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Research Article

Analysis of Historical Climate Change and Variability in the Selected districts of Eastern Ethiopia

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Abstract

Climate change and variability pose major challenges to agriculture and food security in Eastern Ethiopia, where rainfed farming dominates. This study assessed long-term rainfall and temperature trends across districts in East and West Hararghe Zones using daily data from 1992–2022 obtained from the National Meteorological Agency. Statistical methods, including Mann-Kendall and Sen's slope, were applied to detect trends, while precipitation concentration index, anomaly index, and coefficient of variability measured rainfall variability. Results indicated non-significant increasing rainfall trends in Haramaya, Tulo, Chiro, and Gurawa, while Mieso (-4.46 mm/year) and Babile (-3.40 mm/year) showed non-significant decreasing trends ($P > 0.05$). This study analyzed historical climate variability across districts in East and West Hararghe Zones, Oromia Region, Ethiopia. Kiremt rainfall exhibited increasing trends over past decades, though not statistically significant ($P>0.05$). Belg rainfall showed non-significant decreases in all districts except Chiro. Rainfall anomaly analysis revealed positive anomalies in Chiro, Tulo, Gurawa, and Haramaya, while negative anomalies were observed in Mieso and Babile districts. Rainfall patterns demonstrated high inter-annual variability, with delayed onset, early cessation, and frequent dry spells, directly impacting crop growth and yield. Spatial differences highlighted localized vulnerabilities, with lowland areas experiencing more frequent droughts compared to highland zones. Results further indicated significant increases in mean annual and seasonal maximum and minimum temperatures, with pronounced warming during the main cropping season. Over the past thirty years, most districts experienced rising temperatures, rainfall fluctuations, increased water stress, and notable El Niño events in 2015, 2016, and 2017. These findings provide critical insights for climate adaptation strategies.

Keywords: *Adaptation strategy, Climate change, Drought, Variability, Wheat.*

1. Introduction

Climate changes is currently the most pressing issue facing the world due to its detrimental effects on a number of different fronts (Gebrawayni *et al.*, 2020). Climate change and climate variability have been named the biggest environmental concerns of the twenty-first century, and they will persist over the next few years all over the planet. Global climate change negatively impacts both industrialized and developing nations, posing significant challenges to people's survival and livelihoods (World Bank, 2023). Some researchers project an increase in global temperatures ranging from 1.4 to 5.8°C in the year 2100, along with an anticipated rise in sea levels of approximately 10 cm (IPCC, 2007). The increase in global temperatures is linked to the ongoing emissions of greenhouse gases, which continue to escalate (Bouts et al., 2024). Mokonen (2021) reported that temperatures increased by 0.85°C between 1980 and 2012, indicating a warming trend in the average global temperature. Indicators of these changes include rising temperatures, an increase in irregular rainfall, severe floods, and frequent droughts. Over the years 1880 to 2012, there was a 0.85°C warming trend in the average world temperature (Mekonen, 2021).

Currently, climate change and variability are the primary drivers of food security challenges in the developing world, as the majority of these nations depend on rain-fed agriculture for their economies (IPCC, 2019). Similarly, Kirby et al., (2016) reported that developing country primarily relies on subsistence farming and lacks the technical expertise and financial resources necessary to mitigate the adverse effects of climate change. Precipitation and Temperatures are the most fundamental climate parameters that determine the environmental condition of a particular region (Panda and Sahu, 2019). Precipitation is the most significant climatic variable, as it is directly associated with several natural hazards, including droughts and flooding (Reda et al., 2021).

Ethiopia ranks among the top ten nation's most vulnerable to the climate change impact among the East Africa which is characterized by significant climatic extremes primarily due to variations in rainfall and temperature across different regions and periods (Mohammed and Yimam, 2022). Over the past decade, studies have indicated that Ethiopia's mean minimum and maximum temperatures have increased by approximately 0.25°C and 0.1°C, respectively (World Bank, 2019). Furthermore, it is projected that by 2050, the mean temperature in the country will increase by 1.7 to 2.1°C (Tadege, 2007). Earlier research has shown fluctuating results in annual and seasonal rainfall patterns (Gebre, 2014), with both rainfall and temperature trends exhibiting significant regional variations (Zerga and Gebeyehu, 2016). In the past, the country faced unpredictable rain in some years and completes failure seasonal rainfall in another year that is linked to climate changes and variability (MoFAN, 2018).

The Variation of the precipitation and temperature have adverse impacts on agriculture and food security in Ethiopia for instance, in 1983/84 main rainfall season failure resulted in a 9.7 percent decline in GDP, with agricultural production decreasing by 21% (USAID, 2019). In Ethiopia, droughts linked to El Niño exacerbated food insecurity in both the 2015/16 and 2017 periods, and projections indicate that by 2045, climate change may lead to a 10% decrease in Ethiopia's GDP (USAID, 2016). This atypical pattern of extreme climate events has serious consequences for both local communities and the environment in the region (Worku et al., 2019). Therefore, the analysis of long-term changes in climatic variables is a fundamental task in studies on climate change detection. The understanding of past and recent climate change has received considerable attention through improvements and extensions of numerous datasets and more sophisticated data analyses across the globe (Kumar *et al.,* 2010).

Eastern Ethiopia has been affected by the impact of climate change, induced drought, erratic rainfall reduction, and increasing temperature (Shumetie and Alemayehu, 2018). Mulugeta et al. (2017) reported that Eastern Ethiopia and South-eastern Ethiopia parts of Ethiopia were severely affected by recurrent drought, erratic rainfall, and increasing temperature conditions between 1981-2009. February to May (Belg) rainy season was lower than the mean by rainfall amount in the region was up to 60%. As a result, cereal yield was estimated to be below average with crop failures reported in some areas (FAO, 2019). Most smallholder farmers in these areas operate on small plots of land and rely on traditional agricultural methods (Tezeze et al., 2019). Additionally, the region's susceptibility to climate variability and changes brought diseases and pests in both direct and indirect ways (EHAO, 2018). In this context, smallholder farmers who encounter risks associated with climate change, which favor disease outbreaks, pest infestations, post-harvest losses, and extreme weather events (Sisay et al., 2019). The principal challenges faced by smallholder farmers include indirect costs, crop failures, livestock deaths, water scarcity, and a reduction in biodiversity due to ongoing climatic events such as droughts, floods, and erratic rainfall (Mulugeta et al., 2018).

Despite the recognition of climate risks, localized and long-term analyses of rainfall and temperature trends remain limited in Eastern Ethiopia. Most existing studies focus on national or regional scales, leaving critical knowledge gaps at the district level where adaptation decisions are made. Understanding historical climate variability at finer spatial scales is essential for identifying vulnerable areas, guiding agricultural planning, and informing climate-resilient strategies. Therefore, this research aims to analysis the trends and variability of rainfall and temperature in the selected district of East and West Hararghe Zone Oromia, Ethiopia.

2. Materials and Methods

2.1. Description of the study areas

The study was conducted in the selected districts of East and West Hararghe Zones. The selected districts were Haramaya, Gurawa, and Babile, which were selected from East Hararghe Zone, whereas Mieso, Chiro, and Tulo districts were selected from West Hararghe Zone.

Haramaya, located in the semi-arid tropical zone, experiences bimodal rainfall, high relative humidity, and average annual temperatures ranging from 6°C to 12°C. Its climate is characteristic of a sub-humid, mid-altitude agro-climatic zone (Simeret et al., 2020; Nigussie et al., 2014).

The Gurawa district is situated between 9°22'N and 41.8'E, with an elevation ranging from 2,460 meters above sea level. The short rainy season typically begins in March and concludes in May, while the long rainy season occurs between June and September (EARO, 2019).

Babile district, located in the East Hararghe Zone of Oromia, has a semi-arid climate characterized by two wet seasons and a prolonged dry season. It receives an average annual rainfall of 731 mm and experiences a high temperature of 28.8°C (Teka et al., 2023).

