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Climate trend analysis for a semi-arid Borana zone in southern Ethiopia during 1981–2018

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Abstract

Background: Understanding the climate variability at local scale could help suggest local adaptation responses to manage climate associated risks. This paper analyzed the variability and trend of climate in semi-arid Borana zone of southern Ethiopia over the period 1981–2018 using Mann–Kendall *(MK)* test, Sen's Slope Estimator *(SEE)* and inverse distance weighted *(IDW)* interpolation technique. Gridded (4 km * 4 km) climate data (daily precipitation, daily maximum temperature *(Tmax)* and minimum temperature *(Tmin)*) were collected from National Meteorology Agency (NMA) of Ethiopia.

Results: The results revealed the study area received a mean monthly precipitation of 39.19 mm and a monthly mean Tmax and Tmin of 29.66 °C and 16.31 °C were observed respectively. Rainfall shows a significant increasing trend during August, October and November and extremely variable during December, January and February where CV > 100%. Tmax shows a significant warming trend during August but January, February, August and October exhibited similar trend for Tmin. Rainfall and Tmin shows a significant trend during *Meher* and no trend for the rest of the seasons. Mean annual rainfall shows a significant increase where no trend observed for both Tmax and Tmin at this timescale. Decadal rainfall and Tmin exhibited no trend but Tmax show significant warming trend during 2001–2010 decade. Better rainfall and cooler temperature were observed in the north central, northeastern and northwestern whereas the southeastern and southwestern regions were drier and warmer.

Conclusion: Rainfall is highly variable than temperature both at temporal and spatial scales in Borana. The intensity of rainfall decreases from the northeastern and northwestern parts towards the southwest while temperature increased from the north central parts towards the southwest for Tmax and the southeast for Tmin. The effect of topography is substantial for the local scale variability observed in the study area. Internal variability is observed at temporal and spatial scales and therefore any adaptation responses to local climate variability should consider the microscale climate.

Keywords: Climate variability, Precipitation, Temperature, Spatiotemporal, Mann–Kendall test, Sen's Slope Estimator

Introduction

The recent report of Intergovernmental Panel on Climate Change (IPCC) indicate that the global mean temperature showed a warming trend of 0.85 °C (0.65–1.06) over the period 1880–2012 (IPCC 2013; Birara et al. 2018). Many developing countries particularly those found in Sub-Saharan Africa are significantly affected by the global average temperature rise, termed as global warming and its consequences (IPCC 2012). The consequences of changing climate are widespread in these countries whose economy is in one way or another depend on climate sensitive sectors such as agriculture and livestock systems. Climate variability and change affects these systems by altering the pattern and distribution of climatic elements including temperature and rainfall.

Ethiopia is one of the largest countries of Africa characterized by diversified physiography. There is a marked

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altitudinal variation that ranges from 125 m below mean sea level in *Dallol Depression* (the lowest) to 4,620 m above mean sea level indicating peak of *Mt Ras Dashen* (the highest). So, based the relationship between altitude and temperature that are inversely proportional, the climate of the country is classified in to five agroecological zones namely *Wurch* (> 3300 m), *Dega* (2300–3300 m), *Wionadega* (1500–2300 m), *Kolla* (500–1500 m) *and Bereha* (< 500 m) (Ethiopian institute of Agricultural research (EIAR), 2011). Climate of Ethiopia is highly modified by altitude than other factors where lowlands are known for warm to hot arid climate while the highland regions are characterized by cool to cold sub humid (humid) type of climate.

In addition to complex topography, the climate of the country is influenced by the seasonal migration of a low-pressure zone namely *Intertropical Convergence Zone* (ITCZ), a region where the northeast and the southeast trade winds converge, following shifting of the overhead Sun to the north and south of the equator (Segele and Lamb 2005; Korecha and Barnston 2007). The seasonal movement of ITCZ is, therefore, responsible for the occurrence of dry and wet conditions over the country during different seasons. The spatial and temporal variability in the climate system (temperature and rainfall) is hence governed by these factors where this variation can have a potential impact on various socio-economic systems such as agricultural practices and livestock systems.

Several research papers on climate trend analysis were conducted using the non-parametric Mann–Kendall test (Mann 1945; Kendall 1975) and Sen's slope estimator (Sen 1968) methods. To mention some, Belay et al. (2021) analyzed climate variability and trends in southern Ethiopia and observed highly variable seasonal rainfall and highly increasing trend for annual Tmin than Tmax. In addition, Berhane et al. (2020) found a significant decrease of annual rainfall totals for most stations and increase in annual mean Tmax in semi-arid areas of Western Tigray, Ethiopia. Tafesse and Tewodros (2020) examined the local level spatiotemporal variability and trends of climate and came to know that annual, *Belg* and *Kiremt* rainfall decreased overtime where it was significant for *Belg* and annual temperature have shown a significant increasing trend in drought-prone districts of rural Sidama, central rift valley region. Alemayehu et al. (2020) observed increasing trends in annual and seasonal rainfall totals while Tmax and Tmin showed decreasing trends in Alwero watershed, western Ethiopia. Tesfamariam et al. (2019) found no significant trend for the annual, *Belg* and *Kiremt* rainfall while significant increasing trends for Tmax and Tmin of several months in Rift Valley Lakes Basin, Ethiopia. Wedajo et al. (2019) found not significant decreasing rainfall trend in almost all agroecological zones but the warming trend of climate for Dhidhessa River Basin.

Furthermore, spatiotemporal trend and variability of climate is studied at various scales in the northeastern highlands (Mekonnen and Berlie 2020); in the Woleka sub-basin, north central Ethiopia (Asfaw et al. 2018); in the central highlands of Ethiopia (Arragaw and Woldeamlak 2017); and in the northwestern parts of Ethiopia (Belay et al. 2021). There were also related paper conducted on similar issue at country level by Gummadi et al. (2018) and even beyond, at East African level by Gebrechorkos et al. (2019). The findings of these papers and others more were discussed in relation to this study under discussion section.

The non-parametric approaches MK and Sen's Slope tests are preferred over other methods for a number of advantages including non-requiring of missing data, no-parameter estimated uncertainty and simplified computation (Kuriki et al. 2020; Gupta and Jain 2018; Jena et al. 2014) and it can tolerate the outliers and skewed distributions (Hamed 2007; Kisi 2015; Wu and Qian 2017; Duan et al. 2018; Ali et al. 2019; Dong et al. 2019). Even though, the application of MK test is relatively effective, it is subjected to the presence of serial correlation in the data series which is a drawback (Yue and Wang 2004; Tian et al., 2018). Biazar and Ferdosi (2020) and Dinpashoh et al. (2019) adopted a Modified MK method introduced by Yue et al. (2002) to eliminate the of *lag-1* serial correlation. On the other hand, 'pre-whitening' approach is often suggested as a remedial measure for autocorrelation (Von Storch and Navarra 1995; Kulkarni and Von Storch 1995; Malik et al., 2019; Wang et al. 2017; Sanikhani et al. 2018; Razavi and Vogel 2018; Ali et al. 2019).

This paper is intended to: (i) analyze the spatiotemporal variability of precipitation and temperature in semi-arid Borana; (ii) identify the existence of monotonic trend (increasing or decreasing) in the climatic variables mainly precipitation and temperature at different temporal scales. The research is conducted based on the fact that, understanding the climate variability and trend at local scale could help policy makers to develop and implement better local adaptation responses to reduce climate-associated risks. The study results further add value to the existing literature especially in the semi-arid Borana where previous similar study is lacking. The following sections of the manuscript is organized as 'Materials and Methods' that describes the study area and the detailed methodology including data types, sources and analysis techniques; 'Results' presents the main findings of the paper; 'Discussion' describes the interpretation of the results and 'Conclusion' which presents the main conclusions drawn in the paper.

Materials and methods

Study area description

This study was conducted in Borana zone which is one of the 21 administrative zones of Oromia regional state, Southern Ethiopia. Borana zone is located in the southern part of the country (Fig. 1) bordered by Kenya in the South, West Guji zone in the North, Somali region and Guji zone in the East and South Nations and Nationalities Peoples' Region (SNNPR) in the West. Astronomically, the study area stretches from 3°30' N to 5°25' N latitude and 36°40' E to 39°45' E longitude. Yabelo is the capital town of Borana zone and located at about 570 km South of Addis Ababa. The zone covers almost 48,360 km^2 out of which more than 75% is a lowland.

The study area exhibits four seasons namely *Bega* the long dry period from December to February, *Belg* the long rainy period from March to May, *Kiremt* the short dry spell from June to August and *Meher* the short rainy period from September to November. The rainfall pattern of the region is different from most parts of the country. It is during *Belg* and *Meher* seasons that Borana zone receives most of its rain. The season naming *'Bona,' 'Ganna,' 'Adolessa'* and *'Hagayya'* are known at the community level and are equivalent respective names at national level *Bega, Belg, Kiremt* and *Meher* (Riche et al. 2009). Borana zone receives an average annual rainfall ranging from 350 mm to about 900 mm which is distributed through the two rainy seasons from March to May and September to October (Debela et al. 2019). Rainfall is highly variable across the zone and it highly erratic resulted in the frequent occurrence of drought in many parts of Borana. Rainfall has bimodal pattern of distribution with increasing unpredictability which necessitates adaptation and risk management as suggested by (Korecha and Barnston 2007). The mean annual temperature is about 19 °C in the Borana zone, where the mean maximum and minimum temperatures are 24.6 °C and 12.96 °C respectively. In general, the warmest period in the year is from March to May, while the lowest annual minimum temperatures occur between the months of November and January (National Meteorological Agency (NMA) of Ethiopia 2007).

