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Spatio-temporal variability and trends of hydroclimatic variables at Zarima Sub-Basin North Western Ethiopia

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Abstract

Globally, hydroclimatic variables have been changed due to human activities and have an impact on agricultural production and water resource management. This study investigated the spatio-temporal variability of hydroclimatic variables in Zarima subbasin using rainfall and temperature data from 1984 to 2018 and stream flow data from 1990 to 2014. The data were analyzed using the coefficient of variation, standardized anomaly index, Mann–Kendall trend and Sen's slope estimator test. The results showed that rainfall, maximum and minimum temperatures of the Zarima subbasin varied spatially and temporally. The annual and Kiremit season rainfall and stream flow showed low to moderate variability (CV < 30%) whereas Bega and Belg season rain fall and stream flow showed high degree of variability (CV < 40%). The annual and Kiremit season rainfall showed relatively higher variability along the northern border of the subbasin. However, maximum temperature showed less degree of variability (CV < 10%) over the subbasin, whereas the annual and seasonal minimum temperatures showed less to moderate variability (CV = 2–28%). The minimum temperature showed moderate variability around the south east lower border of the subbasin on the annual time scale and the north east part of the subbasin during the Kiremit season. The Bega and Belg seasons mean minimum temperatures showed less to high degree of variability (CV = 0–40%). The south east lower part of the subbasin showed moderate to high variability during the Bega and Belg seasons. Results of a standardized anomaly index of the rainfall, temperature and stream flow confirmed that the sub basin experienced fluctuations between dry, wet, cool and warm years. The spatial representation of annual rainfall showed a statically significant increasing trend in some parts of the subbasin and an insignificant increasing trend in the majority of the subbasin up to 300 mm per decade, while the Bega and Belg seasons showed statistically insignificant increasing and decreasing trends. Kiremit season rainfall showed heterogenous results in both statistics and trend direction. The mean annual maximum showed an increasing trend from 0.35 to 0.9 °C. The Bega, Belg and Kiremit seasons' maximum temperatures increased by a range of 0.35 to 0.95 °C; 0.4 from 1.2 °C and 0.1 to 0.55 °C pre decade respectively. While the annual minimum temperature increased by 0.05 to 0.5 °C and decreasing trend by 0.1 to 0.3 °C around the south eastern part of the subbasin. The Bega and Belg season minimum temperatures increased up to 0.5 °C and 1 °C and temperatures decreased in the range of 0.1 to 0.5 °C per decade. The Kiremit season minimum temperature increased by a range of 0.05 to 0.5 °C. The annual, Bega, Belg and Kiremit season stream flow increased insignificantly by 0.32, 0.31, 0.02 and 0.68 mm^3/s respectively. In general, the subbasin experienced hydroclimatic variability which affects the life of

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the people, agricultural production and the economy of the area. This needs further investigation for planning and management of water resource management for the success of future water resources projects.

Keywords: Hydroclimate, Spatial, Temporal, Variability, Trend

Introduction

In recent decades the earth's climate has been changed rapidly with the rise of greenhouse gasses (GHG) in the earth's atmosphere resulted a gradual increment of global temperature (Mahmood et al., 2019; IPCC, 2021). The rise of global temperature resulted in the melting of polar ice caps, an increase in average sea level and evapotranspiration and decrease in infiltration, fresh water availability, and soil humidity (Kiros et al., 2017; IPCC, 2021). As the air temperature rises, the amount and distribution of rainfall changed (Cooper, 2011; Nazeri Tahroudi et al., 2019). Variability in rainfall, temperature and other climatic variables have a significant impact on the variation of streamflow level and timing of hydrologic events (Girma et al., 2020; Orke and Li, 2021).These hydroclimatic variability and change significantly affects water resources with a consequence in various sectors activities such as hydropower generation, agricultural and industrial production, food security and socio economy (Ayehu et al., 2018; Esayas et al., 2018; Weldegerima et al., 2018). The impact will be higher on low income countries with limited institutional capacity, inadequate infrastructure and low technology to cope with the effects of hydroclimate variability and change (Asrat and Simane, 2017; Taye et al., 2015; IPCC, 2021).

Ethiopia is one of the low income and vulnerable country to hydroclimate variability and change effects. The country experiencing hydroclimatic variability and change induced problem, such as flood and drought (Kiros et al., 2017; Orke and Li, 2021). Drought (extreme dry) resulting significant effect on reductions of agricultural output and unemployment as agriculture contributed 42% GDP and 85% employment in the country (Suryabhagavan, 2017; Orke and Li, 2021). These unmitigated hydroclimatic variability and change can increases poverty rates by about 25 percent and costs 38 percent of potential economy growth (Jaweso et al., 2019; Curtis, 2020). Accordingly, the country struggling to achieve the food security and reduce poverty with climate variability adaptation and mitigation strategies (Gari and Chukala, 2020; Anose et al., 2021; Bayable et al., 2021).

Therefore, it's crucial to detect the historical seasonal and interannual variability and trend analysis of hydroclimatic variables (rainfall, temperature and stream flow) at regional and local scales to depict the response of subbasin to hydroclimatic variability and to develop more effective responsive strategies to manage climate induced risks (Mahmood et al., 2019; Anose et al., 2021) for better management and allocation of water resources for future sustainable water resource management (Daba et al., 2020; Etana et al.,2020; Getahun et al., 2021; Orke and Li, 2021). Hence, different watershed based hydroclimatic parameters variability and trend analysis was conducted in Ethiopia. Study conducted at Tekeze river basin find out that the annual rainfall showed statistically significant increasing and decreasing trend at different stations. The seasonal rainfall of the Belg and Kiremt season showed increasing trend over 80% of rain fall stations and decreasing trend during Bega season. On the other hand, annual streamflow of Tekeze basin exhibited statistically insignificant decreasing trend while the seasonal stream flow showed increasing trend in the Kiremt and Belg seasons stream flow and decreasing trend during Bega (dry) season similar to rainfall (Fentaw et al., 2017). Upper Omo Gibe River basin trend analysis of hydroclimate variables between 1981 to 2008 annual rainfall revealed statistically significant decreasing trends while seasonal rainfall depicted heterogeneous results in both directions. Mean annual temperature showed statistically significant increasing trends in majority of the stations. Besides this stream flow showed decreasing trend (Jaweso et al., 2019). Awash River basin annual rain fall and stream flow varied by 11% and 38% from the mean value, respectively. Lowland area of Awash River basin showed that insignificant seasonal and annual increasing trend except the autumn season. Midland area annual and seasonal rainfall showed decreasing trend except Sendafa station. The highland area exhibited decreasing trend annual basis. The Awash-Hombole main tributary showed increasing trends during the summer season. Mojo main tributary resulted in a significantly decreasing trend during the spring, summer, and autumn seasons with a 99% level of significance during time period 1991 to 2015 (Duguma et al., 2021).

The Zarima subbasin is one of the subbasins found in the northwestern part of Ethiopia where the Zarima river flows. The Zarima river is the only source of water for water supply and the traditional irrigation system. In the subbasin, there is high competition for irrigation water (Lemma et al., 2010). Additionally, the Zarima subbasin and its tributaries have been selected by the Ethiopian Sugar Corporation as one of the key irrigation development areas for sugar cane crop cultivation. 9,650 ha of dam was under construction in Zarima subbasin. A Dam can store a total of 3.6 billion cubic meters of water used to cultivate 50,000 ha of irrigated land. By generating jobs and exporting industrial goods, it plays a significant role in ensuring local food security and boosting the economy of the nation. However, the development of the dam and the irrigation project led to changes in the subbasin's land cover, climate and hydrology. For the water resource management of subbasin, the relationship between the climate and stream flow needs to be assessed. Thus, this study was aimed to analyze variability and trends of seasonal and annual rainfall, temperature and stream flow at Zarima subbasin North West Ethiopia.

Methodology

Description of zarima subbasin

Zarima sub basin is located where the Zarima river flows, which is one of the west bank tributaries of the Tekeze river basin. It is found 804.9 km from Addis Ababa. Geographically it is located at 13^{0}15'-14^{0}13' N latitude and 37^{0}30'–38^{0}27'E longitude with altitude ranges from 736 to 4399 m a.s.l (Fig. 1). The data collected from Ministry of Water irrigation and Electricity (MoWIE) the subbasin covers total of 663,157.58 ha. Topography of the sub basin dominated by steep and undulating terrain and narrow gorge comprising part of Semen Mountain (Weldesadik, 2021).

The soil types of the subbasin are Umbric Leptosol, Lithic Leptosol, Haphic Luvisol, Haphic Alisol, Euric Vertisol, Eutric Luvisol, Eutric Leptosol, Eutric Cambisol. Among the soil types of the subbasin Eutric Leptosol accounts 62.43%, Umbric Leptosol 13.83%, Halpic Aliso l 9.46% the remaining soil types cover 14.28% (Fig. 2). The major land use types of the subbasin are Agricultural land, forest, shrubland, grassland, bare land and water. forests and shrubland found in the upper portions of the basin, while most of the lower portions are lowland area, owing to the increased demand for agricultural. The agricultural land covers 57.81% of thee subbasin, the shrubland covers 23.81% and forest land covers 16.26% of the subbasin (Fig. 3).

According to Hurni (1998), Zarima subbasin comprises four agro-climatic zones namely Lowlands (Kolla), Midland (Weyina Dega), Highland (Dega) and Upper highland (Wurch). Majority of the subbasin is covered by Lowland agroclimate which accounts 74.83% followed by Midland 18.96%, Highland 4.09% and Upper highland 2.12% (Fig. 2). Information obtained from National Metrological Service Agency of Ethiopia indicated that rain fall is unimodal type. Average annual rainfall of subbasin ranges from 600 to 2100 mm. The Zarima subbasin receives highest rainfall during June, July, August, and September main rainy season (Fig. 5). The average

