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Long term climate variability, trend and drought occurrence: the case of Loka Abaya, Ethiopia

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ABSTRACT: This study investigates the variability and trends in rainfall and temperature, as well as drought patterns in the Loka Abaya district of Ethiopia, over a 42-year period (1981–2022). The Coefficient of Variation (CV), Mann-Kendall trend test, and Standardized Precipitation Evapotranspiration Index (SPEI) were employed to examine variability, trends, and drought occurrences, respectively. Results indicate that the annual rainfall exhibited low variability (CV: 17.54%), while seasonal rainfall showed higher variability: Belg (spring) at 28.3%, Kiremt (summer) at 26.6%, and Bega (dry season) at 37.8%. Although the annual rainfall trend declined over time, it was not statistically significant ($p > 0.05$). Seasonal trends revealed a significant decrease in Belg rainfall, whereas Kiremt rainfall increased slightly but without statistical significance. The annual minimum and maximum temperatures showed an increasing trend, with the minimum temperature increase being statistically significant. The minimum temperatures during the Kiremt and Belg seasons also showed significant increases, whereas the maximum temperatures did not significant trend. Drought occurrences were assessed using the SPEI at 3-month and 12-month time scales. Severe to extremely severe droughts were identified in the years 1984, 1986, 1987, 1993, 2002, 2004, 2009, 2012, 2015, 2016, and 2022. These findings highlight the increasing frequency and intensity of droughts, as well as significant temperature increases and variability in rainfall patterns. The insights provide critical guidance for policymakers and stakeholders to develop effective adaptation and mitigation strategies, enhancing resilience to climate variability and its associated risks in the region.

KEYWORDS: rainfall, temperature, Mann-Kendall test, coefficient of variation, anomalies.

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1. INTRODUCTION

Climate change is one of the most significant challenges facing the world today, impacting ecosystems, economies, and human societies on a global scale (Abidoye & Odusola, 2015; Intergovernmental Panel on Climate Change - IPCC, 2023). While climate change results from both natural processes and anthropogenic activities, the latter has driven more frequent and severe climate extremes, with far-reaching consequences (Belay et al., 2021). In particular, human-driven climate change has led to disruptions in weather patterns, contributing to adverse impacts such as droughts, flooding, and rising temperatures (IPCC, 2023).

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Ethiopia, like many regions in sub-Saharan Africa, is particularly vulnerable to the effects of climate change, especially in climate-sensitive sectors such as agriculture, forestry, fisheries, energy, and tourism (IPCC, 2023; Ware, 2022). Recent studies indicate noticeable shifts in Ethiopia's climate over the past few decades, with some showing declining rainfall trends and others suggesting an increase in certain regions (Belay et al., 2021; Benti & Abara, 2019). For example, Cheung et al. (2018) found a significant reduction in Kiremt (June–September) rainfall, particularly in the southwestern and central Rift Valley areas. Additionally, research by Gashaw et al. (2023) in Southern Ethiopia revealed a decline in annual rainfall and a rise in temperatures, along with severe drought events in 2009 and 2015. The Standardized Precipitation Evapotranspiration Index (SPEI) has become a valuable tool for assessing drought conditions and temperature-induced precipitation deficits (Kourouma et al., 2022).

Despite these findings, there remain gaps in understanding the specific climate dynamics in certain regions of Ethiopia, particularly in the Loka Abaya area. This region is known for its vulnerability to droughts, but there is limited information on seasonal and long-term variations in rainfall and temperature trends. Previous studies have not fully addressed how these factors interact and influence drought severity in the region. A comprehensive analysis of these trends is essential for improving climate prediction models and developing effective mitigation strategies.

This study focuses on the Loka Abaya area in Southern Ethiopia, aiming to examine trends in rainfall and temperature variability, as well as the occurrence and severity of droughts over the past four decades (1981–2022). The study addresses the following research questions: have rainfall and temperature trends changed in the Loka Abaya region between 1981 and 2022? what is the distribution of rainfall anomalies in the area? And how do seasonal and annual rainfall patterns vary, and what are the characteristics of drought in this region? By filling these gaps, this research seeks to contribute to a better understanding of the region's climate dynamics, providing valuable insights for adaptation and mitigation strategies.

2. LITERATURE REVIEW

Climate change and variability encompass both natural and anthropogenic influences on climate patterns over extended periods. Natural variability arises from dynamic interactions within the climate system, including ocean-atmosphere processes such as El Niño and La Niña events, which significantly impact global and regional weather patterns. Additional natural factors, such as volcanic activity and variations in solar radiation, also contribute to fluctuations in the Earth's climate. These processes are fundamental drivers of climatic conditions and play a pivotal role in shaping weather patterns and climate systems over time. In contrast, anthropogenic activities have considerably intensified climate change and variability, creating unprecedented challenges for global systems. The burning of fossil fuels, large-scale deforestation, and industrial processes has dramatically increased greenhouse gas (GHG) concentrations in the atmosphere (IPCC, 2023). These processes are fundamental drivers of climatic conditions, shaping weather patterns and climate systems over time; however, the rise in GHG levels has accelerated the greenhouse effect, leading to global warming and its associated consequences, such as rising temperatures, melting ice caps, and shifting weather patterns.

Climate trends refer to the consistent and directional changes in climate variables, such as temperature and rainfall, observed over extended periods. These trends provide critical insights into how climate systems evolve over time and their implications for various sectors. Understanding both long-term climate variability and trends is essential for assessing the impacts of climate change. The effects of these changes are widespread, influencing ecosystems, agriculture, water resources, and human livelihoods (IPCC, 2023). The Intergovernmental Panel on Climate Change, (2014) reported a clear and measurable upward trend in global temperatures. Over the period of 2006–2015, global temperatures rose approximately 0.87°C compared to the late 19th century. This warming has been accompanied by notable changes in rainfall distribution and patterns, as well as shifts in the timing and frequency of extreme weather events, including heatwaves, floods, and droughts. These changes underscore the need to study climate variability and trends on both global and regional scales to fully understand their potential consequences.

