Heliyon 10 (2024) e28184

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Analysis of rainfall and temperature variabilities in Sidama regional state, Ethiopia

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ARTICLE INFO

Keywords:
Rainfall and temperature trends
Precipitation and temperature variability
Ethiopia

ABSTRACT

The objective of the study was to examine local-scale fluctuation in precipitation and temperature in selected districts of Sidama regional state. Specifically, it focuses on three districts—Hawassa Zuriya, Wonsho, and Hula—using **precipitation** and temperature **records** obtained from the Climate Hazards Group Infrared Precipitation with Station (CHIRPS) database which covers the period from 1981 to 2022. **Various statistical measures such as mean, standard deviation, as well as coefficient of variation was employed to detect fluctuation**. For trend detection, the Mann-Kendall (MK) and Sen's slope tests were also employed. **Observations revealed that the average yearly precipitation** spatially varied from 1331 mm in Hula, followed by 1275 mm in Wonsho, and 1013 mm at Hawassa Zuriya. Rainfall was bimodal which 53% rains in Kiremt and 33% in Belg season respectively. Annual rainfall show relatively low variability (<20%) for Hula and Wonsho districts, and moderate variability (CV>20%) for Hawassa Zuriya respectively. The findings also revealed **noticeable rising tendencies** ($p < 0.05$) for average temperature across all three agroecosystems over the years under consideration with the highest slope at Hawassa Zuriya (0.038 °C/year), followed by Hula (0.031 °C/year), and Wonsho (0.022 °C/year) respectively.

Moreover, both temperature and rainfall exhibited spatial and inter-annual variability. The results of this study necessitate farmers for systematic planning and implementing location specific crop calendar **in the context of fluctuating climatic settings**. Policy-makers as well as development practitioners can also utilize the finding to better devise and execute plans for adapting and minimizing the effects of climate change.

1. Introduction

The latest report from the Intergovernmental Panel on Climate Change (IPCC) highlights that the consequences of human-induced climate change **have led to extensive and permanent adverse effects on both the global ecosystem and human populations** [1,2]. There is also a high confidence among the scientific community that **climate change significantly diminished food and water security, posing obstacles to the attainment of Sustainable Development Goals** (SDGs) [3,4]. The genesis of the current anthropogenic climate change goes back to 1950s where the emision of green house gases (GHGs) has triggered average global

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https://doi.org/10.1016/j.heliyon.2024.e28184
Received 28 October 2023; Received in revised form 12 March 2024; Accepted 13 March 2024
Available online 26 March 2024

surface temperature rise [1,2]. **According to projections**, in near-term (2040), there will be 1.5 °C rise in global surface temperature and this would cause further multiple risks to ecosystems and humans [5] though the level of risk will depend on **changes in susceptibility, subjected to hazard, degree of economic advancement and the types of response mechanisms** [6–8].

Sub-Saharan Africa (SSA) is one of the world's regions most at risk from climate change because fragile environment, **climate-dependent economies, and low adaptation abilities** [6,9]. **Other research studies have also indicated that, depending on the emission scenarios considered, climate change may lead to a decrease in global crop yields ranging from 3% to 12% by 2050 and 11% to 25% by 2090** [6,10,11]. **Conversely, the General Circulation Models (GCMs) predict that Ethiopia will experience heightened changes and fluctuations in precipitation and temperature in the coming decades. According to the models, Ethiopia is expected to experience average annual temperature increases of approximately** 0.9–1.1 °C, 1.7–2.1 °C, and 2.7–3.4 °C by the years 2030, 2050, and 2080, respectively [10]. The EPCC report also **predicted notable fluctuations in rainfall patterns, occurring at different times within a year and from year to year, throughout the country.**

Rainfall and Gross Domestic Product (GDP) have strong direct relationship in Ethiopia because its dependence on rain fed agriculture [11,12]. **Consequently, in the most severe scenarios, climate change has the potential to cause an up to 8% reduction**

