RESEARCH

Spatiotemporal variability and trend of rainfall and temperature in Sidama Regional State, Ethiopia

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Abstract

This study aims to investigate spatiotemporal variability, trends, and anomaly in rainfall and temperature in the Sidama region, Ethiopia. The TerraClimate gridded dataset on a monthly time scale for 30 years (1991–2020) with a horizontal resolution of approximately 4 km was used for the study. Trends in annual and seasonal rainfall and temperature were assessed using a nonparametric test (Mann-Kendal test) and Sen's slope to test the statistical significance and magnitude of trends (increase/decrease), respectively. Our findings revealed that annual rainfall, summer (*Hawado*), and spring (*Badhessa*) rainfall have shown an increasing trend in most parts of the region, except for its northwest parts. We found a low annual rainfall variability (CV < 13%) over the southeastern and northwestern parts of the region. Rainfall variability revealed the difference in both time and space across the region. Six drought years (1999, 2001, 2002, 2003, 2012, and 2019) with different magnitudes were identified across the region. Annual average maximum (up to 0.4 °C decade^{-1}) and minimum (up to 0.25 °C decade^{-1}) temperatures revealed significantly increasing trends across the region. The standardized anomaly in the mean annual temperature indicated that the years in the recent decade (2011–2020) are getting warmer compared to the past two decades (1991–2010) due to natural and anthropogenic activities causing weather extremes in the region. The results of this study for rainfall contradict the other studies in the rift valley part of the region. Therefore, we suggest appropriate climate change adaptation strategies so that there is high rainfall and temperature variability across the region and between seasons.

Keywords Climate change · Rainfall · Temperature · TerraClimate · Anomalies · Sidama region

1 Introduction

Human-induced climate change and variability are worldwide phenomena that have a detrimental effect on people's socioeconomic activities such as health, livelihood, and food security. Between 1850 and 2012, the global average temperature increased by 0.78 °C (Esayas et al. 2018). The Intergovernmental Panel on Climate Change (IPCC) predictions indicated a 1.5 to 2 °C rise by the end of the twenty-first century (IPCC 2014). Several researchers have examined the historical trends of climate change and variability in Ethiopia. Recent studies, for example, discovered that the average annual maximum temperature rose by 0.3 to 0.6 °C per decade between 1985 and 2018 across the country (Ware et al. 2022). Similarly, the minimum temperature rose by 0.37 °C per decade between 1951 and 2006 (Bogale and Tolossa 2021). The changing amount and intensity of rainfall over space and time is another feature of climate variability. Rainfall in *Belg* and *Kiremt* reduced by 15–20% across the country's southern, southwestern, and central parts (Belay et al. 2019). The annual and seasonal rainfall variability ranges between 50 and 80%, the average temperature rises at a rate of 0.37 °C decade^{-1}, and the maximum daily temperature has risen a total of 1.5 °C since 1900 impacting food security, livelihoods, and health, and well-being, and other socioeconomic aspects of people (Belay et al. 2019; IPCC 2022).

Ethiopia is one of Africa's most vulnerable countries to climate change and variability that threaten people's lives and livelihoods (Matewos and Tefera 2020). The uncertainty

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and ever-changing patterns of rainfall and temperature have caused unprecedented challenges to the rural poor in the country. Several empirical pieces of evidence reveal rainfall variability and temperature rise impact agricultural productivity, water availability, and biodiversity (Parry et al. 2009; Ripple et al. 2017; IPCC 2021). Rural livelihoods in Ethiopia, such as agriculture, pastoralism, and agropastoralism, are extremely sensitive to climate variability and change due to their close ties to the natural environment.

While agriculture contributes over 40% to the gross domestic product (GDP), generates about 85% of national export earnings, and employs 75% of the country's workforce (Taffesse et al. 2013), its productivity is closely linked with climate because of its rainfed characteristics. Thus, changes in rainfall and temperature result in reductions in agricultural productivity impacting the country's overall food security and socioeconomic status (Bezabih et al. 2014; Gleixner et al. 2017; Matewos 2019; Teshome and Zhang 2019). Although the association between cereal production and rainfall variability differs depending on the crop type, the correlation between the mean cereals production and rainfall variability is about 0.23 (Lewis 2017).

Aside from agriculture, the ever-changing conditions of rainfall and temperature will affect several sectors. Climate-related extremes have multidimensional consequences. Many of the impacts of climate change will emerge as changes in extreme weather events such as droughts and floods. Climatic extremes (such as droughts and flooding) have economic and social consequences for farmers' livelihoods as well as national economic growth (Weldearegay and Tedla 2018). Ethiopia has experienced numerous severe drought events over the last 40 years, including those in 1983–1985, 1988, 2000, 2002–2003, 2006, 2011, and 2015, with the 1983–1985 drought being the worst, affecting millions of poor rural farmers, pastoralists, and livestock (Alemayehu and Bewket 2017; Matewos 2019; Matewos and Tefera Matewos and Tefera 2020; Ayehu et al. 2021).

Although the susceptibility of the country's regions to climate change and variability is not markedly different, the impacts differ greatly across regions. Drought in Ethiopia occurs during the different seasons that occur in different regions(Zeleke et al. 2017; Annys et al. 2017). Understanding the long-term trends and variability of climate over space and time in various regions is a critical step in obtaining the necessary details on how it has been changing and affecting the country's economy and development. Such data is critical for developing appropriate strategies to deal with current and future trends in climate variability and change (Abeje et al. 2019). The trend in climate change, i.e., the decline in rainfall and increase in temperature, makes livestock rearing more viable than crop production (Godde et al. 2021).

Several studies have been conducted to assess patterns of climate change and variability across Ethiopia; however, their conclusions on trends in rainfall based on location and season are inconsistent and mixed. For example, according to Worku et al. (2022), annual, August, October, and November rainfall show significant increasing trends during 1981–2020. Wagesho and Yohannes (2016) indicated seasonal rainfall in *Halaba*, *Angacha*, *Butajira*, *Durame*, *Fonko*, *Hossana*, and *Wulberag* shows an increasing trend in the Kiremt season. However, they have also reported a decreasing trend at Shone and Wolkite in the same season. In the other case, Belay et al. (2021) reported nonsignificantly increasing trends in rainfall in June and July in southern Ethiopia, while a nonsignificantly decreasing trend in spring with a significantly decreasing trend at a 5% level of significance in *Belg*. On the other hand, Matewos and Tefera (2020) found statistically significant decreasing trends in Belg rainfall in north-eastern Sidama. However, in a nutshell, rainfall trends in many locations in Ethiopia are uncertain because of geographical and/or data-source differences. Unlike the study conducted by Matewos and Tefera (2020), which focuses on the rift valley region, this study embraced the entire Sidama region.

Inconsistencies in previous findings could be attributed to the limited number of ground stations to represent the extensive area as well as the length and quality of rainfall and temperature data used for the studies. Using accurate and long-time series enables us to understand the complexity of local climate variables and develop appropriate policies and strategies to plan for agricultural productivity and ensure food security. However, depending on the topography and other biophysical factors, rainfall in Ethiopia varies along the localities, and results indicate high spatiotemporal variability at small distances. In this regard, using high-resolution gridded datasets such as Terraclimate is not optional.

