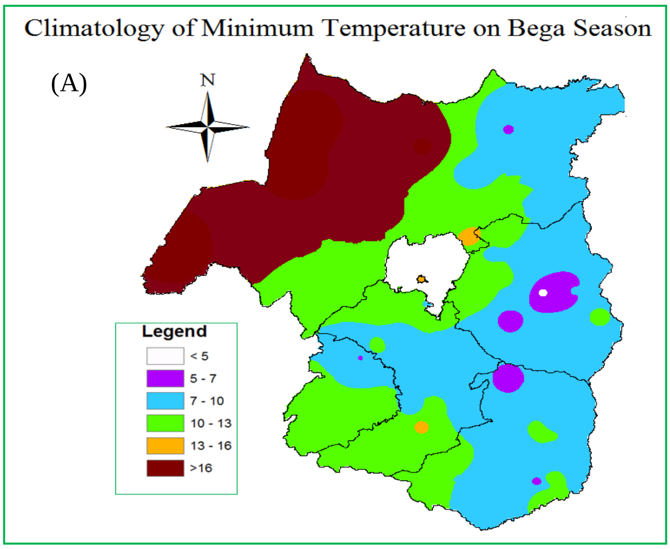
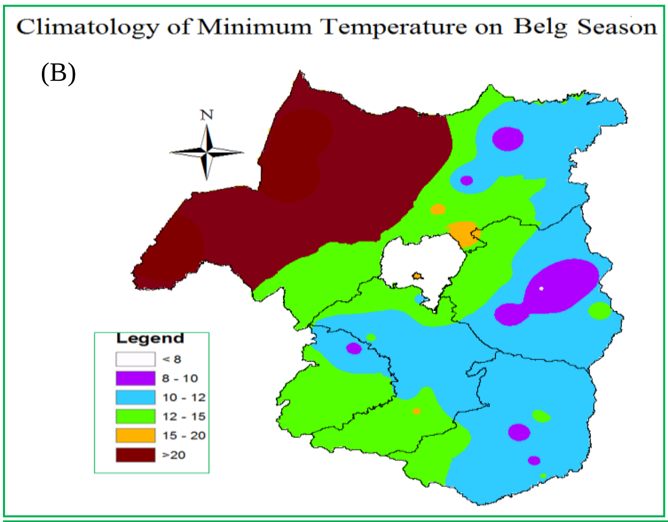


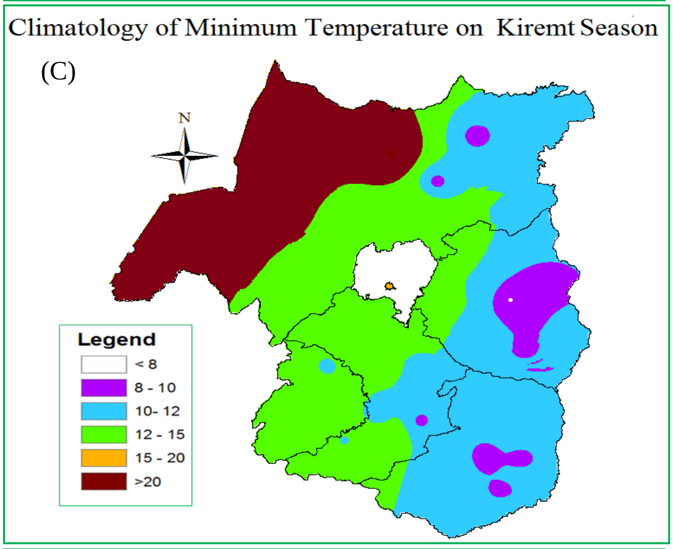
Figure 5. Areal maximum temperature standardization during *Bega (A), Belg* (B), *Kiremt (C)*, and Annual (D)