Chiro District is one of the districts in West Hararghe zone has an average annual rainfall of 927 mm, with yearly temperatures ranging from 12.72°C to 27.87°C. with geographic coordinates of 9°05′N and 40°52′E and an elevation of 1,784 meters above sea level. The area's altitude varies from 1,784 to 1,850 meters above sea level (Tashome et al., 2022).

Similarly, Tulo District, also in West Hararghe, has latitude and longitude coordinates of 9°32'33 and an elevation of 1,845 meters above sea level. This district receives a mean annual rainfall of 1,700 mm. The maximum and minimum yearly temperatures typically range from 26°C to 28.5°C and from 13.7°C to 15.0°C, respectively (ICPAC, 2020).

Mieso, located in the West Hararghe administrative zone, is notable for its mixed agriculture, which includes both animal husbandry and crop cultivation. The district experiences a bimodal rainfall pattern, with a brief rainy season from March to April and a longer rainy season from July to September. The average annual rainfall is 790 mm, with maximum and minimum temperatures ranging from 26.8°C to 30.6°C and from 13.7°C to 15.0°C, respectively (Mokenen et al., 2021).

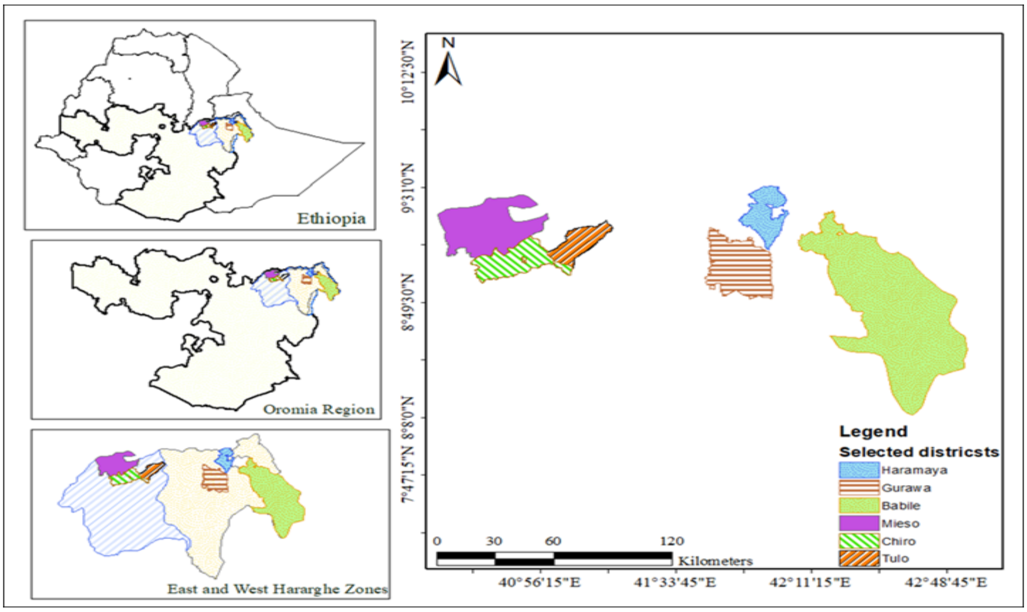


Figure 1: Map of study areas

2.2. Sources of data

Maximum and minimum temperatures and rainfall from 1992 to 2022 for selected districts in the East and West Hararghe Zones, namely, Mieso, Chiro, Tulo, Haramaya, Gurawa, and Babile, have been obtained from the National Meteorological Agency of Ethiopia. The dataset contains fewer than 10% missing values and meets the necessary climate parameters (Seleshi and Zanke, 2004).

Table 1: Climate parameters of selected districts in East and West Hararghe, Ethiopia

No	Districts	Latitude (°N)	Longitude (°E)	Elevation (m.a.s.l)	Data Period
1	Mieso	9.2	40.8	1331	1992-2022
2	Chiro	9.1	40.9	1784	1992-2022
3	Tulo	9.16	41	1845	1992-2022
4	Haramaya	9.4	42.0	2040	1992-2022
5	Gurawa	9.1	41.8	2460	1992-2022
6	Babile	9.1	42.2	1646	1992-2022

Data of study area °N to north degree, °E=east degree, m.a.s. l=meter above sea level

2.3. Data quality control

Detecting Outliers: The emphasis on identifying outliers' suspicious data points has been a crucial aspect of developing climatic databases (Gonzalez-Rouco et al., 2001). Outliers are defined as values that exceed a certain threshold in specific time-series data, which can affect the detection of inhomogeneity (Gonzalez-Hidalgo et al., 2009). For data that is not normally distributed, such as rainfall, the Tukey fence method is recommended for removing outliers (Ngongondo et al., 2011).

$$[Q1 - 1.5 * IQR, Q3 + 1.5 * IQR] \dots \dots \dots \dots \dots \dots \dots \dots \dots . \dots . eq\ (1)$$

In this context, Q1 and Q3 represent the lower and upper quartile values, respectively. A distance of 1.5 is regarded as a standard deviation from the average. The interquartile range, known as IQR, is also relevant here. Observations that fall outside the Tukey fence are identified as outliers. For this analysis, such outliers were capped at a threshold value equivalent to ±1.5×IQR.

Homogeneity test: The second step of the quality control process involved the analysis of homogeneity. In this particular study, a cumulative deviation test was employed for absolute testing, utilizing the station's data due to its lower demands in application and interpretation. This method is commonly used in climatology to detect homogeneities in meteorological time series (Ngongondo et al., 2011; Kang and Yusuf, 2012). Buishand (1982) noted that tests for homogeneity can be based on adjusted partial sums or cumulative deviations from the mean, as outlined below:

$$S_0^* = 0\ and\ S_K^* = \sum_{i=1}^{K}(y - \bar{y}),\ K=1\ldots n \ldots\ldots eq\ (2)$$

Where S*K represents the partial sum of the specified series. In the absence of a meaningful change in the mean, the difference between them is expected to vary around zero. The importance of the change in the mean was assessed using the 'rescaled adjusted range' R, defined as the difference between the maximum and minimum values.
These values are adjusted by the standard deviation of the sample:

$$R = (MaxS_K^* - MinS_{K/SD}^* \ldots\ldots eq\ (3)$$

The critical value for R/n was determined by Buishand (1982), and for a sample size of n=30, the values are 1.5 and 1.4 for the 5% and 10% significance levels, respectively.

2.4. Methods of Data Analysis

2.4.1. Analysis Trend of Climate Parameters

The Mann-Kendall testing: The Mann-Kendall test (MK test) is a non-parametric statistical method used to detect trends in time series data without assuming whether the trend is linear or non-linear (Yue et al., 2002). This test is particularly advantageous in the presence of outliers, as it relies on the signs of differences (+ or -) rather than the actual values of the random variables. Consequently, the trends identified by the MK test are less influenced by outliers (Asfaw et al., 2018; Ketema and Siddaramaiah, 2020). The test statistic for Mann–Kendall is expressed as:

$$S = \sum_{i-1}^{n-1}\sum_{j=i+1}^{N} sgn(xj + xi) \ldots\ldots eq\ (4)$$

The Mann-Kendall test statistic (S) is utilized for identifying trends within sequential data values (xi and xj) in time series analysis. A positive value of S signifies an upward trend, while a negative S value indicates a downward trend. The mathematical expression of the statistic can be represented as follows

$$sign\ (xj - xi) = \begin{cases} 1\ if(xj - xi) > 0 \\ -1\ if(xj - xi) < 0 \\ 0\ if(xj - xi) = 0 \end{cases} \ldots\ldots eq\ (5)$$

The Mann-Kendall test uses statistics xi and xj to analyze data trends. Positive values show an increase while negative values show a decrease. Variance of S accounts for tied x values,

$$Var(s) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} ti(ti-1)(2ti+5)}{18} \dots \dots \dots \dots eq(6)$$

Where m is the number of tied groups in the data set and t_i is the number of data points in the ith tied group. For n larger than 10, Zs approximates the standard normal distribution and is computed as

$$ZS = \begin{cases} \frac{s-1}{\sqrt{var(s)}}\ if\ s > 0 \\ \frac{s+1}{\sqrt{var(s)}}\ ifs < 0 \\ \frac{s-1}{var(s)}\ ifs = 0 \end{cases} \ldots\ldots eq\ (7)$$

Evaluation of a statistically significant trend was carried out using the Zs value. In a two-tailed trend test, the null hypothesis Ho should be accepted if $|Zs|<1-\sigma/2$ at a specified significance level. The significance level represents the likelihood of mistakenly rejecting the null hypothesis when it is true (Type I error). Significance levels are 0.05 (5%), 0.01 (1%), and 0.10 (10%). The critical value ($Z1-\sigma/2$) is derived from the standard normal distribution and indicates the extent of deviation a data point must have from the mean to fall into the rejection region for the null hypothesis.