The region has a semi-arid savannah landscape, marked by gently sloping lowlands and flood plains vegetated predominantly with grass and bush land. The geology is composed of a crystalline basement with overlying sedimentary and volcanic deposits (Gemedo-Dalle et al. 2006; Lasage et al. 2010). People are predominantly involved in small-scale subsistence agriculture production and mainly on livestock husbandry. These sectors are climate-sensitive and frequently hit by climate related hazard, which is of course drought. Small-scale farming is not widely practiced mainly due to the aridity that prevails over the study area and hence government introduced the farming practices as means of income diversification and to support the family .

Data types and sources

Gridded (4 km × 4 km spatial resolution) data for daily precipitation, daily Tmax and Tmin for all the points lying within the study area boundary for the period 1981 to 2018 were collected from National Meteorological Agency (NMA) of Ethoiopia. Therefore, a total of 2702 data points (Fig. 2) were considered as inputs and the mean values were used to analyze the variability and trends of rainfall as well as temperature at multiple timescales including monthly, seasonal, annual and decadal time periods. Therefore, the data generated were prepared for use in R software package to test trend and variability analysis. We prefer to use gridded data for a number of advantages including its accessibility and completeness. On the other hand, due to the remoteness of the location, meteorological stations are sparsely distributed in the study area with serious missing values in the dataset.

Furthermore, the gridded climate used in this study is a product of Enhancing National Climate Services (ENACTS) initiative which has developed and implemented a tool for quality-control of rainfall and temperature observations by national weather stations and then blends these observations with freely available global products. Therefore, with this aim, Columbia University's International Research Institute for Climate and Society (IRI), in close collaboration with the local partners, launched the ENACTS initiative in 2012. The initiative was accomplished using IRI's Climate Data Tool (CDT), which is installed at each meteorological station (https://iri.columbia.edu/resources/enacts/). The dataset is not freely accessible and for the purpose of this study, it is obtained from national Meteorological Agency (NMA) of Ethiopia.

Trend and statistical analysis

Serial correlation

One of the challenges in detecting and interpreting trend in timeseries data is the existence of serial correlation (autocorrelation), is where error terms in a time series transfer from one period to another (Yue et al. 2002; Birara et al. 2018). In the other words, the error for one time period *'a'* is correlated with the error of a subsequent time period *'b'*. Autocorrelation is tested in this paper through calculating the autocorrelation coefficient at *lag-1* and plotting the correlogram. It is said that, there is significant autocorrelation when the value for correlation coefficient, *r*, falls outside the range at 95% confidence interval. Therefore, we took a remedial measure

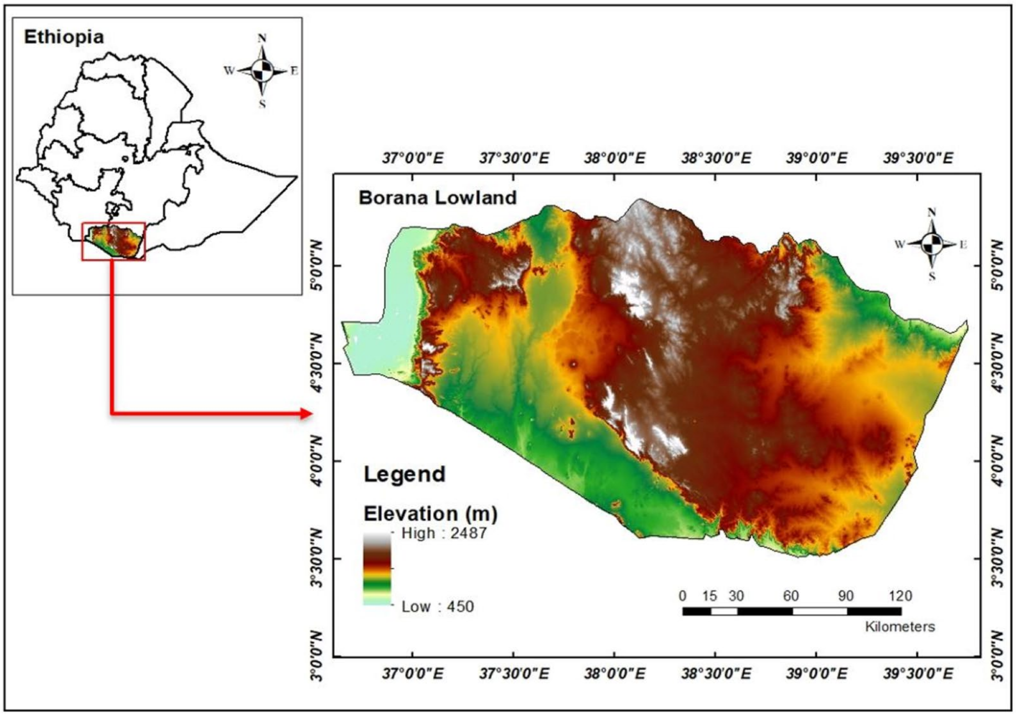

Fig. 1 Location of the study area

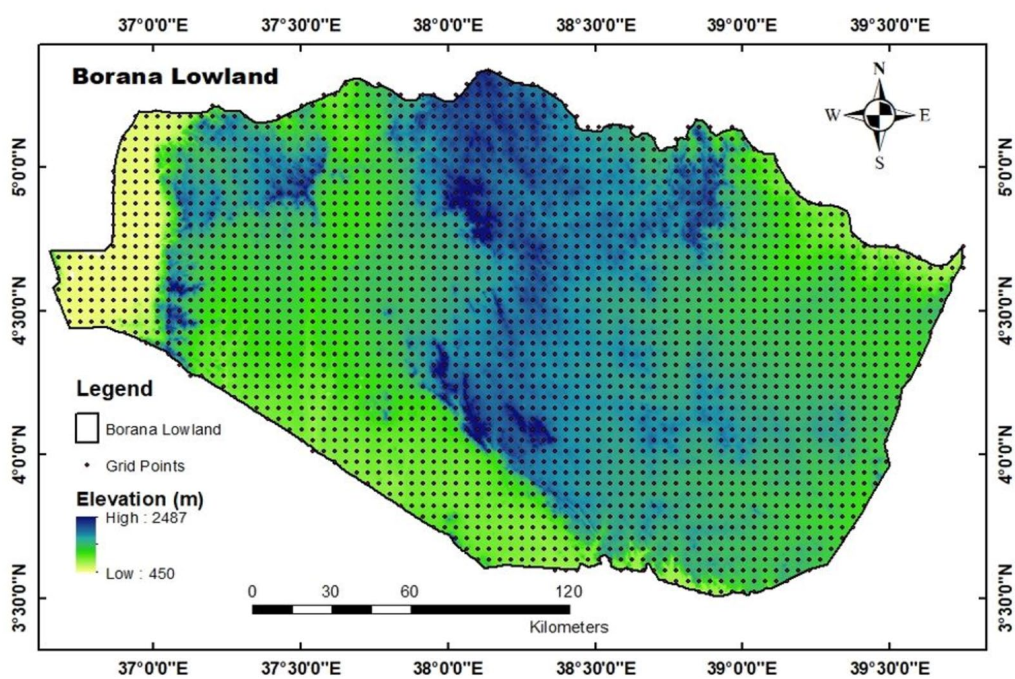

Fig. 2 Data grid points in the Borana lowland

to remove the effect of significant autocorrelation in the timeseries through the 'pre-whitening' procedure (Von Storch and Navarra1995; Kulkarni and Von Storch 1995). Pre-whitening (PW) efficiently removes the finding of significant trend in the MK test when actually there is no trend (Bayazit and Onoz 2007). Based on this, for the data points $(x_1, x_2, x_3, \ldots, x_n)$, the 'pre-whitened' time series was obtained through $(x_2—rx_1, x_3—rx_2, \ldots, x_n—rx_{n-1}$, where r is the correlation coefficient between the two consecutive data points in the time series) procedure before applying Mann–Kendall trend test.

Mann–Kendall (MK) test

Mann–Kendall (MK) test, a popular non-parametric test is used in order to detect trend in climatic variables at 5% level of significance (Mann 1945; Kendall 1975). MK test was then proposed as the null hypothesis (H_0), there is no trend in the time series and alternative hypothesis (H_1), there is a monotonic trend which can either be an upward or a downward.

The MK test (Mann 1945; Kendall, 1975) was first carried out by computing S statistic as:

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} Sgn(xj - xi) \tag{1}$$

where, n is the number of observations, and x_j is the jth observation and Sgn denotes the sign function, defined as:

$$Sgn(xj - xi) = \begin{cases} +1; & xj > xi \\ 0; & xj = xi \\ -1; & xj < xi \end{cases} \tag{2}$$

and variance defined by:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{m} tk(tk-1)(2tk+5)}{18} \tag{3}$$

where, n is the number of data, m is the number of tied groups (a tied group is a set of sample data with the same value), and it is the number of data points in the k^{th} group.

Finally, the statistics of this test, designated by Z, is computed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\ S < 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if\ S > 0 \end{cases} \tag{4}$$

The test statistics Z is used as a measure of significance of trend. If the value of Z is positive, it indicates increasing trends, while negative values of Z show decreasing trends. A significance level of $\alpha = 0.05$ (confidence level of 95%), is also utilized for testing either upward or downward monotonic trend (a two-tailed test) (Jhajharia et al 2012). If Z appears greater than $Z_{\alpha/2}$ where α depicts the significance level, then the trend is considered as significant.

Sen's Slope Estimator (SEE)

If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated by using a simple non-parametric procedure developed by Sen (1968). Sen's slope estimation can be calculated in the form of:

$$ft = Qx + b \tag{5}$$

where Q is the slope and b constant. To obtain slope Q in Eq. 5, it is necessary to calculate the slope for all data with the equation:

$$Qi = \frac{xj - xk}{j - k} \tag{6}$$

where, xj and xk are considered as data values at time j and k $(j > k)$ correspondingly. The median of N values of Qi is ranked from small to large, with an estimated Sen's estimator of slope, given by:

$$Qi = \begin{cases} Q\frac{(N+1)}{2} & N\ is\ odd \\ \frac{1}{2}(Q\frac{N}{2} + Q\frac{(N+2)}{2} & N\ is\ even \end{cases} \tag{7}$$

To obtain estimates of b in Eq. 5, the values of n data from the difference $(x_i—Q_{ti})$ are calculated. The median value is the estimate for b. Finally, Q_{med} is computed by a two-sided test at $\alpha = 0.05$ (95% confidence interval) and then a true slope can be obtained and its value indicates the steepness of the trend.