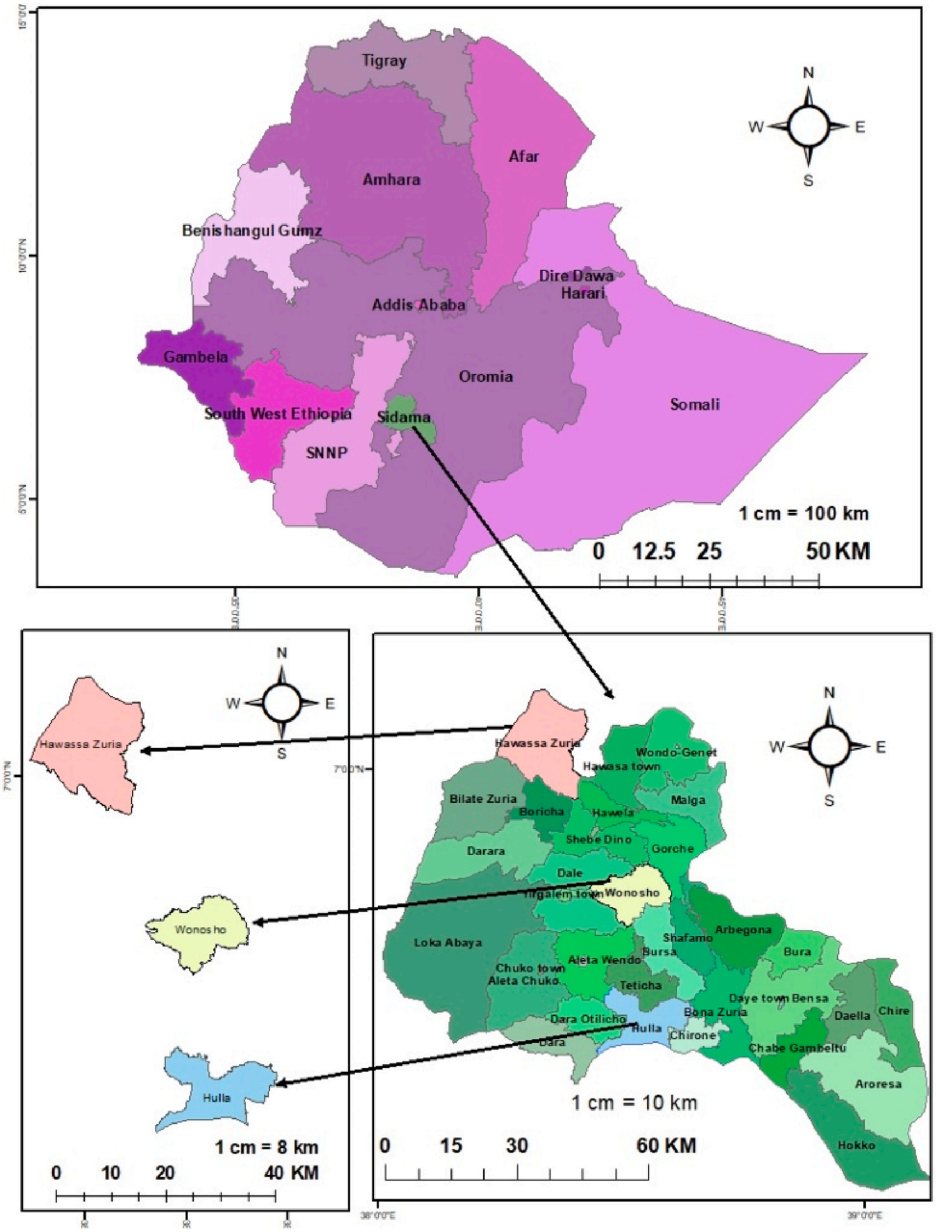

Fig. 1. Study area Map.
Source: Mapped by researcher using Ethiopian 3rd Round Housing and Population Census Cartography Shapefile (CSA, 2007).

in the country's Gross Domestic Product (GDP) [13]. **In the years to come, Ethiopia is anticipated to witness an increase in agricultural productivity due to the prevailing trajectory in precipitation and temperature, despite rising vulnerability and limited capacity to address the associated impacts** [14]. Ethiopia **is currently encountering** significant **effects from climate fluctuation**, including recurring floods, droughts, and transformations in marginal agricultural systems [6,15,16]. **Most Ethiopian farmers depend on rain-fed subsistence farming systems for their livelihood**, making them highly susceptible to the unpredictability of rainfall, which often leads to substantial crop losses and food insecurity [17–19]. The vulnerability of rural livelihoods in Ethiopia, which primarily revolve around agriculture, pastoralism, and agro-pastoralism, is closely interconnected with the natural environment [10,20].Precipitation trends and variabilities have been one of the key factors affecting productivity food insecurity in agrarian economies [17,18,21]. This means apart from fluctuations in the quantity of rainfall, changes in the timing of when rainfall starts, how long it persists, and when it stops can significantly affect food production, income generation, and overall well-being of farmers in these countries.

Annual and seasonal variations in precipitation because of climate change have been affecting agricultural productivity in Ethiopia [22–24]. The effect on agriculture varies across areas, with some regions experiencing more rainfall, while others encounter reduced rainfall **or changes in the beginning and ending time of rainy seasons.** These variations **resulted in some** implications for agriculture productivity and ecosystem services. Besides, studies at country level do not reflect the local level variabilities and its local impacts [25]. Therefore, we argue that obtaining local knowledge on how the climate has been changing and affecting the community's livelihood over time and space is important to identify location-specific climate change adaptation strategies [26]. To this end**, assessing fluctuation and pattern of precipitation and temperature by using** historical data is critical not only for forecasting future scenarios [11,27] but also for enabling policy development to reduce **extreme events** [17,22,26,28]. **There is no consensus among previous studies carried out in the country on how precipitation and temperature change over different regions and periods. Some of them report an increase in rainfall, while others show a decrease** [6,11,25,29–31]. For instance Ref. [32], **findings indicate that Ethiopia experienced less annual rainfall in the past 20 years**. Similarly [22,23], found a decrease in annual rainfall but increasing trends in the kiremt rainy season. Wagesho et al. [33], also observed significant increases in kiremt rains in the southern region but decreasing trends in the short rainy season (belg). Conversely, Belay et al. [30]found nonsignificant **increases** in kiremt rains, nonsignificant decreases in belg rains, and a significant decline in the winter season in southern Ethiopia.

In contrast, Matewos and Tefera [19] **discovered notable and statistically significant declines in short-rainy season rainfall particularly in the northeastern Sidama region**. **More recently** Ware et al. [31] **reported a steady drop in the average yearly precipitation, along with a notable reduction in both the short and long rainy seasons** in Sidama region. Furthermore, Matewos and Tefera [19] **also documented significant variability for the onset and cessation of rainfall**, spatially and temporally. This suggests that **the rainfall pattern displayed inconsistency across diverse locations and time periods, with variations in both the amount and direction of the trend, encompassing both increases and decreases. Considering the context mentioned above, the purpose of this study was to address the current limitations based on** a micro-scale analysis to identify local-level manifestations of **climate variability and devise context-specific adaptive responses. To address the identified gaps, this study sought to investigate the fluctuation and pattern of precipitation and temperature in three districts located in Sidama region over 41 years (1981–2022).**

2. Research methodologies

2.1. The study setting

The study was done in the Sidama Regional State, with a focus on three districts: Hula, Wonsho, and Hawassa Zuria (Fig. 1). Hula is located in the Dega agroecological zone, which has an altitude range of 2600–2800 m [34]. On the other hand, Wonsho and Hawassa Zuriya are situated in the Midland (1800–3200 masl) and lowland (1500–1800 masl) **agri-environmental regions** [35]. The study districts experience two distinct rainy seasons [28,31,36]. **The primary rainy season, known as Kiremt, occurs from June to mid-September, while the shorter rainy season, called Belg, takes place between March and May** [31]. The Belg season's irregularity poses challenges for crop production and harvesting [19]. Due to the delayed onset, early termination, and poor performance of the Belg rainy season, the study districts currently facing food shortages [16,31,34].