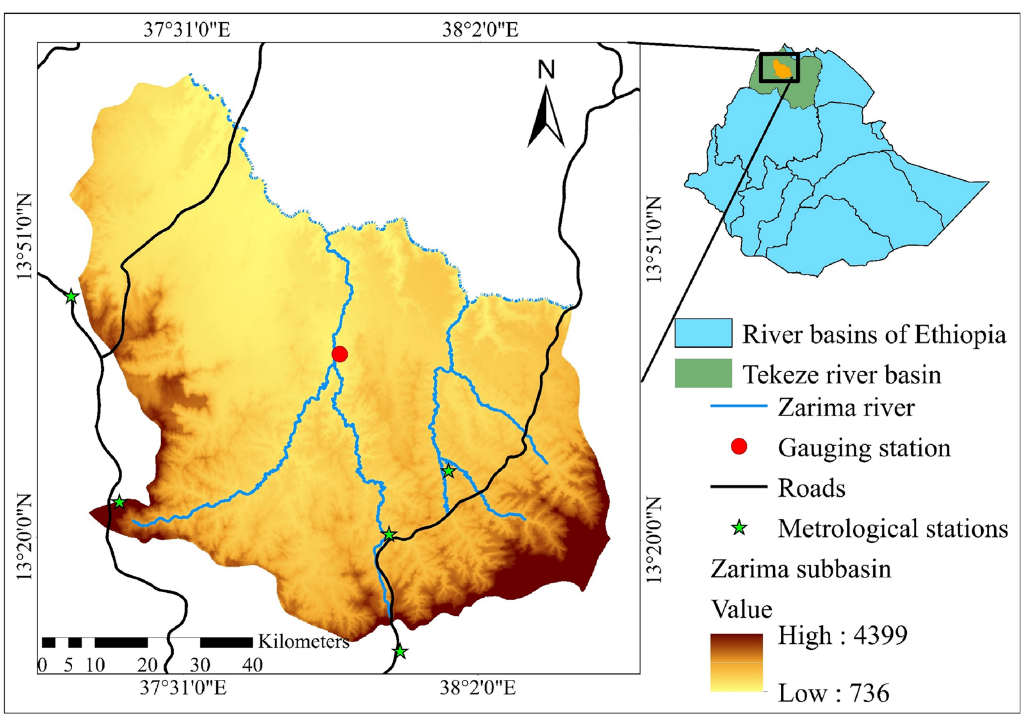

Fig. 1 Topographic map of Zarima Subbasin

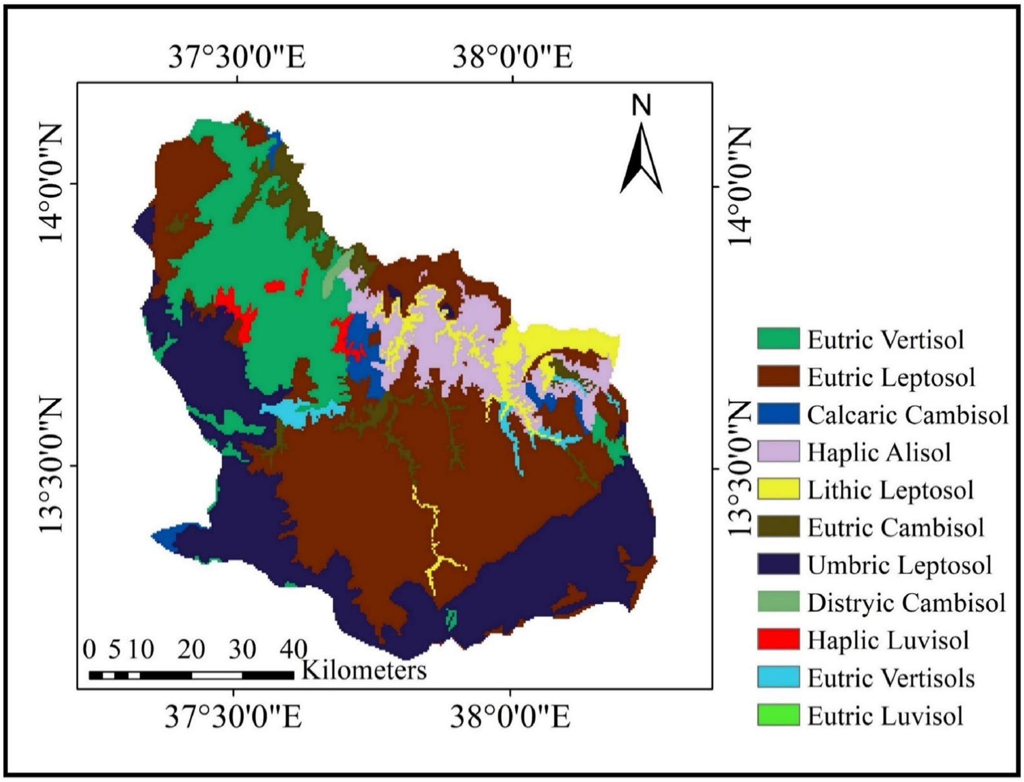

Fig. 2 Soil types found in Zarima subbasin

annual temperature of the Zarima subbasin arranges between 8 to 28 °C (Fig. 4).

Seasonal classification of Zarima subbasin

Based on the rain fall amount Ethiopia has three local seasons namely Bega, Belg and Kiremit. Bega is the dry season covers period from October to January. Bega season is characterized by hot, dry days and cool nights. Frosty in early mornings in majority of the highland areas (NMA, 2015). Belg is the small rainy season in Ethiopia except southern and southeastern low lands areas. It covers the period from February to May. High variability of rainfall in time and space and high maximum temperature are common characters of Belg season (Chow et al., 1988). It's the warmest season as March, April and May months are the warmest months of the year (NMA, 2015). Kiremt is the main rainy season which contributed 85% to 95% of the annual rainfall and food crops production of the country (Chow et al., 1988). It spans from June to September with frequent rains and homogeneous temperatures in July and August (NMA, 2015).

Agriculture is one of the basic economic activities that supports their way of life of the people live in the subbasin. These include irrigated agriculture, commercial farming, agro-pastoral, gum/incense collection systems, cereal-based single cropping, cereal-based double cropping, In the subbasin, mixed agricultural techniques that include both crop and livestock production are popular. Smallholder farmers cultivate grain for sustenance using a traditional ox-drawn plough that is rain-fed (MOWIE, 2009).

Data type and sources

Hydroclimatic data were collected from different sources. Historical grided 35 years rainfall, minimum and maximum temperature data were collected from the National Metrological Service Agency of Ethiopia for the time period of 1984–2018. Stream flow data were collected from Ministry of Water irrigation and Electricity (MoWIE) at Zarima gaging station for the time period 1990–2014.

Data analysis

Variability and trend analysis

Daily rainfall and temperature data obtained from the National Metrological Service Agency of Ethiopia were converted to seasonal and annual data for annual and seasonal rainfall and temperature variability and trend analysis. The temporal variability of rainfall, temperature and stream flow was determined

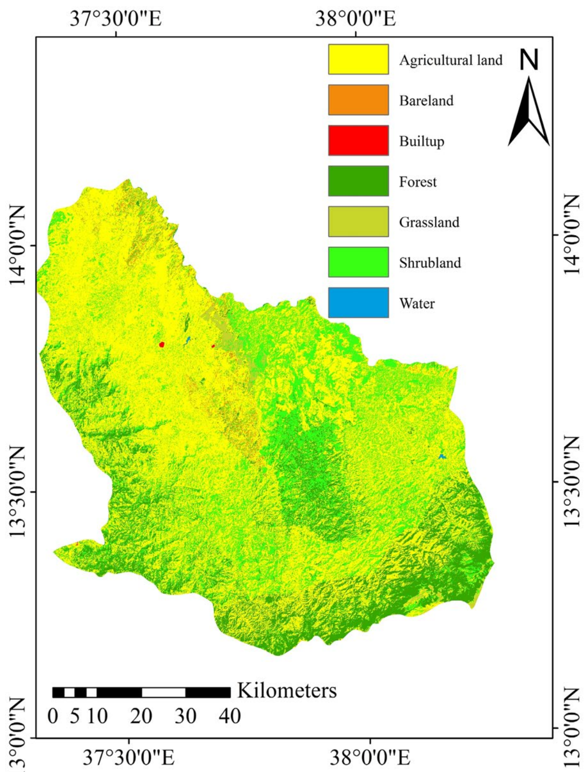

Fig. 3 Land use land cover of Zarima subbasin

using the coefficient of variation (CV), Standardized anomaly index (SAI). Trend analysis was done through non-parametric Mann–Kendall test to detect the trend of rainfall, temperature and stream flow with Sen's slope estimator for the studied period. Data analysis was undertaken using R statistical software modified Mann–Kendall and Climate Data Tool (CDT) packages.

Coefficient of Variation (CV) The coefficient of variation (CV) is the ratio of the standard deviation to the mean rainfall in a given period. CV expressed in percentage useful to determine variation relative to the mean size of observation (Alemu and Bawoke, 2019; Eshetu, 2020; Bayable et al., 2021).

$$CV = \left(\frac{\sigma}{\overline{\overline{X}}}\right) \times 100 \quad (1)$$

where, CV is coefficient of Variation, σ and $\overline{X}$ denotes standard deviation and long term mean of rain fall, respectively.

In this study, CV is used to classify the degree of variability as less (CV < 20%), moderate (20 < CV < 30%), high (CV > 30%), very high (CV > 40%) and CV > 70% indicate extremely high inter annual variability of the hydroclimate data (Eshetu, 2020).

Standard Anomaly index (SAI) SAI measures deviation in standard units, between a data value and its mean. This index is used for rainfall variability and the number of standard deviations that a rainfall event deviates from the average of the years considered (Funk et al., 2015).

SAI with negative values representing periods of below normal rainfall (dry) while positive values reflect above normal rainfall (wet) Table (Muthoni et al., 2019; Anose et al., 2021). For temperature value below long-term mean was dominated considered as cooling period while above long-term average was most persistent is considered as warming period (WMO, 2016). Thus, SAI is applicable to drought monitoring and also makes possible determination of the dry and wet years in the record time periods (WMO, 2016; Koudahe et al., 2017; Alemu & Bawoke, 2019; Bayable et al., 2021). In this study SAI was used to assess the frequency and severity of dry and wet years (Table 1) and to find out the cooling (−ve) and warming (+ve) years of the study period (Alemu and Bawoke 2019; Bayable et al., 2021).

$$SAI = \frac{(X - \overline{X})}{\sigma} \quad (2)$$

where, SAI is standardized anomaly index, X is the annual and seasonal mean rainfall or temperature of a particular year; $\overline{X}$ is mean annual and seasonal rainfall or temperature over a period of observation and σ is the standard deviation of annual and seasonal rainfall or temperature over the period of observation.

Mann–Kendall test Mann–Kendall test and Sen's Slope estimator were used to assess historical rainfall, temperature and stream flow trends and trend magnitude using R statistical software Modified Mann–Kendall package. Mann–Kendall test is most common and preferred non-parametric test as it less sensitive to outliers, missing values and does not require normally distributed dataset which is common in hydro climate data (Ahmad et al., 2015). Mann–Kendall's test is developed by Mann in 1945 further developed by Kendall in 1975 (Shadmani et al., 2012). A Mann–Kendall trend test is used to determine whether or not a trend exists in time series data. H_0 (null hypothesis) describes no trend present in the data.