Statistical data analysis

The study tried to capture the variability of precipitation, maximum and minimum temperature at temporal and spatial basis. Temporally, variability is seen at monthly, seasonally, annually and decadal scales. Descriptive statistics including mean, standard deviation and coefficient of variation were calculated at different scales for the parameters. Hare (2003) computed coefficient of variation (CV) using the following formula:

$$CV = \sigma/\mu * 100 \tag{8}$$

where CV represents the coefficient of variation, σ is the population standard deviation, and μ is the population mean.

Apart from ArcGIS which is used for spatial data analysis and R-software package for statistical and trend tests while Origin software version 17 was used to plot various precipitation and temperature graphs in this study.

Analyzing spatial variation

The inverse distance weighted (IDW) interpolation technique (Shepard 1968; Hodam et al. 2017; Biazar et al. 2019) in ArcGIS was employed to generate surface data for precipitation, Tmax and Tmin from grid points at seasonal and annual scales. To do this, time series precipitation and temperature data from the grid points were analyzed by using ArcGIS 10.5 interface. Hence, spatial maps showing precipitation, maximum and minimum temperature variability across the semi-arid Borana zone were produced at seasonal and annual timescales.

Results

Variability and trends of monthly precipitation, maximum and minimum temperature

Monthly precipitation

In semi-arid Borana, rainfall is highly variable on a monthly basis where six (January, February, June, July, August and December) out of the twelve obtained among the lowest monthly means and each received less than 16 mm per month. On the other hand, April is the month when peak mean rainfall (113 mm) is received during the same period followed by October (81.20 mm). The CV value computed tells us precipitation is highly variable in the Borana lowland and the coefficient of variation for all the months ranges between 38 and 120%. Especially the *CV* values goes beyond 100% for December, January and February in the study area.

The trend of precipitation shows a significant increasing trend (*P-value* < *0.05*) for August, October and November (Table 1 and Fig. 3). The magnitude of change is higher for October and followed by November where the slope estimates exhibited 1.49 and 1.09 respectively (Table 1). Therefore, it is true not to accept the null hypothesis test for August, October and November. No monotonic trend exists *(P-value* > *0.05)* for the rest of the months during the studied years.

Monthly maximum (Tmax) and minimum (Tmin) temperature

The results for mean Tmax shows that, February was the hottest month (32.06 °C) followed by January (31.49 °C) and March (31.03 °C) whereas the lowest mean Tmax was observed during the month of July (28.01 °C). Tmax shows a significant increasing trend *(P-value* < *0.05)* at 5% level of significance only for August. All months other than August show no trend (the null hypothesis cannot be rejected) in the study area (Table 2 and Fig. 4).

On the other hand, the highest mean Tmin was observed in February (16.92 °C) followed by March (16.69 °C) during the entire period. Apart from this, the lowest mean Tmin was recorded in July (15.77 °C) and August (15.93 °C). The MK test result revealed that January, February, August and October have shown a significant increasing trend (*P-value* < *0.05*) for Tmin where the magnitude of change was more or less the same (Table 2 and Fig. 4). No monotonic trend was detected during the rest of the months and hence it is true not to reject the null hypothesis of the test for the study period.

Variability and trends of seasonal precipitation, maximum and minimum temperature

Seasonal precipitation

Precipitation is not evenly distributed during the various seasons and also spatially across the region. The seasonal distribution of precipitation shows that most of the rainfall occurs during *Belg* (March to May) season with a mean record of 229 mm followed by *Meher* (September to October) which obtained a mean precipitation of 162.5 mm. On the other hand, *Kiremt* (June to August) and *Bega* (December to February) were the driest

Table 1 Descriptive statistics and test results of monthly precipitation (1981–2018)

Months	Mean	Standard Deviation	CV (%)	Z-value (MK test)	P-value	Sen's Slope
Jan	10.85	12.34	113.78	0.28	0.78	
Feb	15.12	18.09	119.62	0.08	0.94	
Mar	53.99	37.22	68.95	0.23	0.82	
Apr	113.00	43.11	38.15	− 0.15	0.88	
May	61.99	29.65	47.82	0.28	0.78	
Jun	14.21	9.68	68.11	0.58	0.56	
Jul	10.62	6.03	56.79	0.65	0.51	
Aug	12.17	9.27	76.12	2.29	0.02	0.25
Sep	23.26	12.75	54.84	0.55	0.58	
Oct	81.20	42.88	52.80	2.57	0.01	1.49
Nov	58.04	52.39	90.26	2.67	0.01	1.09
Dec	15.82	17.61	111.32	− 0.38	0.71	

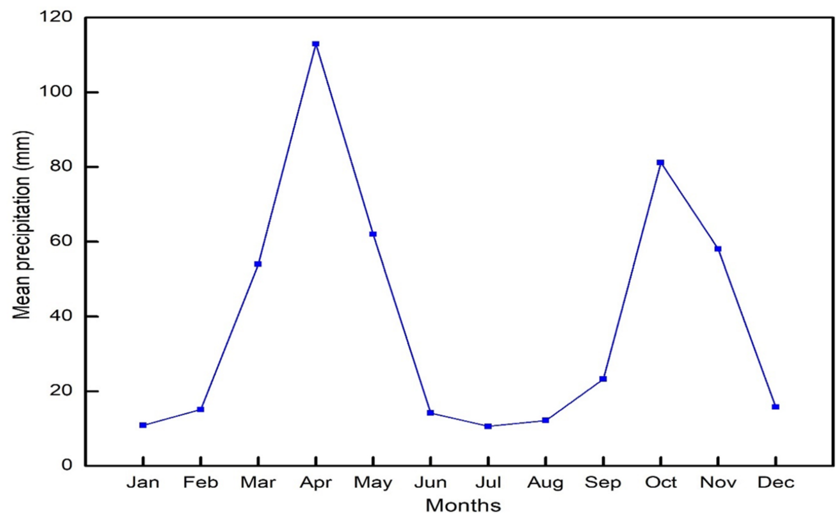

Fig. 3 Mean monthly precipitation in semi-arid Borana (1981–2018)

Table 2 Descriptive statistics and test results for mean Tmax and Tmin

Months	Maximum Temperature (°C)						Minimum Temperature (°C)					
	Mean	Std	CV (%)	Z-value	P-value	Sen's Slope	Mean	Std	CV (%)	Z-value	P-value	Sen's Slope
Jan	31.49	1.09	3.47	0.96	0.34		16.60	0.42	2.55	2.34	0.02	0.02
Feb	32.06	1.10	3.44	1.71	0.09		16.92	0.46	2.70	2.26	0.02	0.02
Mar	31.03	1.50	4.83	0.15	0.88		16.69	0.67	4.04	0.45	0.65	
Apr	28.81	1.03	3.59	− 1.86	0.06		16.50	0.49	2.95	− 0.80	0.42	
May	28.43	0.85	2.99	− 1.86	0.06		16.59	0.38	2.31	0.85	0.39	
Jun	28.09	0.80	2.84	1.84	0.07		16.20	0.45	2.76	0.78	0.44	
Jul	28.01	0.77	2.76	1.13	0.26		15.77	0.47	3.00	0.11	0.16	
Aug	28.55	0.56	1.96	2.97	0.00	0.02	15.93	0.50	3.16	2.09	0.04	0.02
Sep	29.74	0.52	1.75	1.79	0.07		16.04	0.45	2.80	1.056	0.29	
Oct	29.38	0.82	2.78	− 1.61	0.11		16.24	0.33	2.04	2.56	0.01	0.01
Nov	29.85	0.96	3.23	0.18	0.86		15.98	0.35	2.16	1.13	0.26	
Dec	30.48	0.99	3.25	0.98	0.33		16.31	0.34	2.08	1.11	0.27	

periods during the last 38 years of time with 37 mm and 42.63 mm respectively (Table 3 and Fig. 5). Therefore, the study area is characterized by four distinct seasons (two wet and two dry) where the precipitation observed during these seasons is caused by the south easterly winds carrying moisture from Indian Ocean. On the contrary, although *Kiremt* is the main rainy season in the country, the study area remains yet receive little amount of rainfall due to its rain-shadow location from the winds that cause rain to occur (the Guinean Monsoon or Equatorial Westerlies from south Atlantic Ocean).

Rainfall variability is moderate for *Belg* season (26.4%) whereas high for *Bega* (83.25%), *Meher* (55.44%) and *Kiremt* (45.6%) (Table 3). *Kiremt* season followed by *Bega* were the driest seasons in the study area and rainfall is highly variable during *Bega* that exhibited the highest coefficient of variation. The Mann–Kendall (MK) statistical test shows statistically significant increasing trend during *Meher* season *(P-value* < 0.05*)* and the magnitude of the change looks strong *(slope* $= 2.84$*)*. The null hypothesis ($H_0 = No\ trend$) cannot be accepted only for *Meher* season. On the other hand, no monotonic trend is observed in the study area during *Bega, Belg* and *Kiremt* seasons.