Most of the previous studies in the Sidama region are limited to drought-prone districts such as Lokka Abbaya, Boricha, and Hawassa Zuria (Matewos 2019, 2020; Matewos and Tefera 2020). These districts are by nature characterized as dry and hot and are categorized under lowlands (locally called *kola*) (Sup. Fig. 1) . However, highlands and midlands in the region are not exceptions to the impacts of climate change. Besides, most of the previous studies explained rainfall in terms of inter-annual and inter-seasonal variability, trends, and seasonality. All of the previous studies except Matewos and Tefera (2020) used rainfall and temperature data from gauge stations that have several limitations. To address the limitations of previous research, this study used a gridded dataset to investigate the spatiotemporal characteristics of rainfall and temperature variability across different agroecologies of the entire region (Sup. Fig. 2).

Fig. 1 Topographic map of the study area based on the Shuttle Radar Topography Mission (SRTM) data at 90-m resolution
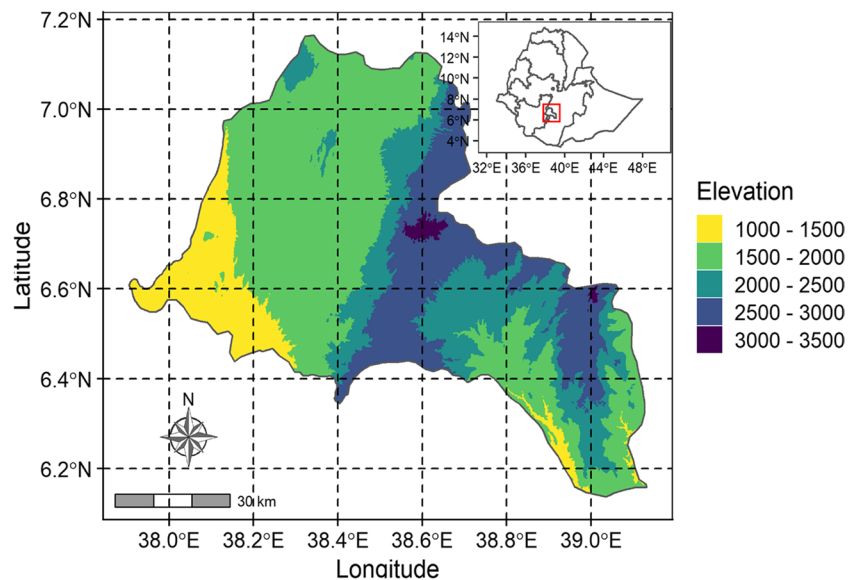
2 Study area description

Sidama National Regional State (hereafter referred to as Sidama) is located between 5′45″–6′45″N latitude and 38′00″–39′20″ E longitude (Fig. 1). The land area of the Sidama region is about 10,000 km², with an estimated human population of 3,668,304 with 1,849,128 male and 1,819,176 female in 2017 (CSA 2013). Sidama region is one of the most densely populated regions in the country with over 460 people per km² with an average household size of 4.99 persons (Kumo 2016). Sidama is bordered from north to southeast by the Oromia region, south by the Gedeo zone, and west by the Wolaita zone. The region has diverse biophysical conditions and rich cultural practices, and its current challenges are achieving food security given land shortage, rapid population growth, deforestation, loss of biodiversity, and climatic change. Sidama region is divided into 32 districts (Woredas).

The climatic conditions in Sidama range from hot and dry conditions in the lowland areas of Lokka Abaya to cold and humid alpine habitats in the highlands of Hula, Teticha, Bursa, Arbegona, Burra, Daeela, and Aroressa. The elevation of Sidama ranges from 1179 m.a.s.l over the northwestern part of the region to > 3127 m.a.s.l, mount Garamba (Elbakidze et al. 2018).

Sidama region grows many crops mainly in the agroforestry system, and subsistent agriculture is a mainstay of the region's economy (Kumo 2016). Given the diversity in elevation, the region follows mixed agricultural (crop and livestock production) practices. The major crops in the region are Enset (*Ensete ventricosum*), coffee, maize, barley, wheat, oat, sorghum, millets, sugar cane, potatoes, and other cereal crops and vegetables. Enset is one of the unexploited and less investigated crops in the region even though it is called

the 'tree against hunger' because of its high tolerance to drought. Coffee is one of the major export crops in Ethiopia, and Sidama coffee is one of the brands in the country. The effects of climate change on coffee are unclear as there have not been many studies in the region either on climate change and variability or the effects of these changes on coffee. As coffee plants need temperatures lower than 22 °C, higher temperatures would adversely affect coffee production in the region. The results of some studies stated that coffee will be forced to move to a higher altitude in long run owing to rising temperatures in low altitudes. Currently, this plant has been suffering the threat of being replaced by Khat (Catha edulis), which is one of the cash crops in the region.

The region's dependency on subsistence agriculture, which relies on archaic technology and vagaries of nature coupled with massive population growth, and limited rural development, made this region prone to frequent hunger and famine recently (Kumo 2016). Even though fisheries are underdeveloped and limited to prominent lakes such as Hawassa and Abaya Lakes, fishing activities are the source of income and livelihood for many people in the region. The potential of several perennial rivers such as Logita, Ganale, and Bilate that are flowing in different directions of the region is not yet exploited. Furthermore, precipitation and temperature variabilities have exposed smallholder farmers in the study area to climate-related epidemics, recurrent drought, harvest loss, and hunger (Matewos 2019).

It roughly can be classified into five categories. Lowlands, less than 1500 m.a.s.l, covers about 10% of the region, which is mainly located over the northwestern (Lokka Abaayya) part of the region. About 48% of the region is categorized as midlands (1500–2000 m.a.s.l). About 21% falls between 2000 and 2500 m.a.s.l, and the next 21% is categorized between 2500 and 3000 m.a.s.l. The mountain of Garamba,

which has a height of greater than 3000 m.a.s.l, is found in the region as well.

3 Materials and methods

3.1 Data sources and acquisition

This study used monthly, seasonal, and annual time series data for the last 30 years (1991–2020) downloaded from the TerraClimate website.[1] We download and used precipitation and maximum and minimum temperatures from the dataset for this study. The dataset is of monthly climate for global terrestrial surfaces with 0.04° spatial resolution and is available from 1958 to the present (Abatzoglou et al. 2018). Details of TerraClimate products are provided in Abatzoglou et al. (2018). The data used in this study was limited to the last 30 years for spatiotemporal variability in precipitation, and temperature because the resulting impacts have been escalating over the last three decades. Moreover, the study follows the recommendation from the World Meteorological Organisation (WMO) to use the most recent 30-year period of 1991–2020 to calculate climatological averages (World Meteorological Organization (WMO) 2017). Due to the absence of data from relevant ground-based gauge stations, we have not included validation analysis.

3.2 Data analysis methods

The total annual rainfall time series was calculated from the monthly rainfall of the TerraClimate. Seasonal rainfall over the respective seasons was obtained by summing corresponding monthly rainfall. Non-parametric methods used to detect trend analysis include the Mann–Kendall test (Mann 1945; Kendall 1975) and Spearman's rho test (Hamed 2016). Because parametric tests require meeting normal distribution assumptions, in this study, a non-parametric (Mann–Kendall) test was used for detecting trends. Non-parametric tests are less sensitive to outliers and do not hold any distribution assumption (Yue et al. 2002).