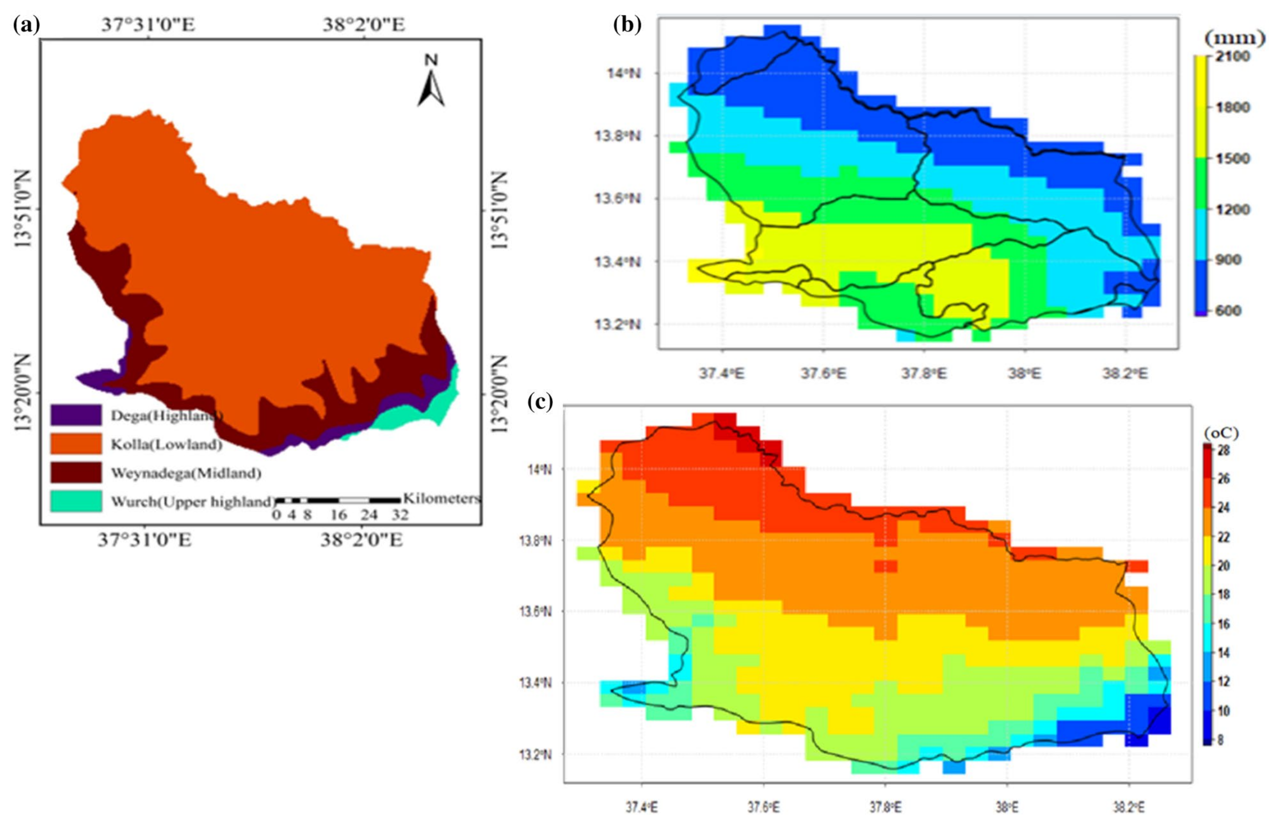

Fig. 4 Agroclimatic Zones **a** mean annual rainfall, **b** average temperature and **c** of Zarima Subbasin

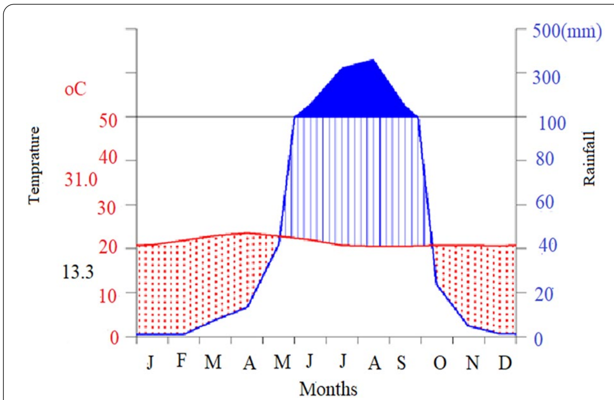

Fig. 5 Climate diagram of Zarima subbasin

H_A (alternative hypothesis) indicates the presence trend in the data (this could be an increasing or decreasing trend). It is used to check whether there is a statistically significant or insignificant trend in hydroclimate variables (Shadmani et al., 2012; Kumar et al., 2010). The MK statistics S is computed using the following formula

Table 1 Standardized Anomaly Index Value interpretation (Funk et al. 2015)

SAI Value	Category
2 +	Extremely wet
1.5 to 1.99	Very Wet
1 to 1.49	Moderately wet
− 0.99 to 0.99	Near normal
− 1.49 to − 1	Moderately dry
− 1.99 to− 1.5	Severely dry
− 2 and less	Extremely dry

$$S = \sum_{i=1}^{n-1} \sum_{j=i-1}^{n} \mathrm{Sign}\left(Y_j - Y_i\right) \quad (3)$$

where Y_i and Y_j are sequential data values for the time series data length and

$$\mathrm{Sign}\left(Y_j - Y_i\right) = \begin{cases} 1 & \text{if } \left(Y_j - Y_i\right) > 0 \\ 0 & \text{if } \left(Y_j - Y_i\right) = 0 \\ -1 & \text{if } \left(Y_j - Y_i\right) < 0 \end{cases}.$$

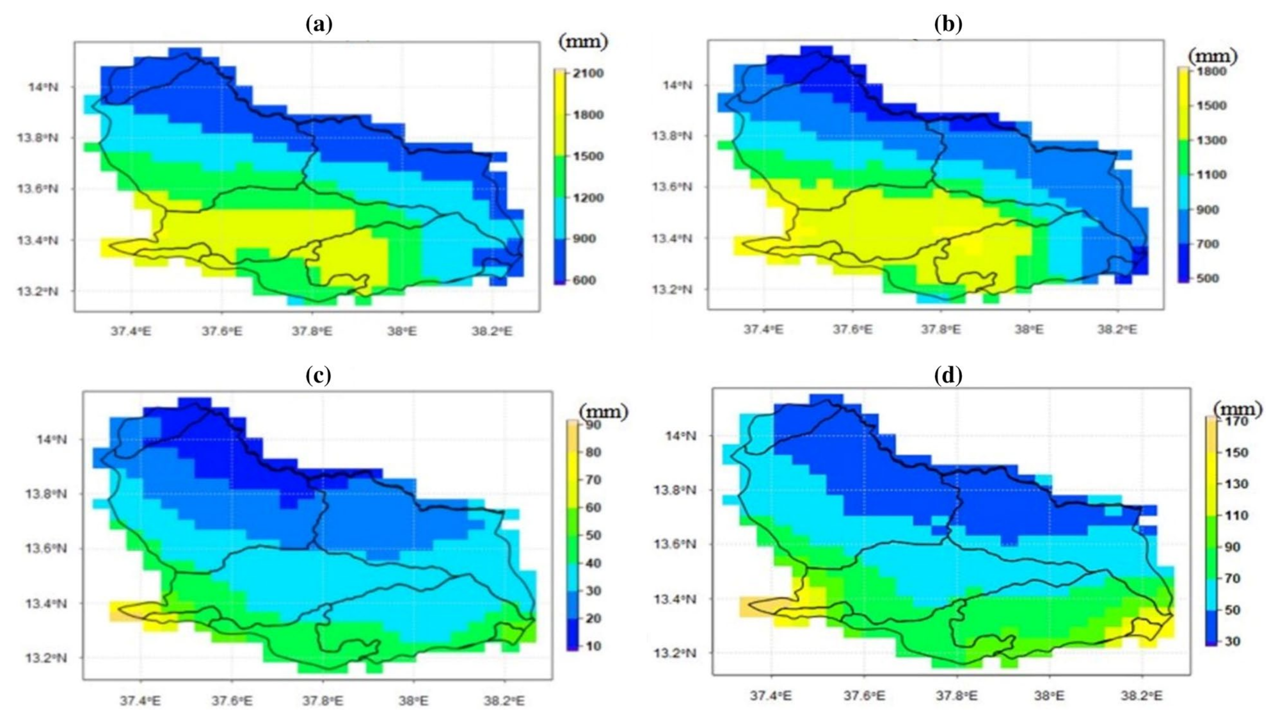

Fig. 6 Spatial representation of mean annual rainfall (**a**), Kiremit (**b**), Bega (**c**), Belg (**d**) seasons rainfall at Zarima subbasin

If the dataset is identically and independently distributed, then the mean of S is zero and the variance of S is given by

$$\mathrm{Var(S)} = \frac{1}{18}(\mathrm{n(n-1)(2n+5)} - \sum_{\mathrm{i=0}}^{\mathrm{m}} \mathrm{ti(ti-1)2ti+5)} \tag{4}$$

where n is the length of the dataset, m is the number of tied groups (a tied group is a set of sample data having the same value) in the time series and ti is the number of data points in the ith group.

The Z statistics are calculated using the formula

$$\mathrm{Z} = \begin{cases} \frac{\mathrm{S+1}}{\sqrt{\mathrm{Var(S)}}} & \text{for S} < 0 \\ 0 & \text{for S} = 0 \\ \frac{\mathrm{S-1}}{\sqrt{\mathrm{Var(S)}}} & \text{for S} > 0 \end{cases} \tag{5}$$

In this study $\alpha = 0.05$ significance level was used to check whether there is an increasing or decreasing monotone trend in considered rainfall, temperature and stream flow. The decision for the two-tail test was made by comparing the computed Z with critical values. The null hypothesis with no trend is rejected when the absolute value of computed Z is greater than the critical values or P-values at significance levels ($\alpha = 0.05$) then result is statistically significant. Once the null hypothesis is rejected, then direction of the trend determined by Z value. Positive Z values indicate an increasing trend while a negative Z reflects a decreasing trend (Du et al., 2013; Hamlaoui-Moulai et al., 2013; Alemu and Bawoke, 2019; Anose et al., 2021; Bayable et al., 2021).

Sen's Slope Estimator was used to determine the magnitude of trend. It is non-parametric estimator used to quantify magnitude of trend in time series data. It is chosen estimator than others due to its relative insensitivity to outliers and miss value (Sen, 1968; Chattopadhyay and Edwards, 2016). Sen's Slope estimator has been widely used for determining the trend magnitude in hydro-meteorological time series per year (Kumar et al., 2010). To derive an estimate of the Slope bi, the Slopes of all data pairs are computed using Eq. (6). If the computed value of bi is positive, it shows an increasing trend, while a negative value indicates a decreasing (Sen, 1968; Chattopadhyay and Edwards, 2016; Abegaz and Mekoya, 2020).

$$\mathrm{bi} = \frac{\mathrm{X_j - X_i}}{\mathrm{j} - i}, \mathrm{i} = 1, 2, 3 \ldots\ldots \mathrm{N}, \mathrm{j} > \mathrm{i} \tag{6}$$

where: bi is Sen's slope; Xj and Xi are data values at the times j and i; j > i respectively.

The Sen's estimator of the Slope is the median of these N values of bi:

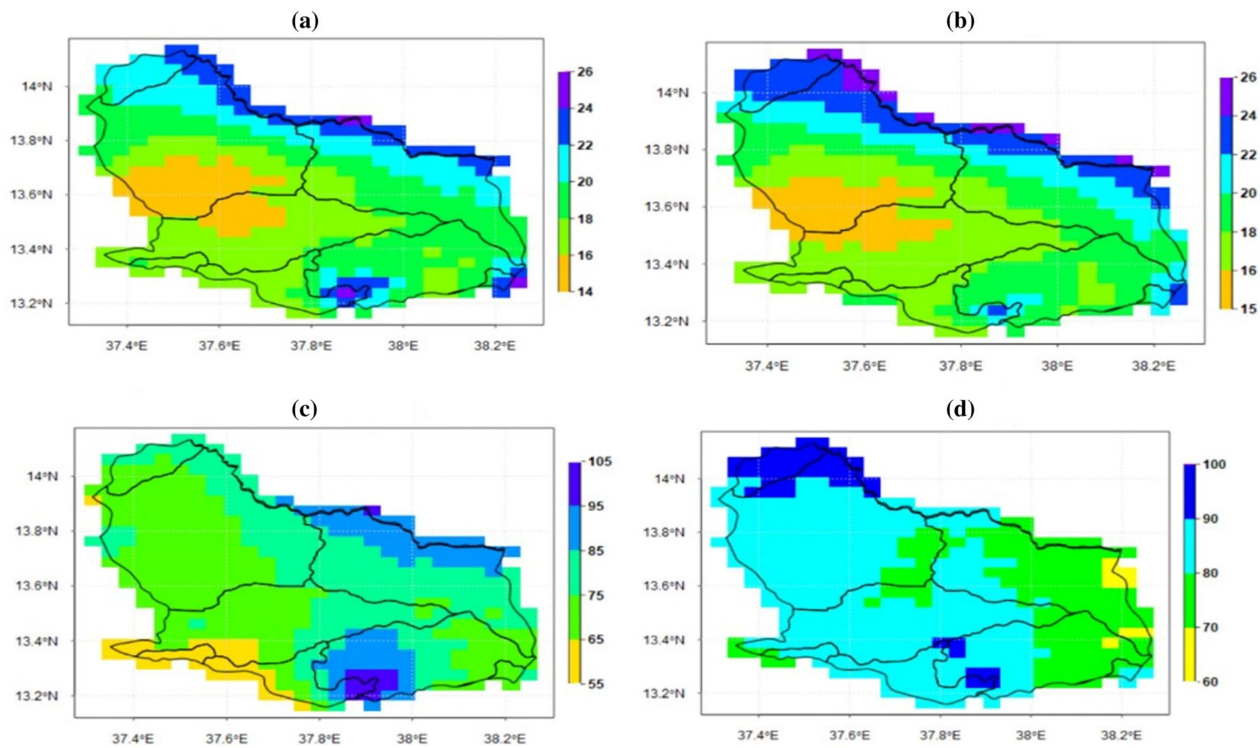

Fig. 7 Coefficient of variation of the annual (**a**) and Kiremit season (**b**), Belg season (**c**) and Bega season

$$\text{bi} = \begin{cases} \text{b}\frac{(\text{N}+1)}{2} & \text{if N is odd} \\ 0.5\left[\text{b}\frac{\text{N}}{2} + \text{b}\frac{(\text{N}+2)}{2}\right] & \text{if N is even} \end{cases} \quad (7)$$