The prevalent agricultural system in the region is characterized by subsistence farming, which involves a combination of cultivating crops and raising livestock [37,38]. The area surrounding the homestead is primarily cultivated with **permanent crops**, specifically **"Enset (Ensete ventricosum)", which serves as a household's source of food and annual income** [28]. Additionally, **the study districts are characterized by extensive cultivation of "Coffee (primarily Coffee Arabica)" and "Chat (Catha edulis)". The region cultivates different kinds of fruits, including papaya, avocado (Persea americana), and mango (Mangifera indica). It also grows staples such as potato (Solanum tuberosum), barley (Hordeum vulgare), wheat (Triticum aestivum), and maize (Zea mays). Cattle, sheep, goats**, and equines are **the main livestock species raised in the study districts**. However, crop production faces challenges due to **unpredictable precipitation patterns**, **impoverished soil fertility**, **small land size per household**, inadequate utilization of advanced agricultural technologies, and low agricultural productivity per acre [28]. Consequently, a significant proportion of households in the region face food insecurity and heavily depend on food aid or assistance from the Productive Safety Nets Program (PSNP) [16,31].

2.2. Data source and acquisition

In this study, **we utilized gridded precipitation as well as temperature data was obtained from the Climate Hazards Group Infrared Precipitation with Station (CHIRPS) version 2.0 dataset, which was accessed on September 20, 2023.** The data set can be found at https://chg.geog.ucsb.edu/data/chirps/. The CHIRPS dataset offers a distinctive collection of data, characterized by its **fine-grained temporal** (diurnal) and **spatial coverage**(0.05°) (5 km) [39,40], and valuable for analyzing **extreme precipitation and temperature** within narrow geographical regions [41]. Similarly, the dataset proves to be particularly valuable in regions where the availability of weather stations is limited, their distribution is uneven, data gaps exist, or the period of observation is relatively short [25,29,31].

Dinku et al. [39]conducted a validation study of the CHIRPS data in East Africa, specifically Ethiopia, comparing it to rain gauge data and found to be a strong consistence between the two data sets. In accordance with the **recommendations acknowledged by the World Meteorological Organization (WMO),** this study utilized a 41-year period spanning from 1981 to 2022 to calculate climatological averages [42]. This extended time frame was chosen to facilitate a comprehensive analysis of long-term climate trends, as climatological studies typically require **at least three decade data** to discern meaningful patterns and variations. Previous studies [43] in Ethiopia also utilize CHIRIPS data base for identifying **how climate change affects the likelihood of droughts**.

2.3. Data analysis techniques

There are various techniques employed to analyze the trends and variability of **precipitation and temperature**, **which can be broadly classified into two** categories: 'variability **analysis'** and 'trend analysis' [21–23,25,26]. For this study we employ the coefficient of variation (CV) [44], '**the Mann-Kendall test'** [45–47],and '**Sen's estimator'** [48–51].

Non-parametric tests are particularly suitable for analyzing hydrological time series data that exhibit non-normal distributions, outliers, censoring, and missing values, which are common in this type of data [26,47]. These tests are designed to handle these complexities effectively. The computations for the aforementioned analyses were carried out using various packages available in the R-project [48–50] and XLSTAT, 2021. These software tools provide a range of statistical functions and algorithms necessary for conducting comprehensive trend and variability analyses.

We used Coefficient of Variability (CV) to assess the variability of **annual and seasonal precipitation,** as **well as the highest and lowest air temperatures**, we calculated average, standard deviation, and coefficients of variation (CVs) for both climatic elements. By computing the CV, we determined the extent to which rainfall and temperature deviated from the long-term average at both annual and seasonal scales. Previous research, such as the work conducted by Ref. [20], and [52] also employed **similar approach** to **analyze the fluctuation of precipitation and temperature** in the study region. CV values estimated in our study allowed us to classify the level of rainfall variability into three categories: **relatively stable** (CV $\leq$ 20%), **intermediate fluctuations** (CV = 20%–30%), and **pronounced variations** (CV > 30%), as established by Ref. [53]. By utilizing the CV metric and referring to established thresholds, we were able to quantify and characterize **how much the rainfall patterns varies**. This analysis yielded valuable insights into the nature of climate fluctuations within the study districts.

$$\textbf{The Coefficient of Variation (CV) is calculated by dividing the standard deviation } (\sigma) \textbf{ by the mean } (\mu)\textbf{, expressed as } CV = \sigma/\mu. \tag{1}$$

The study used '**Mann-Kendall test'** [54] and '**Sen's slope estimator'** [51] to analyze RF and temperature trend over time. **The former is** a non-parametric statistical technique widely utilized to analyze climate **fluctuations** [29,55]. It is particularly preferred in climate studies due to its robustness and ability to handle outliers effectively [25,54]. **The Mann-Kendall test calculates a score that represents the overall trend in longitudinal data, specifically in rainfall or temperature. This score is subsequently compared to a critical value to determine whether the data exhibits a positive, negative, or no trend in the variables being analyzed.** The Mann-Kendall statistic's magnitude indicates the trend's strength [54]. **Through the application of the test and careful analysis of the ensuing statistics, we successfully evaluated the existence and the direction of trends in the climate variables being investigated. This analysis provides valuable insights into the evolving patterns of climatic elements, thereby enhancing our understanding of climatic trends within the study area.**

