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Research Article

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Variability and time series trend analysis of temperature over 1981-2018 in semi-arid Borana zone, southern Ethiopia

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Abstract

Background: Understanding the climate variability at local scale could help suggest local adaptation responses to manage climate driven impacts. This paper analyzed the variability and trends of temperature over the period 1981-2018 in semi-arid Borana zone of southern Ethiopia using Mann-Kendall (MK) test and inverse distance weighted (IDW) interpolation technique. Gridded (4 km * 4 km) daily temperature data was used to study variability at temporal and spatial scales.

Results: The results revealed that monthly temperature shows a warming trend where February was the warmest month for both maximum and minimum temperature. Seasonally, the highest maximum and minimum temperatures were observed during Bega. Minimum temperature shows a warming trend during all seasons unlike maximum temperature. Both minimum and maximum temperature shows not significant warming trend at annual timescale. The later decades (2001-2018) have shown a warming trend compared to a period ahead especially for minimum temperature. The southwestern and southeastern areas across the zone were warmer than any other areas in the region during the studied period.

Conclusion: Temperature shows variability at shorter than longer timescales. There is a pronounced warming trend for minimum than maximum temperature. Warming condition advances from the northcentral parts towards the southwestern and southeastern areas. Internal variability was observed at temporal and spatial scales and therefore any adaptation responses to local climate variability should consider the microscale climate.

Keywords: climate variability, temperature, spatial, temporal, Mann-Kendall test

Introduction

The recent report of Intergovernmental Panel on Climate Change (IPCC) indicate that the global mean temperature showed a warming trend of 0.85 ^{0}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 altitudinal variation that ranges from 125 m below mean sea level in *Dallol Depression* in the northeastern parts to 4,620 m above mean sea level indicating peak of *Mt Ras Dashen* in the north central highland group of the country. 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. 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* (> 3,300 m), *Dega* (2,300-3,300 m), *Wionadega* (1,500-2,300 m), *Kolla* (500-1,500 m) *and Bereha* (< 500 m) (Ethiopian institute of Agricultural research (EIAR), 2011).

In addition to complex topography, the climate of the country is influenced by the seasonal migration a low-pressure zone namely *Intertropical Convergence Zone* (ITCZ), a region where the northeast and the southeast trade winds converge, following the overhead Sun (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 systems, livestock systems, etc. Apart from this, climate variability and extreme events like drought exacerbates the conditions in pastoral and agropastoral communities inhabiting in lowland regions.

Climate variability study gained careful attention and the most important parameters either temperature and/or rainfall were studied at national/sub-national scale to watershed level. A range of studies has been carried out in this aspect (Gebrehiwot and van der Veen 2013; Jury and Funk 2013; Mengistu et al. 2014; Fazzini et al. 2015; Wassie and Fekadu 2015; Biraraet al. 2018; Asfaw et al. 2018; Wedajo et al. 2019; Tesfamariam et al. 2019; Esayas et al. 2019; Gedefaw et al. 2019; Mekonnen and Berlie 2020; Berhane et al. 2020; Alemayehu et al. 2020; Belay et al. 2021; Bayable and Alemu 2021; Belay and Demissie et al. 2021). Some of these studies used satellite-based data sources which provides long-term data over a century but coarse resolution; while others studied large-scale spatial variability such as country level or beyond. On top of that, most of the papers were conducted in the highland areas of northwestern, northcentral, northeastern and western regions where the issue of temperature variability is not a main concern. The limitation with the usage of coarse resolution climate data and larger scale spatial analysis could be the difficulty of observing local level variability. This means the existing internal variability might not be captured by employing these data types. In the context of Ethiopia, the various agroecological zones respond differently to climate variability and hence, lowland areas with warm (hot) semi-arid (arid) type of climate are highly sensitive to climate variability than highland areas. Borana zone of southern Ethiopia is one of the regions frequently affected by climate variability and extremes where local scale variability study is lacking especially in this area. Therefore, it is ideal to emphasize on climate sensitive geographical regions.