Figure 6a–d shows that precipitation is not equally distributed across Borana during the different seasons. The seasonal precipitation maps were produced through IDW interpolation technique taking in to account the average

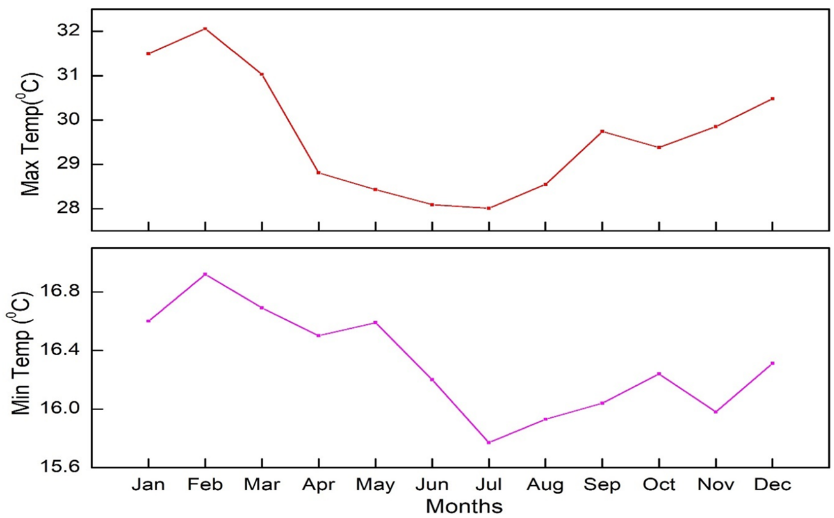

Fig. 4 Mean monthly Tmax and Tmin in semi-arid Borana (1981–2018)

Table 3 Descriptive statistics and test results of seasonal precipitation (1981–2018)

Seasons	Mean	Standard deviation	CV (%)	Z-value (MK test)	P-value	Sen's Slope
Bega	42.63	35.49	83.25	− 0.28	0.78	
Belg	228.98	60.45	26.40	− 0.33	0.74	
Kiremt	37.00	16.80	45.40	1.74	0.08	
Meher	162.50	90.09	55.44	2.77	0.01	2.84

values of almost the last four decades. Precipitation is relatively intense in the northeastern parts of Borana except for *Bega* where the topography is a continuation of the Sidamo highlands while the southwestern parts are characterized by scarcity of rainfall. During *Kiremt* season (Fig. 6c), the northern parts of the lowland attached to the *'Kiremt-maximum rainfall regions'* in the north obtained some amount of rainfall. But as it stretches far south and east, the region is getting drier. Figure 6b (*Belg*) and 6d (*Meher*) are the two wettest seasons with relatively good amount of precipitation in the study region.

Seasonal temperature

Bega is the warmest season in the study area with mean Tmax of 31.34 °C whereas *Kiremt* is characterized by relatively lowest mean (28.22 °C). The mean Tmin observed is relatively the highest (16.61 °C) and lowest (15.97 °C) for *Bega* and *Kiremt* respectively as shown in Table 4 and Fig. 7. There is a range of 3.12 °C between the highest and the lowest values for mean Tmax. On the other hand, a mean temperature variation of 0.64 °C is detected between highest and the lowest means for Tmin. Therefore, high seasonal temperature variability is observed for Tmax than Tmin.

On seasonal timescale, no monotonic trend was observed in the study area for mean Tmax hence the null hypothesis *(H_0 = No monotonic trend)* cannot be rejected and the *P-value* at all cases is greater than 0.05. On the other hand, the mean Tmin shows a significant trend *(P-value < 0.05)* for Meher while no trend is observed during the rest of the seasons at 5% level of significance as indicated in Table 4 and Fig. 7.

The spatial maps for mean Tmax in Fig. 8a show temperature varies from one season to another in the semi-arid Borana. The north central parts were cold spots whereas the southwestern parts were hotspots whereas other regions of the study area were characterized by moderate temperature. During the *Belg* season, relatively colder temperature stretches far southward while during *Kiremt*, the eastern, southwestern and western regions were dominated by warmer temperatures. On average, the seasonal temperature range during each season reach 4.57 °C where this is the highest for *Meher* (6.46 °C) and lowest for *Kiremt* (5 °C). The maximum temperature observed in the study area reach highest during *Bega* (32.29–33.39 °C)

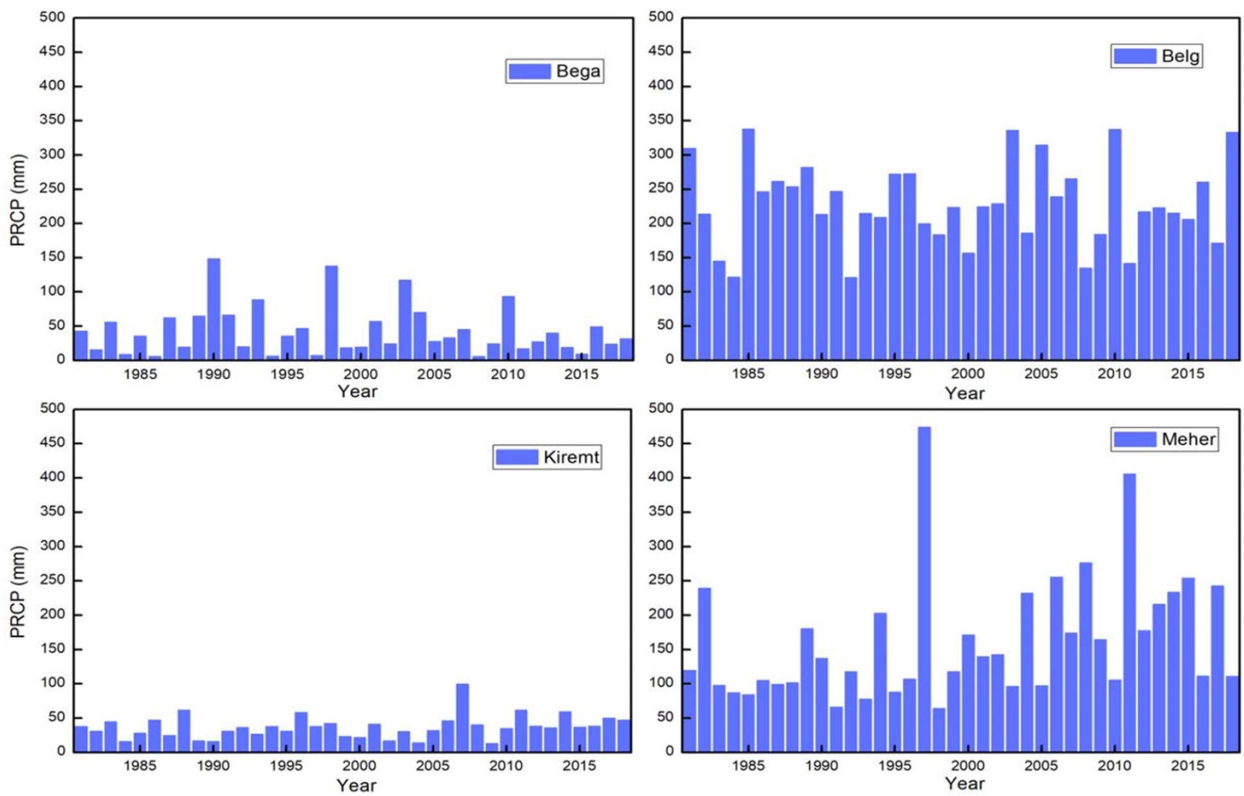

Fig. 5 Seasonal precipitation distribution in semi-arid Borana (1981–2018)

followed by *Meher* season (30.78–32.08 °C) in the southwestern parts of the lowland. On the other hand, the lowest mean maximum temperature was observed roughly in the north central parts during *Belg, Kiremt and Meher* reach between 24.51 and 25.4 °C. Temperature is unevenly distributed across the semi-arid Borana zone.

Figure 8b is about the spatial distribution of mean Tmin in the study area. During *Bega* (12.67–21.61 °C) followed by *Belg* (13.16–20.49 °C), the highest average Tmin is observed in the Borana area. It is only during these seasons that the highest average value for Tmin exceeds 20 °C and the Tmin range for *Bega* and *Belg* was 8.94 °C and 7.33 °C respectively. On the other hand, relatively lowest average Tmin (cold spot) is observed in the northern part of Borana, more or less similar to that of the Tmax, and this stretches far south during *Kiremt* followed by *Meher* seasons. The lowest average Tmin observed during *Meher* is 12.36–13.74 °C and this is followed by *Kiremt* with 12.48–13.64 °C. Overall, the highest mean value for Tmin (> 18.67 °C) is confined to the far southeastern parts of Borana during all the seasons although the area under influence slightly differs, which means a very small area during *Kiremt* and *Meher* than *Bega* and *Belg* seasons.

Variability and trends of annual precipitation, mean maximum and minimum temperature

Annual precipitation

The study area received a mean annual rainfall of 470.27 mm from 1981 to 2018 and 1997 (750.64 mm) was the year when the peak rainfall observed. It was followed by 2011 (644.16 mm) and 2006 (606.52 mm). On the other hand, 1984 was the driest year with 250.09 mm per year. Rainfall was less variable from year to year with 19.2% coefficient of variation (CV) during the studied period (Table 5 and Fig. 9a). The annual trend of rainfall shows an increasing trend where it is statistically significant *(P-value < 0.05)* at 95% level of significance. The spatial distribution of rainfall across Borana shows variability and the overall pattern looks similar with the rainy seasons (*Belg* and *Meher*). The northeastern parts of the semi-arid Borana received relatively better rainfall over the years than any other areas and decrease towards the southwestern (Fig. 9b).