The theoretical calculation of the 'Mann-Kendall statistic', denoted as S [54]**, is presented in Equation** …. … (2).

$$S = \sum_{i=1}^{n-1} \cdot \sum_{j=i+1}^{n} sgn\left(x_j - x_i\right)$$

Where

$$sgn\left(x_j - x_i\right) = \begin{cases} +1, x_j > x_i \\ 0, x_j = x_i \\ -1, x_j < x_i \end{cases} \tag{3}$$

Sign function, written as Sign(Xj X k), **gives the values** −1, 0, or 1 **depending on whether** Xj - Xk is **negative, zero, or positive, respectively, where** j > k. It is defined as follows:

$$\tau = S/B \tag{4}$$

Where,

$$\frac{\sqrt{1}}{2n(n-1)} - 1 \Big/ 2B = \sqrt{\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{j^-=1} tj(t_j-1)}\sqrt{\frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{n}(n-1)} \tag{5}$$

To derive the standardized test measurement Z, the calculations involve estimating both (S) and VAR(S). This estimation process follows a specific formula outlined by Ref. [56]. … (6)

$$z = \sum^{\frac{s-1}{\sqrt[0]{vAR(s)}} - if s>0}_{\frac{s+1}{\sqrt{vAR(S)}} \cdot 1^{\dot{\Delta} - s=0}_{l\ fs<0}}$$

A positive Z statistic shows that the time series is trending upward, while a negative one means it is trending downward. The null hypothesis (H0) and alternative hypothesis (Ha) **correspond to the absence of trends and the presence of trends in the selected** data set, respectively [57].

The calculation of the degrees of rainfall and temperature variations involved utilizing Sen's slope estimator [51], known as slope Q. This estimator, which can be derived from N pairs of data, is computed as the difference between each data point Xi and the average value X_i-X_{avg}:

$$\text{Sen's slope} = \text{Median} = \left\{\left(\frac{x_{tn} - x_{tm}}{t_n - t_m}\right)\right\} \tag{7}$$

If the value of Sen's slope, calculated using the changing values of the variable at time steps t_n and t_m (X_{tn} and X_{tm}), is close to zero, it indicates that there is minimal or no significant variation in the variable over time.

3. Results and discussions

3.1. Analysis of spatial variability

3.1.1. Variability in temperature

The **investigation of temperature data** has revealed that average annual, minimum, and maximum temperature records exhibited spatial variation. The mean annual temperature is 13.4 °C at Hula, 19.2 °C at Wonsho, and 23.75^{0}c in Hawassa Zuriya districts (Fig. 2). **Alternatively, the yearly lowest temperature** is 10.5^{0}c at Hula, 14.0^{0}c at Wonsho, and 19.0^{0}c is at Hawassa Zuriya. The spatial variation in temperature is also evident in the maximum annual temperature records across the three agroecologies where it is 17.3^{0}c, 21.5^{0}c, and 28.5^{0}c for Hula, Wonsho and Hawassa Zuriya districts **respectively**. **This finding aligns with the results of other studies conducted** in Sidama region and country wide studies [6,16,28,31,56]. Understanding the spatial variation in maximum and minimum temperatures across different agroecologies provides valuable insights into each region's unique climatic challenges and opportunities [6,58].

Altitude plays a significant role in influencing temperature patterns. As elevation increases, the average annual temperature tends to decrease [59]. **This phenomenon is commonly referred to as the 'lapse rate'** [59,60], **whereby** temperature drops with a higher altitude due to decreased atmospheric pressure and the associated adiabatic cooling effect [61,62]. Areas at higher altitudes generally experience lower minimum temperatures compared to lower-lying regions. This is because colder air is denser and tends to sink to lower elevations, resulting in cooler temperatures at higher altitudes [62].

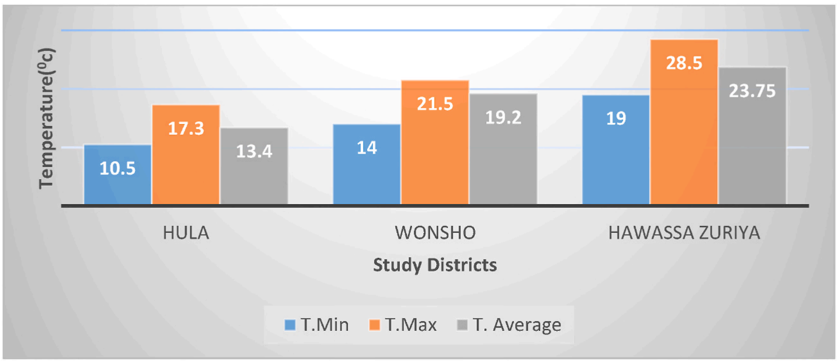

Fig. 2. Spatial Temperature distribution.
Source: Computed from CHIRPS data

3.1.2. Rainfall variability

The analysis of rainfall data also depicted spatial and seasonal variations among the three districts. The mean annual rainfall varied from 1331 mm in Hula±188 mm followed by 1275 ± 182 mm in Wonsho, and 1013 ± 172 mm at Hawassa Zuriya (Table 1). **Among the three districts, Hula district has the most variable mean annual rainfall, while Hawassa Zuriya district has the least variable mean annual rainfall. This finding is corroborated by** other studies conducted on the subject area by Ref. [19] who reported a mean annual rainfall of 1101.27 mm/year for **the moisture-stress districts of the region ('Lokka Abaya, Boricha, and Hawassa Zuria'**) for the period 1983 to 2014. Similarly, other studies carried out in the Central Rift Valley area also reported similar findings [28,31,63].