Regional climate trends exhibit distinct patterns that are influenced by various factors such as geographic location, altitude, and proximity to large bodies of water (Serreze & Barry, 2011; Yamanouchi & Takata, 2020). The tropical regions are experiencing a rise in the frequency and intensity of extreme weather events, including hurricanes, floods, and droughts. These changes are largely driven by increasing sea surface temperatures, which influence atmospheric circulation and intensify storm patterns (Bolan et al., 2024). The contrasting trends between the tropical and Arctic regions highlight the complex ways in which climate change manifests at a regional scale, underscoring the need for targeted climate mitigation and adaptation strategies (Bolan et al., 2024).

Droughts are prolonged periods of abnormally low precipitation, leading to water shortages and significant socioeconomic impacts, particularly in agriculture-dependent regions. Drought occurrence has been a subject of extensive research, as changes in climate are expected to alter both the frequency and intensity of droughts (Bharambe et al., 2023). Recent studies have shown that long-term climate variability and trends have significantly affected the occurrence of droughts worldwide (Kendon et al., 2019; Mera, 2018). Some regions, particularly the tropics and subtropics, are experiencing more frequent droughts due to reduced rainfall, others may experience increased drought intensity as temperatures rise, accelerating evaporation (Bolan et al., 2024; IPCC, 2023).

Statistical approaches to analyzing droughts. To assess long-term climate variability and drought occurrences, researchers employ a range of statistical methods, including trend analysis and drought indices. One of the widely used methods for identifying trends in temperature and precipitation is the Mann-Kendall test, which is employed to determine whether there is a significant upward or downward trend in climate variables over a specific period (Mann, 2013). Additionally, Standardized precipitation evapotranspiration index (SPEI), Standardized Precipitation Index (SPI) and the Palmer Drought Severity Index (PDSI) are frequently used to quantify and monitor drought severity over time (Burka et al., 2023; Mckee et al., 1993; Vicente, 2010). These indices, when used alongside temperature and rainfall data, help in evaluating the long-term behavior of droughts and the role of climate change in their frequency and intensity.

3. RESEARCH METHODS

3.1. Description of study area

The study was conducted in Loka Abaya, located on the western border of the Sidama Regional State in Ethiopia, at coordinates 6°17′25″ N latitude and 37°49′44″ E longitude (Figure 1). The area is situated 325 km southwest of the capital, Addis Ababa, and 50 km southwest of the regional city of Hawassa. The study area is located in a major agroecological zone characterized by hot to warm submoist lakes and great rift valleys with a total area of 119,000 ha. It experiences a bimodal rainfall pattern, with a short rainy season from March to May and the main rainy season from June to September. Mean annual rainfall in the region ranges from 636.5 mm to 1,320 mm, with an average of 967.1 mm. The mean annual temperature ranges from 27.4°C to 31.2°C. The mean seasonal maximum temperatures were recorded as 30.5°C for Belg (February–May), 27.5°C for Kiremt (June–September), and 30.12°C for Bega (October–January), respectively. The mean seasonal minimum temperatures were recorded as 12.62°C for Belg, 12.53°C for Kiremt, and 12.06°C for Bega, respectively. The area is also characterized by erratic rainfall, moisture stress, and high temperatures during the different seasons. Specifically, rainfall during the Belg season exhibited a statistically significant decreasing trend ($P < 0.05$), leading to increased moisture stress (Table 2). This season is particularly critical for farmers, as it dictates the timing of land preparation and planting activities, which are essential for agricultural productivity. The altitude varies from 1,178 m to 1,851 m above sea level. Agriculture is the primary livelihood source for most of the population, and the predominant soil type is grey sandy loam, which is prone to erosion. Based on the 2007 Census conducted by the CSA, this woreda has a total population of 99,233, of whom 50,603 are men and 48,630 women; 1,059 or 1.07% of its population are urban dwellers. The district is endowed with forest vegetation that is dominated by species such as Acacia species, Erythrina brucei, Commiphora africana, Albizia gummifera, Balanite eagyptiaca, Ficus species, Cordia africana, Calpurnia aurea, Croton macrostachyus, and others.

Exotic plant species such as Grevillea robusta, Pinus patula, and Eucalyptus and Cupressus lusitanica occupy the plantation forest of the district.