Annual maximum and minimum temperature

The annual mean Tmax during the last 38 years was 29.66 °C, where the highest observed value is 30.49 °C (1994) and the lowest is 28.68 °C (1985). On the other hand, the

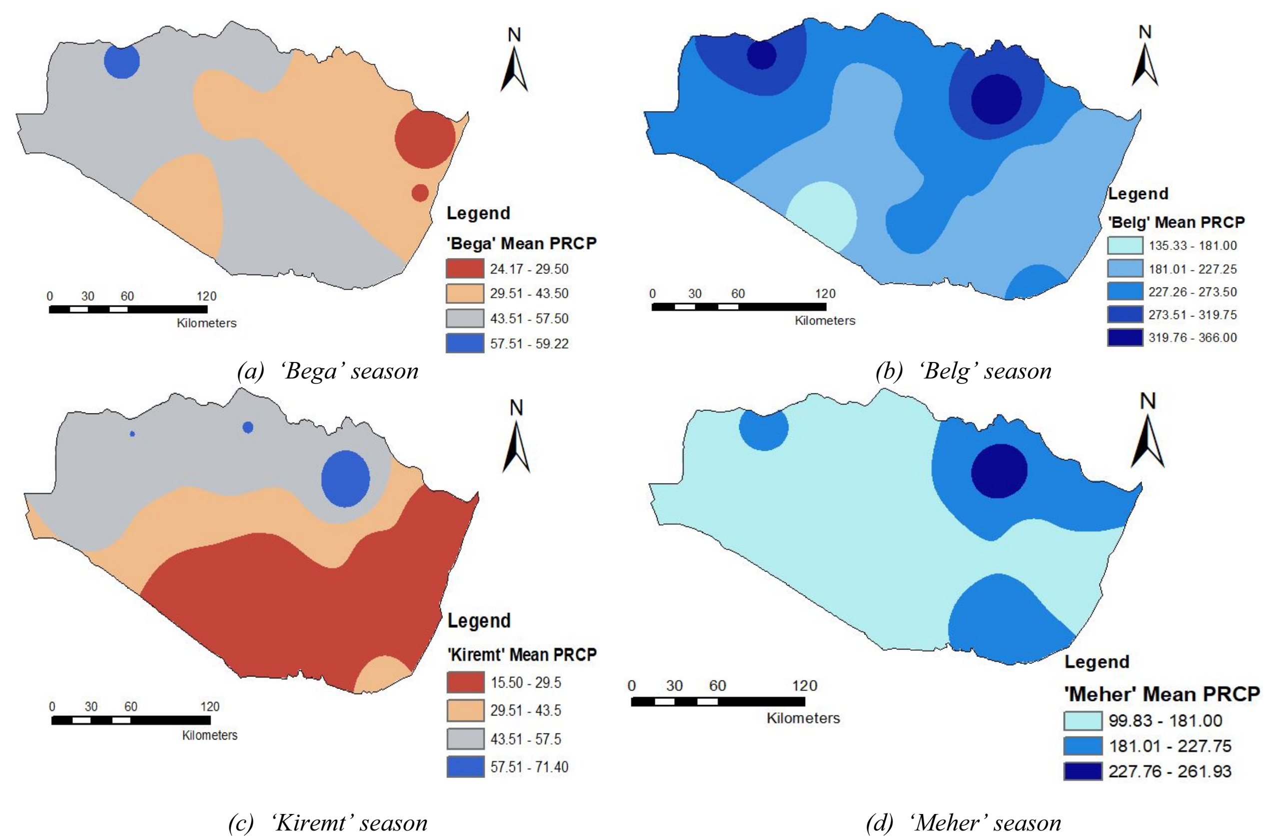

Fig. 6 Spatial variation of mean precipitation during different seasons (1981–2018)

Table 4 Descriptive statistics and test results seasonal Tmax and Tmin (1981–2018)

Seasons	Maximum Temperature (°C)						Minimum Temperature (°C)					
	Mean	Std	CV (%)	Z-value	P-value	Sen's Slope	Mean	Std	CV (%)	Z-value	P-value	Sen's Slope
Bega	31.34	0.88	2.82	1.68	0.09		16.61	0.33	2.01	1.73	0.08	
Belg	29.42	0.86	2.93	− 1.11	0.27		16.59	0.41	2.47	0.08	0.94	
Kiremt	28.22	0.64	2.25	1.18	0.07		15.97	0.45	2.79	1.18	0.24	
Meher	29.66	0.57	1.91	− 0.23	0.82		16.09	0.45	1.82	2.67	0.01	0.01

mean Tmin for the same period was 16.31 °C where the highest and lowest means observed were 16.93 °C (2016) and 15.73 °C (1985) respectively as shown in Table 6 and Fig. 10. The range of temperature between the highest and lowest mean values over the studied periods were 1.81 °C for Tmax and 1.2 °C for Tmin. Both Tmax and Tmin shows no trend of temperature at annual timescale in this study. The test results revealed the *P-value* > *0.05* in both cases is and proved not to reject the null hypothesis of no monotonic trend.

As shown in Fig. 11a, the annual mean Tmax of Borana ranges between 25.85—31.6 °C during the studied period. The northern and north central parts of the lowland were areas of lowest mean Tmax. The southwestern areas of Borana along the Ethio-Kenyan border were known for highest mean Tmax that ranges between 30.45 and 31.6 °C. Most of the remaining parts of the Borana were characterized by moderate mean Tmax (24.15–29.3 °C). On the other hand, the annual mean Tmin shows moderate temperature that ranges between 15.17 and 17.17 °C prevailed in most parts of the study area. A smaller area in the southeastern and southwestern part of the Borana shows the highest mean Tmin of 18.67 °C but below 20.17 °C for the entire

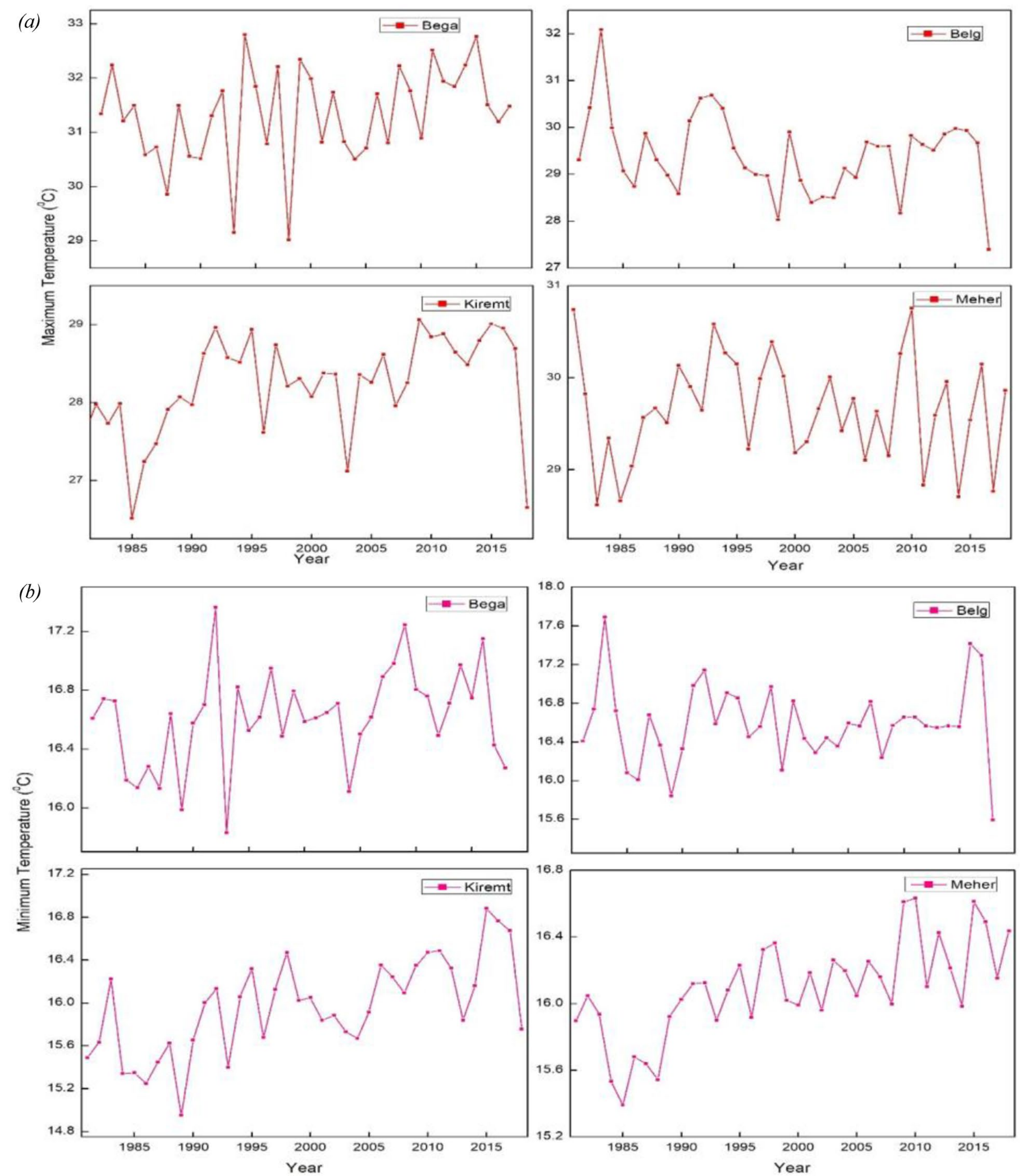

Fig. 7 Seasonal Tmax (**a**) and Tmin (**b**) in semi-arid Borana (1981–2018)

studied period as observed from Fig. 8b. On the contrary, the northern parts of Borana exhibited the lowest mean Tmin of between 12.67 and 14.17 °C. Overall, the hotspot areas for mean Tmax and Tmin were observed in the southwestern and southeastern parts respectively whereas relatively cooler conditions were observed in the north and northcentral areas of the study area.