The RF and Temperature data analysis also shown seasonal variation in the study area (Fig. 3).

Fig. 2 illustrates the presence of both inter-annual and intra-annual variability in rainfall. **The yearly precipitation has two main seasons: kiremt and belg (**Table 1**).Kiremt is the longer rainy season, and it provides 51 to 54% of the annual rainfall. Belg is the shorter rainy season, and it supplies 33 to 34% of the yearly rainfall (**Table 2**).**

However, the contribution of the winter season to the annual rainfall ranges between 11.6% mm to 13.9% mm, which is large compared to the findings of [64]. Furthermore, this result reinforces the concentration of rainfall occurring during the kiremt and belg seasons in Sidama region [16,31]. **Additionally, this finding aligns with the results of a study conducted by Alemayehu and Bewket** [11]**, which also identified the kiremt and belg seasons as the primary contributors to the annual rainfall.**

The CV was calculated to quantity degree of precipitation distribution patterns over different years, seasons, and locations between 1981 and 2022 (as shown in Table 2). **A greater CV value suggests greater variability, indicating larger fluctuations in rainfall amounts, while a lower CV value indicates more consistent or stable rainfall patterns** [53]. **In our investigation, we used the CV labeling system proposed by Ref. [53] . According to this system, areas with CV values less than 20% are stable, areas with CV values between 20% and 30% are intermediate, and areas with CV values greater than 30% are characterized as highly variable. Accordingly, the results** from data analysis have reveled less variability for Hula and Wonsho (CV<20%), while it is moderately variable Hawassa Zuriya (CV >20%) during the study period (1981–2022) (Table 2). The result indicating higher RF variability over lowlands is consistent with other studies [19,31,43] **carried out in** Southern part of Ethiopia. **The examination of the data additionally uncovered fluctuations in rainfall (RF) patterns across different seasons, as indicated in** Table 2. The Belg season RF rainfall depicted higher CV compared with Kiremt Season RF. Although the inter-belg rainfall variation is equivalent to the inter-annual rainfall variation (CV = 21.3%), the inter-summer rainfall variation is relatively below the inter-annual variability (Table 2)**.This finding aligns with the conclusions drawn by previous studies** [9,25,29] **which reported greater fluctuation in Belg rainfall compared to Kiremt rainfall in their particular research areas**. In contrast to our study [19], found significant **variability in precipitation** in the Central Rift Valley districts that experience moisture stress. They reported that **the coefficient of variation** (CV) values ranged from 18% to 40% **for the annual**, 17%–39% **for the kiremt season**, and 27%–57% **for the belg season**.

3.2. Temporal variability analysis

3.2.1. Analysis of temperature trends

A closer look at the temperature data revealed that there were fluctuations from one year to another in the period studied. Temperature records exhibited an increasing trends (see Figs. 4 and 5 below).

As indicated by Fig. 4A, B, and 4C, maximum temperature depicted an increasing trend in all districts. **The results of this study are consistent with similar research done in different parts of Ethiopia and other East African countries, which have reported comparable findings** [6,19,43,55,65].

The result of Mann-Kendal test result (under Table 3**) demonstrated** a statistically significant positive trend ($P < 0.001$) in **the yearly, maximum, and minimum temperature** records are statistically significant for the three study districts. This result is concurrent with the findings reported from different parts of Ethiopia including Sidama region [4,6,16,28,31].

On the annual basis the three districts show upward trend in average temperature at a significance level of ($p < 0.05$) (Table 3). Accordingly, the highest slope is reported at Hawassa Zuriya (0.038 °C/year), followed by Hula (0.031 °C/year), and Wonsho (0.022 °C/year) respectively. The magnitude of change (Sen's slope) for maximum temperature, is highest for Hula (0.038^{0}c/year) followed by Hawassa Zuriya (0.037^{0}c/year), and Wonsho (0.022^{0}c/year/respectively (Table 3). Other studies on temperature trend over Ethiopia also have shown an increasing mean annual [6,11,20,30]. Based on the data shown above (Table 3), we can conclude **that there is a clear trend of increasing temperatures in the three districts. Numerous studies indicated that** the previous three decades have been "the warmest in the history of the planet Earth" [7,41].

The analysis of rainfall data across the study districts has revealed variability throughout the years under study. As it is

Table 1
Rainfall distribution across the districts, (1981–2022).

Variable	Minimum	Maximum	Mean	Std. deviation	CV (%)
Hula RF	565.493	1661.966	1330.831	188.390	14.2%
Wonsho RF	569.599	1574.520	1275.824	182.328	17.8%
Hawassa RF	511.474	1265.896	1013.472	137.393	20.5%

Source: Computed from CHIRPS data

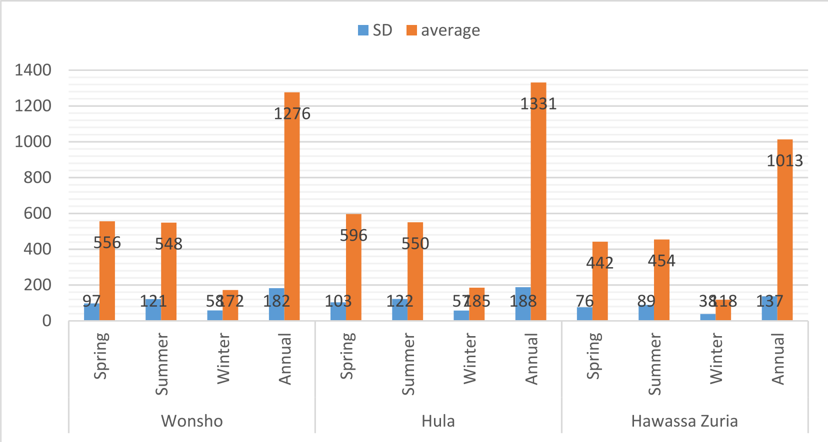

Fig. 3. Seasonal RF variation across the districts (1981–2022).
Source: Computed from CHIRPS data

Table 2
Seasonal Distribution of CV across the districts (1981–2022).