Results and discussion

Spatiotemporal distribution of the annual and seasonal rainfall

The long-term mean annual rainfall of the Zarima subbasin from 1984 to 2018 was spatially distributed ranged between 600 and 2100 mm. The central, southern and western parts of the subbasin received the highest (amount), while majority of the northern part of subbasin received the least amount of rainfall (600–900 mm) (Fig. 6a). During the Bega season the subbasin received 10–90 mm; majority of southwest part and south eastern boundary of the subbasin received maximum rainfall value while the northern parts received the lowest rainfall value. Similarly, during Belg season, the highest rainfall values (150–170 mm) were observed in the south eastern and south eastern tip parts, whereas the lowest rainfall values (30–50 mm) were recorded in northern and northeastern parts of the subbasin. During Kiremt, the highest rainfall amount (1500-1800 mm) was recorded in the southwest and some portion of the south east part while the lowest rainfall amount (500–800 mm) was recorded in the northern and south eastern parts of the subbasin (Fig. 6b). Kiremit season rainfall was almost followed the similar spatial distribution to the annual rainfall. Significant spatial and temporal variation showed over Zarima subbasin. This result lines with study conducted in different parts of Ethiopia; rainfall in Ethiopia varies greatly across space and time due to the country's complex topography, which ranges from 120 m bsl to 4620 m asl (Reda et al., 2015); lake tana basin (Addisu et al., 2015); Southern Tigray of Northern Ethiopia (Indris et al., 2018); Welka subbasin (Asfaw et al., 2018); Amhara region (Alemu and Bawoke, 2019); West Harerge zone of Ethiopia (Bayable et al., 2021); Ethiopian Highland area (Ademe et al., 2020); Great rift valley of Ethiopia (Fitih et al., 2020); Modjo watershed Awash river basin (Eshetu, 2020); Billate watershed (Orke and Li, 2021); Omo-Gibe river basin (Anose et al., 2021). The amount and spatial distribution of rainfall is typically the most significant determinant of interannual fluctuations in crop production in Ethiopia. These factors have significant effects on the nation's economy and food production.

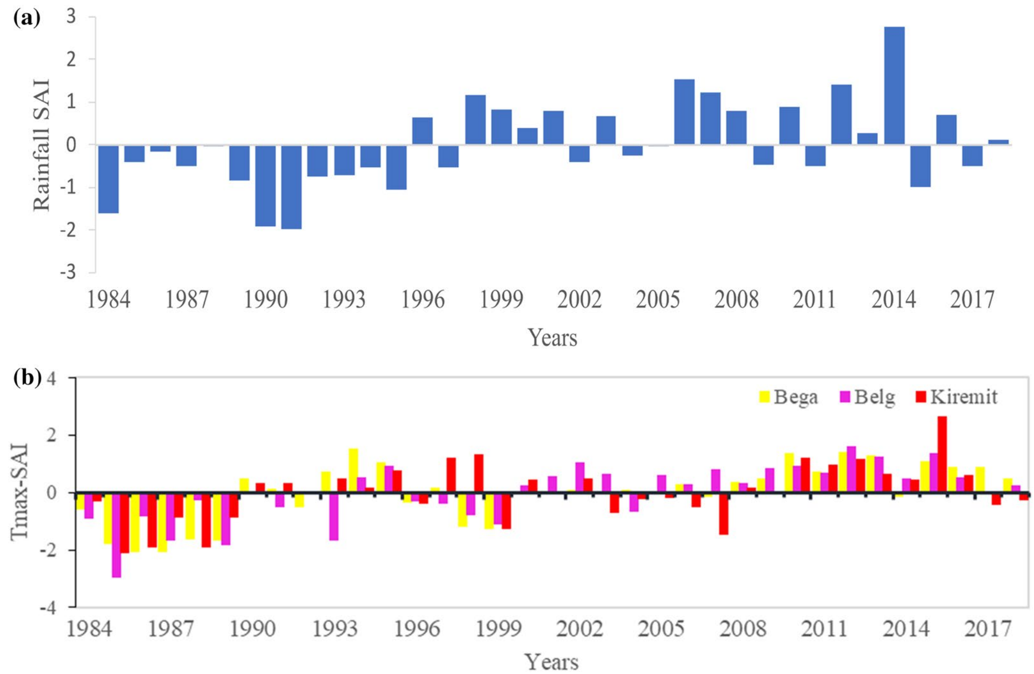

Fig. 8 Standardized anomaly index for the Annual (**a**) and seasonal (**b**) rainfall

Spatio temporal variability and trend analysis of rainfall

Spatio temporal variability of the rainfall

The coefficient of variation (CV) of the annual and seasonal rain fall presented in Fig. 7 (a–d). The coefficient of variation of mean annual rainfall was 14–26% and Kiremit season rainfall was 15–26%. Variation of the annual and seasonal rainfall ranges from low to moderate. The majority of the subbasin area experienced less annual rainfall variability while north border of the subbasin and south eastern portion of the subbasin's experienced moderate variability. The Bega and Belg season rainfall coefficient of variation (CV) ranges between 65 to 100% and 55–105% respectively. The Bega and Belg season rainfall exhibited high variability than Kiremit season over Zarima subbasin. The maximum spatial variability in annual and seasonal timescales lies in the low rainfall areas. As a result, this suggests that the subbasin is more vulnerable to drought events, which could have a direct impact on agricultural and livestock rearing, the main economic activity. This finding is in line with the study at the Awash River basin, the annual rainfall showed low variability whereas seasonal rainfall exhibited low to high variability which has a significant effect on agricultural production (Gebre et al., 2013); mean annual rainfall was less variable during Kiremit season which showed less to moderate variability in Central highland of Ethiopia (Alemayehu and Bewket, 2017). The annual mean rain fall showed moderately variable (CV = 20.82–23.73%) whereas Belg season (CV = 65.64–69.43%) and Bega season (CV = 84.77–91.35%) rainfall variation was higher than Kiremt season rainfall (CV = 30.52–40.26%) during 1980 to 2016 (Indris et al., 2018); annual and Kiremit season rainfall showed low variation while Belg season rainfall exhibited extremely high variable for time period 1983–2010 at Modjio watershed (Eshetu, 2020). The north eastern part of Ethiopia mean annual rainfall was less variable (CV = 14.8–17%) while Bega (41.8–43%) and Belg (59.3–68.3%) seasons rainfall showed much more variation than Kiremit season rainfall(CV < 30%) (Abegaz, 2020). The mean annual and Kiremit season rain fall was moderately variable whereas the Bega and Belg season rainfall was highly and extremely variable at central part of Ethiopia (Abegaz and Mekoya, 2020). Bega and Belg season rainfall was highly variated than the Kiremit season rainfall at Bilate watershed (Orke and Li, 2021). High variability in Belg rainfall affect the availability of water and create unfavorable condition for crop growth which directly affect agricultural production and food security (Kassie et al., 2014). The variation of rainfall in the subbasin could be caused by global atmospheric circulation forcing and regional features such as topography, modification of land use and land cover change and water bodies (Zeleke et al., 2013; Anose et al., 2021). According to the results, the agricultural activities in the subbasin are significantly impacted by the high seasonal rainfall variability. Further, this variability will have a significant

Table 2 Annual and Seasonal rainfall Standardized anomaly index category

Standardized anomaly index	Bega		Belg		Kerimit		Annual	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Extreme wet	2	5.71	2	5.71	1	2.86	1	2.86
Severe wet	1	2.86	1	2.86	2	5.71	1	2.86
Moderate wet	4	11.43	2	5.71	4	11.43	3	8.57
Normal	24	68.57	28	80.01	23	65.72	26	74.28
Moderately dry	4	11.43	2	5.71	2	5.71	1	2.86
Severe dry	–	–	–	–	3	8.57	3	8.57
Extreme dry	–	–	–	–	–	–	–	–
Total	35	100	35	100	35	100	35	100

impact on the sugar cane plantation and sugar production and foreign currency (Singh et al., 2018). Thus, the future climate of the subbasin should be assessed for better planning water resource management, success of the proposed project and agricultural production.

In addition to CV standardized anomaly index of the rain fall used to assess the annual year to variability. The annual rainfall anomaly (1984–2018) over the Zarima subbasin is shown in Fig. 8(a). The rainfall anomalies showed the presence of inter-annual variability of rainfall. The percentages of negative and positive anomalies were 57.14% and 42.86%, respectively. The studied years fall under extreme wet (2014) and sever wet (2006) level each category accounted 2.86% and moderately wet (1998, 2007 and 2012) accounted 8.7%. Negative anomaly was observed in 1984–1995, 1997, 2002, 2004/05, 2009, 2011, 2015, and 2017. Negative rainfall anomalies are a symptom of severe to extreme dry conditions. Negative anomaly years two 1997 and 2015 (5.71%) showed moderate dry and 3 years 1984, 1990 and 1991(8.57%) showed severe dry; about 26 years (74.28%) is under near normal even though the negative anomaly percentage is high. These correspond to the historical dry (drought) years 1957/58, 1962/63, 1964–1966, 1971–1973, 1978/79; 1982, 1984/85, 1990–92, 1994, 1997, 1999, 2003/04, 2005, 2008/9, 2011, 2016/17 in different parts of Ethiopia caused by El Niño and climate change (Fekadu, 2015; Mera, 2018); West Harerge zone of Ethiopia experienced negative anomalies in 1984–1995, 1997, 2002, 2004, 2005, 2009, 2011, 2016, and 2017 (Bayable et al., 2021); Janamora woreda experienced high number of negative anomaly years for the time period of 1981 to 2018 (Marelign, 2021). The findings highlight the importance of developing local adaptation strategies to mitigate the effects of temperature and rainfall variability and change on agriculture. This is due to the fact that rain fed agriculture accounts for the majority of crop production and water related activities in developing countries, including Ethiopia (Kassie et al., 2014; Addisu et al., 2015; Asfaw et al., 2018; Meseret and Belay, 2019; Bayable et al., 2021).