This paper is intended to study the variability and timeseries trend analysis of maximum and minimum temperature in the semi-arid Borana zone over the period 1981-2018. The research is conducted based on the fact that, understanding the climate variability as local scale could help suggest local adaptation responses to manage climate driven impacts. It also helps local communities, actors and decision makers to take planned intervention measures so as to reduce climate associated risks. Apart from these, the study result add value to the existing literature especially in the Borana where study on spatiotemporal variability of climate is lacking at high spatial resolution.

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 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 $3^0$30' N to $5^0$25' N latitude and $36^0$40' E to $39^0$45' E longitude. Yabelo is the capital town of Borana zone and located at about 570 kilometers 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* / *'Bona'* the long dry period from December to February, *Belg* / *'Ganna'* the long rainy period from March to May, *Kiremt* / '*Adolessa'* the short dry spell from June to August and *Meher* / *'Hagayya'* 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 ^{0}C and 12.96 ^{0}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) 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.

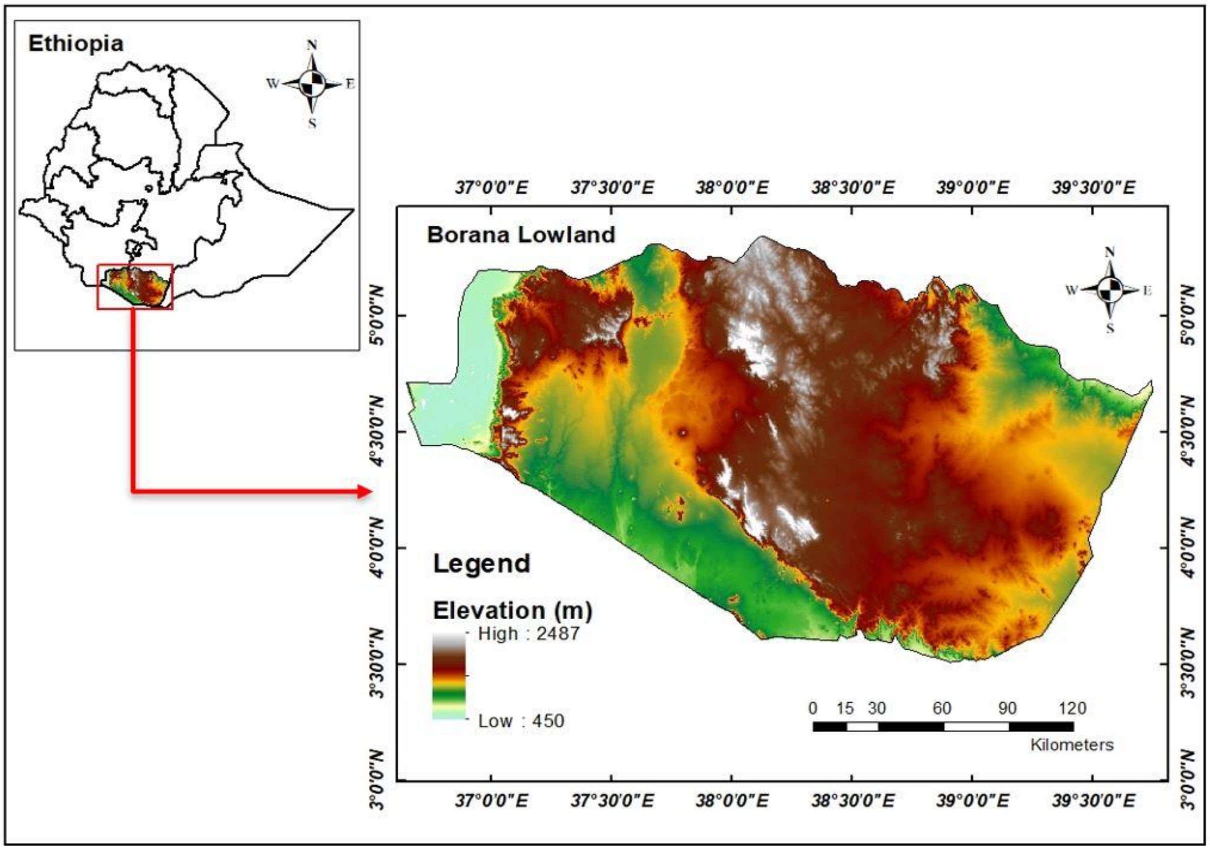


Figure 1: Location of the study area

Data types and sources

Gridded (4km * 4km spatial resolution) data for daily maximum and minimum temperature precipitation for all the points lying within the study area boundary for the period 1981 to 2018 were collected from National Meteorological Agency (NMA). Therefore, a total of 2,702 data points (Figure 2) were considered as inputs and the mean values were used to analyze the variability and trends of rainfall 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.

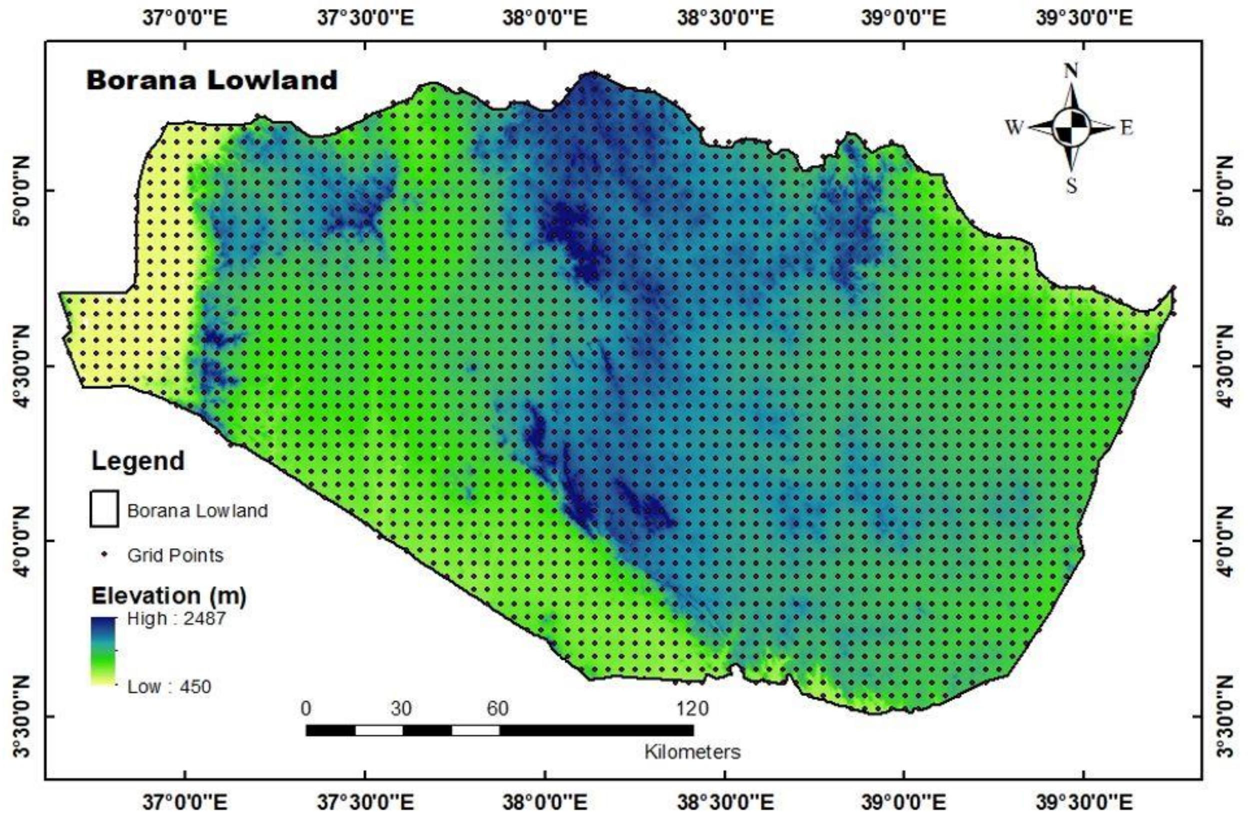


Figure 2: Data grid points in the Borana lowland

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 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 to remove the effect of significant autocorrelation in the timeseries through the 'pre-whitening' procedure (Von

Storch 1995). Based on this, for the data points (x_1, x_2, x_3, …, x_n), the 'pre-whitened' time series was obtained through (x_2 - rx_1, x_3 - rx_2, …, x_n - rx_{n-1}) procedure before applying Mann-Kendall trend test.