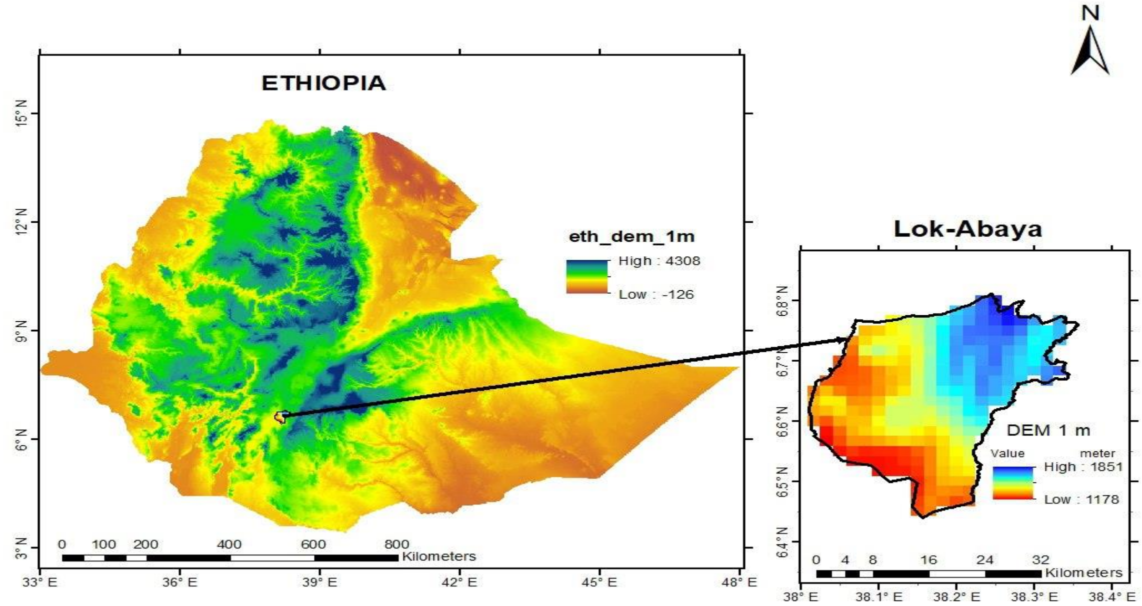


Figure 1. Map of the study area.
Source: Author analysis.

3.2. Data type and sources

The climate data used in this study were obtained from the Ethiopian Meteorological Institute (EMI). The dataset included daily temperature and rainfall data, which were gridded by merging station data with satellite data. The data had a grid cell size of 0.0375 degrees (approximately 4 km × 4 km) and covered the period from 1981 to 2022. The Ethiopian Meteorological Institute used the latest type of instruments installed at stations for ground observations, including Raingauges for rainfall and Thermometers for temperature.

3.3. Data analysis

Different techniques were employed to analyze rainfall and temperature, typically falling under the categories of variability and trend analysis. The data were analyzed using the Coefficient of Variation (CV), Mann-Kendall (MK) test, percentage departure from the mean (anomalies), and the Standardized Precipitation Evapotranspiration Index (SPEI). Data analysis was conducted using XLSTAT software. The Coefficient of Variation (CV) was used to assess the variability of rainfall. A higher CV value indicates greater variability, while a lower CV suggests less variability. The CV is calculated as follows:

$$CV = \frac{\sigma}{\mu} \times 100, \tag{1}$$

where σ is the standard deviation and μ is the mean precipitation. CV is used to classify the degree of rainfall variability as follows: low variability (CV < 20), moderate variability (20 < CV < 30), and high variability (CV > 30). Additionally, the standardized anomaly of rainfall was calculated to examine the nature of the trends, identify dry and wet years, and assess the frequency and severity of droughts (Asfaw et al., 2018; Dad et al., 2021; Mihiretu et al., 2021) as:

$$Z = \frac{(Xi - \overline{Xi})}{s}, \tag{2}$$

where Z is the standardized rainfall anomaly, X_i is the annual rainfall for a particular year, $\overline{Xi}$ is long term mean annual rainfall over a period of observation, and s is the standard deviation of annual rainfall over the same period. The drought severity classes are extreme drought (Z < _1.65), severe drought (_1.28 > Z > _1.65), moderate drought (_0.84 > Z > _1.28 and no drought (Z > _0.84) (Burka et al., 2023; Mckee et al., 1993; Vicente, 2010).

Mann-Kendall (MK) trend test is a non-parametric method commonly used to detect monotonic trends in environmental, climate, or hydrological data. In this study, the MK test was applied to identify the presence of monotonic (increasing or decreasing) trends in the climate data for the study area and to assess whether these trends were statistically significant. Since the dataset may contain outliers, the non-parametric nature of the MK test makes it particularly useful. This is because the MK test statistic trusts on the signs (+ or -) of the data points, rather than their actual values. As a result, the trends identified by the MK test are less sensitive to outliers (Asfaw et al., 2018; Birsan et al., 2005). The MK test is widely used to detect trends in meteorological variables (Adnew & Woldeamlak, 2013; Kiros et al., 2016; Willems, 2015). Trend analysis was conducted on an annual basis, as well as for the Belg and Kiremt seasons. Given that the Kiremt rainfall occurs from June to September in the study area, monthly trends for these four months were also analyzed separately.

The MK test statistic 'S' is calculated based on Mann, (2013) and Yue & Wang, (2002) using the formula (3):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \tag{3}$$

The application of trend test is done to a time series x_i that is ranked from i 1, 2…n-1 and x_j, which is ranked from j ¼ i þ 1, 2…. n. Each of the data point x_i is taken as a reference point which is compared with the rest of the data point's x_j so that:

$$sgn(x_j - x_i) = \begin{cases} +1 \; if \; (x_j - x_i) > 0 \\ 0 \; if \; (x_j - x_i) = 0 \\ -1 \; if \; (x_j - x_i) < 0 \end{cases}, \tag{4}$$

where X_i and X_j are the annual values in years i and j (j > i) respectively.

It has been documented that when the number of observations is more than 10 (n ≥ 10), the statistic 'S' is approximately normally distributed with the mean and E(S) becomes 0. In this case, the variance statistic is given as:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{t=1}^{m} t_1(t_1-1)(2t_1+5)}{18}, \tag{5}$$

where n is the number of observation and t_i are the ties of the sample time series. The test statistics Zc is as follows:

$$Z = \begin{cases} \frac{S-1}{\sigma} \quad if \; S > 0 \\ 0 \quad if \; S = 0 \\ \frac{S+1}{\sigma} \quad if \; S < 0 \end{cases}, \tag{6}$$

where Z follows a normal distribution, a positive Zc indicates an upward trend, while a negative Zc indicates a downward trend over the given period. Sen's Slope Estimation method computes both the slope (i.e., the linear rate of change) and the intercept. The magnitude of the trend is predicted using Theil's and Sen's (1968) (Sen et al., 2016) slope estimation methods. A positive value of β indicates an upward trend (increasing values over time), while a negative value of β indicates a downward trend. In this method, the slope β for all data pairs is computed. Generally, the slope β between any two values in a time series x can be estimated using the following formula (7):

$$\beta = \frac{x_j - x_i}{j - i} \tag{7}$$

Let x_j and x_i represent data values at times j and k (j > i) correspondingly. A positive value of β indicates an increasing trend, while a negative value of β indicates a decreasing trend. The sign of β reflects the direction of the trend, while its magnitude indicates the steepness of the trend. One key advantage of this method is that it reduces the influence of missing values or outliers on the slope compared to traditional linear regression. Additionally, the coefficient of variation (CV) is used to evaluate the variability of rainfall data in relation to its standard deviation, and it is typically expressed as a percentage.