Furthermore, the results of the SAI analysis of seasonal rainfall of Zarima subbasin (1984–2018) are shown in Fig. 8b. The percentage of negative anomalies was larger than positive anomalies in all seasons except Kiremit season. Similar to annual rainfall, inter seasonal variability of rainfall was observed in Kiremt, Belg and Bega seasons with negative anomalies 48.57%, 62.86% and 68.57%, respectively. The annual and seasonal rainfall standardized anomaly index category Table 2 and Figure (8b) showed that the highest positive anomaly (extremely wet) was observed in 2014 (2.87%) in Kiremit season and in 1997 and 1999 (5.71%) during Bega and Belg seasons. Severe wet was observed in 1992 and 1987 (2.86%) in Bega and Belg season respectively; 1998 and 2012 (5.71%) in Kiremit season. Moderately wet was observed 11.43% of the studied years during Bega and Kiremit season and 5.71% in Belg season. On the other hand, the negative anomaly showed that Zarima subbasin experienced moderately dry and severely dry years. Severe dry was observed during Belg and Kiremit season which accounts 5.71% (1986, 2012) and 8.57% (1984, 1990 and 1991) respectively. About 11.4% of studied year 1984, 1990, 1995 and 2005 showed moderate dry in Bega season in 1997 and 2015 (5.71%) Kiremit season. The findings of this study supported by Alemu and Bawoke (2019), revealed that the percentage of negative anomalies exceeded that of positive anomalies in all seasons except Kiremt in the Amhara region. The percentage of negative anomalies was larger than positive anomalies in all seasons in Mecha area (Meseret and Belay, 2019); West Harege Zone of Ethiopia (Bayable et al., 2021); Bilate watershed (Orke and Li, 2021). Similarly in 2012 severe dry was observed at Janamora woreda (Marelign, 2021). The greater number of negative anomalies signaled that there was a possibility of a fall in stream flows and ground water levels, which would seriously threaten

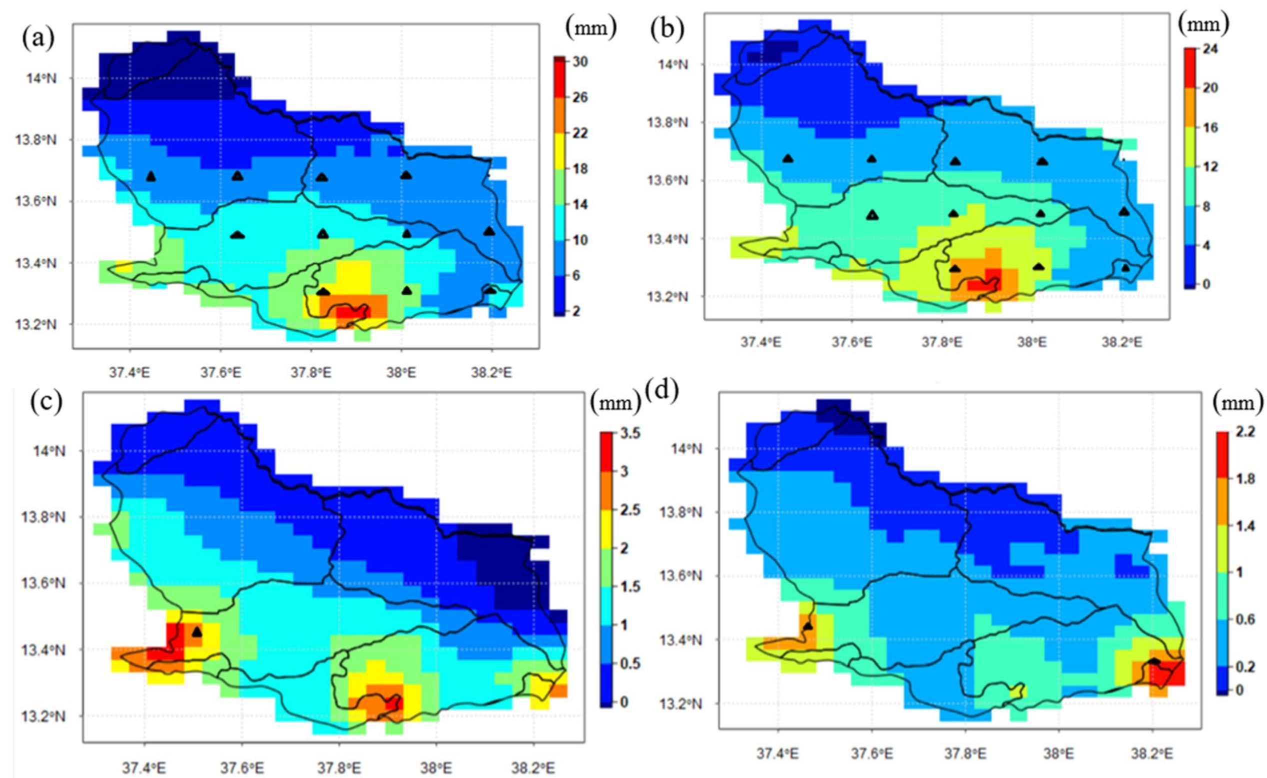

Fig. 9 Direction and magnitude of trend annual (**a**), Kiremit season (**b**), Belg season (**c**) and Bega season (**d**) rainfall (grids that showed significant trend)

irrigated agriculture and irrigation related industrial activity (Peña-Guerrero et al., 2020).

Trend analysis of the annual and seasonal rainfall

The annual and seasonal Mann- Kendall (MK) trend test results and Sen's slop estimation are shown in the Fig. 9a–d. The direction and magnitude of annual and seasonal rainfall trend was not uniform throughout Zarima subbasin. The mean annual rainfall of Zarima subbasin showed both statistically significant and insignificant increasing trend at $P<=0.05$. The spatial representation of annual rainfall trend revealed a statistically significant increasing trend with magnitudes up to 240 mm/decade in some part of the subbasin and insignificant increasing trend with magnitudes up to 300 mm/decade in majority the subbasin. The south west part of the subbasin showed relatively higher increasing trend, compared with lower increasing trend in the northern part. Bega season showed a statistically insignificant increasing and decreasing trend. The southern, eastern, and western parts of the subbasin experienced an increasing trend of up to 22 mm/decade, whereas the northern part experienced a decreasing trend of up to 2 mm/decade. The Belg season revealed that the sub basin experiences both statistically insignificant increasing and decreasing trends. A decreasing trend up to 5 mm/decade was observed around the eastern part of the subbasin. Whereas the remaining part of sub basin experienced an increasing trend of up to 35 mm/decade. Kiremit season rainfall showed a statistically significant increasing trend with amounts ranging from 40 to 180 mm/decade and statistically insignificant increasing trend up to 240 mm/decade, while the northern part of the subbasin showed a statistically insignificant decreasing trend up to −20 mm/decade. Similarly, mean annual and Kiremit season rainfall showed an increasing trend, the Belg season showed declining trend at Mojdo watershed of Awash river basin (Eshetu, 2020); upper Awash River basin showed mixed trend in Bega season rain fall between time period 1980 to 2017 (Daba et al., 2020). The north eastern part of Ethiopia Belg season rainfall trends showed insignificant decreasing trend and increasing in during Kiremt and Bega season (Abegaz, 2020a). Fentale district of Oromiya region showed that the annual and Kiremit season rain fall showed increasing trend while Belg rainfall significant decreasing trend for the period 1983–2017 at $P<=0.05$ (Mekuyie and Mulu, 2021). This result was different from the study conducted at upper Blue Nile basin Tesfaye (2019) and Huru guduru Wollega

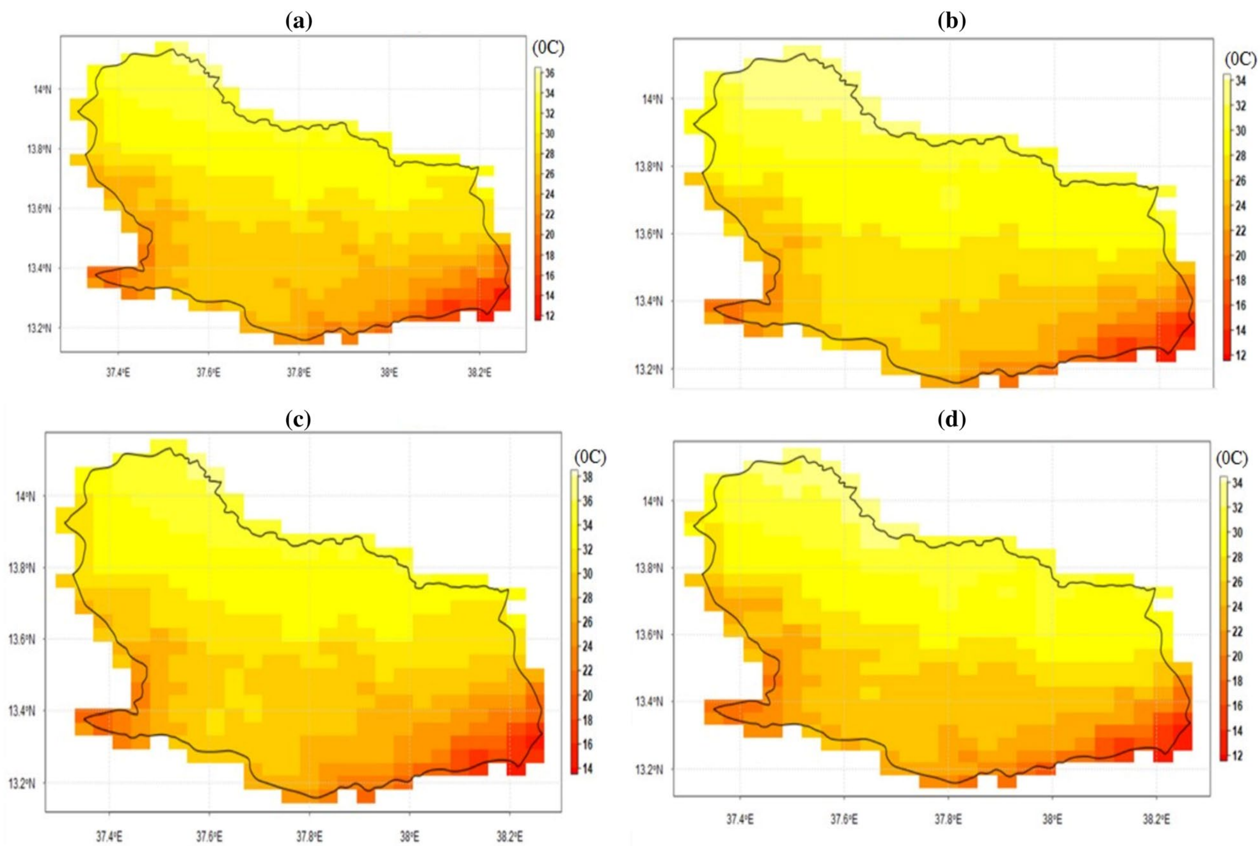

Fig. 10 Annual and seasonal mean maximum temperature Annual (**a**), Bega season (**b**), Belg season and (**c**) Kiremit season of Zarima subbasin

Zone (Feke et al., 2021) stated that the annual and Kiremit season rainfall showed decreasing trend. Significant decreasing trend was observed in annual and seasonal rainfall at some stations of Upper Awash River basin except Addis Ababa Bole station increasing trend was observed during the Bega season between time period 1980 to 2017 (Daba et al., 2020). Bilate watershed showed decreasing trend at annual and seasonal time scale except the Bega season between 1983–2014 (Orke and Li, 2021). The increasing trend of the rainfall can result flooding which needs further assessment.