Sen's slope estimator: This method is applied when a linear trend is assumed, allowing for the measurement of changes over time. It can effectively handle missing data and remains robust against outliers or significant errors (Karp ouzos et al., 2010). The analysis was performed on annual, seasonal (Kiremt and Belg), and monthly totals (from January to December) using the aforementioned procedure. Consequently, the magnitude is typically assessed using Sen's test (Sen, 1968), which is also a non-parametric method and is computed as:

$$Ti = \frac{xi-xk}{j-k} \ldots\ldots\ldots\ldots\ldots\ldots \text{eq (8)}$$

Where x_j and x_k represent data values at time j and k, respectively.

2.4.2. Analysis of Rainfall Variability

Coefficient of Variation (CV %)

Rainfall data were classified according to the coefficient of variation (CV) and standard deviation (δ). Based on the CV classification, the values were separated into three categories: low variability (< 20%), moderate variability (20-30%), and high variability (> 30%). The consistency of the rainfall was evaluated using Reddy's classification system, which spans from very high stability (<10) to less stable situations (>40).

$$CV = \frac{\delta}{\mu} * 100 \ldots\ldots\ldots\ldots \text{eq(9)}$$

Precipitation Concentration Index (PCI)

In this study, the precipitation concentration index (PCI) was chosen because it simply computes highly helpful in determining the level of seasonal and annual precipitation regimes across climates at different times over the year (Zhang et al., 2019). The PCI measures the degree of uniformity or concentration of rainfall throughout the months. Historical precipitation data is evaluated by using the Precipitation Concentration Index (PCI) and the Precipitation Anomaly Index, which are computed based on a specific formula established by (De Luis et al., 1999).

$$PCI = \frac{\sum_{t-1}^{12} pi^2}{(\sum_{t-1}^{12} pi^2)} \ldots\ldots\ldots\ldots \text{eq(11)}$$

The Precipitation Concentration Index (PCI) classifies the distribution of monthly rainfall into three categories: uniform (<10), high concentration (11-20), and very high concentration (>21). Positive precipitation anomalies signify rainfall levels exceeding the average, while negative anomalies indicate rainfall below average expectations (De-Luis et al., 2011).

Rainfall Anomaly Index (RAI): The index evaluates the discrepancies between the total annual rainfall for a given year and the long-term average rainfall figures, thereby facilitating the identification of exceptionally dry and wet years within the dataset.

$$RAi = \frac{pt - Pm}{\sigma} \ldots\ldots\ldots\ldots \text{eq(12)}$$

The equation $RAi = (Pt - Pm)/\delta$ represents the normalized rainfall total for station i in year j. Positive anomalies suggest above-average rainfall, and negative suggest below-average.

3. Result and Discussion

3.1. Analysis of Annual Rainfall across the Districts (1992-2022)

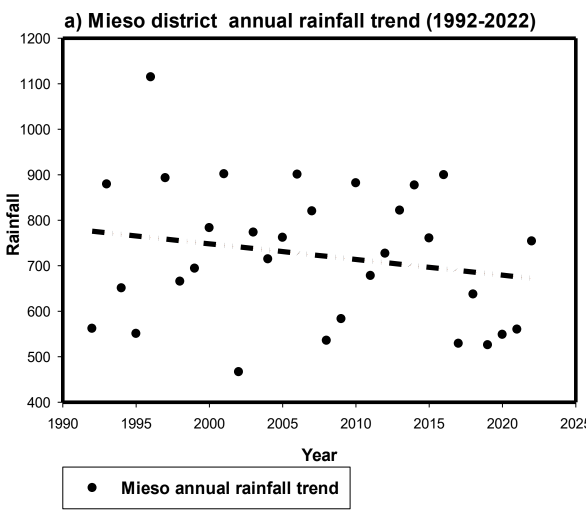
Descriptive Statistics of mean annual rainfall totals revealed considerable variation over the past thirty years in the study areas. The highest annual rainfall, 909.7 was recorded in the Tulo district, followed closely by Gurawa, which received mm 902.2 mm (Table 2). Conversely, the lowest mean annual rainfall 736.3 mm was observed in Mieso districtat. This variation can be attributed to geographical differences, localized climate patterns, and altered weather conditions resulting from climate change. Asfaw et al. (2018) corroborated these findings, emphasizing the notable variability and unpredictability of climate trends in Ethiopia. Inter annual variations in rainfall can negatively impact crop yields, particularly for wheat yields. The coefficient of variation (CV) for annual rainfall varied as follows: 33.7% for Mieso, 28.8% for Chiro, 26.5% for Tulo, 29.3% for Haramaya, 35.7% for Gurawa, and 32.5% for Babile (Table 2). These results indicate that Mieso, Gurawa, and Babile districts exhibited higher inter annual variability (CV > 30) as compared to Chiro, Tulo, and Haramaya over the past three decades in the study areas (Table 2, Figure 2). This indicates a lack of consistent trends in annual total rainfall from 1992 to 2022. In agreement with these findings, Zhang et al. (2019) reported significant precipitation variability and patterns across different districts of Ethiopia, which show fewer consistencies over time.

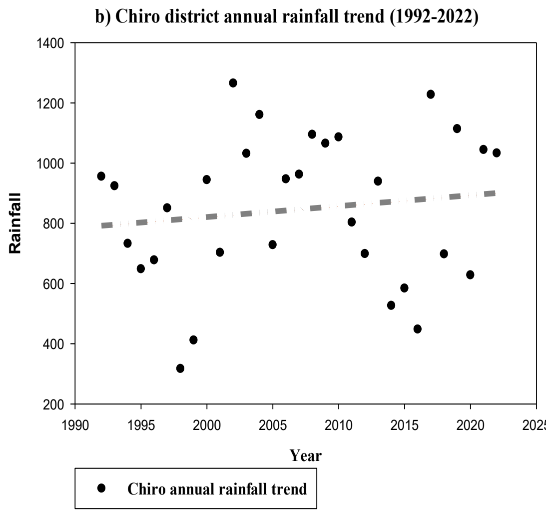
Statistically significant increasing annual rainfall for Haramaya (0.250 mm per year), while the increasing trends observed in Chiro (0.075 mm) and Tulo (0.01 mm per year) were not statistically significant (Table 2). In contrast, Mieso (-4.46 mm per year) and Babile (-3.40 mm per year) experienced decreasing trends, which were also not statistically significant ($P < 0.05$). This result aligns with the findings of Negash and Eshetu (2016), which reported a decrease of 16.08 mm per year at the Chida station and an increase of 6.26 mm per year at the Butajira station. Furthermore, there was an increase in annual rainfall of 3.93 mm per year from 1982 to 2012 (Abiy et al., 2014). Figure 2 illustrates the varied annual rainfall trends across the districts, highlighting some areas with upward trends while others experienced downward shifts. These findings are consistent with research conducted by Alemu et al. (2020), which emphasized the pronounced fluctuations and unpredictability of seasonal and annual climate trends in Ethiopia, potentially affecting crop production and household food security. According to the East Hararghe Agricultural Office (2023), the zone was affected by drought for three consecutive years (2015, 2016, and 2017) due to the climate change-induced El Niño in 2015. This finding also corroborates the FAO's report, which indicated that the extreme drought caused by El Niño in 2015 left 10.2 million people food insecure in Ethiopia, including those in the East Hararghe Zone (FAO, 2016).