Standardized precipitation evapotranspiration index (SPEI) is a multiscalar/meteorological drought index, and it responds to weather conditions that have been abnormally dry or abnormally wet. The severity of drought is influenced not only by precipitation deficit but also by the increased atmospheric evaporative demand. Evaporative demand plays a particularly significant role during periods of low precipitation. We describe here a simple multiscalar drought index (the SPEI) that combines precipitation and temperature data. The SPEI is very easy to calculate, and it is based on the original SPI calculation procedure. The SPEI uses the monthly (or weekly) difference between precipitation and PET (Vicente, 2010). Calculating the Standardized Precipitation-Evapotranspiration Index (SPEI) requires long-term, high-quality datasets of precipitation and atmospheric evaporative demand (Mckee et al., 1993). In order to estimate the value of SPEI, the difference of the water balance is normalized as log- logistic probability distribution. The following equation (8) expresses the probability density function:

$$f(x) = \frac{\beta}{\alpha}(\frac{X-Y}{\alpha})\left[1+(\frac{X-Y}{\alpha})\right]2\,, \tag{8}$$

where parameters α, β, and γ represent scale, shape and origin, respectively. Therefore, the probability distribution function can be expressed as:

$$f(x) = \left[1+(\frac{\alpha}{x-y})\beta\right]^{-1} \tag{9}$$

Vicente–Serrano (Vicente et al 2009) calculated the SPEI as follow:

$$SPEI = W - \frac{C_O + C_1W + C_2W^2}{1+d_1w+d_2w^2+d_3w^3}\,, \tag{10}$$

when *P* is the probability of exceeding a determined *D* value $P \leq 0.5$ W = _−2 in (P), and when P ≥ 0.5, W = −2 ln (1 − P), The constants are C_0 = 2.5155, C_1 = 0.8028, C_2 = 0.0203, d_1 = 1.4327, d_2 = 0.1892, d_3 = 0.0013.

The average value of SPEI is 0, and the standard deviation is 1. The SPEI is a standardized variable, and it can therefore be compared with other SPEI values over time and space. An SPEI of 0 indicates a value corresponding to 50% of the cumulative probability of *D*, according to a log-logistic distribution. The categorization of drought classified by the SPEI is show in Table 1.

Table1. Climatic moisture categories for the SPEI classes as per Vicente-Serrano et al. (2010).

Categorization	SPEI Values
Extremely wet	SPEI≥ 2.0
Severely wet	1.5 < SPEI<2
Moderately wet	1< SPEI< 1.5
Mildly wet	0.5<SPEI<1
Normal	-0.5<SPEI<0.5
Mild drought	-1<SPEI<-0.5
Moderate drought	– 1.0 <SPEI< – 1.5
Severe drought	-2<SPEI<-1.5
Extreme drought	SPEI<-2

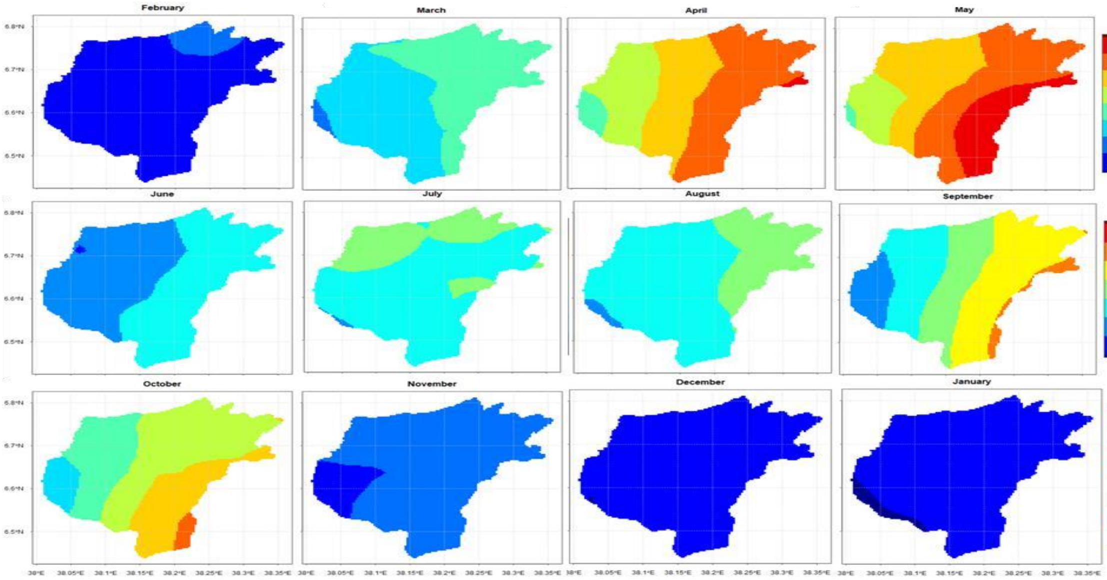
Source: Liu et al., 2021.