5.3. Climatology of Minimum Temperature

During *Bega* season, minimum temperature in the majority of western Amhara have been reported between 7 and 13 degrees Celsius (Figure 6). In contrast, several low-lying places (Funteselam, Dekestifanos, and Gondar zuria) have reported 13–16^{o}c. Certain highland areas in South Gondar and East Gojjam, such as Gassay, Debark, Agergent, Mekaneyesus, Motta, and Yetnora, have fewer than 7^{o}c. During the *Bega* season, temperature over 16^{o}C have been observed in the northwestern region of western Amhara. Similarly, during *Belg* season, minimum temperature have been reported in most of western Amhara, ranging from 10 to 15 degrees Celsius (Figure 6). Furthermore, during *Belg* season, minimum temperature of over 20 degrees Celsius have been observed in the north-western region of western Amhara. Nonetheless, less than 10^{o}C has been recorded in a few select places of South Gondar, East Gojjam, North Gondar, and Awi, such as Gassay, Debark, Ambagiorgis, Dangila, N/mehucha, Agergent, M/Eyessus, Diguastion, and Yetnora. *Kiremt* temperature in the majority of western Amhara have been reported to range from 10 to 15 degrees Celsius (Figure 6). On the other hand, less than 10^{o}C has been recorded in a few particular areas in South Gondar, East Gojjam, North Gojjam, and West Gojjam, including Gassay, Debark, Ambagiorgis, Nefas mewucha, Simada, Agergent, Dingayber, Yetnora, Bichena, and Diguastion (Figure 6). Furthermore, in the northwestern region of western Amhara, such as Quara, Metema, and Sanja, the minimum temperature of over 20^{o}C have been observed. The annual minimum temperature in most of western Amhara has been reported between 10 and 15 degrees Celsius (Figure 6). Nonetheless, the annual minimum temperature in nearly all of South Gondar's highland areas, as well as in some specific areas of East, North, and West Gojjam, Awi, such as Gassay Debark, Ambagiorgis, Dangila, Adet, Digustion, Yetnora, D/work, and Bichenia, has been recorded to be lower than 10^{o}C. Furthermore, records show that the annual minimum temperature in Quara, Metema, Sanja, and other northwestern Amhara areas ranges from 15 to 20 degrees Celsius (Figure 6).







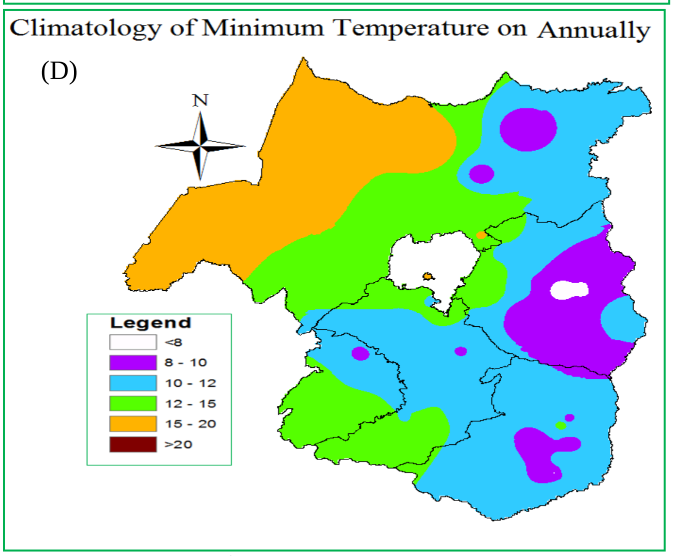


Figure 6. Climatology of western Amhara on minimum temperature during *Bega (A), Belg (B) Kiremt* (C), and (D), Annual

The standardization of minimum temperature over western Amhara (areal) on *Bega* and *Belg* season increased by 0.0815oc and 0.0787oc , respectively, every year from 1989 to 2018 (Figure 7). Similarly, area minimum temperature standardization during the *Kiremt* (C) season and annual (D) increased by 0.0707°c and 0.0886°c, respectively (Figure 7). So, the minimum temperature over western Amhara has shown a highly increased trend from 1989 to 2018. The mean annual maximum and minimum temperature vary from year to year, as depicted in Figures 6 and 7, respectively. When compared to the 1990s, the 2000s were the warmest decade.