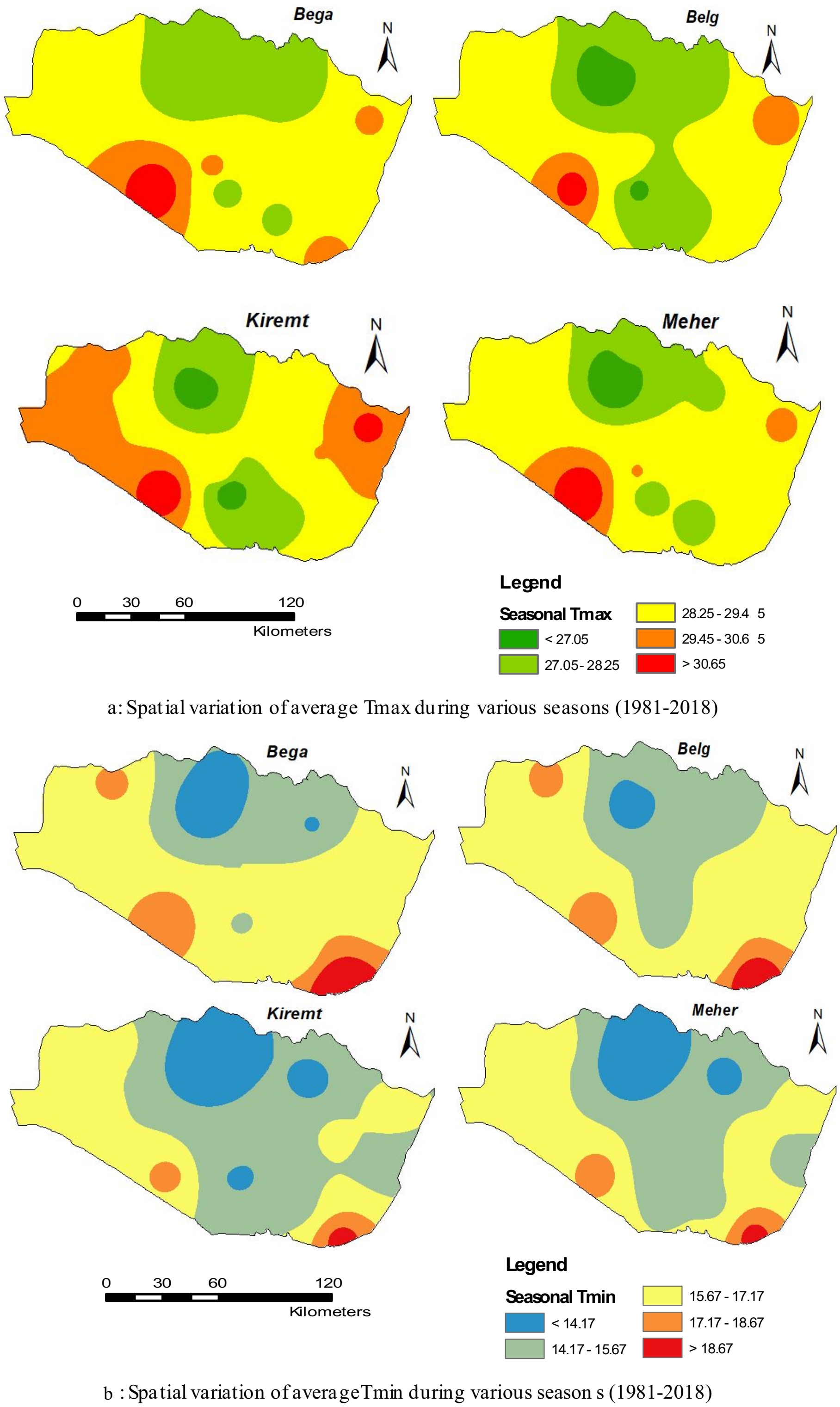

Fig. 8 **a** Spatial variation of average Tmax during various seasons (1981–2018). **b** Spatial variation of average Tmin during various seasons (1981–2018)

Table 5 Descriptive statistics and test results of annual rainfall (1981–2018)

Period	Mean	Standard deviation	CV (%)	Z-value (MK test)	*P-value*	Sen's Slope
Annual	470.27	90.27	19.20	2.26	0.02	2.63

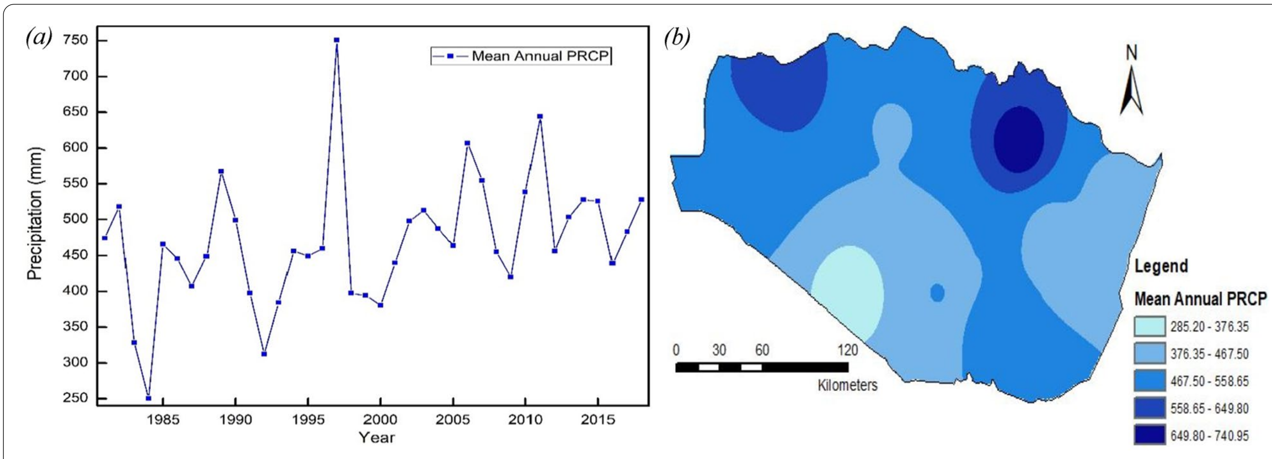

Fig. 9 Mean annual rainfall trend (**a**) and spatial variation (**b**) in the semi-arid Borana (1981–2018)

Table 6 Annual mean maximum and minimum temperature (1981–2018)

Period	*Maximum temperature (°C)*						*Minimum temperature (°C)*					
	Mean	Std	CV (%)	Z-value	P-value	Sen's Slope	Mean	Std	CV (%)	Z-value	P-value	Sen's Slope
Annual	29.66	0.41	1.39	0.20	0.84		16.31	0.29	1.74	0.83	0.41	

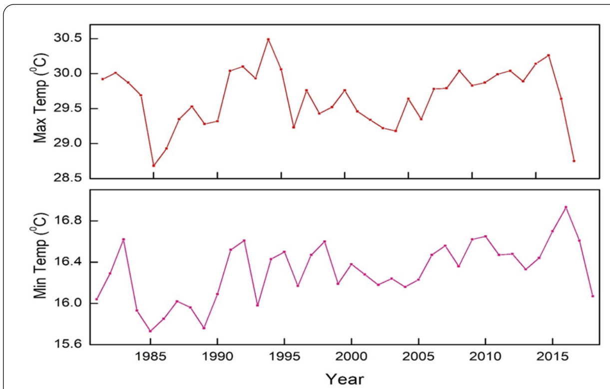

Fig. 10 Trends of annual mean Tmax and Tmin in semi-arid Borana (1981–2018)

Decadal variability and trends of precipitation, maximum and minimum temperature

Decadal precipitation

Rainfall distribution at decadal scale is characterized by less variability compared to other timescales in this study. The study area received an average decadal rainfall of 472.42 mm per decade (Table 7 and Fig. 12). There was a slight change (a decrease) in the mean rainfall received from the first decade (1981–1990) 440.44 mm to the second decade (1991–2000) which was 438.25. But from then onwards, rainfall shows an increase to 513.36 mm (2011–2018). Rainfall is moderately variable for the first two decades where the coefficient of variation falls between 20 and 30% whereas during the third and fourth decades, it shows less variability and the CV value equals 11.49% and 12.20% respectively. Therefore, the distribution of rainfall shows more or less similar pattern and less to moderate variability at decadal scale in semi-arid Borana.

In addition, the study area received better *Belg* season rainfall during the first and the third decades while average decadal rainfall was weak during second decade. For the second and last decade, rainfall distribution during *Meher* shows similar pattern with *Belg*. On the other hand, the average *Meher* rainfall shows decrement for the first and third decade and the decrease

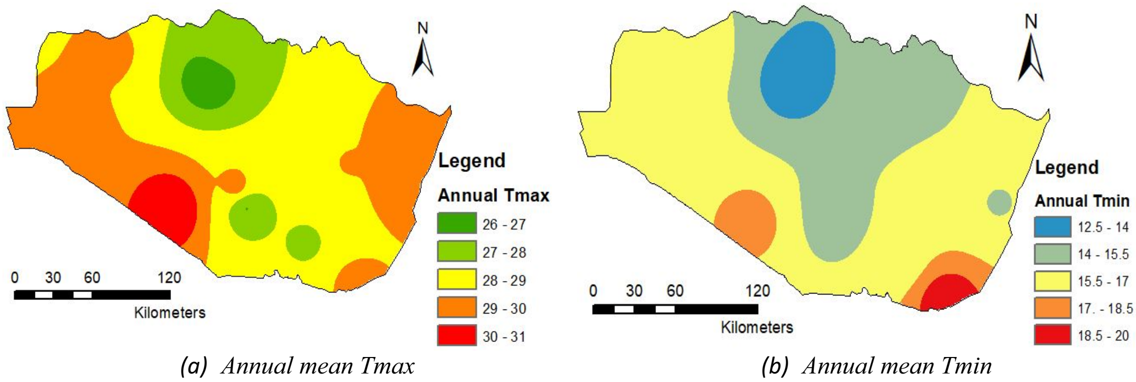

Fig. 11 Spatial distribution of annual mean Tmax (a) and Tmin (1981–2018)

Table 7 Descriptive statistics and test results of decadal rainfall (1981–2018)