4. RESULTS

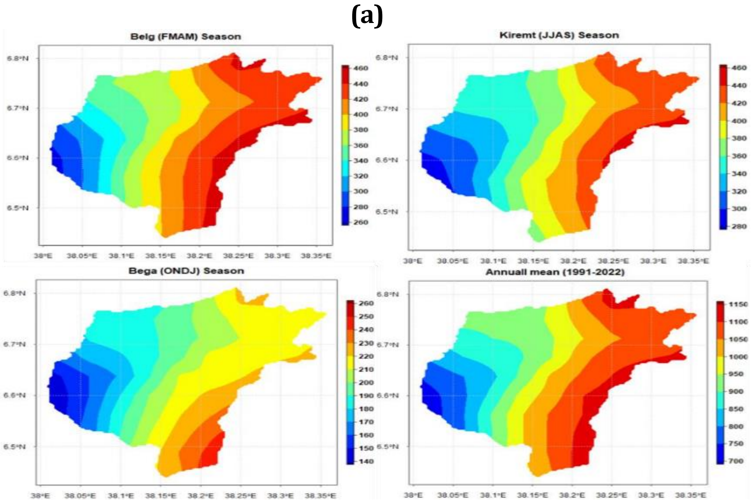
4.1. Rainfall and temperature

4.1.1. Rainfall patterns and trends

Rainfall data spanning 42 years was analyzed for the Loka Abaya district, revealing that the mean annual rainfall ranged from 636.5 mm to 1320 mm, with an overall mean of 967.1 mm. The Belg season (February–May) contributed more to the total annual rainfall than the Kiremt season (June–September), with the mean seasonal rainfall for Belg and Kiremt at 387mm and 379 mm, respectively. Seasonal rainfall showed notable variability: Belg ranged from 138 mm to 614 mm, and Kiremt ranged from 218 mm to 616 mm (Figure 2 a, b).



(a)



(b)

Figure 2. Monthly rainfall distribution climatology (**a**); Seasonal rainfall distribution climatology (**b**).
Source: Author analysis.

Table 2. Basic statistics and MK trend analysis of rainfall in Loke Abaya.

Variables Rainfall	Mean(mm)	SD (mm)	CV (%)	Sen.'s (β)	MK Test (P-Value)	RF Trends Contribution (%)
Belg	387.123	109.65	28.3	-2.525	0.046*	40.03
Kiremt	379.808	100.96	26.6	0.589	0.618	39.27
Bega	200.212	75.72	37.8	0.811	0.488	20.7
Annual	967.127	169.6	17.54	-2.178	0.448	100

MK is the Mann–Kendall trend test, β = Sen's slope, SD = Standard Deviation; CV = coefficient of variation.
*= indicate significant at $p < 0.05$.
Source: Author analysis.

Annual rainfall variability was low, with a coefficient of variation (CV) of 17.54%. However, seasonal rainfall exhibited higher variability, with Belg showing 28.3% CV, Kiremt at 26.6%, and Bega at 37.8%. Statistical analysis indicated a significant decreasing trend in the Belg season's rainfall ($P < 0.05$) (Table

2), while the overall annual rainfall showed a non-significant decreasing trend, with a slope (β) of -1.713 (Figure 3). This decreasing trend in rainfall was also evident in decadal analyses, where rainfall from 2000 to 2020 showed an average deficit of about 82.3 mm annually (Figure 5).

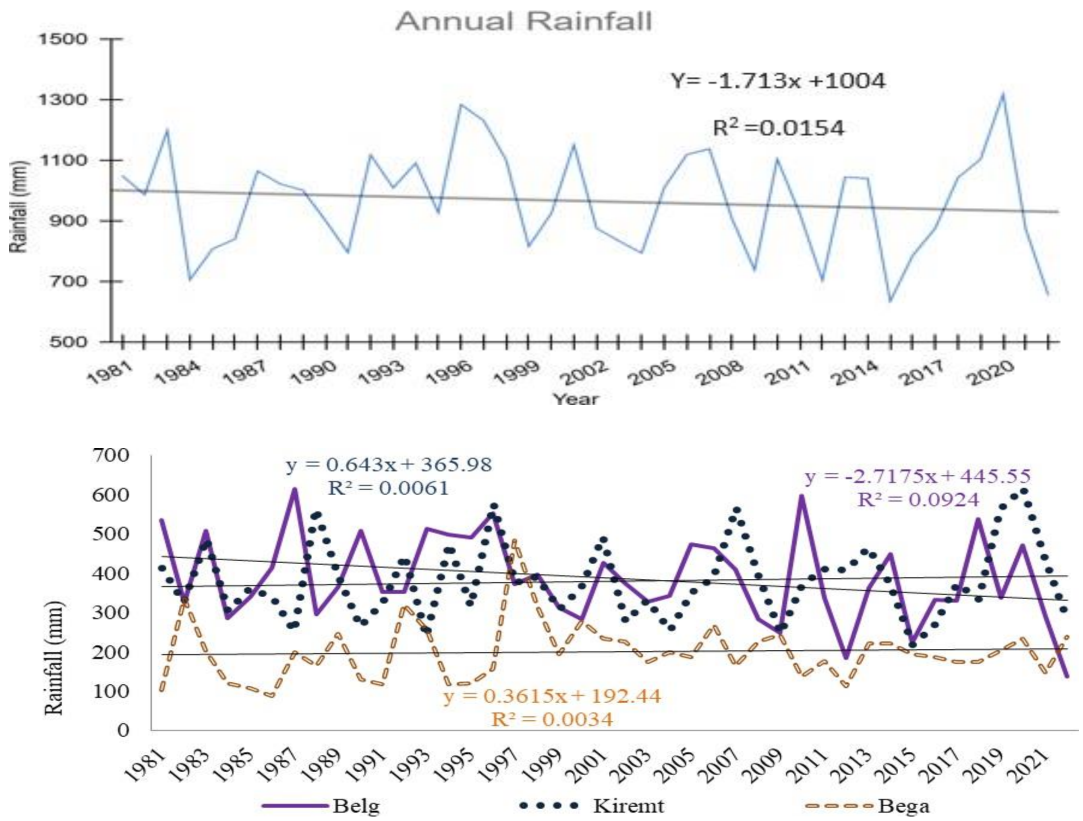


Figure 3. Long-term annual and seasonal rainfall variability of Loka Abaya (1981–2022).
Source: Author analysis.