Seasonal and annual trends in rainfall and temperature from 1991 to 2020 were used to explore homogeneous climatic regions of the study area. The trends in the seasonal and annual precipitation, as well as in the minimum and maximum temperature time series, were detected by fitting a linear regression model to each grid cell. The study used the Mann–Kendall (MK) test to assess the significance of the trends. The trends over each climatic region were extracted using a mask of a climatic region area. In this case, linear regression is computed as:

$$y(t) = a + \beta t \tag{1}$$

The slope β of the time series over each grid cell is calculated following the recommendation of Mann (1945) and Kendall (1975):

$$\beta = \frac{\frac{12}{n}\left(\sum_{n=1}^{N}(t_n x_n) - \frac{N+1}{2}\sum_{n=1}^{N} x_n\right)}{N^2 - 1} \tag{2}$$

where $n = 1, 2, \ldots, N$ and the value x_n at the time t_n. The null hypothesis was $\beta = 0$, and the alternative hypothesis was $\beta \neq 0$.

Then, the statistical significance of the trend in time series was assessed using the Mann-Kendal test (Mann 1945; Kendall 1975). The nonparametric test is chosen due to its resilience to outliers, non-normality, missing values, and seasonality (Helsel and Hirsch 2002; Borges et al. 2014). The statistics S of the MK test for the time series x is computed as a sum of the signs of the slopes (Rustum et al. 2017) which is given as:

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

where n is the total number of data points, x_j is the jth observation, and x_i is the ith observation where $j > i$. Then, $sgn(.)$ can be computed as:

Mann (1945) and Kendall (1975) noted that when $n \geq 8$, the statistics S is approximately normally distributed with mean and variance V given as follows:

$$\operatorname{mean}(S) = 0 \tag{4}$$

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{q} p_i(i-1)(2i+5)}{18} \tag{5}$$

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} 1 & if\, x_j - x_i > 0 \\ 0 & if\, x_j - x_i = 0 \\ -1 & if\, x_j - x_i < 0 \end{cases} \tag{6}$$

where p_i is the number of data points in the ith tie group and q is the number of tie groups in the time series. Where there are ties in the data, the variance $V(S)$ should be standardized as:

$$Z_{mk} = \begin{cases} \frac{S-1}{\sqrt{V(S)}} & S > 0 \\ 0 & S = 0 \\ -\frac{S+1}{\sqrt{V(S)}} & S < 0 \end{cases} \tag{7}$$

where Z_{mk} is the result of a trend statistics test. Positive (negative) Z_{mk} values indicate an upward (downward) trend. If the computed values of Z_{mk} is greater than $Z\alpha/2$, where α

Fig. 2 Seasonal variation of the mean (Tmean), maximum (Tmax), and minimum (Tmin) temperature (°C) and rainfall (mm) in the Sidama region
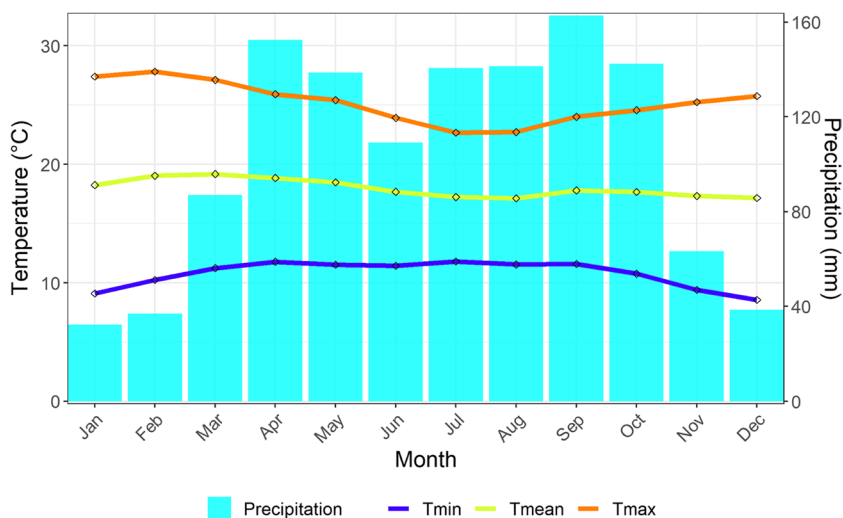
represents a level of statistical significance, then the trend of the time series is considered significant. In this study, 95% of the confidence level was used to test the hypothesis, meaning that the null hypothesis has no trend if $|Z_{mk}| > 1.96$, and otherwise, the alternative hypothesis with a monotonically increasing or decreasing trend exists in the time series (Liou and Mulualem 2019). The magnitude of the change per unit of time was predicted using Sen's slope estimator (Sen 1968) as follows:

$$\text{Sen's Slope} = \text{Median} = \left\{ \frac{(X_{tn} - X_{tm})}{(tn - tm)} \right\}, tn > tm, \quad (8)$$

where X_{tn} and X_{tm} are the changing values of the variable at time steps t_n and t_m. If Sen's slope value is close to zero, then there is no considerable variation in the variable over time.

The variability analysis was performed using the coefficient of variation (CV) which is the percentage departure of rainfall from the long-term mean. The variability analysis measures conditions of temperature and rainfall over the specified geographic area within the study time frame (1991–2020). CV is computed as:

$$C = \frac{\sigma}{\mu} x 100 \quad (9)$$

where CV is the coefficient of variation, σ is the standard deviation, and μ is the mean precipitation. According to Hare et al. (1983) and Samy et al. (2019), the variation of rainfall is classified as CV < 20, low variability, 20 < CV < 30, moderate variability; and CV > 30, high variability. In this regard, the coefficient of variation was calculated for each month of the years (1991–2020). Maximum and minimum rainfall was calculated along with its mean, standard deviation, Skewness, and Kurtosis. Eventually, from the obtained result, the coefficient of variation was calculated using equation 9 above.

All the above computations were performed using several packages provided in R-project (R Core Team 2018). The major packages that were used in this study were RASTER (Hijmans et al. 2022) and CMSAF (Kothe et al. 2019).

4 Results and discussions

4.1 Annual and seasonal rainfall variability

Sidama region is characterized by a diverse climate, which ranges from dry and hot lowlands to wet and cold highlands. The area-averaged annual maximum temperature of the region is approximately 24.5 °C, and it varies from 13 to 34 °C. The average annual precipitation in the region is about 1243 mm (Fig. 2). In the Central Rift Valley Region (CRVR), part of the Sidama region Matewos and Tefera (2020) found that annual rainfall is 1101.27 mm. The region receives rainfall for 7 months from April to October although there was a modest reduction in June. The region receives a high average monthly rainfall between July and October with the second season between April and June.