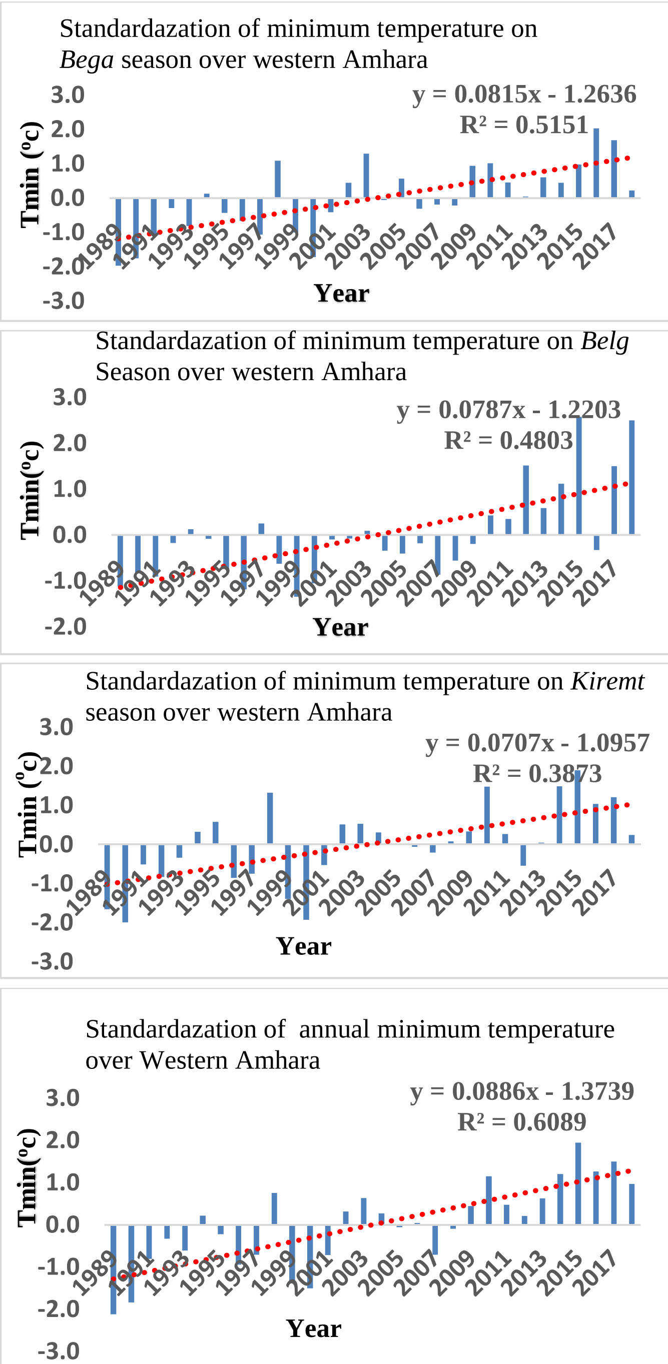


Figure 7. Areal minimum temperature standardization during *Bega (A), Belg (B), Kiremt*(C), and Annual (D)

6. Conclusion and Recommendation

In this study, the rainfall distribution and trends in *Bega*, *Belg*, *Kiremt*, and annually over western Amhara were assessed. After a thorough examination of the monthly rainfall patterns for 75 stations in the study area, were observed variability in rainfall distribution among the various zones: Awi (1600–2000 mm), East Gojjam (1200–1400 mm), West Gojjam (1200–1400 mm), West Gondar (1000–1100 mm), Central Gondar (1100–1100 mm), North Gondar (1200–1400 mm), and South Gondar (1200–1400 mm) annually.

Awi zone has a relatively good rainfall distribution, and some parts of the zone, like Enjibara and Tilili, recorded greater than 2200 mm of annual rainfall. On the other hand, the West Gondar zone has the lowest rainfall distribution in the region. I also analyzed seasonal patterns and trends in temperature over western Amhara. Among those zones, South Gondar, East Gojjam, and North Gondar have a lower average temperature than West Gondar and Awi zones in all seasons. The West Gondar zone is warmer in all seasons, and its average temperature annually exceeds 25°c. Western Amhara experienced an increase in the maximum and minimum temperature annually by 0.0905°c and 0.0886°c, respectively. Similarly, the rainfall trend slightly increased across years during the *Belg* season, *Kiremt*, and annual, but not during the *Bega* season.