To assess deviations in rainfall from the established average for the period 1981–2022, the anomaly of the rainfall variables was calculated, with results shown in Figure 4. Any deviation from the baseline annual mean rainfall indicates variability. The baseline is represented by the zero, corresponding to the total mean rainfall value of 967.13 mm. Annual rainfall fell below the average in the following years: - 1984, 1985, 1986, 1991, 1999, 2003, 2004, 2005, 2008, 2009, 2013, 2015, 2016, 2017, 2021, and 2022 (Figure 4).

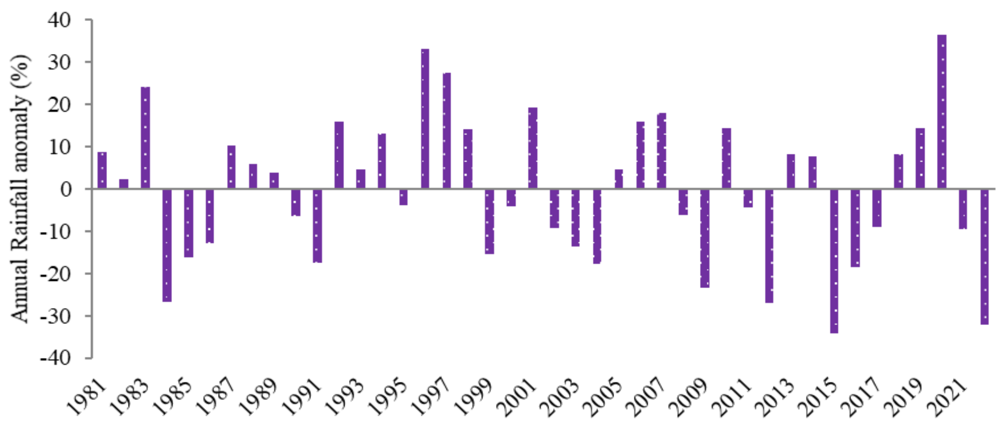


Figure 4. Long-term annual rainfall anomaly of Loke Abaya (1981–2022).
Source: Author analysis.

The decadal mean annual rainfall for the periods 1981–1990, 1991–2000, 2001–2010, and 2011–2020 were recorded as 959.54 mm, 1031.51 mm, 968.68 mm, and 949.21 mm, respectively (Figure 5). This shows that, over the last two decades, the rainfall pattern has exhibited a decreasing trend, with an average rainfall deficiency of about 82.3 mm per year from 2000 to 2020. These results are consistent with findings from recent studies conducted in Ethiopia and the broader East Africa region (Belay, et al., 2021; Fink & Knippertz, 2019).

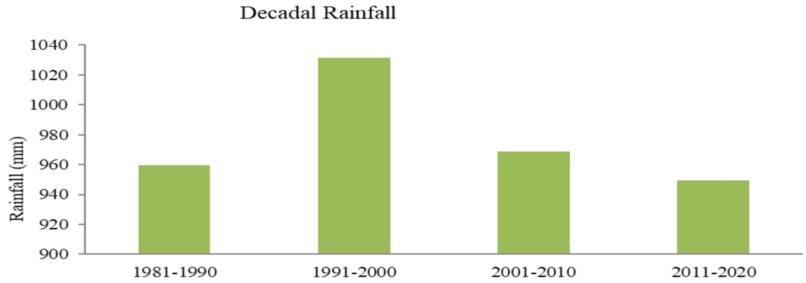


Figure 5. Average decadal annual rainfall trend analysis of Loke Abaya (1981–2022).
Source: Author analysis.

4.1.2. Temperature variability and trends

Analysis of temperature data for the past 42 years revealed an increase in both minimum and maximum temperatures. The mean annual minimum temperature was 12.41°C, and the maximum was 29.36°C. A statistically significant increase in the minimum temperature was observed over time, with a slope (β) of 0.07 (P = 0.001) for annual data. Seasonal minimum temperatures showed significant increases across all seasons, with the largest rate of increase in the Belg season at 2.7°C. However, the maximum temperatures did not show significant trends (Table 3). These trends are consistent with prior studies in Ethiopia, indicating a warming trend over the past decades (Figure 6).