Table 2: Descriptive statistics for annual rainfall total (mm) at each district (1992-2022)

Station	Mini (mm)	Max (mm)	Mean	SD	CV (%)	Zs	P-v	β
Mieso	366.5	1237.3	736.3	174.3	33.7	-1.019	0.307	-4.46
Chiro	422.7	1163.2	904.9	265.0	28.8	0.577	0.563	3.61
Tulo	444.35	1280.96	909.7	268.0	26.5	0.067	0.945	2.021
Haramaya	514.9	1180.05	797.0	260.5	29.3	1.296	0.066	6.63
Gurawa	704.2	1100.3	902.2	110.5	35.7	1.999	0.089	2.23
Babile	380.3	1114.3	747.5	178.1	32.5	-0.357	0.721	-3.401

Note: SD stands for Standard Deviation, CV refers to Coefficient of Variation, r denotes Correlation, Min. represents Minimum, Max. Signifies Maximum, and * indicates significance at the 5% probability level according to the Mann-Kendall test.





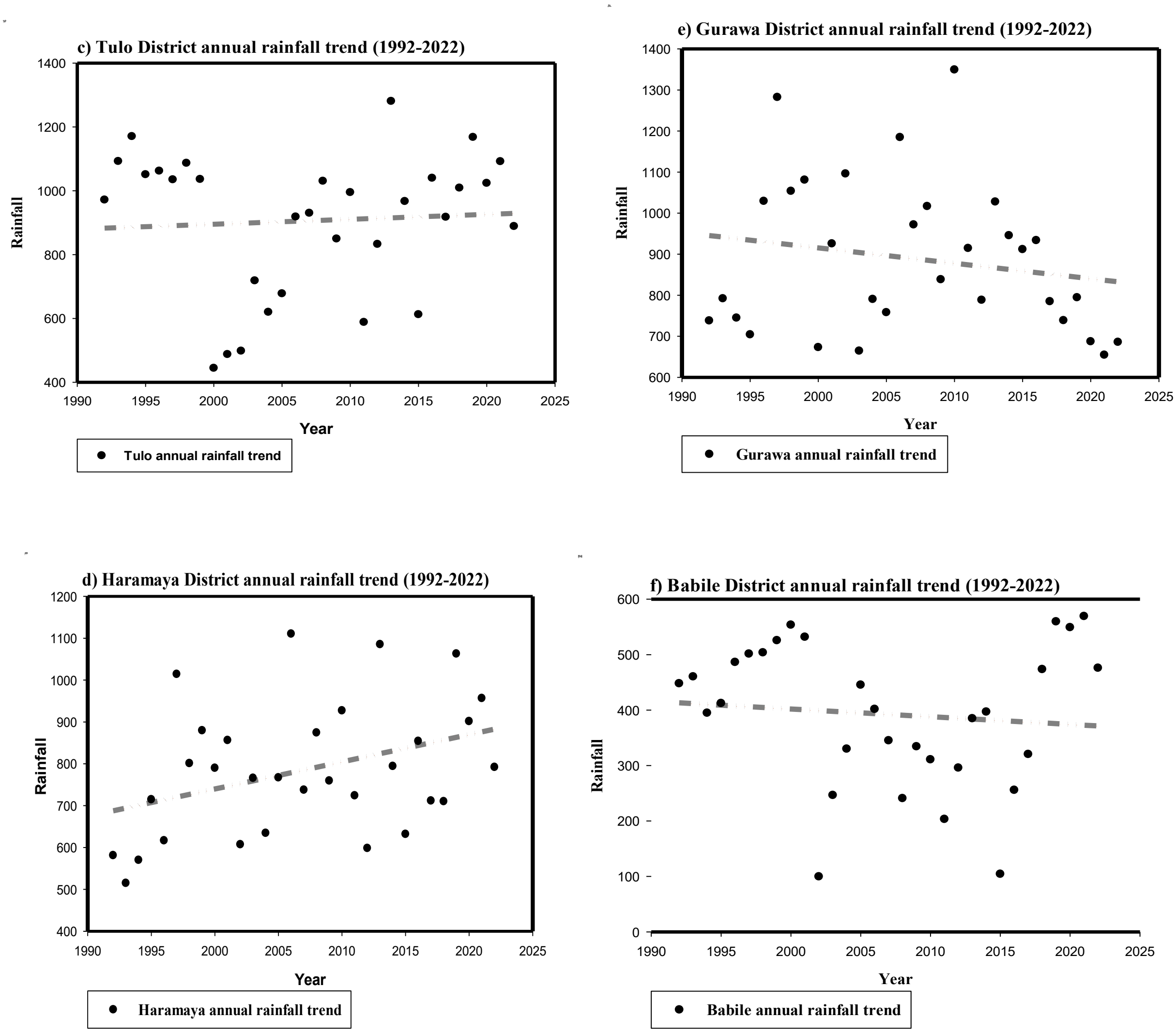


Figure 2: Trends of annual rainfall across the districts.

3.2. Analysis of Seasonal Rainfall

3.2.1. Analysis of Kiremt rainfall (June to September)

The mean total precipitation during the Kiremt season was varied among districts in the East and West Hararghe Zones over past thirty years. Gurawa experienced the highest average rainfall at 495.3 mm, while Mieso recorded the lowest at 312.7 mm over study periods. This indicates significant seasonal and spatial variation in Kiremt rainfall, which is influenced by the topographic diversity of Eastern Ethiopia. On the other hand, the benefit from the increasing rainfall amount in the Kiremt season might be counterbalanced by the increasing temperature that could alter the crop growth and development.

High variability in Kiremt rainfall (coefficient of variation > 30) was observed in Mieso, Chiro, and Babile; whereas Tulo, Haramaya, and Gurawa exhibited moderate rainfall trends were observed throughout the study period. These fluctuations in Kiremt rainfall adversely affect crop production in the study areas. During the study period, Kiremt rainfall was generally more consistent compared to the Belg season. This finding aligns with the research of Gari et al. (2018) and Moges and Bhat (2021), who reported that the coefficient of variation for Kiremt is notably lower than that of the Belg and Bega seasons.

The Mann-Kendall tests revealed an increasing trend in Kiremt rainfall in the Chiro, Tulo, Haramaya, and Gurawa districts; however, these increasing trends were not statistically significant ($P > 0.05$) (Table 3). In contrast, Mieso and Babile experienced decreasing trends in Kiremt rainfall, which also lacked statistical significance (Table 3). These findings underscore the complex dynamics of rainfall patterns in Eastern Ethiopia, which are crucial for agricultural planning and water resource management. This variability in rainfall poses challenges for smallholder farmers in Eastern Ethiopia who depend on rain-fed agriculture. In line with these results, Negash and Eshetu (2016) reported a general increase in Kiremt seasonal rainfall in the Southern Nations, Nationalities, and Peoples' Region (SNNPRS), despite some stations indicating declines. Similarly, Belay et al. (2014) noted increases in both annual and Kiremt rainfall, while the Belg rainfall at the Butajira station decreased from 1975 to 2009.