Mann-Kendall 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 1955). Non-parametric methods are more suitable to the detection of trend in hydrological data (Helsel et al. 2002). MK test is a rank-based test, used where autocorrelation is not significant and it can tolerate to outliers, distribution free and has higher power than the other test (Duhan and Pandey 2013). 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 1955) 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 j^{th} 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

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:

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

where Q is the slope and b constant. To obtain slope Q in Equation 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 Equation 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 α = 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 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 parameter. Hare (2003) computed coefficient of variation (CV) using the following formula:

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

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 temperature graphs in this study.

Analyzing spatial variation

The inverse distance weighted (IDW) interpolation technique in ArcGIS was employed to generate surface data for both maximum and minimum temperature from grid points at different temporal scales. To do this, time series temperature data from the grid points were analyzed by using ArcGIS 10.5 interface. Hence, spatial maps showing maximum and minimum temperature variability across the Borana lowland were produced at seasonal and annual timescales.

Results

Variability and trends of monthly maximum and minimum temperatures

The mean maximum and minimum temperatures for the last 38 years were computed for the Borana lowland. The results show that, February was the hottest month (32.06 ^{0}C) followed by January (31.49 ^{0}C) and March (31.03 ^{0}C) whereas the lowest mean maximum temperature was observed during the month of July (28.01 ^{0}C). For most of the months, the trend for mean maximum temperature shows an upward trend where it is statistically significant at 95% level of confidence *(P-value < 0.05)* only for August whereas it shows not statistically significant decreasing trend *(P-value > 0.05)* for April, May and October (Table 1 and Figure 3).

On the other hand, the highest mean minimum temperature was observed in February (16.92 ^{0}C) followed by March (16.69 ^{0}C) during the entire period. Apart from this, the lowest mean minimum temperature was recorded in July (15.77 ^{0}C) and August (15.93 ^{0}C). The MK and Sen's slope test results revealed that all months except April shows an increasing trend where it is statistically significant for January, February, August and October at 95% level of significance *(P-value < 0.05)*. In addition to this, the decreasing trend for the month of April is not statistically significant *(P-value> 0.05)* as observed in Table 1.