Decades	Mean	Standard Deviation	CV (%)	Z-value (MK test)	*P-value*	Sen's Slope
1981–1990	440.44	92.67	21.04	0.54	0.59	
1991–2000	438.25	118.25	26.98	0.18	0.86	
2001–2010	497.63	57.18	11.49	0	1	
2011–2018	513.36	62.63	12.20	− 0.12	0.90	

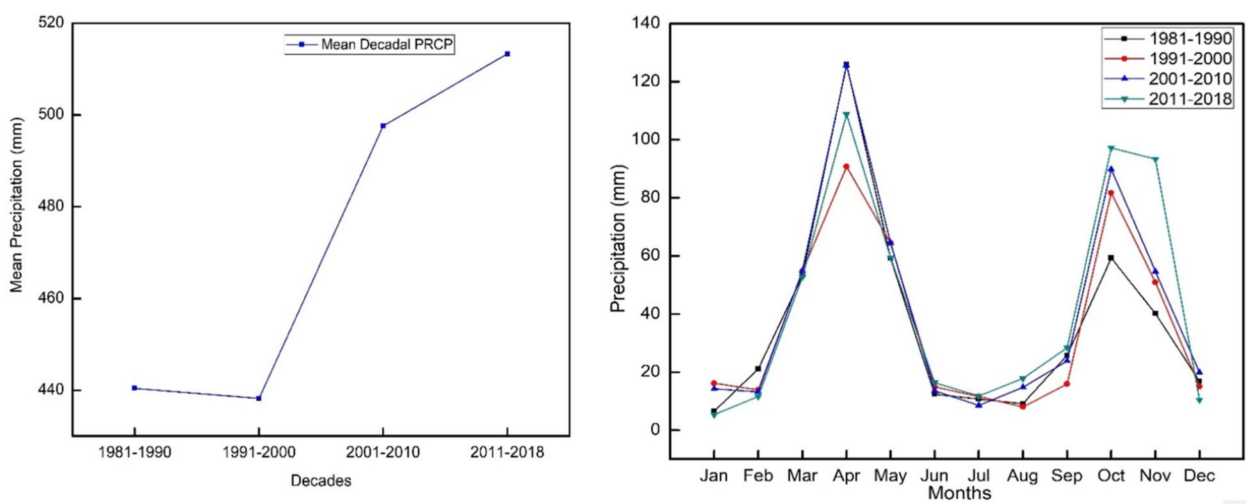

Fig. 12 Mean decadal rainfall distribution in semi-arid Borana (1981–2018)

was by more than 50% for the first decade (Fig. 12). Overall, the decadal mean rainfall shows a slight positive change since the second decade in the study area and no monotonic trend *(P-value > 0.05)* is observed during all decades and hence it is true not to reject the null hypothesis.

Decadal maximum and minimum temperature

The results show that the mean Tmax at decadal scale was 29.46 °C, 29.83 °C, 29.56 °C and 29.82 °C from the first to the last decade respectively and the overall average was 29.67 °C during the entire period. The second decade was slightly warmer and followed by the last decade in the study area. Concerning the mean Tmin, 16.33

°C is observed over the decades in the study area where the highest Tmin 16.5 °C in the last decade and the lowest 16.03 °C in the first decade. The difference between the highest and lowest decadal means (range) for Tmax and Tmin were 0.37 °C and 0.47 °C respectively. Only the third decade (2001–2010) shows a statistically significant warming trend (P-value < 0.05) for both Tmax and Tmin over the studied years as shown in Table 8 and Fig. 13. In addition, both mean decadal Tmax and Tmin shows a similar pattern during various months and seasons except for the first decade in the study area.

Discussion

Rainfall is highly variable in the study area on a monthly basis and the mean rainfall 39.19 mm is received in Borana during the studied period. The coefficient of variation (CV) is very high for all the months and particularly for January, February and December, it even exceeds 100%. The low and highly variable rainfall observed during December to February is attributed to the influence dry continental winds from Middle East and Arabian landmass invading the country during this period. Bewket and Conway (2007) and Ayalew et al. (2012) found similar result that rainfall is highly variable during the months December to February. The inter-annual variation (monthly and seasonal) of rainfall is found to be very high in this study and this is strongly supported by the findings of Mulugeta et al. (2017) in eastern and southeastern Ethiopia and Harka et al. (2021) in the upper Wabishebelle River Basin. Mean monthly rainfall shows a statistically significant increasing trend *(P-value < 0.05)* during August, October and November whereas during the remaining months, it is true to not to reject the null hypothesis for the existence of trend in the time series. Bayable et al. (2021) also found not significant decreasing trend of rainfall during all the months except in July, October and November between 1983 and 2019 in Western Harerghe zone, eastern Ethiopia.

Concerning temperature, the mean Tmax and Tmin observed in the study area were 29.66 °C and 16.33 °C respectively. The highest Tmax during the studied period was observed in February while the lowest was during

Table 8 Decadal Tmax and Tmin in the study area (1981–2018)

Decades	Maximum Temperature (°C)						Minimum Temperature (°C)					
	Mean	Std	CV (%)	Z-value	P-value	Sen's Slope	Mean	Std	CV (%)	Z-value	P-value	Sen's Slope
1981–1990	29.46	0.43	1.47	− 1.79	0.07		16.03	0.26	1.65	− 0.72	0.47	
1991–2000	29.83	0.37	1.24	− 1.43	0.15		16.39	0.21	1.27	− 0.54	0.59	
2001–2010	29.56	0.29	0.99	2.33	0.02	0.07	16.38	0.19	1.14	2.33	0.02	0.05
2011–2018	29.82	0.47	1.58	− 0.124	0.90		16.50	0.26	1.55	0.124	0.90	

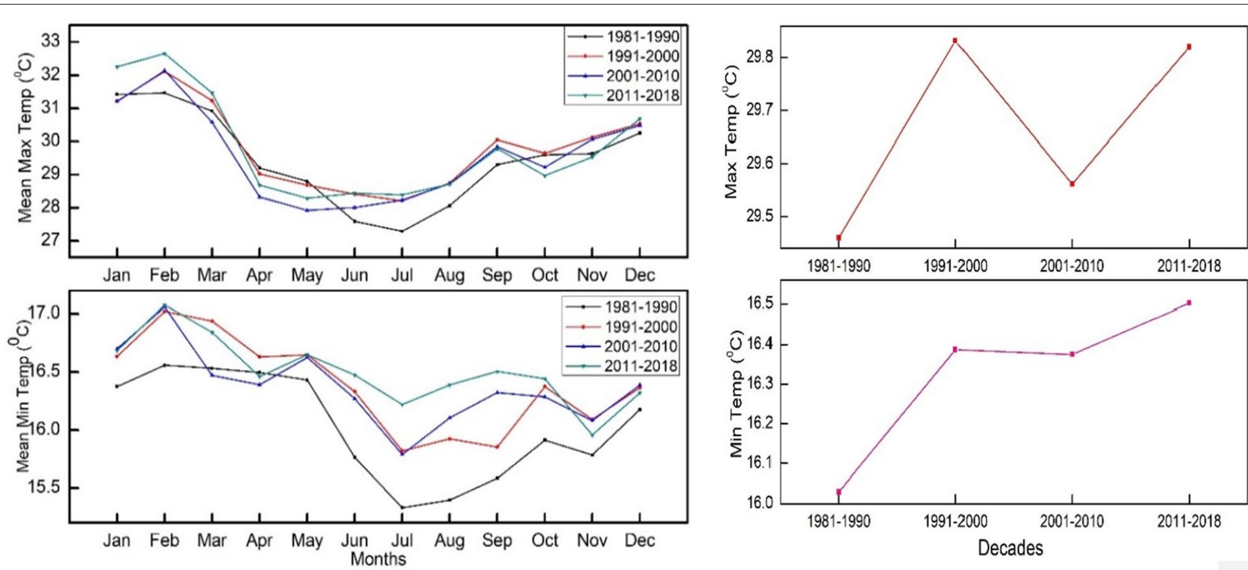

Fig. 13 Decadal mean Tmax and Tmin in semi-arid Borana (1981–2018)

July. The same condition observed for Tmin where February and July were respectively the warmest and the coldest months. The range of temperature between these months is by far smaller for Tmin than Tmax. Only August shows a statistically significant increasing trend for Tmax where no monotonic trend observed during the rest of the months. But January, February and October exhibited significant warming trend for Tmin in addition to August. This means, both Tmax and Tmin shows a significant warming trend during the month of August. Tesfamariam et al. (2019) observed the significant warming trend of monthly temperature in the rift valley lakes basin which could aggravate drought conditions in the area. In addition to this, Tmax exhibited non-significant increasing trend while a significant increasing trend for Tmin was obtained for all months in the northern central Ethiopia (Asfaw et al. 2018).

Seasonally, *Belg* (March to May) received most of the rainfall followed by *Meher* (September to November). Rainfall variability is moderate only for *Belg* whereas it is high for the other seasons. Getenet (2013) investigated significant spatial variation of rainfall at seasonal and annual scales in the eastern and southeastern arid and semi-arid areas. The result of this study is also consistent with the works of Harka et al. (2021) where majority of the stations in the upper Wabishebelle River Basin show high rainfall variability for *Kiremt* and *Belg* seasons and all stations show very high variability of rainfall during *Bega* season. Bekele et al. (2017a, b) and Cheung et al. (2008) found high seasonal rainfall variability respectively for most of the stations located in the Awash River Basin and throughout Ethiopia and the results agree with the current study. Moreover, a very recent study conducted by Mohamed et al. (2022) reported more inter-annual variability of *Bega* rainfall than *Kiremt* seasons (Coefficient of Variation (CV) of *Bega* > *Belg* > *Kiremt* seasons) in the Blue Nile Basin.