Generally, the rainfall distribution and amount have increased from *Bega* to *Kiremt* over western Amhara. Similarly, the temperature pattern shows increased intensity from *Bega* to *Belg*, a slight decrease in *Kiremt*, and an increase again at the end of the *Kiremt* season. Based on our findings, I recommend further research be undertaken on the impact of climate change and variability on different socio-economic activities in the community. Development planners should design strategies and plans by taking into account declining *Bega* rainfall and increasing temperature impacts on rural livelihoods.

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Conflicts of Interest
The authors declare no conflict of interest.

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References

[1] F. Fentaw, D. Hailu, and A. Nigussie, "Trend and Variability Analysis of Rainfall & Stream Flow Series at Tekeze River Basin, Ethiopia," Vol.**8**, No.**11, 2017.**

[2] M. Taye, F. Zewdu, and D. Ayalew, "Characterizing the climate system of Western Amhara, Ethiopia: a GIS approach," *Am. J. Res. Commun.*, Vol.**1**, No.**10**, pp.**319–355, 2013.**

[3] R. Bhavani, S. Vordzorgbe, M. Owor, and F. Bousquet, "Status of disaster risk reduction in the sub-Saharan Africa region," The World Bank, **2008.**

[4] J. Chang *et al.*, "Reservoir operations to mitigate drought effects with a hedging policy triggered by the drought prevention limiting water level," *Water Resour. Res.*, Vol.**55**, No.**2**, pp.**904–922, 2019.**

[5] J. R. Jones, J. S. Schwartz, K. N. Ellis, J. M. Hathaway, and C. M. Jawdy, "Temporal variability of precipitation in the Upper Tennessee Valley," *J. Hydrol. Reg. Stud.*, Vol.**3**, pp.**125–138, 2015.**

[6] H. Mahmood and M. Furqan, "Oil rents and greenhouse gas emissions: spatial analysis of Gulf Cooperation Council countries," *Environ. Dev. Sustain.*, Vol.**23**, No.**4**, pp.**6215–6233, 2021.**

[7] IPCC, "Intergovernmental Panel on Climate Change(IPCC) releases its next report titled "Climate Change 2021: the Physical Science Basis," *No Title*, **2021.**

[8] M. Hulme, R. Doherty, T. Ngara, M. New, and D. Lister, "African climate change: 1900-2100," *Clim. Res.*, Vol.**17**, No.**2**, pp.**145–168, 2001.**

[9] T. Schellnhuber, R. Pachauri, and blair, *Avoiding dangerous climate change*. Cambridge University Press, **2006.**

[10] U. Adhikari, A. P. Nejadhashemi, and S. A. Woznicki, "Climate change and eastern Africa: a review of impact on major crops," *Food Energy Secur.*, Vol.**4**, No.**2**, pp.**110–132, 2015**, doi: 10.1002/fes3.61.

[11] Z. Meseret and S. Belay, "Spatial and Temporal Variability in Temperature and Rainfall over Mecha area, Ethiopia," Vol.**5**, **2019.**

[12] M. O. Kisaka, M. Mucheru-Muna, F. Ngetich, J. Mugwe, D. Mugendi, and F. Mairura, "Rainfall variability, drought characterization, and efficacy of rainfall data reconstruction: case of Eastern Kenya," *Adv. Meteorol.*, vol. 2015, **2015.**

[13] C. Michael, "World Wide Fund for Nature Climate Change Scientist," *Gland Switz.*, **2006.**

[14] G. M. Geremew, S. Mini, and A. Abegaz, "Spatiotemporal variability and trends in rainfall extremes in Enebsie Sar Midir district, northwest Ethiopia," *Model. Earth Syst. Environ.*, vol. 6, no. 2, pp. 1177–1187, Jun. 2020, doi: 10.1007/s40808-020-00749-2.