Figure 3 shows the spatial distribution of seasonal and monthly rainfall from 1991 to 2020 over the Sidama region. The rainfall starts in March in the central part of the region though the amount is less than 100 mm/month (see Fig. 1). Most parts of the region receive rain during April and May with an increasing tendency toward the southern and southeastern parts of the region. These areas include the kebeles such as Teticha, Hula, Chirone, Dara, and Dara Otilicho in the southern tips of the region, while Aroressa and Hokko (southeastern part) also receive the relatively optimum amount of rainfall during these months. The monthly rainfall amount reaches up to 200 mm in parts of the region during this period. In June, rainfall showed a decreasing pattern throughout the

Fig. 3 Average monthly variation in precipitation (in mm) across the Sidama region for 1990–2020 from Terraclimate
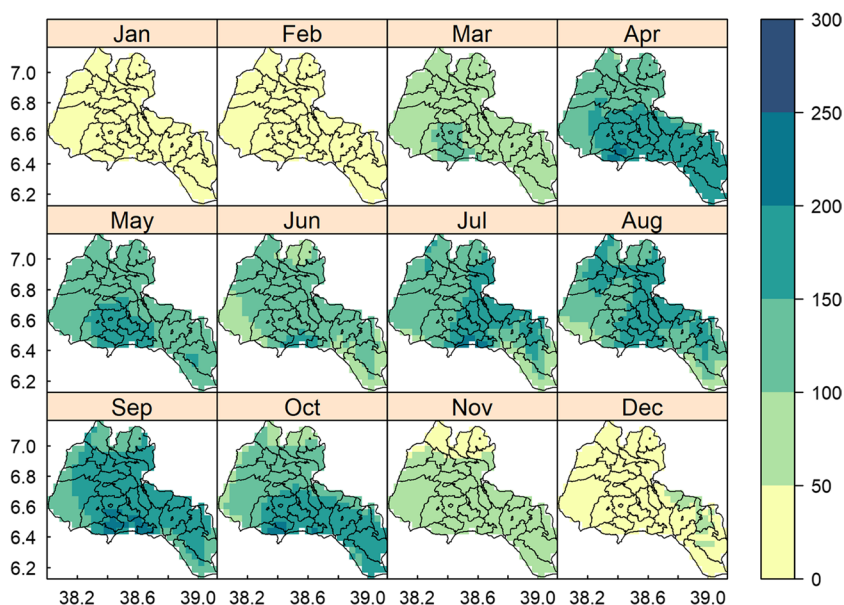
region and was limited only to central and southeastern highlands. Thus, the northwestern and southwest parts of the region such as Hawassa Zuria, Boricha, Darara, and Loka Abaya remain moisture deficient. Meanwhile, the results revealed that the rainfall increased and its distribution covered back the entire region starting from Mid of July to October. In Sidama, this season stays from July to October and it is locally called *Hawado*. Thus, during *Hawado*, the majority of the districts in the Sidama region receive modest rainfall except for Cabe Ganbeltu and Dara. In a few parts of the rift valley region, rainfall showed a decreasing tendency contrary to a few areas in the Sidama region. For instance, a decrease in the number of rainy days with an increase in the mean rainfall per rainy day has been observed over the past few decades, signifying an increase in the intensity of rainfall, particularly for the Kiremt (Kassie et al. 2014). The region received minimal (< 50 mm/month) rainfall between November and February, which is locally known as *Arro*. Similar to this finding, Degefu and Bewket (2014) reported a strong and statistically significant annual rainfall increase was observed in the southwestern part of Ethiopia at Wolaita Sodo (143 mm/decade) during the 1980–2007 periods. During this season, these areas receive limited precipitation. The region received rainfall in two seasons, *Badheessa* (March, April, and May) and *Hawado* (June, July, August, September, and October) (Fig. 3). The dry (*Arro*) season extends from November to February. Following conventional seasonal classification does not reflect the region's reality because rainfall extends from March to October almost without any jump between. Therefore, we

classified only into two: from March to May as *Badheessa* and Hawado between June to October.

The average seasonal rainfall ranges in the region range between 65 mm during December–January–February (DJF: dry season) and 579 mm in March–April–May (MAM) season. Occasionally, the region receives a minimal rainfall shower during the dry season as well; however, it is barely useful for the production in the region. Badhessa rainfall starts in March in the southern part of the region and moves towards the north. The average seasonal rainfall in MAM (Badhessa) season ranges from 204 to 579 mm. The region continues receiving rainfall during June–July–August (JJA: Hawado); nevertheless, the amount of rainfall in this season showed a reduction in the southeastern part of the region such as Hokko, Aroressa, Gambelto, and Bensa (Fig. 4). Region, in a nutshell, receives higher average rainfall in Badhessa than Hawaso. Nonetheless, both seasons are vital for regional production. Moreover, in September–October–November (SON) season, the region continued receiving rainfall primarily in its central parts. The total amount of rainfall during this season is accounted for limited heavy showers.

The mean annual rainfall of the region is 1244 mm/year for 1991–2020. The mean for the dry northeastern part of the region, for example, Lokka Abaya, Boricha, and Hawassa Zuria reported having 1101.27 mm/year for 1983–2014 (Matewos and Tefera, 2020b). It is found that the central and eastern highlands receive up to 1700 mm/year from 1991 to 2020. The region receives an annual rainfall ranging from 800 to 1800 mm (Fig. 5). The distribution of annual rainfall over the region has shown local characteristics. Annual rainfall gradients corresponding