Districts	Annual	Winter			Main season/kiremt/			Belg		
	CV (%)	mean	% to annual	CV	Mean	% to annual	CV (%)	Mean	% to annual	CV (%)
Hula	14.2	185	13.9	31	550	51.3	22	596	34.8	17
Wonsho	17.8	172	13.5	34	548	52.9	22	556	33.6	18
H/Zuriya	20.5	118	11.6	32	454	54.8	20	442	33.7	17
Average	17.3	396.3	13	32.3	517	53	21.3	531.3	33	17.3

Source: Computed from CHIRPS data

indicated in (Fig. 5), annual RF has depicted inter-annual variability. All the three districts had received lower amount of annual RF in the years 1983/84, 1990/91, 1998, 2007/8, 2001/2, 2015/16, 20118/19and 2020. This finding is align with the earlier studies conducted in the study districts [3,16,31,34]. Whereas in the years 1981, 1987, 1995, 2005, and 2017 the districts receive maximum amount of rainfall (Fig. 5). This findings augments similar claims of other studies on the cyclical nature of drought years **in the country** [17], [66].

As indicated in the linear regression line on (Fig. 5), **the upward direction of regression line** shows the **annual rainfall for the three study districts has generally been rising**, although the magnitude vary across the districts. Similarly, the study noted positive slope for the two agriculturally important rainy seasons (kiremt and belg) for all study districts (Figs. 6–8).

When examining the amplitude of RF changes, the Mann-Kendall and Sens' slope tests revealed a positive increasing trend with the ($p > 0.05$), implying that the observed trend is not statistically significant(Table 4**). The current finding contradicts the results of** Legesse [32] **who identified a statistically significant positive trend in yearly rainfall for the northern part of the country.**

When comparing the amplitude of increasing trends among the studied districts, Wonsho has the highest value at 0.17 mm/decade, followed by Hula at 0.106mm/decade and Hawassa Zuriya at 0.09mm/decade with a significant level of $p > 0.001$(Table 4). The positive Sen's slope suggests that all districts, regardless of agroecological zone, **had an upward pattern in precipitation**.

With regards to seasonality, this study revealed a variation in the trend of rainfall (as shown in Table 4). Specifically, the **June-September** rainfall exhibited **pronounced upward trends** in both the Hula and Wonsho districts (Table 4). **Conversely**, the belg rainfall showed a **statistically notable increasing pattern** in the Hula district, with a 90% confidence interval (Table 5). These results highlight the varying patterns of rainfall trends across different seasons and districts, emphasizing the importance of considering seasonal variations and agroecological factors when planning any adaptation strategies (Table 5).

Although the analysis found positive outcomes for Hawassa Zuriya (Table 5**), none of the seasons were statistically significant.** This **implies that** while there were indications of increasing trends in rainfall, none of the seasons in the Hawassa Zuriya district exhibited statistically significant changes.

4. Conclusion and recommendations

The research investigated the **changes over time** and monotonic trends of **precipitation** and temperature distribution of Hula, Wonsho, and Hawassa Zuriya districts of the Sidama region for the period 1981–2022. **The study analyzed how rainfall and temperature variables changed over the year and in different seasons. It paid special attention to variables like precipitation**