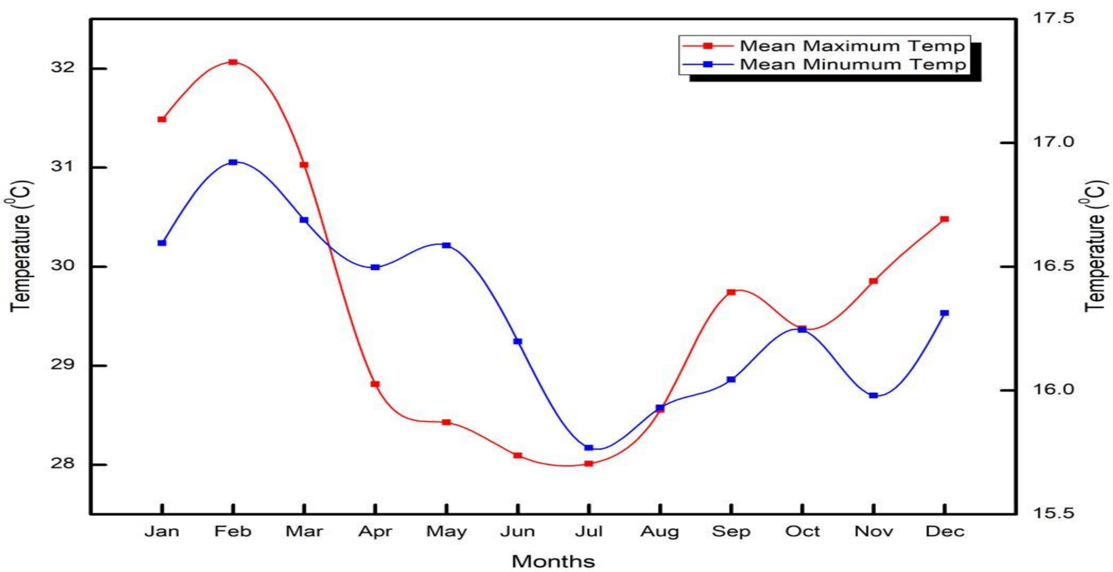


Figure 3: Summarized mean monthly maximum and minimum temperature (1981-2018)

Table 1: Descriptive statistics and tests applied for mean maximum temperature.

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	0.3393	0.012	16.60	0.42	2.55	2.34	0.0194	0.016
Feb	32.06	1.10	3.44	1.71	0.08731	0.03	16.92	0.46	2.70	2.26	0.024	0.015
Mar	31.03	1.50	4.83	0.15	0.8801	0.0038	16.69	0.67	4.04	0.45	0.65	0.0049
Apr	28.81	1.03	3.59	-1.86	0.06279	-0.028	16.50	0.49	2.95	-0.80	0.421	-0.007
May	28.43	0.85	2.99	-1.86	0.06279	-0.026	16.59	0.38	2.31	0.85	0.39	0.005
Jun	28.09	0.80	2.84	1.84	0.067	0.024	16.20	0.45	2.76	0.78	0.4357	0.0046
Jul	28.01	0.77	2.76	1.13	0.2579	0.011	15.77	0.47	3.00	0.11	0.1591	0.011
Aug	28.55	0.56	1.96	2.97	0.003	0.023	15.93	0.50	3.16	2.087	0.037	0.015
Sep	29.74	0.52	1.75	1.79	0.07	0.015	16.04	0.45	2.80	1.056	0.2909	0.006
Oct	29.38	0.82	2.78	-1.61	0.11	-0.023	16.24	0.33	2.04	2.5647	0.01033	0.013
Nov	29.85	0.96	3.23	0.18	0.86	0.0012	15.98	0.35	2.16	1.13	0.26	0.0065
Dec	30.48	0.99	3.25	0.98	0.33	0.014	16.31	0.34	2.08	1.11	0.27	0.006