Table 3: Mankendll trend test of kiremt rainfall (mm) trends across the station (1992-2022)

Station	Mini	Max	Mean	SD	CV (%)	Zs	P-value	β
Mieso	155.8	542.4	312.7	102.24	33.6	-0.23	0.811	-3.46
Chiro	133.9	593.6	363.8	127.5	34.1	0.06	0.94	1.07
Tulo	197.2	677.1	488.8	149.5	30.2	0.13	0.89	1.93
Haramaya	215.9	552.2	384.7	87.2	25.5	2.70	0.076	4.85
Gurawa	377.7	598.3	495.3	93.06	19.3	0.47	0.63	1.31
Babile	71.7	673.3	372.3	129.46	32.9	-0.23	0.81	-1.39

Note: SD stands for Standard Deviation, CV represents Coefficient of Variation, Min denotes Minimum, Max signifies Maximum, and * indicates significance at the 5% probability level according to the Mann-Kendall test. P-v = Probability value, and β = Sen's slope

3.2.2. Analysis of Belg Rainfall (February-May)

The Belg season, which occurs from February to March, is critical for crop development in the study areas. An analysis of Belg rainfall over the study periods revealed that the Tulo district had the highest average total rainfall at 302.2 mm, followed closely by Gurawa at 279.83 mm (Table 4). Decreasing trends in Belg rainfall were observed across all districts, including Tulo (-0.019 mm/year), Haramaya (-6.68 mm/year), Gurawa (-0.303 mm/year), and Babile (-0.073 mm/year). However, these declines were not statistically significant for most districts. In contrast, the decrease in Belg rainfall in Gurawa was statistically significant ($P < 0.05$) (Table 4). Such decreased Belg season rainfall could have adversely affected agriculture and related activities in the Zones. For instance, long maturing cultivars of sorghum and maize have been seriously affected due to reduction of short (Belg) season rainfall in the Eastern Ethiopia. In contrast, increasing trends of Belg (February-May) were observed in the Mieso and Chiro districts (Table 4). The lowest mean Belg rainfall 224.9 mm was recorded from the Mieso while Babile's precipitation was slightly higher at 237.7 mm. Consequently, these two districts are more vulnerable to drought and lower agricultural production compared to the other four districts in eastern Ethiopia.

The analysis of inter seasonal variability during the Belg season indicated that all study areas experienced high variability (CV > 30%) in Belg rainfall. Leta (2023) noted that in the Metekele Zone of Ethiopia, rainfall variability was classified based on coefficient of variation (CV) values; a CV above 30% indicates high variability, while a CV below 20% indicates low variability. This reinforces the concept that a higher CV indicates greater fluctuations in rainfall patterns.

Table 4: Mankendll trend test of Belg rainfall (mm) trends across the station (1992-2022)

Station	Mini (mm)	Max (mm)	Mean	SD	CV (%)	Zs	P-value	β
Mieso	97.1	535	224.9	82.8	36.16	1.087	0.27	0.139
Chiro	67.7	538.4	249.6	125.4	50.2	0.12	0.26	0.14
Tulo	136.3	572.7	302.2	85.19	30.2	-0.135	0.89	-0.019
Haramaya	117.3	386	233.4	68.86	32.9	-0.52	0.59	-6.68
Gurawa	108.3	450.3	279.8	112.01	40.3	-2.37	0.017*	-0.30
Babile	26.3	457.3	237.7	109.35	46.7	-0.56	0.5748	-0.073

Note: SD =refers to Standard deviation; CV stands for Coefficient of variation Min denotes Minimum, Minimum, and Max represents Maximum. (*) indicates significance at the 5% probability. P-v =Probability value, while β =Sen's slope.

3.3. Precipitation Concentration Index (PCI)

The annual distribution of mean Precipitation Concentration Index (PCI) values for each station from 1992 to 2022 is presented in Table 5. Uniform rainfall concentration (PCI < 10) has never been recorded at any location in the study areas. The analysis of the precipitation concentration index for Mieso, with a PCI of 15.24, indicates a moderate level; this suggests that rainfall is concentrated in certain months while being scarce in others. Chiro reflects irregular annual precipitation patterns, where rainfall may be concentrated in specific months and limited in others. Irregular rainfall patterns were also observed in Tulo. Gurawa experienced very wet conditions, while several years between 2002 and 2015 exhibited very dry conditions in the study area (see Table 5).

The annual PCI values for Haramaya, Gurawa, and Babile demonstrate moderate rainfall distributions. These findings align with research conducted by Apaydin et al. (2006) and Zamani et al. (2018), which highlight the importance of precipitation variability for effective water resource management, soil erosion prevention, and conservation strategies. Trend of the PCI value index for the Gurawa and Haramaya districts shows an increasing trend that is not statistically significant ($P < 0.05$) due to heavy rainfall and uneven topography. These factors may lead to soil erosion, waterlogging, reduced fertility, and lower crop yields, highlighting a consistent seasonal variation in precipitation patterns in the study areas. This phenomenon may contribute to sensitive soil erosion and slope instability (M. De Lius et al., 2010; Zamani, 2018). Similarly, Megersa et al. (2022) found that changing planting dates and implementing soil and water conservation measures positively and significantly influence adaptation strategies.

The Kiremt Precipitation Concentration Index (PCI) values for various districts indicate high precipitation concentrations during the Kiremt season: Tulo (38.5), Chiro (33.1), Gurawa (33.7), and Haramaya (32.9) face significant risks due to the uneven distribution of rainfall, which complicates water management and agricultural planning. Additionally, Babile (31.5) and Mieso (27.5) also exhibit considerable irregularity in precipitation, indicating variable rainfall patterns over the study period. The PCI for Kiremt is generally lower than that of Belg, suggesting a more uniform distribution of rainfall across the months within this season (Table 5). In agreement with this result, Dereje et al. (2023) and Abebe et al. (2023) reported that the PCI for Kiremt rainfall ranges from 29% to 48%, indicating significant irregularity in precipitation distribution across different districts, including Babile and Mieso. The study reveals that all districts are influenced by variable rainfall patterns, with Kiremt showing lower PCI values than Belg (Table 5). Significant variability was observed in the Mieso, Haramaya, and Babile districts, while moderate variability was noted in Chiro, Tulo, and Gurawa.

Table 5: Mean annual and seasonal precipitation concentration index (PCI) OF the study areas

Period	Test	Mieso	Chiro	Tulo	Haramaya	Gurawa	Babile
Annual	PCI	15.24	16.5	16.74	14.491	14.25	14.04
	SD	1.7367	9.38	1.71	2.007	1.97	3.17
	CV	32.2%	26.9%	12.2%	33.9%	23.10%	38.9%
	P-value	0.62	0.57	0.067	0.099	0.74	0.82
	Slope	0.018	0.0075	0.071	0.045	0.092	0.12
Kiremt	PCI	27.5	33.1	38.5	32.9	33.7	31.5
	SD	9.4	8.2	11.5	19.4	16.9	19.33
	CV	31.7	25.87%	28.3%	30.5	22.9%	31.7%
	P-value	0.66	0.23	0.51	0.092	0.72	0.07
	Slope	0.003	0.012	1.098	0.311	0.43	0.06
Belg	PCI	33.65	41.5	40.5	35.6	39.75	32.1
	SD	23.7%	15.7%	21.95	23.9%	12.8%	11.6%
	CV	37.1%	32.5%	29.6%	33.7	27.21%	36.3%
	P-value	0.554	0.0821	0.073	0.05	0.072	0.05
	Slope	-0.0350	0.0481	0.054	0.034	0.011	-0.025

Note: Zs = Mann–Kendall test; RAI = Rainfall Anomaly Index; PCI = Precipitation Concentration Index; * = indicates significance at $P < 0.05$

3.4. Analysis of Rainfall Anomaly Index (RAI)

The Rainfall Anomaly Index (RAI) serves as a crucial tool for assessing shifts in rainfall patterns over time, particularly within the specified study areas. The results of the mean annual rainfall anomalies from 1992 to 2022 in selected wheat-growing districts of Eastern Ethiopia are as follows: Mieso (0.08), Chiro (0.19), Tulo (0.17), Haramaya RAI (0.09), Gurawa RAI (0.13) and Babile RAI (0.02) (Table 6). The findings indicate that all districts fall within the range of 0 to 2, suggesting that these areas experienced humid conditions throughout the study period (Table 6). Notably, the mean RAI values for Chiro (0.19) and Tulo (0.17) are the highest among the districts, indicating that these areas received significantly more rainfall compared to the other four districts (Table 5). This increased rainfall could enhance agricultural productivity but also raises concerns regarding flooding and water management. The mean anomaly index for Gurawa (0.13) further suggests relatively favorable conditions for agriculture compared to historical norms.