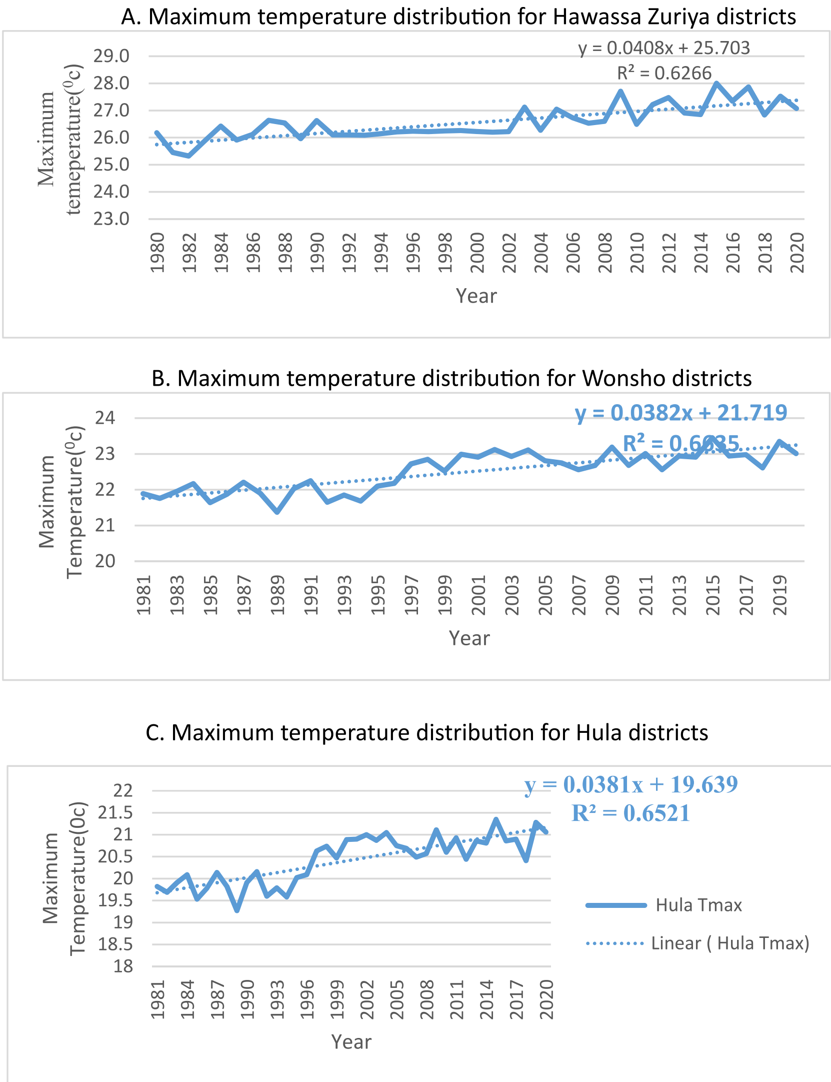

Fig. 4A. Maximum temperature distribution for Hawassa Zuriya districts
Fig. 4B. Maximum temperature distribution for Wonsho districts
Fig. 4C. Maximum temperature distribution for Hula districts.
Source: Computed from CHIRPS data

in each season, rainfall in the whole year, lowest and highest temperatures, and average temperature. The study's findings revealed noteworthy variations and patterns in cyclical and yearly rainfall, as shown in long-term data series with varied degrees of unpredictability. The study relies on Kiremt and Belg, the two critical rainy seasons, for agricultural activity in the study districts. These seasons are critical for the agricultural sector because they influence crop productivity and quality. **The longest rainy season**, Kiremt, accounts for 53% of the yearly rainfall, while **the shortest rainy season**, Belg, contributes 33%. **The average amount of precipitation that occurs over a year in the study woredas** ranges between 1013 mm and 1331 mm, with a standard deviation between 137 and 188 mm, and a coefficient of variation of 14.2%–20.5%. **Standard deviation along with coefficient of variation indicated rainfall variability as well as irregular distribution. The coefficient of variation of precipitation** for the Hula and Wonsho districts, which was found to be less than 20%, indicates that rainfall is still reliable in the highland and mid-land agroecological zones. On the other hand, the coefficient of variation for Hawassa Zuriya, which is greater than 20%, reveals that rainfall in the low-land zone is more unreliable.

Several statistical tests were carried out to determine the distribution and frequency of precipitation and temperature. **Accordingly, it was found that temperatures exhibited an upward trend in all study districts during the period under consideration. Both the minimum and maximum temperatures exhibited upward trends across all study districts on an annual and seasonal basis.** The rainfall in the investigated districts **exhibits multiple types of variability**, including both seasonal and **year-to-year variability**, as well as spatial variability. **The statistical tests conducted in the study districts revealed fluctuations in**

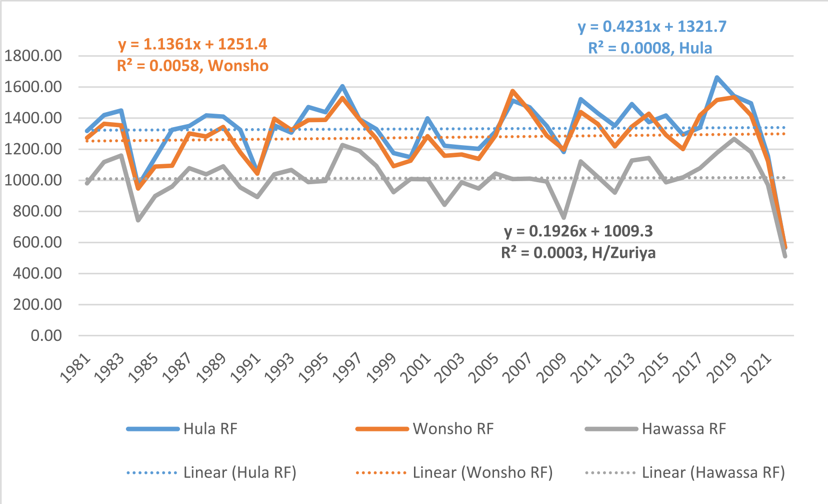

Fig. 5. Annual rainfall distribution in the study districts (1981–2022).

Table 3
Mann-Kendall test result (1981–2022).

Districts	T_{Min}			T_{Max}			Yearly mean		
	Kendal's tau	Sen's slope	Trend	Kendal's tau	Sen' s slope	Trend	Kendal's tau	Sen' slope	Trend
Hula	0.4***	0.022	I	0.554***	0.038	I	0.554***	0.031	I
Wonsho	0.39***	0.022	I	0.575***	0.022	I	0.575***	0.022	I
H/Zuriya	0.38***	0.021	I	0.561***	0.037	I	0.561***	0.038	I

Note: *** statistically significant at 0.001 level; I= **Increasing**.