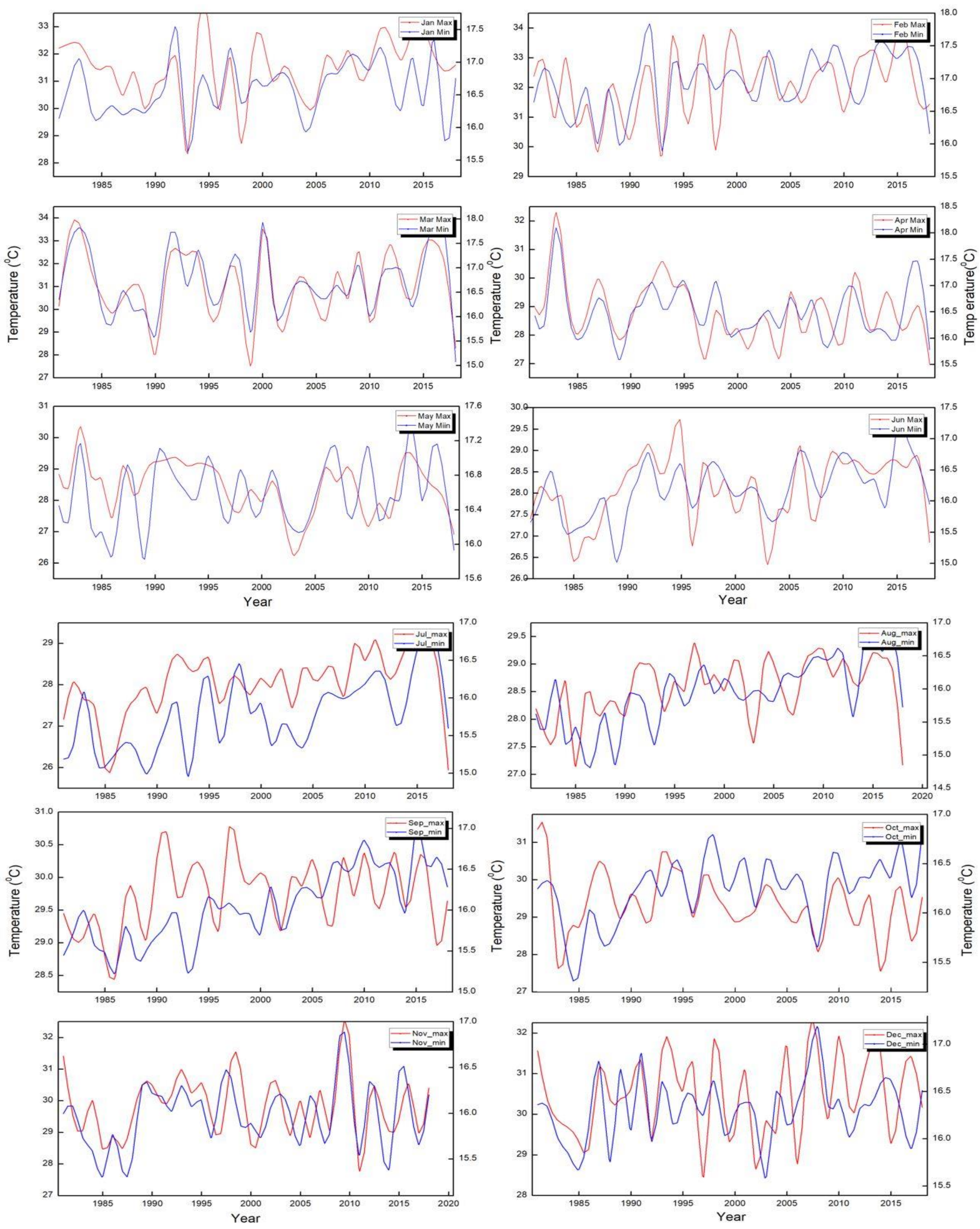


Figure 4: Mean monthly maximum and minimum temperatures for each month (1981-2018)

Variability and trends of seasonal maximum and minimum temperature

Bega (*DJF*) is the warmest season in Borana lowland with mean maximum temperature of 31.34 ^{0}C whereas *Kiremt* (*JJA*) is characterized by relatively lowest mean maximum temperature (28.22 ^{0}C). When it comes to seasonal mean minimum temperature, the relatively highest (16.61 ^{0}C) and lowest (15.97 ^{0}C) temperature were observed during *Bega* and *Kiremt* respectively as shown in Table 2 and Figure 5. Therefore, Bega and Kiremt seasons were known for their extreme temperatures in Borana lowland during the studied period. Temperature shows a decreasing trend for *Belg (MAM)* and *Meher (SON)* seasons while an increasing trend for *Bega* and *Kiremt*. But in all cases, the increase as well as decrease in seasonal mean maximum temperature was not statistically significant *(P-value > 0.05).* On the other hand, the prevailing seasonal mean minimum temperature shows an increasing trend during all seasons where only *Meher* season exhibited statistically significant increasing trend *(P-value < 0.05)* at 95% level of significance as indicated in Table 2.