Fig. 4 Average accumulated seasonal rainfall (mm) over the Sidama region in Ethiopia from 1991 to 2020 as calculated based on TerraClimate monthly rainfall for the reference period
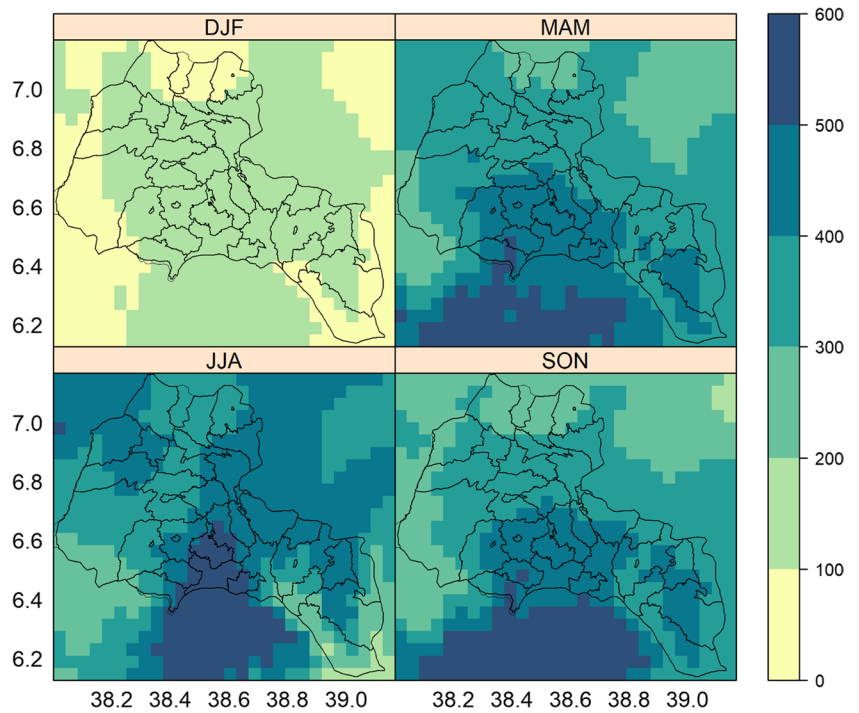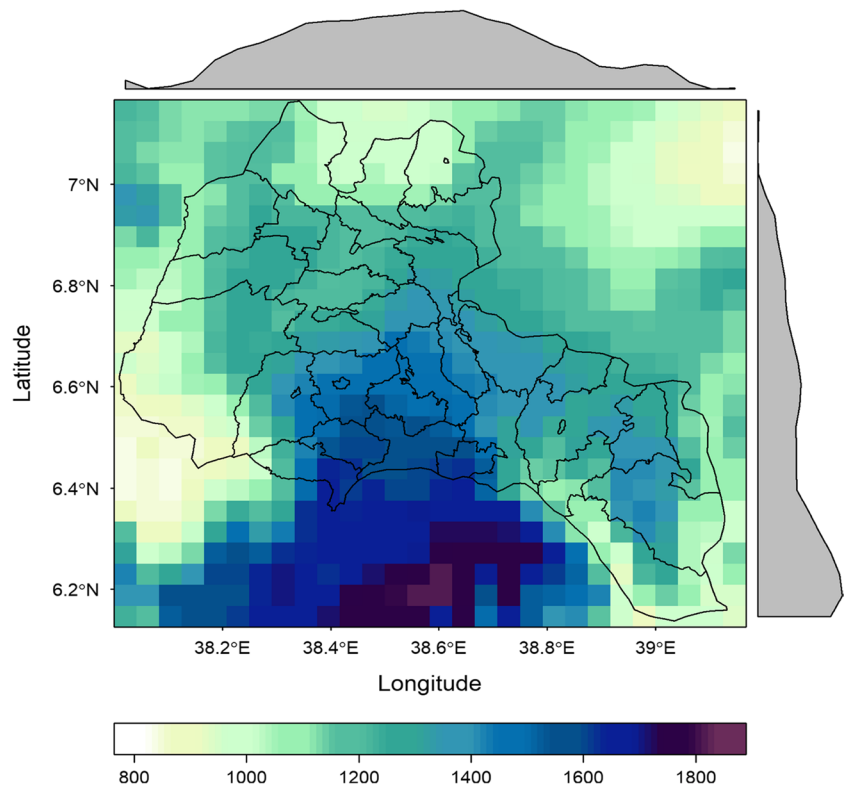

Fig. 5 The spatial distribution of mean annual rainfall (mm) over the Sidama region in Ethiopia (1991 to 2020). The gray shades indicate the zonal and meridional distribution of mean annual rainfall in the region

to latitude/longitude values respective to each pixel were estimated for the region. The maximum and strong rainfall gradients are oriented along with the central and southern tip of the region which receives total annual rainfall exceeding 1700 mm (Fig. 5). Western and southeastern
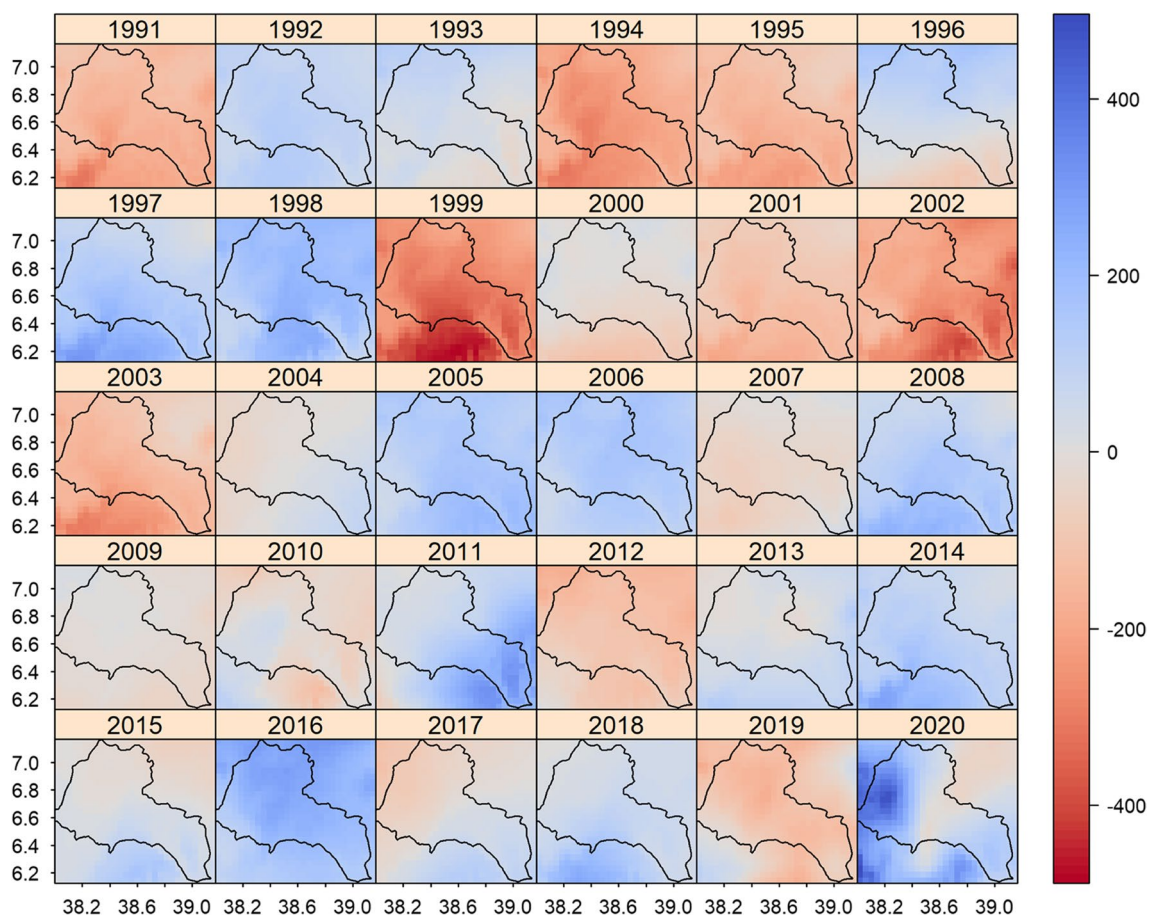
Fig. 6 Anomalies of annual rainfall in the Sidama region as the magnitude of departure from their long-term mean rainfall (1991 to 2020)

and northeastern margins of the region receive the lowest total annual rainfall from 1991 to 2020.