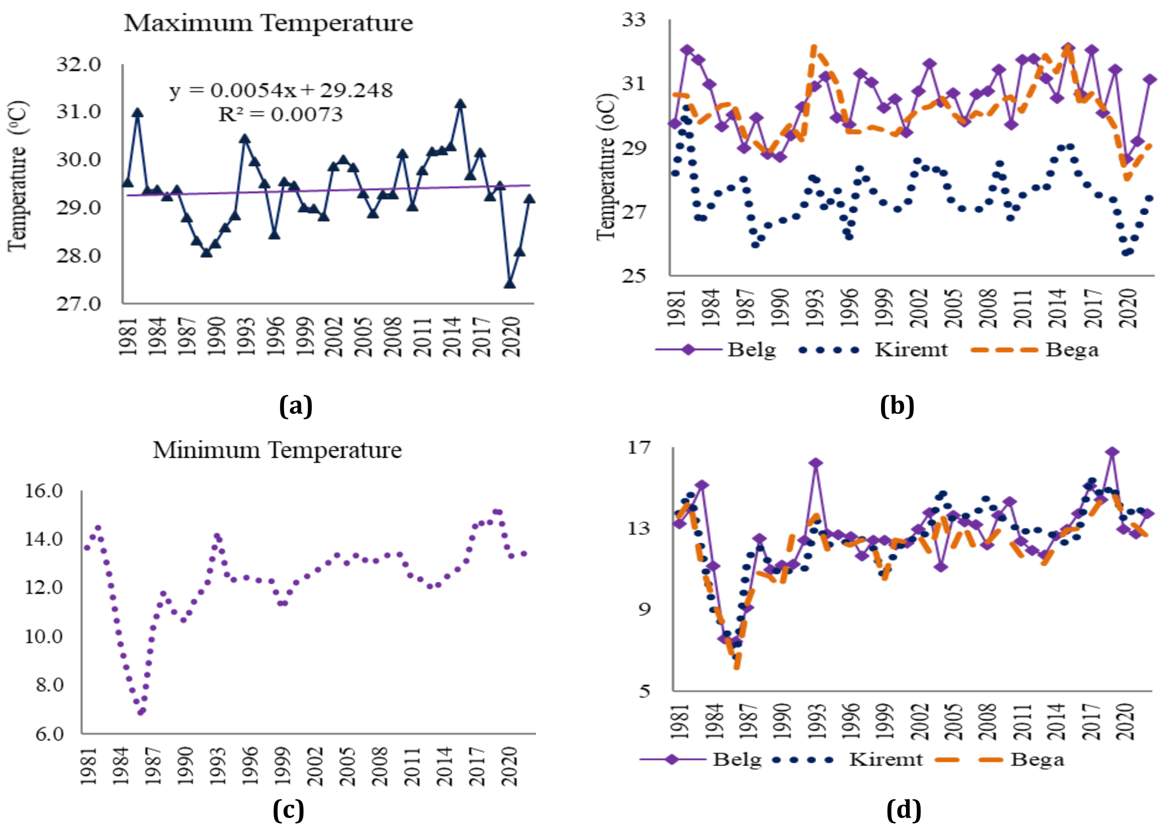


Figure 6. Annual and seasonal Maximum (**a** and **b**) and Minimum (**c** and **d**) average temperature of Loke Abaya (1981-2022).
Source: Author analysis.

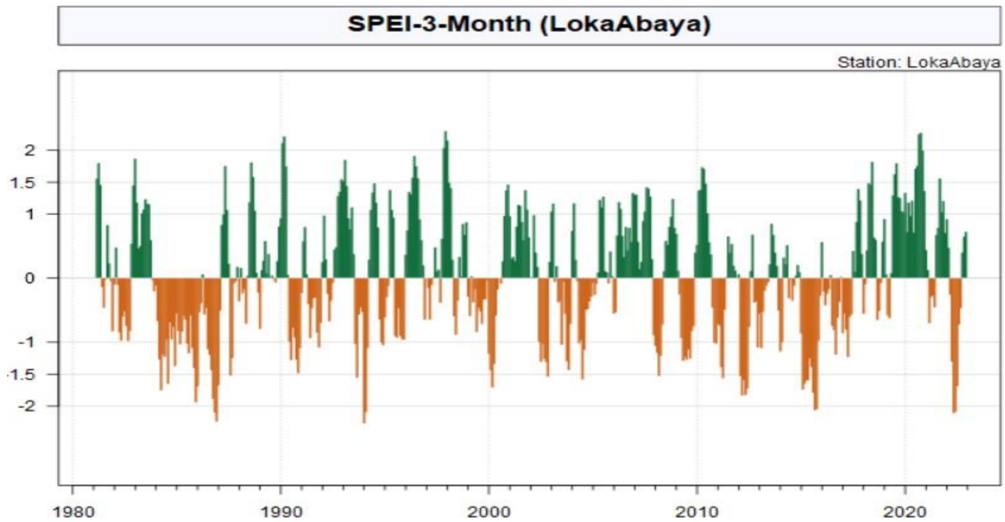
Table 3. Basic statistics and MK trend analysis of temperature in Loke Abaya (1981–2022).

Variable	Mean	SD	CV	Slope (β)	MK test (p-value)
Tmin (Annual)	12.41	1.64	13.18	0.07	0.001*
Tmax (Annual)	29.36	0.775	2.61	0.013	0.308
Tmin (Belg)	12.65	1.76	14.26	0.062	0.002*
Tmin (Kiremit)	12.53	1.78	14.02	0.077	0.0001*
Tmin (Bega)	12.05	1.74	13.89	0.055	0.009*
Tmax (Belg)	30.5	0.95	3.11	0.027	0.119
Tmax (Kiremit)	27.5	0.904	3.25	0.007	0.603
Tmax (Bega)	30.1	1.03	2.98	0.006	0.665

MK is the Mann–Kendall trend test, β = Sen's slope, SD = Standard Deviation; CV = coefficient of variation. *= indicate significant at $p < 0.05$.
Source: Author analysis.

4.2. Drought patterns

The 3-month Standardized Precipitation Evapotranspiration Index (SPEI-3) was used to assess short-term drought patterns from 1981 to 2022. Severe to extreme droughts were recorded in the years 1984, 1985, 1986, 1987, 1993, 2002, 2004, 2009, 2012, 2015, 2016, and 2022 (Figure 7a).



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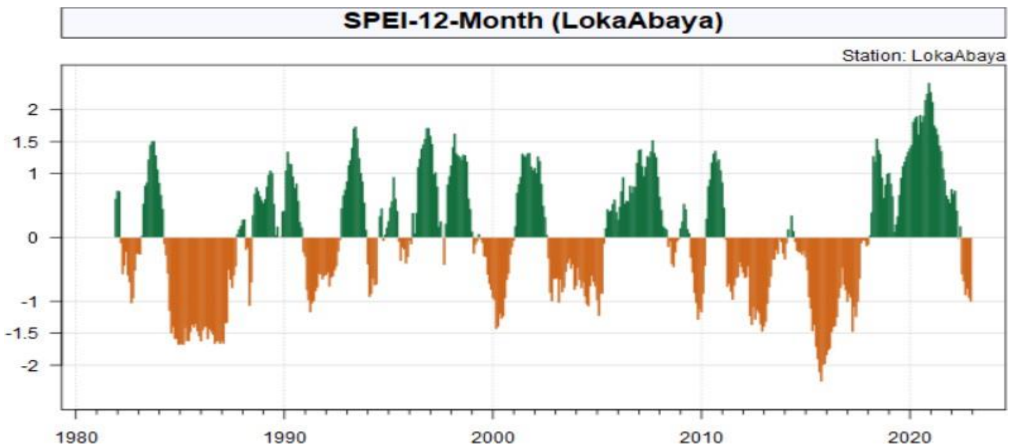

(b)

Figure 7. Three-month (**a**) and annual (**b**) time steps SPEI of Loka Abaya (1981-2022).
Source: Author's analysis.