Table 2: Descriptive statistics and test results for 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 (DJF)	31.34	0.88	2.82	1.68	0.09	0.019	16.61	0.33	2.01	1.73	0.083	0.009
Belg (MAM)	29.42	0.86	2.93	-1.11	0.2686	-0.013	16.59	0.41	2.47	0.08	0.94	0.0005
Kiremt (JJA)	28.22	0.64	2.25	1.18	0.07	0.013	15.97	0.45	2.79	1.18	0.2373	0.0078
Meher (SON)	29.66	0.57	1.91	-0.23	0.821	-0.002	16.09	0.45	1.82	2.67	0.0077	0.0104

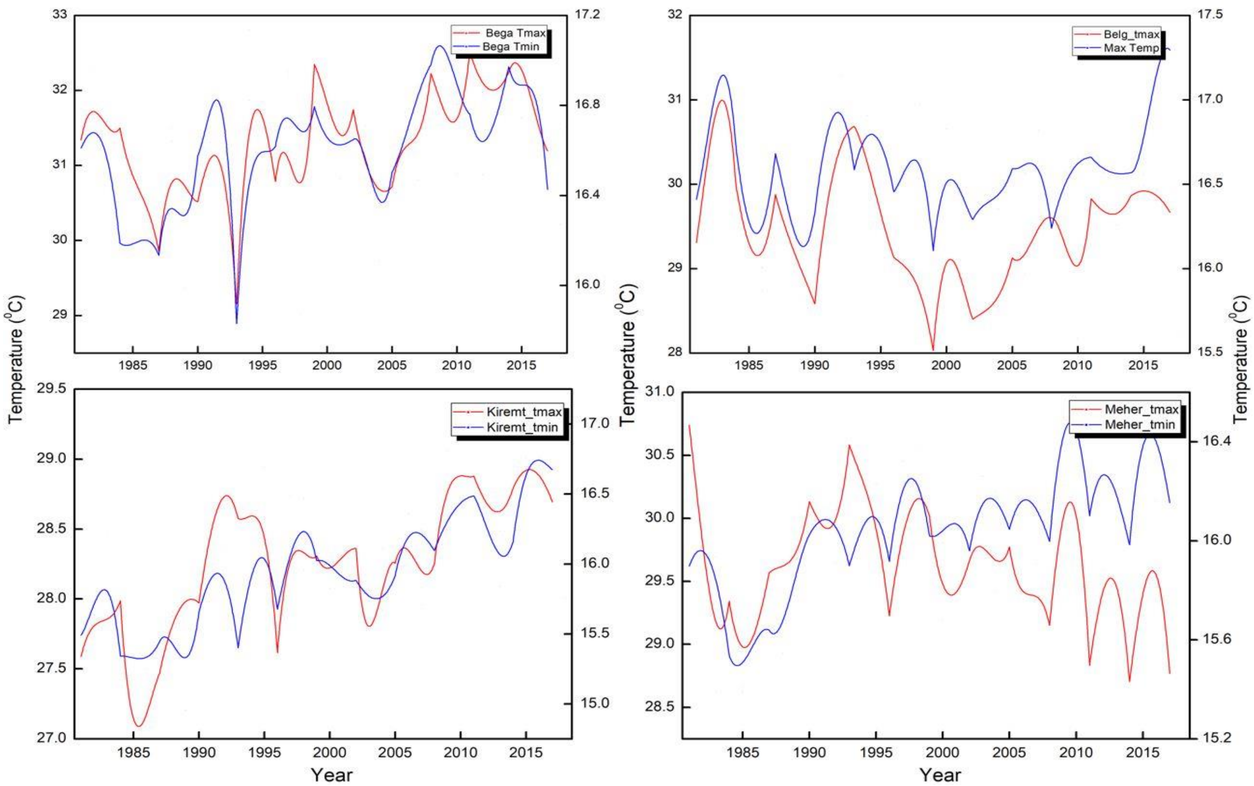
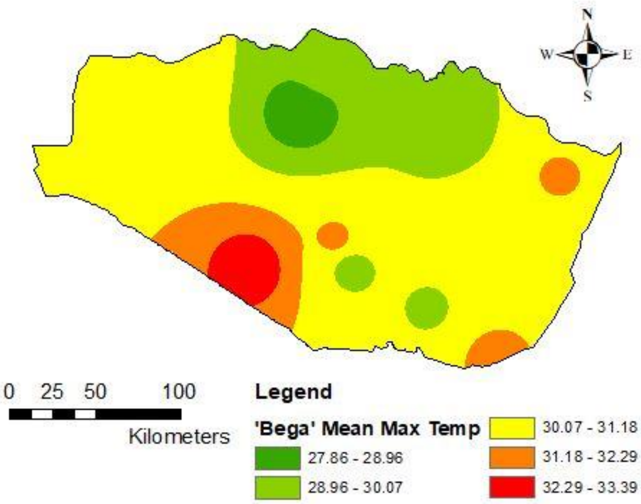