4.2 Precipitation trends and anomalies

The annual rainfall anomalies presented in Fig. 6 revealed that there were variations in the amount of rainfall spatiotemporally. Many areas in the region have received lower than long-term average annual rainfall in 1991, 1994, 1995, 1999, 2001, 2002, 2003, 2012, and 2019. However, in 1992, 1993, 1997, 1998, 2005, 2006, 2008, 2011, 2014, 2016, and 2020, many places in the region received higher than long-term annual average rainfall. However, the years 1991, 1999, and 2002 were identified as the driest years recorded in the region. In 2016 and 2020, the region received extremely high rainfall, particularly in the northern and northwestern parts. However, annual rainfall in the remaining years showed a slight deviation from the long-term mean, which indicates the region had received nearly normal annual rainfall distribution during these years. High inter-annual rainfall variability, combined with precipitation deficit, resulted in long-term drought in several areas. Many studies

on climate change noted that Ethiopia has experienced eight major droughts since 1980: in 1984, 1987, 1991, 1994, 1999 2002, 2012, and 2015 (Seleshi and Zanke 2004; Suryabhagavan 2017; Matewos and Tefera 2020). Additionally, the year 2019 can be categorized as a drought year, particularly in our study area. These findings are consistent with other studies in the Sidama and rift valley areas neighboring Sidama which have reported the persistence of drought. For instance, Matewos (2019) indicated that Belg standard rainfall anomalies results showed that the years 2000, 2008, 2009, and 2012 were years of severe drought, with values of − 1.34, − 1.57, − 1.61, and − 1.64, respectively. On the contrary, few regions received rainfall having high regional variability exceeding the long-term mean which caused flash flooding in 2005, 2006, 2016, and 2020.

Figure 7 shows monotonic trends in annual and seasonal rainfall per pixel over the region and stipples on the plot indicate trend significances at $P < 0.05$. The mean annual rainfall over the region showed positive trends across the region with values ranging from 20 to 60 mm per decade. According to the findings, the annual pattern of rainfall revealed only a significant increasing trend (ranging
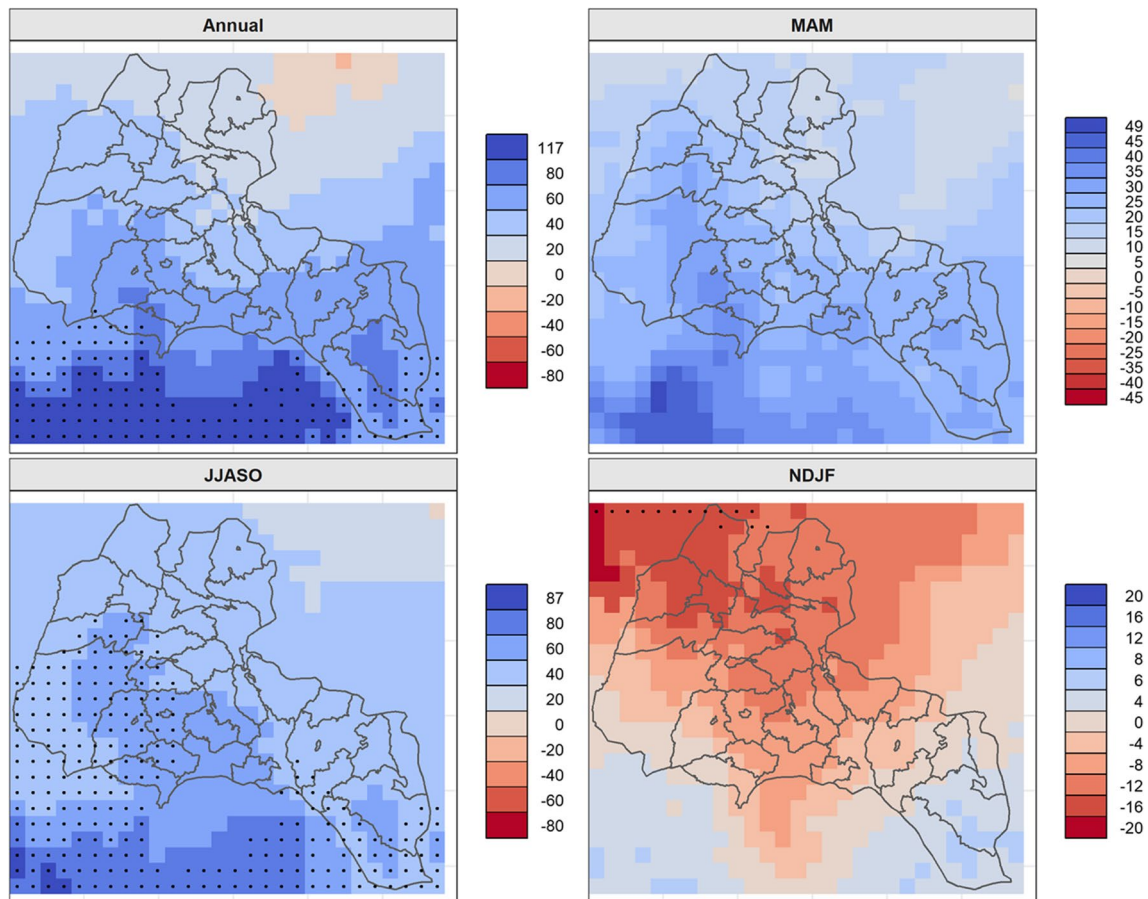
Fig. 7 Trends in annual and seasonal rainfall (mm per decade) in the Sidama region for 1991–2020 from TerraClimate. Stipples on the plot indicate statistical significance at $P < 0.05$

from 20 to 60 mm decade^{-1}) over the southeastern (Aror-essa and Hokko) and southwestern (Darra) parts of the region. At the same time, rainfall data from the Hawassa weather station showed a tendency of increasing trend (18 mm decade^{-1}) although the trend is not statistically significant during the study period (Ware et al. 2022). Similar to these results, Ayehu et al. (2021) reported increasing trends in annual (2.48 mm year^{-1}), summer (1.16 mm year^{-1}), spring (0.92 mm year^{-1}), and autumn (0.67 mm year^{-1}) rainfall and decreasing trend in the winter season (-0.15 mm year^{-1}) over the Upper Blue Nile area. Moreover, Alemayehu et al. (2020) reported statistically significant increasing trends in annual and *Bega* rainfall and a non-significant increasing trend in *Belg* in the *Alwero* watershed, western Ethiopia. On the contrary, Matewos and Tefera (2020) found decreasing trends in annual, *Kiremt*, and *Belg* rainfall over the CRVR although it is statistically significant only in Belg. Besides, Belihu et al. (2018) reported significantly decreasing trends in annual rainfall in the *Gidabo* catchment in the Sidama region.

Seasonal trend analysis shows a non-significant (except for small areas) increasing trend in rainfall during both *Kiremt* (*Hawado*) and *Belg* (*Badhesa*) seasons in the region. Only the Hawado season revealed a significant increase in rainfall in the region's northwestern and south-eastern regions. However, we discovered a decreasing trend in the Arro (NDJF) season across the central and northern parts of the region, with only a few areas of the northern tip of Hawasa Zuria showing a statistically significant trend during this season. Unlike this result, Muluneh et al. (2017) have indicated increasing an annual rainfall trend in the Central Rift Valley escarpment of Ethiopia with an altitudinal range of 1400–1700 m.a.s.l.