[15] D. Mesfin, B. Simane, A. Belay, J. W. Recha, and U. Schmiedel, "Assessing the adaptive capacity of households to climate change in the Central Rift Valley of Ethiopia," *Climate*, Vol.**8**, No.**10**, pp.**106, 2020.**

[16] A. Alemayehu, M. Maru, W. Bewket, and M. Assen, "Spatiotemporal variability and trends in rainfall and temperature in Alwero watershed, western Ethiopia," *Environ. Syst. Res.*, Vol.**9**, No.**1**, pp.**22**, Dec. **2020**, doi: 10.1186/s40068-020-00184-3.

[17] W. Bewket, "Rainfall variability and crop production in Ethiopia: Case study in the Amhara region," in *Proceedings of the 16th international conference of Ethiopian studies*, Norwegian University of Science and Technology Trondheim, Norway, pp.**823–836, 2009.**

[18] R. Masika, *Gender, development, and climate change*. Oxfam, 2002.

[19] P. Döll, "Impact of climate change and variability on irrigation requirements: a global perspective," *Clim. Change*, Vol.**54**, No.**3**, pp.**269–293, 2002.**

[20] U. Kim and J. J. Kaluarachchi, "Climate change impacts on water resources in the upper blue Nile River Basin, Ethiopia 1," *JAWRA J. Am. Water Resour. Assoc.*, Vol.**45**, No.**6**, pp.**1361–1378, 2009.**

[21] W. Bewket, "Rainfall variability and crop production in Ethiopia: Case study in the Amhara region," in *Proceedings of the 16th international conference of Ethiopian studies*, Norwegian University of Science and Technology Trondheim, Norway, **2009**, pp. 823–836.

[22] M. Teshome, "Perceived Impact of Climate Change on Crop Yield Trend in Denbia Woreda of Amhara Region, Northwest Ethiopia," *MOJ Ecol. Environ. Sci.*, Vol.**2**, No.**7**, **2017**, doi: 10.15406/mojes.2017.02.00047.

[23] A. Alemayehu and W. Bewket, "Local spatiotemporal variability and trends in rainfall and temperature in the central highlands of Ethiopia," *Geogr. Ann. Ser. Phys. Geogr.*, Vol.**99**, No.**2**, pp.**85–101, 2017.**

[24] W. Bewket, "Rainfall variability and crop production in Ethiopia: Case study in the Amhara region," in *Proceedings of the 16th international conference of Ethiopian studies*, Norwegian University of Science and Technology Trondheim, Norway, pp.**823–836, 2009.**

[25] T. T. Deressa, R. M. Hassan, and C. Ringler, "Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia," *J. Agric. Sci.*, Vol.**149**, No.**1**, pp.**23–31, 2011.**

[26] P. Döll, "Impact of climate change and variability on irrigation requirements: a global perspective," *Clim. Change*, Vol.**54**, No.**3**, pp.**269–293, 2002.**

[27] W. H. Cheung, G. B. Senay, and A. Singh, "Trends and spatial distribution of annual and seasonal rainfall in Ethiopia," *Int. J. Climatol. J. R. Meteorol. Soc.*, Vol.**28**, No.**13**, pp.**1723–1734, 2008.**

[28] D. Conway, "Some aspects of climate variability in the north east Ethiopian Highlands-Wollo and Tigray," *Sinet Ethiop. J. Sci.*, vol. 23, no. 2, pp.**139–161, 2000.**

[29] W. Bewket and D. Conway, "A note on the temporal and spatial variability of rainfall in the drought-prone Amhara region of Ethiopia," *Int. J. Climatol.*, vol. 27, no. 11, pp.**1467–1477, 2007**, doi: 10.1002/joc.1481.

[30] G. Kiros, A. Shetty, and L. Nandagiri, "Analysis of variability and trends in rainfall over northern Ethiopia," *Arab. J. Geosci.*, vol. 9, no. 6, pp.**451, 2016**, doi: 10.1007/s12517-016-2471-1.