In this study, rainfall shows an upward trend only for Meher season where it is statistically significant at 5% level of significance and no monotonic trend is observed during other seasons. But, Arragaw and Woldeamlak (2017) founded significant decreasing trend for rainfall in central highlands of the country. Kheireldin et al. (2016) also found a declining trend of precipitation for wet and dry seasons over the Blue Nile basin in the north central Ethiopia. Evidences of declining trends in *Belg* season rainfall in Eastern Africa in general and in Ethiopia in particular were reported by (Ahmed et al. 2017; IPCC 2014; Rosell 2011 and Conway et al. 2007) though *Belg* season rainfall is extremely important for the performance of agricultural and pastoral systems. Desalegn et al. (2018) also founded that, there was a decrease in the annual and main rainy season (*Belg*) in semi-arid Borana whereas Gummadi et al. (2018) observed a general declining trend in the entire country between 1980 and 2010.

Bega season exhibited the highest mean value for both Tmax and Tmin while the lowest is observed during *Kiremt*. Regarding the trend in the time series data for temperature, no season shows increasing or decreasing trend for Tmax whereas Tmin shows a significant increasing trend for *Meher* season. It is observed in the study area that, seasonal variability of temperature is observed even though it is not at the scale of precipitation. Similar pattern of temperature was observed in the studies conducted by (Mengistu et al. 2014; Wedajo et al. 2019; Bayable and Alemu 2021; Belay et al. 2021). On the contrary to this result, Alemayehu et al. (2020) found a significant decreasing trend of maximum temperature particularly during Bega season and an overall decreasing trend of annual and seasonal temperature in Alwero watershed in western part of Ethiopia. The inconsistency in the results is attributed to the location of the study areas in terms agroecological zones where topography affects local temperature greatly in Ethiopia. Alwero watershed is found in association with western highlands that are wet for most of the seasons unlike Borana which is characterized by warm and semi-arid climate.

An average annual rainfall of 470.27 mm is received in Borana and 1997 and 1984 were the wettest and driest years respectively during the studied years. Rainfall was less variable in the region at annual scale compared to smaller timescales where the coefficient of variation was less than 20%. Precipitation shows a significant increasing trend at an annual basis in Borana. Wassie and Fekadu (2015) also reported the increasing trend of mean annual rainfall in Yabelo district of Borana lowland. Insignificant increase in annual rainfall trend is observed in Ethiopian eastern and central parts (Arragaw and Woldeamlak 2017; Wagesho et al. 2013). On the contrary to the current finding, Tafesse and Tewodros (2020) reported that, annual rainfall amount decreased over time where the trend is not significant between 1983 and 2014 over drought-prone districts of rural Sidama zone in Ethiopia. Gebrechorkos et al. (2019) reported no general pattern of rainfall over the entire country; but simultaneously increasing and decreasing trends of rainfall. Rainfall was highly variable at annual scale and no significant trend was observed over Ethiopia during 1980–2010 (Gummadi et al. 2018).

The annual mean Tmax in Borana over the period 1981–2018 was 29.66 °C while the mean Tmin observed during the same period was 16.31 °C. Both Tmax and Tmin shows no increasing or decreasing trends, the test results revealed. Asfaw et al. (2018) observed non-significant increase in the trend of maximum temperature but significant increase in Tmin. Positive trends were observed in the annual Tmax in lowlands and highlands of southern Ethiopia and there was observed significant positive trend of annual Tmin, consistent in all agroecological zones (Esayas et al. 2019). On the contrary, an upward trend of mean temperature has been observed over southwestern region of Ethiopia as found by (Jury and Funk 2013). Furthermore, the averages of annual maximum and minimum temperatures has shown an increasing trend in the northeastern highlands (Mekonnen and Berlie 2020) and Lake Tana basin (Birara et al. 2018). Gedefaw et al. (2019) and Berhane et al. (2020) observed a general tendency of increasing trend of temperature in two eco-regions of Ethiopia and semi-arid areas of western Tigray respectively. Temperature shows a markedly increasing trend especially as regards the minimum values over the country as observed by Fazzini et al. (2015). Gebrehiwot and van der Veen (2013) also observed a faster rate of increase for annual mean maximum than mean minimum temperature over northern Ethiopia.

A mean rainfall amount of 472.42 mm is received at decadal scale and a slight positive change is observed since the second decade. Rainfall is moderately variable for the first two decades (1981–2000) and less variable then after. The rainfall variability at decadal scale is from less to moderate during the studied years and rainfall is almost fairly distributed at this scale. None of the decade has shown either a significant decreasing or decreasing trend during the studied period in Borana. Belay et al. (2021) also found similar result that non-significant and less variable average decadal rainfall was observed between 1987 and 2019 over the northwestern parts of the country. The result is also in agreement with Mohamed et al. (2022) who observed a further reduction of mean annual and *Kiremt* rainfall by 1149.4 mm and 783.7 mm respectively in the Blue Nile Basin during the 1981–2018 compared to the preceding decades.

The decadal mean Tmax and Tmin in Borana were 29.67 °C and 16.33 °C respectively. The temperature range between relatively warmest and coldest decades was calculated to 0.37 °C for mean Tmax while it was 0.47 °C for mean Tmin. The 1990s decade was warmest for Tmax whereas and the warmest Tmin was observed in the recent decade (2010s). The result was consistent with Belay et al. (2021) who studied decadal variability of temperature over the northwestern parts of the country and observed the highest mean minimum temperature during the decade (2007–2016). In this study, the decadal average Tmax and Tmin shows a significant warming trend only during the third decade (2001–2010) while no monotonic trend observed during the other decades. In general, temperature shows a slight variation between the studied decades and the later period show warmer condition than the previous in Borana. Mekonnen and Berlie (2020) also observed the increasing trend of decadal minimum (0.098 °C), maximum (0.041 °C) and average (0.069 °C) temperatures in the northeastern highlands. Asfaw et al. (2018) found the change of temperature to be 0.046, 0.067 and 0.026 °C per decade for mean, minimum and maximum respectively during the period of 1901–2014 in the north central Ethiopia.

Spatially, rainfall varies across the semi-arid Borana. The high intensity of rainfall is received in the northeastern parts of the region followed by northwestern parts and decrease towards the southeastern areas along the Ethio-Kenyan border. Areas that received better rainfall are attached to the foot hills of mountains in the north and rainfall intensity decrease towards lower altitude in the region. Fitsum et al. (2017) stated that the spatial distribution of rainfall in Ethiopia is drastically influenced by complex topography and altitude is one of the major controls of climate in Ethiopia. Gummadi et al. (2018) observed changes in the intensity of rainfall events over the southeastern parts of Ethiopia extending to the southwest covering Somali and Oromia regions. Both Tmax and Tmin were unevenly distributed during the different timescales across the lowland. Relatively warmer conditions for Tmax and Tmin were observed over southwestern and southeastern respectively. In addition, cooler conditions were observed and confined to the north and north central areas of Borana attached to the foothills Sidamo highlands adjacent the study area in the north. A significant proportion of Borana in the east, central and western is dominated by moderate temperature.

In general, the study area is one of the warm and semi-arid climatic regions in the country. The characteristics of precipitation and temperature is significantly altered by the effects of topography both temporally and spatially. Since substantial area of Borana is not a lowland, the north, northcentral, northeastern and northwestern parts that are attached to the Sidamo highlands *(Jemjem Plateau)* relatively received better precipitation and also cooler than other parts. Areas in the south, east, southeast, west and southwest are found adjacent to the low-lying regions, where rainfall is scarce and exhibited warmer conditions. Therefore, the observed climate variability could have significant impacts on the biophysical aspects of the region including the growth of pasture or feed resource and the availability of water resources. With this, it alters the livelihood of the pastoral and agropastoral communities in the region.

Conclusion

This paper examined the variability and trend of climate at temporal and spatial scales in semi-arid Borana of southern Ethiopia. Each month received an average rainfall of 39.19 mm. On the other hand, the mean monthly and annual Tmax and Tmin over the studied years were 29.66 °C and 16.31 °C respectively. *Belg* is the wettest season with moderate variability while *Meher* season has shown a significant increasing trend of rainfall. *Bega* season was the warmest for both Tmax and Tmin and no trend observed during all the seasons. A mean rainfall of 470.27 mm per year is received in the study area and 1997 and 1984 were years of highest and lowest total rainfall respectively. Rainfall is less variable and shows a significant increasing trend at annual timescale where no trend was observed for both annual Tmax and Tmin. The mean decadal rainfall exhibited a slight positive change in the later decades and shows no trend whereas both Tmax and Tmin have shown a significant warming trend only for 2001–2010 decade. Rainfall is highly variable at shorter (months and seasons) than longer (annual and decadal) timescales. Spatially, the northeastern and northwestern parts of the Borana obtain the highest mean rainfall and decreases towards the southwest. Temperature increases from the northcentral parts towards the southwest for Tmax and the southeast for Tmin in the region. Altitude significantly affects the spatial and temporal distribution of rainfall and temperature in the study area in particular and in the country in general. This significantly alters the biophysical components including rangeland and water aspects and communities living in this region. Therefore, the findings of this paper could be helpful for policy makers to devise and implement better adaptation strategies in response to local climate variability.

Abbreviations
CV: Coefficient of variation; EIAR: Ethiopian institute of agricultural research; IPCC: Intergovernmental panel on climate change; MK: Mann–Kendall; NMA: National meteorological agency; Std: Standard deviation; Tmax: Maximum temperature; Tmin: Minimum temperature; °C: Degree centigrade.

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Authors' contributions
All authors equally contribute in design, review and writing the manuscript. They all read and approved the paper. All authors read and approved the final manuscript.

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Availability of data and materials
All the data used in this study are available from the corresponding author up on reasonable request.

Declarations

Ethics approval and consent to participate
There is ethical conflict.

Consent for publication
All authors read the manuscript and agreed for publication.

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

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