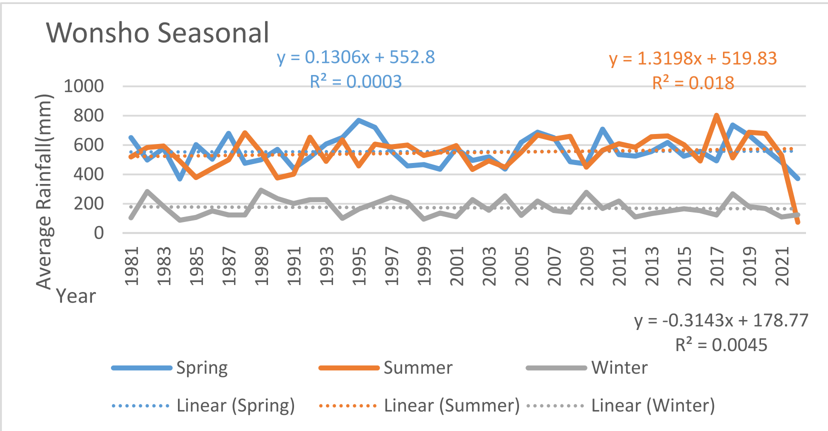

Fig. 6. Seasonal rainfall distribution for Wonsho district.

precipitation and temperature trends during the study period, highlighting the impact of worldwide increase in temperature on the local climate. This study can help government authorities, development professionals, and farmers. Authorities can use the evidence to make better policies. Professionals can use reality to plan resilient infrastructure. Farmers can use the information to choose the best adaptation strategies and improve irrigation.

Ethics declaration

Not applicable for this study.

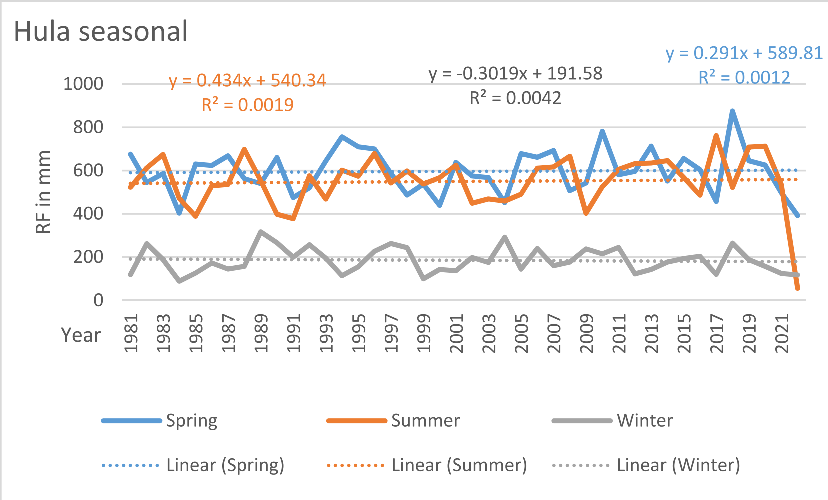

Fig. 7. Seasonal rainfall distribution for Hula district.

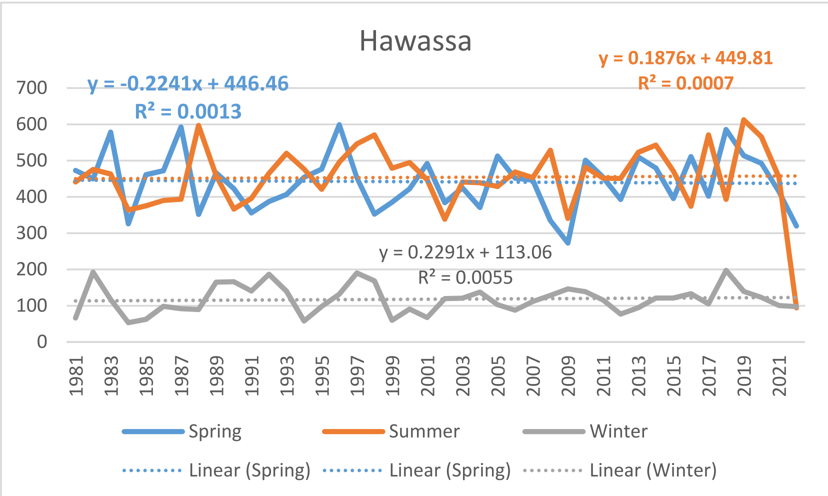

Fig. 8. Seasonal rainfall distribution for Hawassa Zuriya.

Table 4
Non-parametric Test Result of annual rainfall of the study districts (1981–2022).

Hula		Wonsho		H/Zuriya	
Kendall's tau	0.106	**Kendall's tau**	0.166	**Kendall's tau**	0.094
S	91	S	143	S	81
Var(S)	8514.333	Var(S)	8514.333	Var(S)	8514.333
Significance level	0.329(ns)	**Significance level**	0.124(ns)	**Significance level**	0.386(ns)
Critical value	0.05	**Critical value**	0.05	**Critical value**	0.05
Sen's Slope	1.999	**Sen's Slope**	2.955	**Sens slope**	1.307

Note: ns = non-significant.

Table 5
Seasonal Trend of Rainfall across the study Districts (1981–2022).

Variable	Attribute		Hula	Wonsho	H/Zuriya
Seasonal Rainfall Trend Analysis	Belg Rain	**Kendall's rank correlation**	0.056	0.017	0.024
		S statistics	46	15	21
		Critical value	**0.0612***	0.879	0.828
		Median slope estimator	0.65	0.263	0.21
	Kiremt Rain	**Kendall's rank correlation**	0.202	0.208	0.129
		S statistics	166	179	111
		Critical value	**0.064***	**0.054***	0.233
		Median slope estimator	2.931	2.641	1.345
	Bega Rain	**Kendall's rank correlation**	0	−0.008	0.073
		S statistics	0	−7	63
		Critical value	1	0.94	0.505
		Median slope estimator	0.015	−0.057*	0.311

Note: *, **, *** Confidence level (90%, 95%, and 99%).

Data availability statement

Data associated with the study is made available by request.

CRediT authorship contribution statement

Yohannes Yona: Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tafesse Matewos:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Investigation, Data curation, Conceptualization. **Getachew Sime:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We acknowledge Sidama National Regional state and Hawassa University for their financial support.

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