[31] Y. Seleshi and U. Zanke, "Recent changes in rainfall and rainy days in Ethiopia," *Int. J. Climatol. J. R. Meteorol. Soc.*, Vol.**24**, No.**8**, pp.**973–983, 2004.**

[32] M. Osman and P. Sauerborn, "A preliminary assessment of characteristics and long term variability of rainfall in Ethiopia–Basis for sustainable land use and resource management," *Chall. Org. Farming Sustain. Land Use Trop. Subtrop. Dtsch. Tropentag*, 2002.

[33] Y. Seleshi and G. Demaree, "Rainfall variability in the Ethiopian and Eritrean highlands and its links with the Southern Oscillation Index," *J. Biogeogr.*, pp.**945–952, 1995.**

[34] M. R. Jury and C. Funk, "Climatic trends over Ethiopia: regional signals and drivers," *Int. J. Climatol.*, Vol.**33**, No.**8**, pp.**1924–1935, 2013.**

[35] J. Verdin, C. Funk, G. Senay, and R. Choularton, "Climate science and famine early warning," *Philos. Trans. R. Soc. B Biol. Sci.*, Vol.**360**, No.**1463**, pp.**2155–2168, 2005.**

[36] D. Mengistu, W. Bewket, and R. Lal, "Recent spatiotemporal temperature and rainfall variability and trends over the Upper Blue Nile River Basin, Ethiopia," *Int. J. Climatol.*, Vol.**34**, No.**7**, pp.**2278–2292, 2014**, doi: 10.1002/joc.3837.

[37] A. Alemayehu and W. Bewket, "Local spatiotemporal variability and trends in rainfall and temperature in the central highlands of Ethiopia," *Geogr. Ann. Ser. Phys. Geogr.*, Vol.**99**, No.**2**, pp.**85–101, 2017.**

[38] M. A. Degefu and W. Bewket, "Variability and trends in rainfall amount and extreme event indices in the Omo-Ghibe River Basin, Ethiopia," *Reg. Environ. Change*, Vol.**14**, No.**2**, pp.**799–810, 2014**, doi: 10.1007/s10113-013-0538-z.

[39] D. Ayalew, K. Tesfaye, G. Mamo, B. Yitaferu, and W. Bayu, "Variability of rainfall and its current trend in Amhara region, Ethiopia," *Afr. J. Agric. Res.*, Vol.**7**, No.**10**, pp.**1475–1486, 2012.**

[40] M. Gedefaw *et al.*, "Innovative Trend Analysis of Annual and Seasonal Rainfall Variability in Amhara Regional State, Ethiopia," *Atmosphere*, Vol.**9**, No.**9**, pp.**326, 2018**, doi: 10.3390/atmos9090326.

[41] S. Addisu, Y. G. Selassie, G. Fissha, and B. Gedif, "Time series trend analysis of temperature and rainfall in lake Tana Sub-basin,