These droughts were particularly pronounced during the Belg and Kiremt seasons. Over the past decade, the frequency of drought years has increased, leading to challenges for crop production. The 12-month SPEI also showed prolonged droughts, especially in the years 1984, 1985, 1986, 1987, 2009, 2012, 2015, 2016, and 2022 (Figure 7b). These long-term droughts indicate a shift toward more persistent water scarcity in the region, with implications for agriculture and water supply systems.

In addition, the 12-month SPEI from 1981 to 2022 shows us long-term hydrological reflects, groundwater level, and reservoir capacities as it prolonged periods of below-average precipitation. According to 1984, 1985, 1986, 1987, 2009, 2012, 2015, 2016, and 2022, 12-month SPEI showed that a severe to extremely severe drought was observed (Figure 7b). This region is facing longer-term water shortages, which could impact water supply systems, reservoirs, and long-term agricultural productivity.

5. DISCUSSION

The analysis of rainfall and temperature trends in the Loka Abaya district aligns with broader research on climate variability in Ethiopia and East Africa. The findings indicate notable variability and declining trends in rainfall, alongside significant increases in temperature over the past four decades. The study's results reveal an overall declining trend in annual rainfall, with significant variability during the Belg season, important period for agricultural activities in Loka Abaya. The decrease in Belg rainfall (-2.525 mm/year) aligns with findings by Belay et al. (2021) and Advances et al. (2019), Who documented reductions in rainfall during critical growing seasons across Ethiopia. Additionally, the high variability of seasonal rainfall, particularly during the Belg season (CV = 28.3%), reflects the increasing unpredictability of precipitation patterns. This aligns with research by Belay, et al., (2021) which highlights the growing frequency of extreme rainfall events, including droughts and heavy rains, as a hallmark of climate change in East Africa. The declining trend in decadal rainfall from 2000 to 2020 (average deficiency of 82.3 mm per year) further underscores the need for adaptive strategies to mitigate the impacts on agriculture and water resources.

The study's findings on increasing temperatures in Loka Abaya, particularly the significant rise in minimum temperatures during the Belg (0.062°C/year), Kiremt (0.077°C/year), and Bega (0.055°C/year) seasons, are consistent with previous research. Asfaw et al. (2018) and Suryabhagavan (2017) also observed similar trends in Ethiopia, where annual minimum and maximum temperatures have risen gradually over the past century. These temperature increases are linked to global warming and its localized effects, such as higher evapotranspiration rates and reduced soil moisture, which exacerbate drought conditions.

The study's use of the Standardized Precipitation-Evapotranspiration Index (SPEI) reveals an alarming increase in the frequency and severity of droughts, with extreme episodes recorded in 1984, 1999, 2015, and 2022. These findings align with those of Kourouma et al. (2022), who highlighted the intensification of droughts in Ethiopia, attributing this to warming temperatures and reduced rainfall. The observed long-term hydrological droughts, as reflected in the 3-month and 12-month SPEI data, further indicate water shortages, threatening agricultural productivity and water availability. Increasing temperatures and erratic rainfall patterns contribute to the vulnerability of rain-fed agricultural systems, upon which the majority of the population relies. The findings underline the urgency of implementing sustainable land and water management practices, such as soil and water conservation, improved irrigation systems, and climate-resilient crop varieties. Policymakers and stakeholders must prioritize the integration of climate adaptation strategies into regional planning to address the dual challenges of declining rainfall and rising temperatures.

6. CONCLUSIONS

The analysis of rainfall and temperature trends in the Loka Abaya district from 1981 to 2022 highlights significant climatic shifts, underscoring the need for immediate attention to agricultural and water resource management practices. The decreasing trend in Belg season rainfall, combined with rising minimum temperatures, points to heightened vulnerability to droughts and water shortages, particularly during critical agricultural periods. The study underscores the urgency of adaptive strategies, such as improved water resource management and climate-resilient agricultural practices, to address the increasing frequency of droughts and shifting climate patterns.

Despite the absence of statistically significant trends in some seasonal rainfall patterns and maximum temperatures, the overall findings suggest a concerning long-term decline in rainfall, exacerbated by temperature increases. The frequency of severe drought events, particularly in recent years, further reinforces the need for a proactive approach to mitigate the negative impacts of climate change on local livelihoods.

While this study provides essential insights, there are avenues for further research to explore. For example, more detailed studies on the interaction between temperature and evapotranspiration, as well as the potential for climate adaptation strategies tailored to local agricultural practices, would enhance the understanding of climate resilience in the region. Additionally, expanding the scope to include socio-economic impacts on local communities would provide a more comprehensive view of the challenges posed by climate change.

The limitations of this study, such as the reliance on historical data and potential variability in local microclimates, should be acknowledged, but they do not diminish the significance of the findings. The implications of this research are clear: without prompt action to address the adverse impacts of climate variability, Loka Abaya's agricultural productivity and water security will continue to face significant challenges.

Finally, this study emphasizes the importance of timely and targeted interventions to mitigate climate risks, foster sustainable agricultural practices, and ensure long-term water availability for the region. The findings serve as a call to action for policymakers, researchers, and local communities to collaborate in developing effective strategies for climate adaptation and resilience.

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Use of AI tools declaration
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Author contributions
All authors contributed equally to this work. All authors read and approved the final manuscript.

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