The spatial and temporal variabilities in annual and seasonal rainfall are assessed using a coefficient variation (CV). The CV for over 30 years (1991 to 2020) indicates that the variability in seasonal rainfall is much higher than that of annual rainfall variability (Fig. 8). The CV in annual rainfall ranges from 6 to 13% and in seasonal rainfall from 12 to 65%. The seasonal rainfall variability

Fig. 8 Coefficient of variations (CV) in annual and seasonal rainfalls (%) over the Sidama region
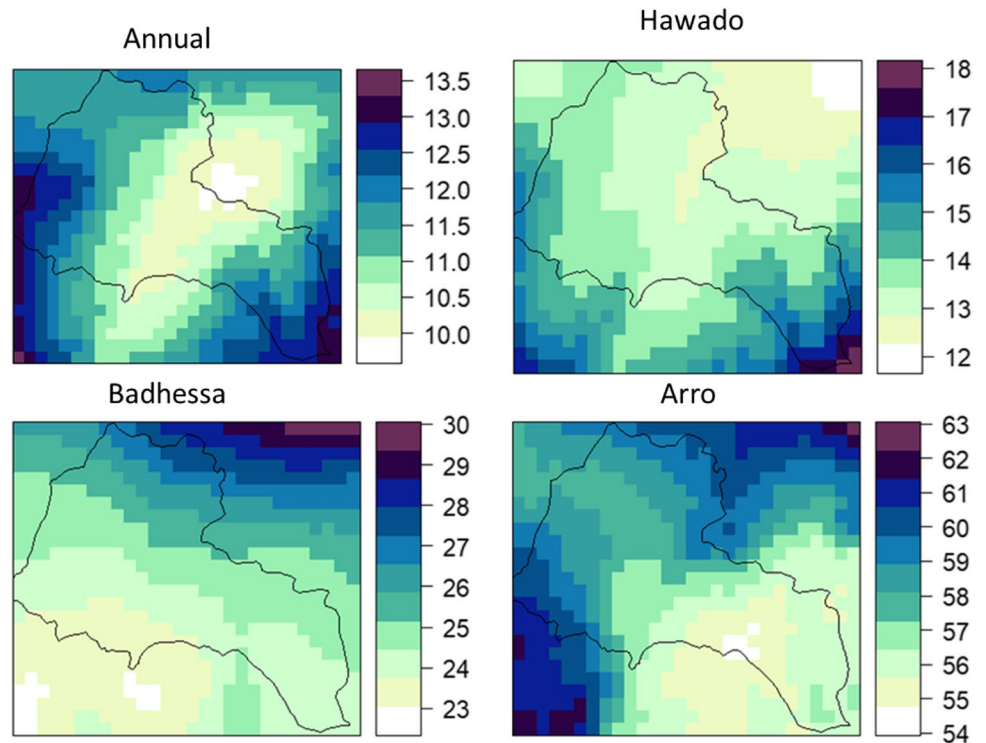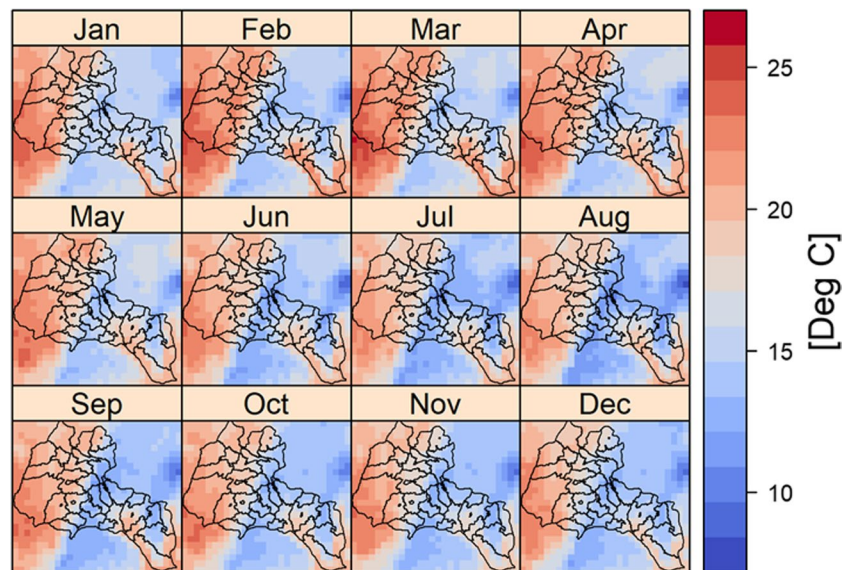

Fig. 9 The same as Fig. 3 but for mean monthly temperature (°C)

showed the CV ranging from 12 to 18%, 23 to 30%, and 50 to 63% for the Hawado, Badhessa, and Arro seasons, respectively (Fig. 8). The highest seasonal variability was observed in the Arro season, and it is the most significant contributors to annual rainfall variability. As the finding of Matewos and Tefera (2020) showed the CV in the Bega rainfall is 35%, which is higher compared to annual (13%), and *Kiremt* and *Belg* account for 23% of each in the CRVR.

4.3 Annual and seasonal temperature variations

The overall temperature of the region ranges between 8 and 28 °C. Northwestern parts of the region are hotter compared with the central and southeastern parts of the region. Regarding seasonalities in the temperature, January to May was hotter relative to June to August, which is colder in over the lowlands (Fig. 9). The average temperature over the central Sidama highlands was less than 20 °C throughout the year.
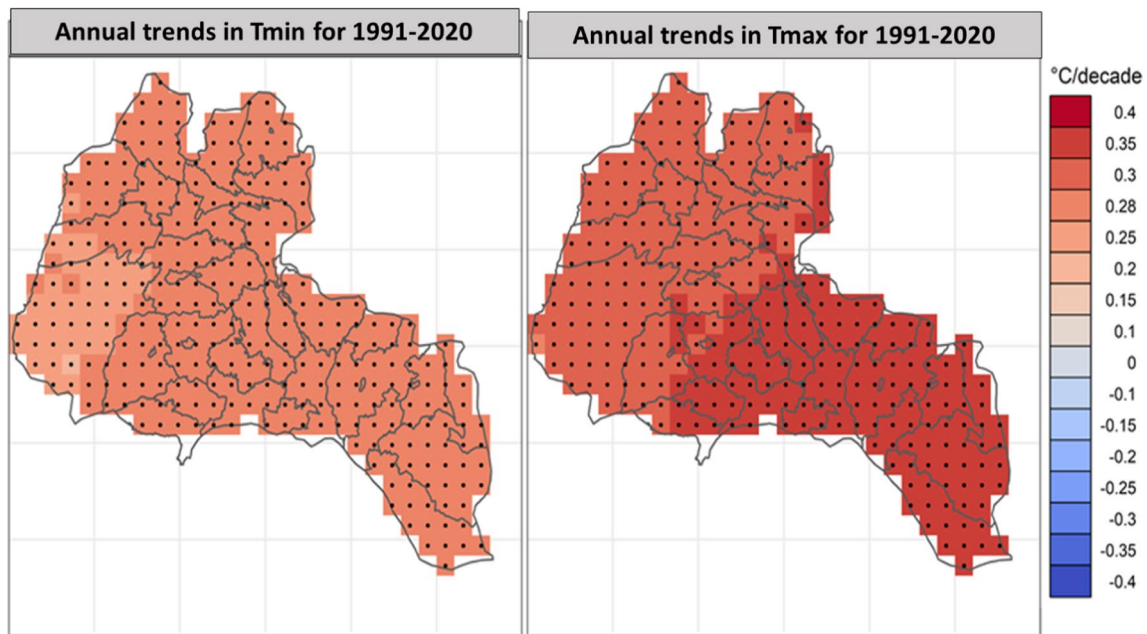
Fig. 10 Trends in annual minimum (Tmin) and maximum (Tmax) temperature (°C per decade) in the Sidama region. Stipples indicate statistically significant points at $P < 0.01$