The annual rainfall anomaly indices for Mieso, Chiro, Tulo, Haramaya, and Gurawa indicated moderately wet weather in the years 2021 (1.6), 1996 (1.76), 1993 (1.62), and 2020 (1.75), respectively (Fig. 3a and 3b). In 2014, all districts experienced wet conditions, with a particularly high anomaly index of 2.4 recorded in 2019. Conversely, negative anomalies were observed in eastern Ethiopia during 2015, 2016, and 2017, which could be indicative of El Niño conditions (Figures 3a and 3b). Similarly, negative anomalies in the Babile and Mieso districts have increased since the early 2000s, adversely affecting food security in eastern Ethiopia. However, trend analysis revealed that these declining trends were not statistically significant over the study periods (Table 6). It was also observed that the frequency occurrence of below normal rainfall at all districts has been increased in the last decade. In this regard 40-60% of the year in the recent decade had recorded below long term average in all districts. In agreement with these results, the IDP (2019) reported that East and West Hararghe frequently experience below-average rainfall, resulting in drought conditions that leave over a million people reliant on emergency relief assistance. The CSA (2019) also noted that the East and West Hararghe zones in Ethiopia are classified as food deficit areas due to fluctuations in rainfall and temperature.

Table 6: Descriptive statistics and Mann-Kendall of Rainfall Anomaly Index (RAI)

Parameters	Statistics	Mieso	Chiro	Tulo	Haramaya	Gurawa	Babile
RAI	Min.	-3.2	-3.39	-3.4	-3.7	-3.8	-3.5
	Max.	3.7	3.72	3.8	3.5	3.05	0.14
	Mean	0.08	0.19	0.17	0.09	0.13	0.02
	Zs	-0.17	0.09	0.08	0.21	0.23	-0.01

Note: Zs = Mann–Kendall test; RAI = Rainfall Anomaly Index; * = denotes significance at P < 0.05.

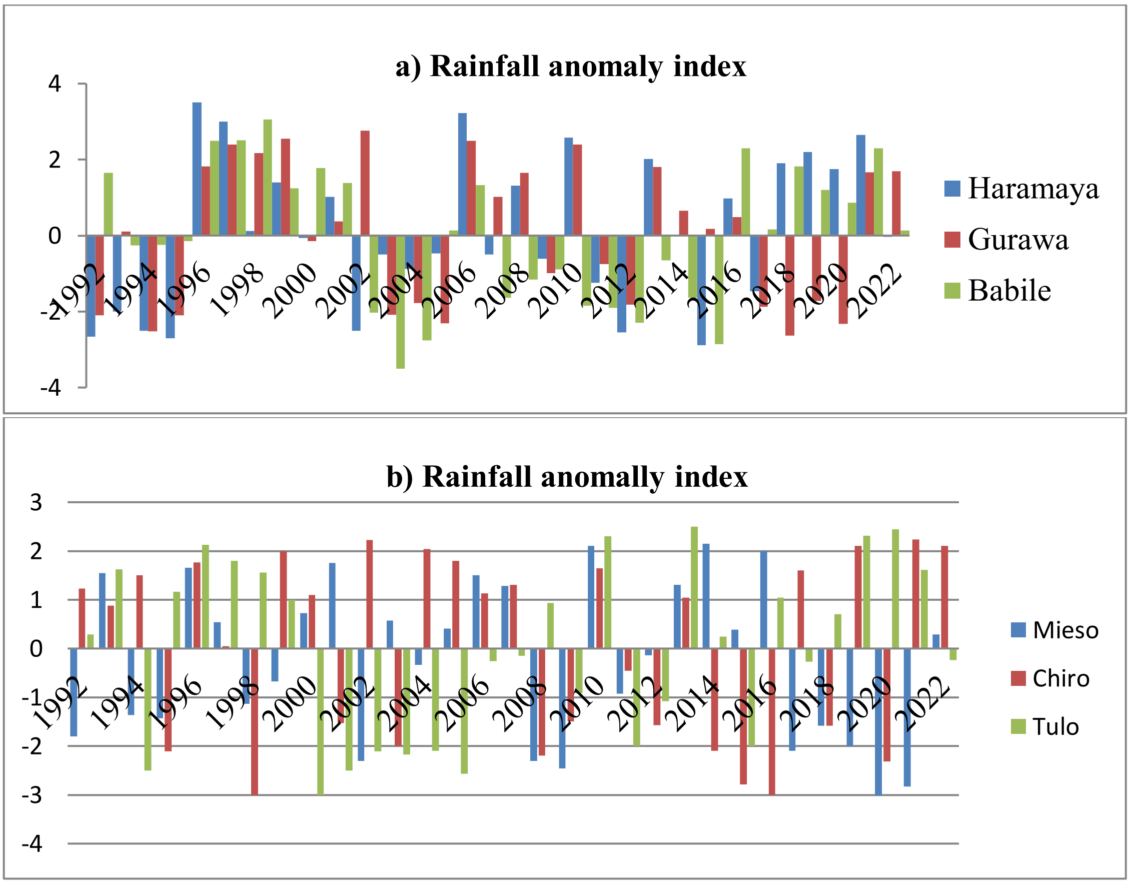


Figure 3: Rainfall anomaly index of selected districts of east and west Hararghe from (1992-2022)

3.5. Analysis of annual, and seasonal maximum temperature

Analysis of annual maximum temperatures in selected wheat-growing districts of Eastern Ethiopia varied between 24.1°C and 30.9°C (Table 7). A statistically significant (P<0.05) increasing trend of yearly average maximum temperatures was observed in the Mieso, Gurawa, and Babile districts. Conversely, the increasing trends of mean annual maximum temperature of in the Chiro, Tulo, and Haramaya districts did not show statistically significant (Table 11). Increases in mean annual maximum temperatures of 0.029°C, 0.021°C, and 0.022°C per year were recorded for Mieso, Gurawa, and Babile, respectively.

During the Kiremt season, maximum temperatures varied significantly across all districts. The results revealed that the highest average maximum Kiremt temperature (31.6°C) was recorded from the Mieso district, whereas the lowest Kiremt maximum temperature (24.0°C) was recorded from the Haramaya district. The coefficient of variation for mean Kiremt maximum temperatures ranged from 2.1% to 5.52%, showing notable seasonal variability of Kiremt maximum temperature. Increased maximum temperatures during Kiremt can negatively impact crop production, affecting germination, vegetative growth, reproductive stages, and overall yield. Gemada et al. (2021) reported significant increases in maximum temperatures in Jimma, Ethiopia, consistent with broader climatic trends observed in recent years.

An evaluation of average maximum temperature during the Belg season over the last thirty years showed that an increasing trend of Belg maximum temperature, which is statistically significant, was observed in the Mieso, Chiro, Haramaya, and Babile districts, whereas the Tulo and Gurawa districts exhibited an increasing trend of mean maximum temperature statistically not significant at the 5% level (Table 7, fig. 4). Belg maximum temperatures over the past thirty years in selected districts of East and West Hararghe zone districts show significant variations of the Belg maximum temperature. The highest mean temperatures were recorded in Mieso, ranging from 28.5°C to 33.1°C, averaging 31.7°C, showing a warm climate over study periods, which affects crop production. In contrast, the Chiro district had a mean temperature of 28.6°C, with a range of 23.3°C to 30.6°C, suggesting less suitability for heat-sensitive crops. Tulo and Haramaya districts were cooler, with average temperatures of 25.5°C, while Gurawa and Babile averaged 25.1°C and 29.1°C, respectively (Table 7, fig. 4e and f). Rate of change of maximum temperature per year Mieso shows the highest rate (0.0278°C per year), while Tulo shows the lowest (0.0194°C/year) increase rate of maximum temperature per year (Table 7).