Spatio temporal variability of annual and seasonal temperature

The spatial patterns of annual and seasonal maximum and minimum temperature

The spatial representation of annual and seasonal maximum and minimum temperature is shown in Figs. 10a–d and 11a–d. The mean annual and seasonal maximum and minimum temperature of Zarima sub basin showed spatial and temporal variation. The annual maximum and minimum temperature ranges between 12 to 36 °C and 2–20 °C, respectively (Figs. 10a and 11a). The highest maximum (32–36 °C) and minimum temperature (16–20 °C) showed on the northern border of the sub basin while lower part of south west and south eastern side of the subbasin had lowest maximum temperature. The south east border of the subbasin showed the lowest minimum temperature (20 °C) during the 1984 to 2018.

Seasonally, Bega season mean maximum and minimum temperature varies spatially from 12–34 °C and 2–18 °C respectively (Figs. 10b and 11b). The northern east part and northern border of the sub basin was hot areas where relatively higher maximum (32–34 °C) and minimum (10–18 °C) temperature was observed. Belg season maximum and minimum temperature of the sub basin was ranged 14–38 °C and 4–20 °C (Figs. 10c and 11c). Kiremit season maximum temperature range was 12–34 °C (Fig. 10 d) and minimum temperature ranged between 4–20 °C (Fig. 11d). The spatial pattern of the seasonal mean maximum and minimum temperature showed that the northern part of the subbasin was the hottest, while the south west tip and south east lower border of the subbasin were the coolest. The coldest part of the subbasin was the highland area, and the hottest part was the lowland area, implying that temperature and

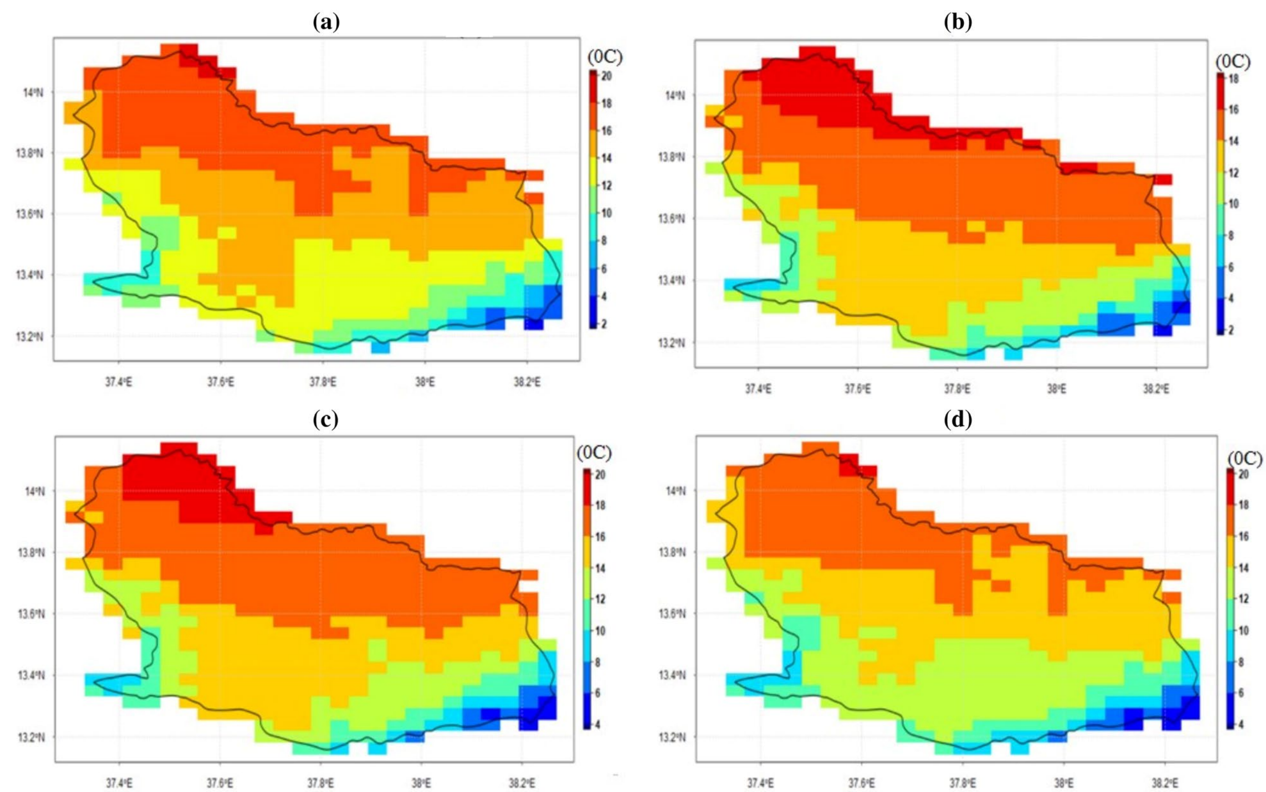

Fig. 11 Mean annual and seasonal minimum temperature: Annual (**a**), Bega season (**b**), Belg season (**c**) and Kiremit season (**d**) at Zarima subbasin

elevation had a direct correlation. Temporally the Belg season was the hotter season than the Bega and Kiremit seasons this is due the Belg season months of March, April, and May are the hottest of the year (Legese et al., 2018). The spatial temporal variability of the maximum and minimum temperature was observed over Zarima subbasin. Similarly, Alemayehu and Bewket (2017); summarizes previous studies conducted in different parts of Ethiopia stated that spatial and temporal variability of temperature was observed. Spatial and temporal variability observed Welka sub basin (Asfaw et al., 2018); Mecha area (Meseret and Belay, 2019), Awash River basin (Tadese et al., 2019); Tekeze river basin (Tesfaye et al., 2019), Choke Mountain area (Ademe et al., 2020), Bilate watershed (Orke and Li, 2021). Like the rainfall the maximum and minimum temperature spatial variability affected by the global forces, topography and characteristics of the subbasin.

Spatiotemporal variability of annual and seasonal temperature

The Spatiotemporal variation of the maximum and minimum temperature showed in Fig. 12 (a-d) and 12 (e–h) respectively. The coefficient of variation used to evaluate the degree of variability of the annual and seasonal maximum and minimum temperature. The annual and seasonal mean maximum temperature showed less degree of variability (CV < 10) over the subbasin. On the other hand, annual and Kiremit season mean minimum temperature exhibited less to moderate variability (CV = 2–28%). Minimum temperature showed moderate variability around the south east lower border of the subbasin at annual time scale and north east part of the subbasin during Kiremit season. The Bega and Belg season mean minimum temperature showed less to high degree of variability (CV = 0–40%). South east lower part of the subbasin showed moderate to high variability during Bega and Belg seasons. The minimum temperature showed higher variability than the maximum temperature annual and seasonal time scale was observed between 1984 and 2018 over the subbasin. This finding is in line with the findings of Bilate watershed mean annual minimum temperature CV of 6%, which is much higher than those of average annual temperature (2.7%) and the annual maximum temperature (1.5%). Minimum temperature showed high variability over the past 30 years (Orke and Li, 2021).

Inter annual variability of the mean maximum and minimum temperatures was described in standardized temperature anomalies for the time period 1984 to

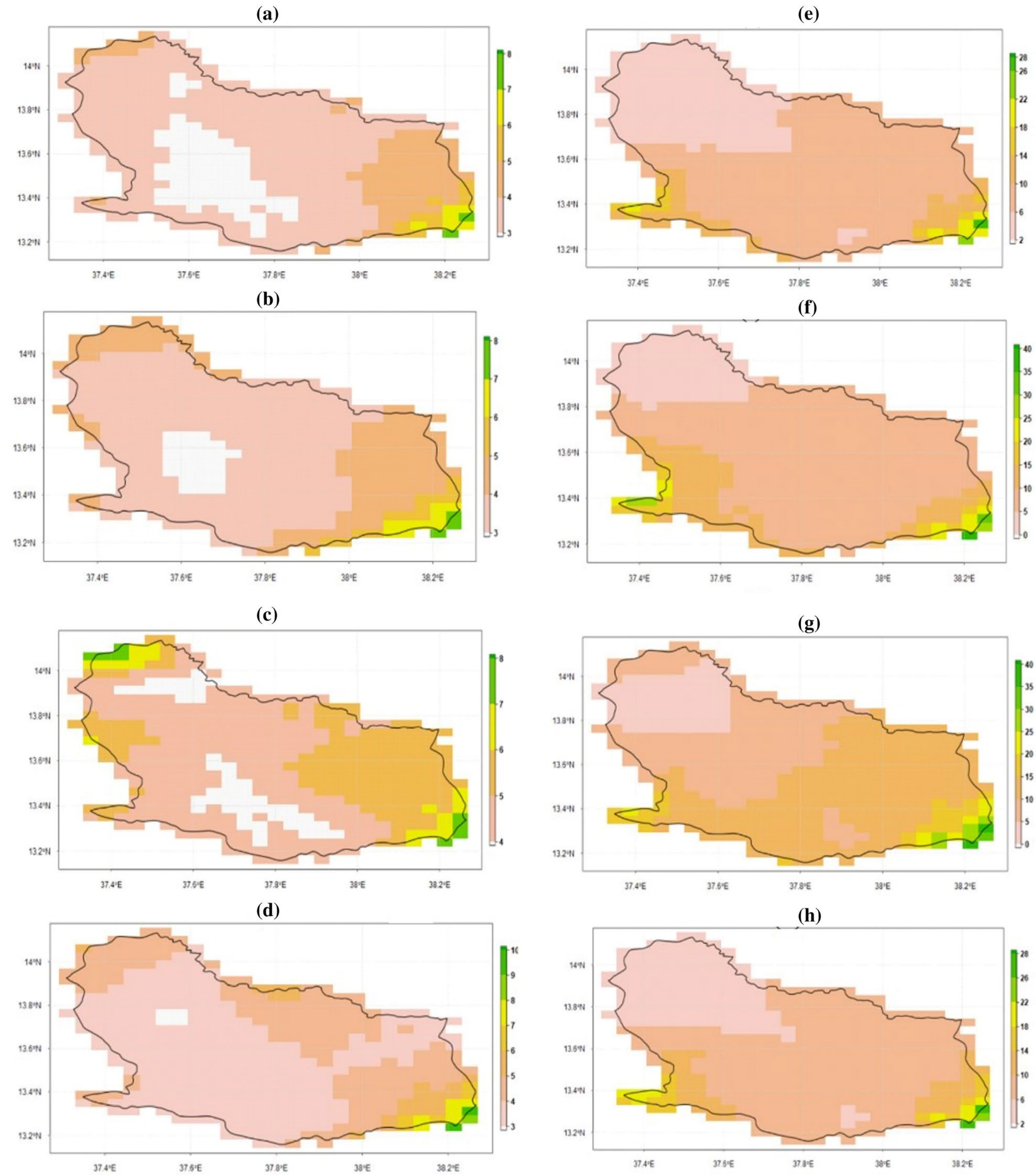

Fig. 12 Coefficient of variation annual (**a**), Bega season (**b**), Belg season (**c**) and Kiremit season (d) mean maximum temperature annual (**e**), Bega season (**f**), Belg season (g) and Kiremit season (**h**) mean minimum temperature

2018 in terms of annual and seasonal mean maximum and minimum temperatures. Figures 13a & b and 14a & b depicts the standardized anomaly index for the annual and seasonal mean maximum and minimum temperature respectively. Mean Annual and Belg season maximum temperature standardized anomaly index showed