Ethiopia," *Environ. Syst. Res.*, Vol.**4**, No.**1**, pp.**25**, **2015**, doi: 10.1186/s40068-015-0051-0.
[42] B. Getachew, "Trend analysis of temperature and rainfall in South Gonder zone, Anhara Ethiopia," *J. Degraded Min. Lands Manag.*, Vol.**5**, No.**2**, pp.**1111, 2018.**
[43] S. Rosell and B. Holmer, "Rainfall change and its implications for belg harvest in south wollo, ethiopia," *Geogr. Ann. Ser. Phys. Geogr.*, Vol.**89**, No.**4**, pp.**287–299**, **2007**, doi: 10.1111/j.1468-0459.2007.00327.x.
[44] M. K. Zegeye, K. T. Bekitie, and D. N. Hailu, "Spatio-temporal variability and trends of hydroclimatic variables at Zarima Sub-Basin North Western Ethiopia," *Environ. Syst. Res.*, Vol.**11**, No.**1**, pp.**27**, **2022**, doi: 10.1186/s40068-022-00273-5.
[45] M. M. Alemu and G. T. Bawoke, "Analysis of spatial variability and temporal trends of rainfall in Amhara region, Ethiopia," *J. Water Clim. Change*, Vol.**11**, No.**4**, pp.**1505–1520**, **2020**, doi: 10.2166/wcc.2019.084.
[46] S. Mesfin, A. A. Adem, A. Mullu, and A. M. Melesse, "Historical Trend Analysis of Rainfall in Amhara National Regional State," in *Nile and Grand Ethiopian Renaissance Dam*, A. M. Melesse, W. Abtew, and S. A. Moges, Eds., in Springer Geography. , Cham: Springer International Publishing, pp.**475–491, 2021.** doi: 10.1007/978-3-030-76437-1_25.
[47] NMSA, "Climatic and agroclimatic resources of Ethiopia," *Natl Meteorol Serv Agency Ethiop. Meteorol Res Rep Ser*, Vol.**1**, No.**1**, pp.**1–137, 1996.**
[48] W. Degefu, "Some aspects of meteorological drought in Ethiopia," *Drought Hunger Afr. Denying Famine Future*, pp. 23–36, 1987.
[49] A. Mesay, "The Onset," *Cessat. Dry Spells Small Rainy Seas. Belg Ethiop. Addis Ababa*, **2006**.
[50] C. Funk *et al.*, "Recent drought tendencies in Ethiopia and equatorial-subtropical eastern Africa," *Wash. DC FEWS-NET*, **2005**.
[51] C. McSweeney, M. New, and G. Lizcano, "UNDP climate change country profiles: Ethiopia," *Profiles 52 Ctries.*, **2008**.
[52] T. Gissila, E. Black, D. I. F. Grimes, and J. M. Slingo, "Seasonal forecasting of the Ethiopian summer rains," *Int. J. Climatol.*, Vol.**24**, No.**11**, pp.**1345–1358**, Sep. **2004**, doi: 10.1002/joc.1078.
[53] T. Haile, "A case study of seasonal forecasting in Ethiopia," *WMO Reg. Assoc. I*, pp. 53–76, 1987.
[54] D. Pedgley, "The red sea convergence zone," *Weather*, Vol.**21**, No.**11**, pp.**394–406, 1966.**
[55] D. Korecha and A. G. Barnston, "Predictability of June–September Rainfall in Ethiopia," *Mon. WEATHER Rev.*, Vol.**135, 2007.**
[56] Z. T. Segele and P. J. Lamb, "Characterization and variability of Kiremt rainy season over Ethiopia," *Meteorol. Atmospheric Phys.*, Vol.**89**, No.**1–4**, pp.**153–180**, Jun. **2005**, doi: 10.1007/s00703-005-0127-x.
[57] B. Kassahun, "Weather systems over Ethiopia," in *Proc. First Tech. Conf. on Meteorological Research in Eastern and Southern Africa, Nairobi, Kenya, UCAR*, pp.**53–57, 1987.**
[58] A. Belay *et al.*, "Analysis of Climate Variability and Trends in Southern Ethiopia," *Climate*, Vol.**9**, No.**6**, pp.**96**, **2021**, doi: 10.3390/cli9060096.
[59] A. E. Harka, N. B. Jilo, and F. Behulu, "Spatial-temporal rainfall trend and variability assessment in the Upper Wabe Shebelle River Basin, Ethiopia: Application of innovative trend analysis method," *J. Hydrol. Reg. Stud.*, Vol.**37**, pp.**100915, 2021.**
[60] M. G. Kendall, "Rank correlation methods.," **1975.**
[61] H. B. Mann, "Nonparametric tests against trend," *Econom. J. Econom. Soc.*, pp.**245–259, 1945.**
[62] D. Conway, C. Mould, and W. Bewket, "Over one century of rainfall and temperature observations in Addis Ababa, Ethiopia: RAINFALL AND TEMPERATURE IN ADDIS ABABA," *Int. J. Climatol.*, Vol.**24**, No.**1**, pp.**77–91**, **2004**, doi: 10.1002/joc.989.
[63] B. Kassahun and C. Hamer, "Effects of climate variability in South Ari woreda, South Omo zone, Ethiopia," *Int. J. Sci. Res. Multidiscip. Stud.*, Vol.**6**, No.**12**, pp.**42–52, 2020.**

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