Table 7: Descriptive statistics and Mann-Kendall test of maximum temperature of annual and seasonal (1992–2022)

Variable	Test	Mieso	Chiro	Tulo	Haramaya	Gurawa	Babile
Belg	Min	28.7	23.3	24.1	24.3	23.1	27.6
	Max	33.05	30.6	28.2	27.3	26.5	30.4
	Mean	31.6	28.2	26.6	25.5	25.1	29.1
	SD	0.83	1.2	1.23	0.8	0.9	0.8
	CV (%)	2.62	4.3	5.01	3.14	4.46	2.69
	ZS	2.176	1.463	0.136	0.527	1.685	0.323
	PV	0.029*	0.043*	0.891	0.049*	0.091	0.036*
	Slope	0.0278	0.188	0.0194	0.069	0.0216	0.224
Kiremt	Min	30.0	22.3	23.54	23.0	22.5	24.3
	Max	33.2	29.5	27.2	24.9	26.1	30.3
	Mean	31.6	27.8	26.03	24.0	24.8	27.3
	SD	0.8	1.2	0.94	0.50	0.819	1.5
	CV (%)	2.58	4.3	3.62	2.1	3.29	5.52
	ZS	3.026	0.476	0.36	0.442	3.041	3.830
	PV	0.0024*	0.633	0.717	0.658	0.0025*	0.0001*
	Slope	0.018	0.062	0.0043	0.058	0.033	0.019
Annual	Min	29.6	25.8	23.9	22.4	23.8	27.6
	Max	32.2	28.85	27.9	25.2	27.1	29.8
	Mean	30.9	27.74	26.66	24.1	25.9	28.5
	SD	0.6	0.67	0.978	0.5	0.99	0.5
	CV (%)	1.8	2.42	5.11	2.13	3.84	1.86
	ZS	3.9267	0.204	0.136	0.543	2.66	2.912
	PV	0.00861*	0.83	0.891	0.586	0.0077*	0.0035*
	Slope	0.0299	0.0281	0.0194	0.252	0.0212	0.0275

Note: SD and CV stand for standard deviation and coefficient of variation, respectively. * Significant at a 5% probability level

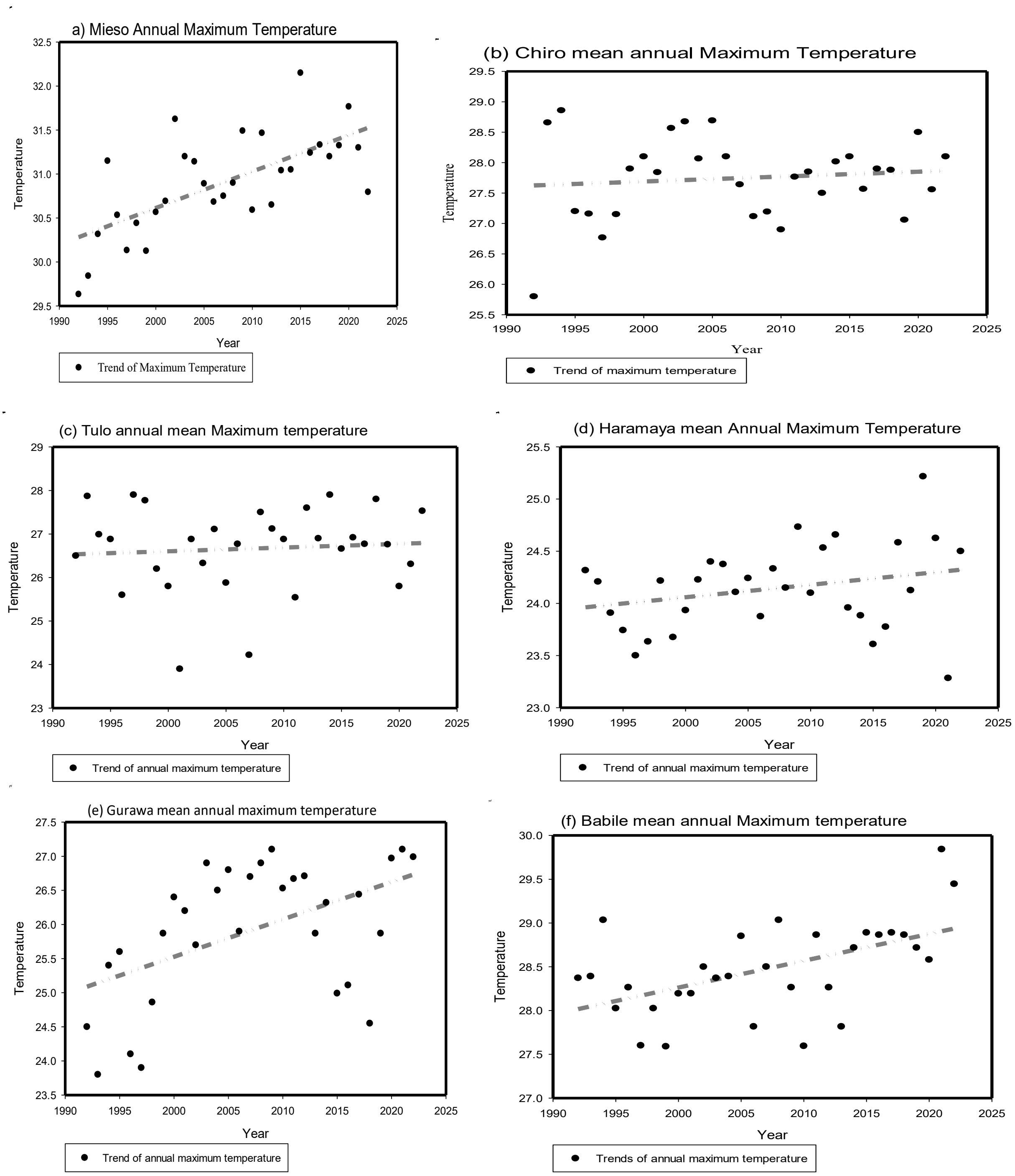


Figure 4: Trends of annual maximum temperature across the district (1992-2022)

3.6. Analysis of annual, seasonal, and minimum temperatures across the districts

The analysis of annual minimum temperature showed that Mieso district shows the most significant increase at 0.29°C, Chiro at 0.18°C, Tulo at 0.23°C, Haramaya at 0.21°C, Gurawa at 0.15°C, and Babile at 0.102°C per decade, respectively (Table 8). These trends may indicate wider climatic changes in the study areas, possibly associated with global warming or environmental variations in the local district. The increased temperatures contribute to the irregularity of rainfall and recurrent droughts, leading to reduced pasture and water availability in Eastern Ethiopia. In line with the above results, NMA (2007) reported that in Ethiopia, average annual minimum and maximum temperatures have increased by about 0.25°C and 0.1°C every ten years. Concerning the variability of minimum temperature, Tulo district shows the highest variability (12.3), suggesting uneven climatic conditions, while Babile has the lowest (1.86) and shows more stable temperatures. This increase in minimum temperature is a critical indicator of global warming (IPCC, 2001).

Kiremt means minimum temperatures reveal significant climatic variability across all study areas in Eastern Ethiopia, which could affect agriculture and water management. The highest mean minimum temperature range (16.0°C to 19.1°C, average 18.0°C) was recorded from the Mieso district, indicating dry conditions, followed by Babile (14.8°C to 16.8°C, average 15.6°C). Babile district had the highest coefficient of variation (CV = 9.70), indicating high variability in minimum temperature was observed, which could create challenges for agricultural practices and water resource management in the study areas. Conversely, Tulo, Haramaya, and Gurawa districts had lower average temperatures, showing greater temperature fluctuations, which may pose challenges for agricultural practices in the study area. The Mann-Kendall and Sen's slope tests showed that kiremt minimum temperatures in all districts showed an increasing trend over the study areas. Mieso experienced the highest increase per year (0.075x), followed by Babile (0.0354x), indicating that these areas may face the most significant effects of rising temperature challenges. The results showed that overall, mean minimum temperatures during the Kiremt season were higher than those of the Belg season, contrasting with maximum temperatures. In agreement with the above results, Solomon et al. (2020) reported there was a significant increase in both maximum and minimum temperatures, particularly during the Kiremt season, highlighting the implications of these changes for agriculture and water resources management.