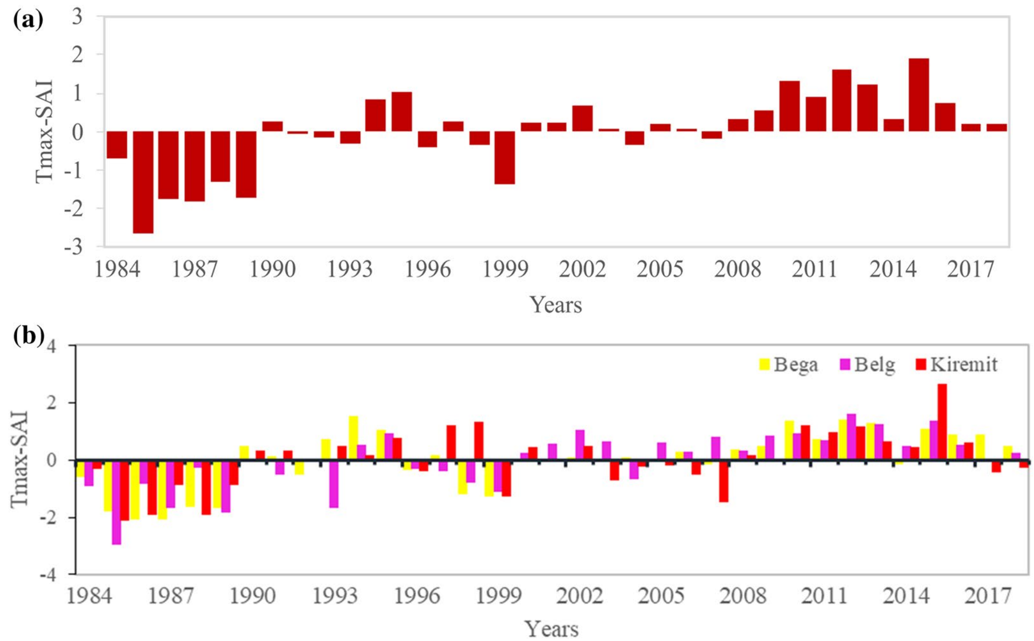

Fig. 13 Maximum temperature annual (**a**) and seasonal (**b**) standardized anomaly index

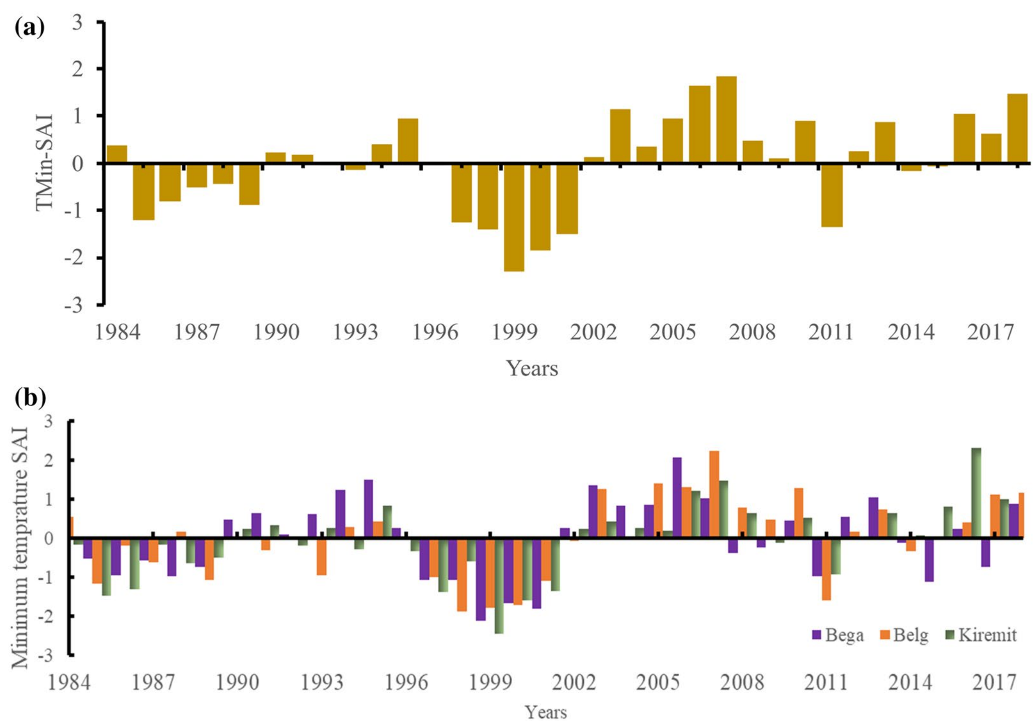

Fig. 14 Annual (**a**) and Seasonal (**b**) minimum temperature standardized anomaly index

60% warming year and 40% cooling year whereas Bega and Kiremit season showed 57.14% warming and 42.86% cooling years (Fig. 13a & b). The standardized anomaly index of the annual and seasonal mean maximum temperature showed higher percentage of warming (positive anomaly) and cyclic pattern of variations with alternating warming and cooling years over Zarima subbasin. This result is similar with year to year variability observed in Welka watershed (Asfaw et al., 2018); in Alwero watershed, western Ethiopia (Alemayehu et al., 2020); Bilate watershed (Orke and Li, 2021). Between 1984 and 1989, mean annual and seasonal maximum temperatures were lower than the long-term average (negative) indicating a cooling period. Furthermore, in 2016 and 2017, the Kiremit season produced less value than the long-term mean. The From 2008 to 2018, there was higher value than long term mean with positive departures was observed in annual time scale and Bega season; in Belg from 2005 to 2018; and in Kiremit from 2008 to 2016. From 1990 to 2007 years showed mixed (positive and negative) departure (Fig. 13b). Extended warming was observed in the twentieth century in annual and seasonal time scale. This finding showed similarity with Welka watershed (Asfaw et al., 2018); Omo-Gibe subbasin (Anose et al., 2021).

Between 1984 and 2018, the standardized anomaly index of the mean annual and seasonal minimum temperature had similar pattern and percentage. Standardized anomaly index of the annual and seasonal minimum temperature accounts 57.29% warming year (positive anomaly) and 45.71% of cooling year (negative anomaly) (Fig. 14a & b). This result coincide with study conducted in Awelaro watershed southern Ethiopia (Alemayehu et al., 2020). The annual and Bega season minimum temperature had consecutive cooling years with below long-term average during the period 1985 to 1989; from 1996 to 2001 at annual; 1997 to 2001 during Bega season. Warming years with above the long-term average value was observed successively from 2002 to 2018 at annual time scale (Fig. 14a). From 1990 to 1996 and 2002 to 2008 at Bega season. Belg season standardized anomaly index revealed that cooling (below the average) and warming (above the average) was consecutively recorded from 1997 to 2002 and from 2003 to 2018 respectively. The Kiremit season standardized anomaly index showed warming from 1984 to 2001 except 1990, 1991,1993 and 1995 whereas cooling was constantly observed from 2002 to 2018 except 2009 and 2011(Fig. 14b). Result revealed that at annual and seasonal time scale cycling pattern of warming and cooling year was observed evidenced inter annual and seasonal variability over Zarima subbasin (Alemayehu et al., 2020; Marelign, 2021). Similar to the maximum temperature the minimum temperature standardized anomaly index confirmed that Zarima subbasin experienced a year-to-year variation and extended warming around the twentieth century. This finding in line with Asfaw et al., (2018); Anose et al., (2021); Marelign, (2021).

Trend analysis of the annual and seasonal temperature

The spatial representation of MK trend and Sens's slope estimation of the annual and seasonal maximum and minimum temperature is presented in Fig. 15(a–h). The mean annual maximum temperature increased significantly in some parts of the subbasin ranging from 0.4 °C–0.85 °C per decade for and insignificantly $P \leq 0.05$ in majority of the subbasin by the factor of 0.35 °C–0.9 °C per decade. Mean annual minimum temperature however showed inconsistent trend across the subbasin. Consequently, majority of the subbasin showed statistically insignificant increasing trend up to 0.7 °C per decade; significant increasing trend ranging 0.1 °C to 0.6 °C per decade. Mean annual minimum temperature showed a declining trend raged from 0.1 °C to 0.3 °C per decade around the South eastern lower part of the subbasin. The mean annual maximum and minimum temperature increasing trend was relatively high around the north eastern upper part of the subbasin and less around the southeast lower part of the subbasin. The seasonal patterns of the temperature were inconsistent throughout the basin. Bega season mean maximum temperature showed increasing trend by 0.35 to 0.95 °C. The increment of the maximum temperature was relatively higher around the south west part and lower in the south eastern central part of the sub basin. Bega season minimum temperature showed increasing trend with the amount up to 0.5 °C and decreasing trend with magnitude of 0.1 to 0.5 °C around the south east lower border of the subbasin. The Belg season maximum and minimum temperature showed increasing trend by 0.4 to 1.2 °C and up to 1 °C respectively. Mean Belg season minimum temperature showed decreasing trend by the factor of 0.1 to 0.5 °C around the south east lower part to the subbasin. The Kiremit season mean maximum temperature showed an increasing trend by 0.1 to 0.55 °C whereas the mean minimum temperature showed both significant and insignificant increasing trend with magnitude of 0.05 to 0.5 °C; insignificant decreasing trend was showed around south east lower border of the subbasin with magnitude of 0.05 °C. Generally, mean maximum temperature of annual, Bega and Kiremit and minimum temperature of Kiremit season showed increasing trend whereas Belg season maximum and annual, Bega and Belg season minimum temperature showed mixed trend. The south eastern lower part of the subbasin showed declining trend at annual and seasonal time scale. In line with this study climate variability conducted at Central rift valley of the Ethiopia (Kassie et.al., 2014); Southern Tigray (Hayelom et al., 2017); Welka subbasin (Asfaw et al., 2018); Bilate watershed (Orke and Li, 2021) found that the annual mean maximum temperature showed increasing trend at annual and seasonal time scale. Southern part of Ethiopia