4.4 Trends in annual minimum and maximum temperature

Figure 10 shows the decadal monotonic trend in maximum and minimum temperatures (°C decade^{-1}) significantly increased during the last three decades (1991–2020). Similarly, Matewos (2019) reported significantly increasing trends in temperature over the northeastern parts of the Sidama region. Our results revealed significantly increasing trends in both minimum and maximum temperatures across the region. However, the southeastern part of the region experiences higher temperature incidences much faster than the rest of the region, which is probably due to the alarming conversion of forest areas into agriculture, particularly in Aroressa, Chirre, Daeela, Gambeltu, and surrounding areas. Meanwhile, Hameso (2018) conducted a survey study in three districts from different agroecological zones and concluded that the majority of respondents reported a reduction in rainfall and a rise in temperature. For the Gidabo catchment of the Sidama region, Belihu et al. (2018) found the Gidabo catchment is getting warmer from 0.03 to 0.07 °C year^{-1}, which is similar to our finds. Additionally, the national climate change adaptation program of action (NAPA) states that the mean temperature has been increasing by about 0.37 °C decade^{-1} (NMA 2007).

4.5 Anomalies in annual mean temperature

The mean temperature anomaly in the region indicated that the years are getting hotter from time to time. Most of the years in the first decade (1991–2000) were colder than the long-term mean for 1991–2020. The year 2019 was the hottest compared to the years considered for this study. The frequency of having hot years increases from time to time. Similarly, Hansen et al. (2006) have reported rising trends in global temperature. As temperature anomaly refers to a departure from a reference value or long-term average, in this study, the latter was applied. The positive anomaly indicated that the respective year is hotter than the long-term mean. On the other hand, the negative (blue colors) in Fig. 11 indicates years colder than the long-term mean. Therefore, the years 1992, 1993, 1994, and 1999 were considerably colder than the long-term mean during the study time. However, the years 2002, 2006, 2009, 2010, 2011, 2015, 2016, 2017, 2019, and 2020 were hotter than the long-term mean temperature of the region. This is probably due to the fact that changing climate leads to significant increases in temperature extremes (Esayas et al. 2018). Meanwhile, the number of cold days and nights is significantly decreased across all agroecologies in Southern Ethiopia (Esayas et al. 2018); eventually, this leads to higher annual mean temperature compared to its long-term mean.

Fig. 11 Standardized anomalies
of the mean annual temperature
for 1991–2020 as computed
from the TerraClimate dataset
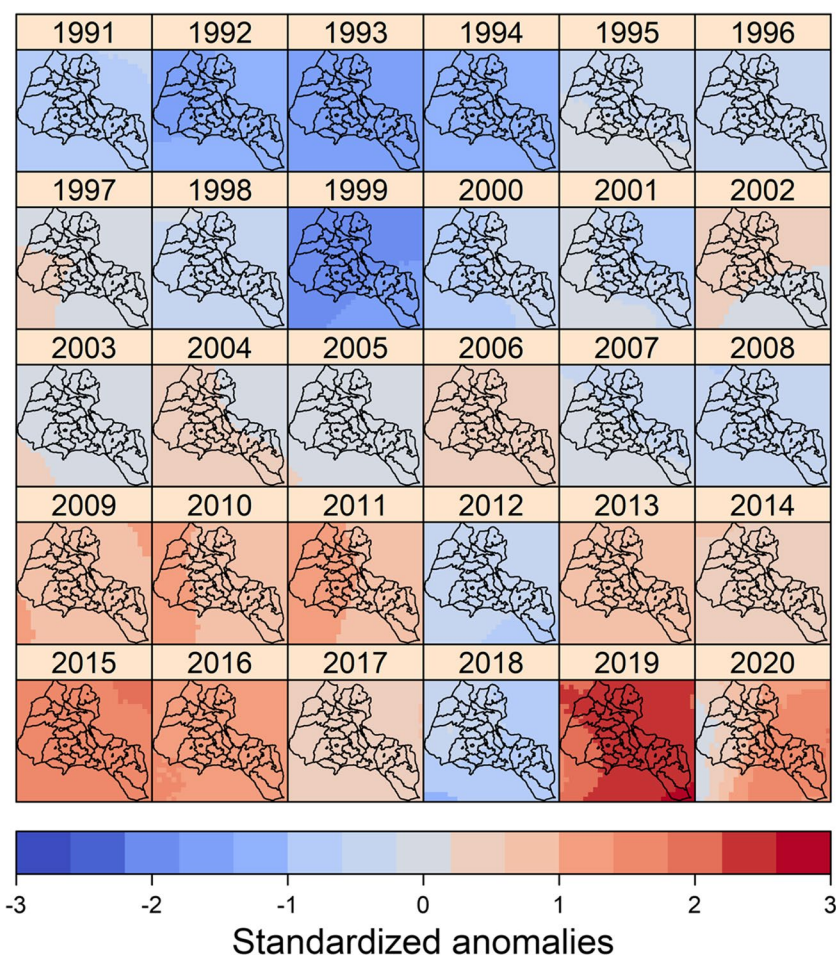
5 Conclusions

In this study, we investigated spatiotemporal variability and trends in both rainfall and temperature in the Sidama region of Ethiopia during 1991–2020. Based on our key findings, we can conclude that the region segregates into three rainfall seasons of which the main rainy season (Hawado) contributes the largest to the annual rainfall for the region having less variability compared to the other two seasons. Hawado rainfall showed statistically increasing trends over the western and southeastern parts of the region. The region received less than the long-term average rainfall in 1991, 1994, 1995, 1999, 2001, 2002, 2003, 2012, and 2019, which means these years refer to the region's drought incidences in different magnitudes. Findings of the annual, *Badhesa*, and Hawado rainfall trends show statistically non-significant increasing trends across most parts of the region. These results contradict the findings of the previous studies (Seleshi and Zanke 2004; NMA 2007; Wagesho et al. 2013; Alemayehu and Bewket 2017; Belihu et al. 2018; Matewos 2019; Matewos and Tefera 2020; Mohammed et al. 2022; Addisu) who reported significantly declining rainfall trends in Rifty valley part of the region. The possible source for

these contradictions is differences in data sources and study locations; we attempted to evaluate this using other data sources (not shown).

The mean annual maximum and minimum temperatures show warming trends across the region for 1991–2020. The rate at which the maximum temperature change is higher over the eastern part of the region compared to their western counterparts. The annual minimum temperature also significantly increased (up to 0.26 °C decade^{-1}) over the region during the study period. There is a considerable difference in rainfall variability across the region by season with high variability (CV up to 63%) in the *Arro* season. As trends in temperature have shown a significant increase during the past three decades and with a quite variable nature of rainfall, the overall situation requires close monitoring of government and other stakeholders as the region is one of the hubs for agricultural products such as coffee. As the variability and trends in climatic variables are localized, local-level studies like this are required for making agricultural decisions and planning for water and climate change adaptation options. Therefore, localized policy interventions are vital to mitigate upcoming climate-change-induced disasters' impacts on the socioeconomic activities of the smallholders in the region.

Declarations

Competing interests The authors declare no competing interests.

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