Increasing Belg minimum temperatures, which are statistically significant increasing trends in Belg by a factor of 0.10°C per decade, (0.28°C) per decade.0.221°C per decade, 0.08°C per decade, and 0.04°C per decade, were observed in Mieso, Chiro, Tulo, Haramaya, Gurawa, and Babile, increasing 0.05°C per decade, respectively, which are not statistically significant increasing trends (Table 8).

The Mankendell statistical test indicated that a significant ($P<0.05$) at a 5% significance level increasing trend in minimum temperatures during the Belg season in all district except Gurawa which shows slighty non-significant trends was observed (Table 8). Similar to this result, Tadesse et al. (2022) reported that the temperature and rainfall trends in Ethiopia are fluctuating, and there is a significant increasing trend in minimum temperatures during the Belg season, which could lead to increased evapotranspiration and affect crop yields negatively. Although observed increasing trends in the mean minimum and maximum temperatures are consistent with global warming trends that are being observed worldwide.

Babile and Mieso districts showed the highest mean minimum Belg temperatures during the study period, indicating relatively drier conditions than other districts. The combination of rising minimum temperatures and fluctuating rainfall patterns raises concerns about increased water stress for crops, particularly during critical growth periods, which could potentially reduce agricultural yields. The differences in temperature range across these districts suggest significant climatic variations influenced by geographical factors, such as altitude, topography, and land use of the study areas. This rise in minimum temperatures is critical as it can significantly impact crop growth, development, and yield within the district. Elevated temperatures during this key agricultural period lead to increased evapotranspiration rates, which in turn heighten water demands for crops. As a result, farmers may face challenges in meeting these water needs, potentially affecting crop health and productivity. The implications of these temperature trends underscore the necessity for adaptive agricultural practices and effective water management strategies to mitigate adverse effects on food security and ensure sustainable farming in response to changing climatic condition. The findings align with Sinore and Wang's (2024) research, which indicates that climate change adversely affects agriculture through alterations in crop suitability, phenology, and productivity.

Table 8: Descriptive statistics and Mann-Kendall test of annual and seasonal minimum temperature

Variable	Test	Mieso	Chiro	Tulo	Haramaya	Gurawa	Babile
Belg	Min	14.6	11.6	13.5	10.1	9.8	11.1
	Max	17.9	17.2	15.22	14.5	11.8	17.4
	Mean	16.5	14.9	14.3	11.9	10.7	15.6
	SD	0.7	1.4	1.5	0.95	0.61	2.118
	CV (%)	4.05	9.06	9.45	7.97	5.74	13.6
	ZS	0.78	2.19**	1.734	0.64	0.34	0.37
	P-value	0.023*	0.048*	0.0321*	0.031*	0.73	0.03*
	Slope	0.10	0.280	0.221	0.08	0.04	0.05
Kiremt	Min	16.0	12.2	12.6	11.0	9.0	14.8
	Max	19.1	17.0	14.2	16.6	12.2	16.8
	Mean	18.0	15.4	13.4	13.6	10.2	15.6
	SD	0.90	1.1	1.3	1.08	0.79	0.62

	CV (%)	5.15	6.9	3.98	8.00	7.83	9.70
	ZS	1.82	0.90	0.24	3.68**	2.704*	1.24
	P-value	0.068	0.367	0.651	0.002*	0.006*	0.21
	Slope	0.23	0.116	0.021	0.17	0.34	0.26
Annual	Min	14.9	10.3	11.9	8.8	9.1	12.9
	Max	17.4	16.1	14.1	12.3	10.5	16.5
	Mean	16.15	13.9	13	10.1	9.8	15.2
	SD	0.6	1.4	1.6	0.8	0.40	0.83
	CV (%)	3.97	9.82	12.3	7.60	4.10	5.51
	ZS	0.13597	1.4617	1.2079	2.04*	0.40	0.784
	P-value	0.8918	0.1438	0.7142	0.04*	0.68	0.432
	Slope	0.0193	0.18709	0.231	0.21	0.015	0.102

Note: Zs = Mann-Kendall test; β = Sen's slope; SD = standard deviation; CV = coefficient of variation; * = indicates significance at $p < 0.05$

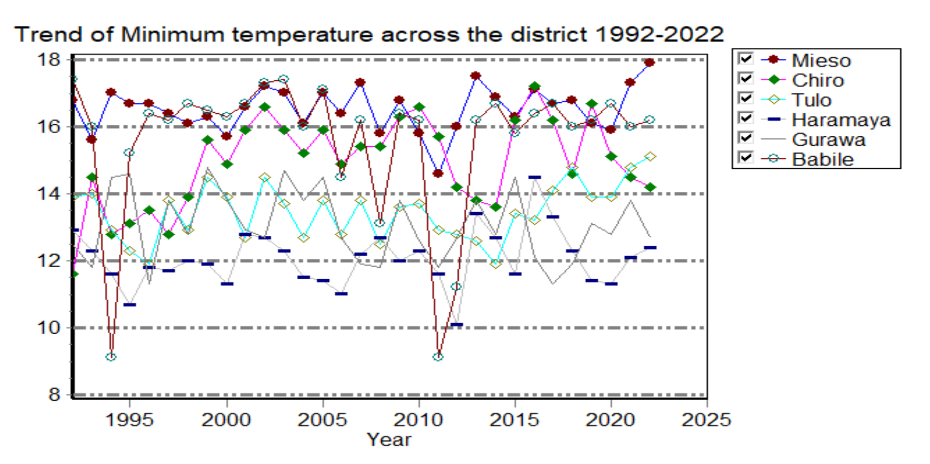


Figure 5: Trend of Belg minimum temperature across the districts

4. Conclusions

Agro-meteorological information is useful to solve many agricultural problems. Without the knowledge of climate change, variability and trends in a given locality, adoption of farming system might be unsuccessful. Metrological data sets are useful to evaluate potential crop management option. Study of regional and global climate changes and variability and their impacts on the society have received considerable attention in the recent years. In this particular study, the analysis of annual rainfall (1992-2022) in the Eastern Ethiopia showed annual rainfall in Mieso, Gurawa, and Babile experienced significant variations over the last 31 years, affecting wheat production. Conversely, Chiro, Tulo, and Haramaya districts showed moderate rainfall trends. The Kiremt season rainfall, which contributes between 41.3% and 54.1% of the total annual rainfall, showed increasing trends in all districts. High variability of Kiremt rainfall in Mieso, Babile, and Gurawa could lead to lower wheat yields and increased disease incidences. Statistically significant increases in maximum temperature trends were observed in the Mieso, Gurawa, and Babile districts. In contrast, a notable warming trend in minimum temperature was recorded in the Haramaya, Gurawa, and Chiro districts.

The minimum temperature in Gurawa, Haramaya, and Chiro increased significantly, and Kiremt rainfall increased in all districts, potentially reducing wheat yields and increasing disease incidences. Solutions to address these fluctuations are needed to ensure the sustainability of wheat production and improve farmers' ability to adapt to climate change. The seasons and among the districts. The results also indicated fluctuation of annual and seasonal rainfall was observed over study periods. This variability has resulted in a higher frequency of drought occurrences. Higher variability of rainfall was observed in the Belg season as compared to the main rainy (Kiremt rainfall). This situation may exacerbate farmers' vulnerability to climate change and drive them to change from wheat to other crops that are less prone to climate variability, such as those affected by drought and diseases.

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