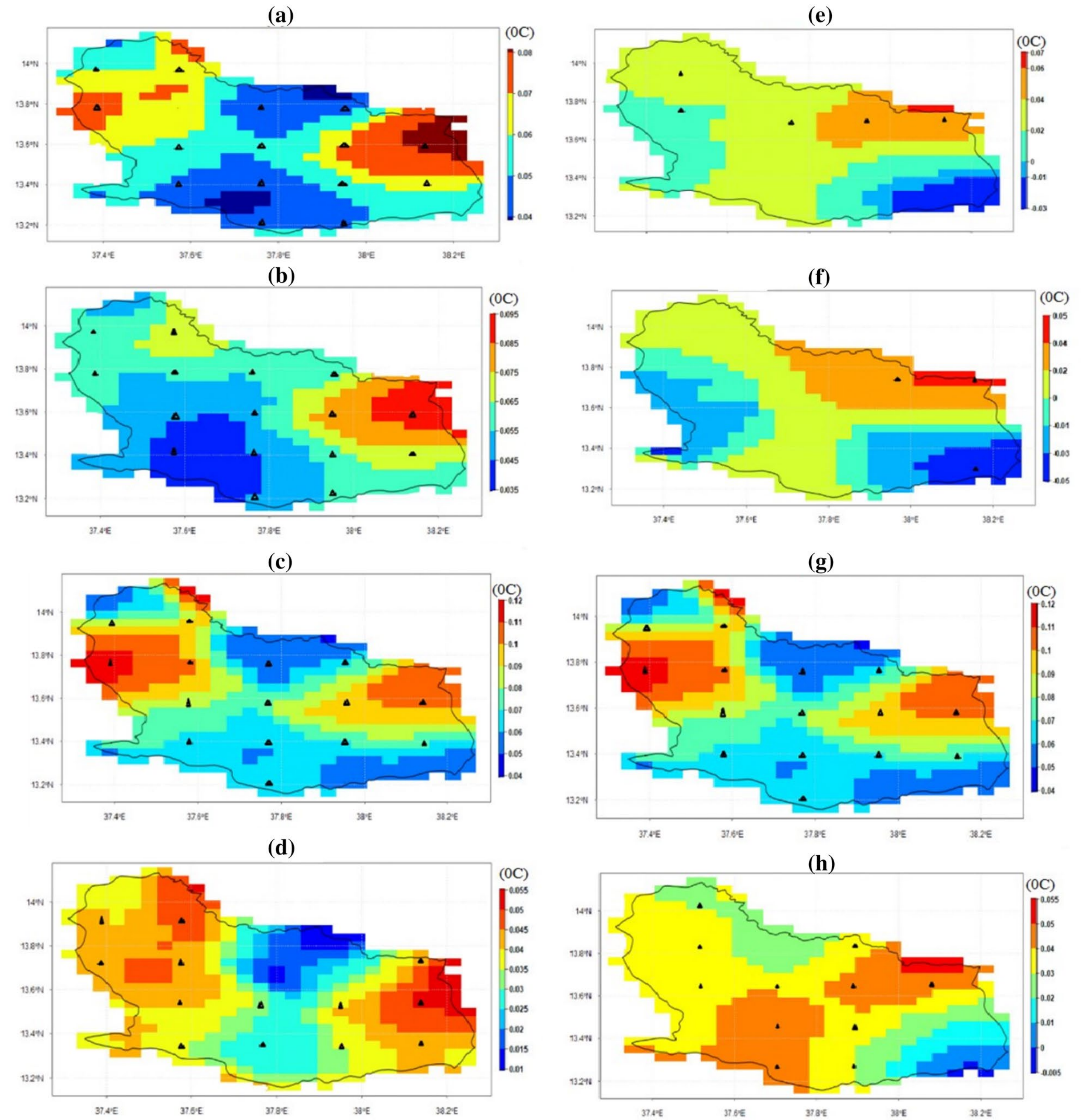

Fig. 15 Trend and magnitude Annual (**a**), Bega season (**b**), Belg season (**c**)and Kiremit season (**d**) mean maximum temperature Annual (**e**), Bega season (**f**), Belg season (**g**) and Kiremit season (**h**) mean minimum temperature (grides showed statistically significant trend at P = < 0.05)

experienced annual rate of change of maximum and minimum temperatures by 0.027 °C and 0.056 °C respectively (Abrham, 2021). Contrary to this study minimum temperature showed only decreasing from 1985–2010 in western Tigray and increasing trend at Welka subbasin trend of the 1901 to 2014 respectively (Asfaw et al., 2018). Modjo watershed mean annual maximum temperature showed increasing trend all over watershed ranging from 0.2 °C to 0.6 °C per decade. However minimum temperature showed inconsistent trend across the stations in the watershed. Annual mean minimum temperature depicted warming and cooling trend by factor of 0.5 °C per decade. On a seasonal basis, the Belg and Kiremt maximum temperature increases with the range of 0.4 °C–0.6 °C

Table 3 Mk test Sen's slope estimation of the annual and seasonal stream flow

Time scale	Z value	Sens's slope	P–Value
Bega season	0.91	0.31	0.36
Belg season	0.023	0.02	0.91
Kiremit season	0.72	0.68	0.47
Annual	0.82	0.32	0.48

and0.1 °C-0.8 °C per decade respectively. The minimum temperature Belg and Kiremit season minimum temperature increased by 0.01 °C–0.6 °C and 0.2 °C–0.3 °C per decade (Eshetu, 2020). Both SAI and trend analyses showed that Zarima subbasin has been warming over the past 35 years. the temperature warming has an impact on the availability of water resources, which difficulties irrigation agricultural and industrial output. Furthermore, the viability of rainfed agriculture and water resources is negatively impacted by the observed patterns of warming and declining rainfall during the Kiremit season in the northern part of the subbasin.

Annual and seasonal stream flow variability and trend

Annual and seasonal stream flow variability

The mean and coefficient of variation of the stream flow of the sub basin at Zarima gauging station tabulated in Table 3. Mean annual stream flow of the sub basin was 132.29 mm^3/s with coefficient of variation 14.39%. The seasonal mean stream flow was 37.9 mm^3/s, 45.21 mm^3/s and 311.78 mm^3/s during Bega, Belg and Kiremit season respectively. The annual and Kiremt season (CV = 14.19%) stream flow coefficients of variation showed less variability, whereas the Bega (CV = 37.37%) and Belg season (CV = 40.17%) stream flow showed very high degree variability. The Bleg and Bega season stream flow was highly varied than the Kiremit season. Annual and seasonal streamflow variability is consistent with the rainfall implies that rain fall has direct effect on the stream flow. Similar result was reported in Modjo, Coefficient of variation of streamflow were 51% and 47% in the Belg season and Bega, season, respectively, which were higher than the annual (CV = 35%) and Kiremt season (CV = 32%) (Eshetu, 2020); in the Rift Valley region of Ethiopia (Kassie et.al., 2014). The higher variability of seasonal streamflow, particularly in the Belg, one of the crops growing seasons, exacerbates water scarcity and challenges the agricultural activities (Anose et al., 2021; Orke and Li, 2021).

Year to year variability of stream flow was observed as depicted in Fig. 16a & b streamflow standardized anomaly index of Zarima gauging station from 1990 to 2014. The number of years having negative anomalies was more than year with positive anomalies in all season implying

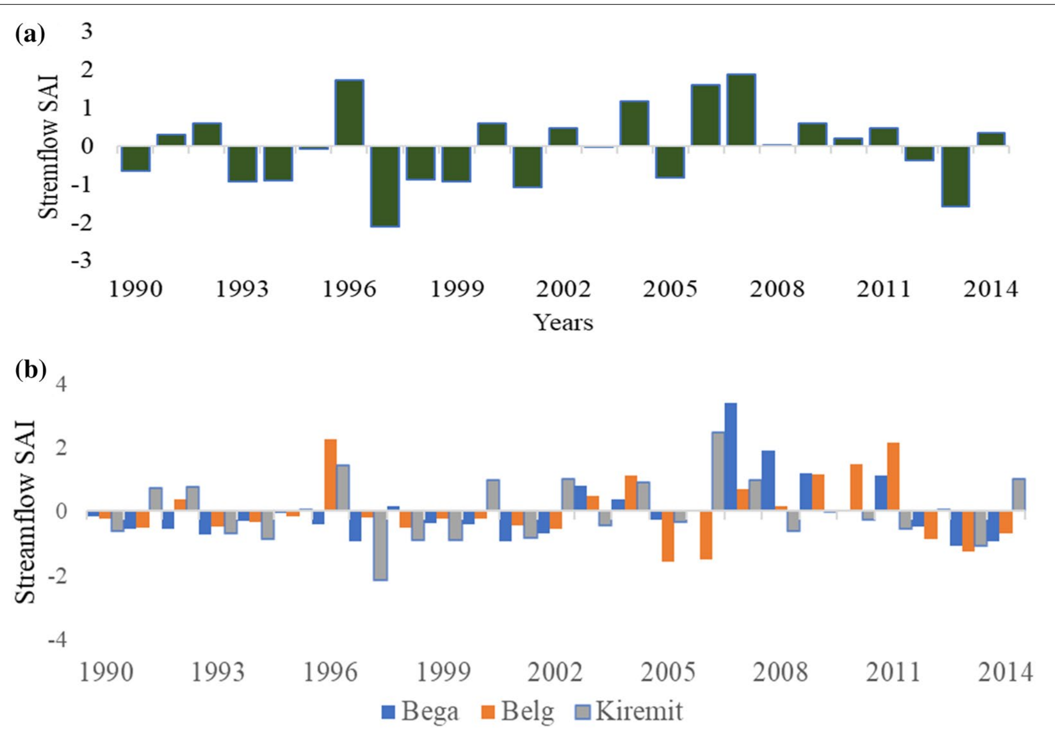

Fig. 16 Annual (**a**) and seasonal (**b**) stream flow standardized anomaly index

that the subbasin was experiencing more dry years than wet years. Similarly, Bilate watershed experienced drier years in streamflow (Orke and Li, 2021).

Trend analysis of the annual and seasonal stream flow

The Mann Kendal and Sen slope estimation analyses of the stream flow revealed a statistically insignificant (p-value) increasing trend in mean annual and seasonal stream flow (Table 3). The mean annual stream flow increased with a magnitude of 3.19 m^3/s per decade. Seasonal stream flow increased by 3.08m^3/s, 0.2m^3/s, and 6.76m^3/s per decade during Bega, Belg, and Kiremit season respectively. Increasing trend in stream flow in this study may be attributed to increasing trend of rainfall in some parts of the subbasin and increasing trend in temperature, as well as other factors. The stream flow increment may be related changes in the basin's catchment characteristic such as climatic factors, environmental change, land cover change and other factors (Fentaw et al., 2017; Eshetu, 2020; Orke and Li, 2021). Generally, the finding of the study help those who make decisions about how to manage water resources and plan irrigation systems. The outcomes may also enable farmers to modify their planting techniques and control the amount of water in the irrigation dam. This finding describes the state of water resources and makes important contributions to knowledge for the management and decision making of water resources.

Conclusion

This study investigated variability and trend of the hydroclimate variables such as rainfall, temperature, and streamflow in the Zarima subbasin from 1984 to 2018. The finding depicted that annual and seasonal rainfall, maximum and minimum temperature showed spatiotemporal variability. The degree of variability of the rainfall and streamflow are consistent having high variability during the Belg and the Bega seasons than the Kiremt season. The Belg season rainfall and streamflow variation has an influence on agricultural production and water availability. The variability of the maximum and the minimum temperatures were less than those of the rainfall and streamflow. However, the subbasin experienced successive drier conditions 1984–1995 and warm years around the 20th which indicates that Zarima subbasin experiences warmer than it was in previous years. The Mann–Kendall trend test and Sen's slope estimation result showed that the spatial annual rainfall showed a statically insignificant trend in majority of the sub basin and significant increasing in some part of the subbasin. While Bega and Belg season showed statistically insignificant mixed trend. Kiremit season rainfall showed heterogenous results in both statistics and trend direction. The annual and seasonal maximum temperature showed increasing trend except Belg season which showed mixed trend. The annual and seasonal minimum temperature showed mixed trend except Kiremit season minimum temperature over Zarima subbasin. Streamflow exhibited insignificant increasing change in the annual and seasonal time series at a 5% significance level. These variations of hydroclimatic variables must be supported by further water resource management research in order to develop effective adaptation strategies. Unless the people of the subbasin, whose existence is solely dependent on rain fed agriculture, suffer due to inconsistent rainfall. Finally, the findings of this study offer a scientific foundation for the current situation of temporal and spatial variations in rainfall, temperature, and stream flow that are essential for agricultural planning and water resource management.

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Author contributions
MKZ: conceptualization, methodology, writing original draft, writing review & editing. KTB: methodology, conceptualization, methodology, writing original draft, writing review & editing. DNH: conceptualization, methodology and editing. All authors read and approved the final manuscript.

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Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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