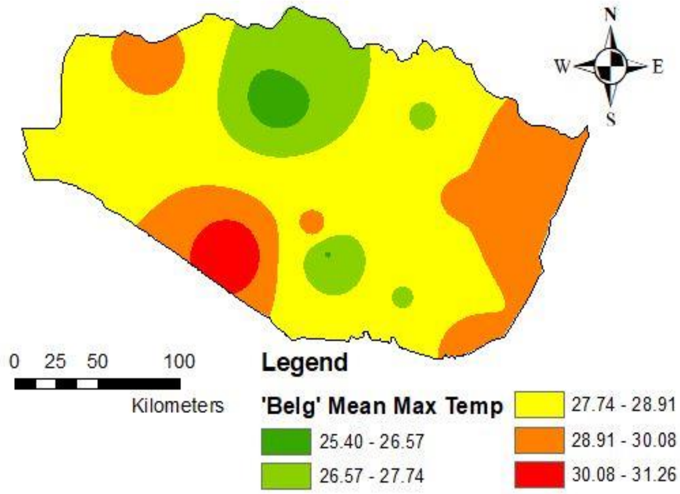
Figure 5: Graphical representation of seasonal Tmax and Tmin (1981-2018)

The spatial maps for mean maximum temperature in Figure 6 *(i-iv)* shows more or less similar distribution pattern during *Bega* and *Meher* seasons across the Borana lowland. The north central parts were cold spots whereas the southwestern parts were hotspots whereas other regions of the lowland were characterized by moderate temperature. During the other seasons, *Belg* and *Kiremt*, the spatial distribution of temperature shows some sort of similarity and during these seasons, the southeastern and western parts of the lowland were areas of mean maximum temperature. The maximum temperature observed in the lowland reach highest during *Bega* (32.29-33.39 ^{0}C) followed by *Meher* season (30.78-32.08 ^{0}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 *Kiremt* (24.51-25.51 ^{0}C) followed by *Belg* season (25.4-26.57 ^{0}C). Temperature is unevenly distributed across the lowland and the two consecutive seasons stretching from September to February as well as March to August showed similarity in the temperature characteristics in the study area.

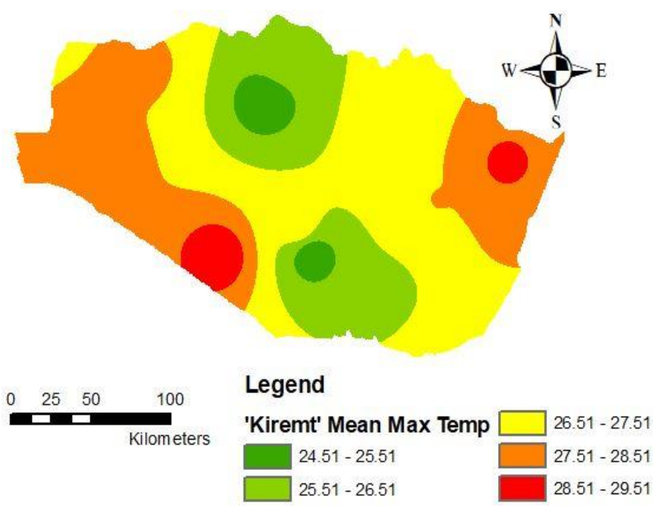
Figure 6 *(v-viii)* is about the spatial distribution of mean minimum temperature in Borana lowland. During *Bega, Belg* and *Kiremt* seasons, mean minimum temperature shows similar pattern in the region. In the north and north central parts of the lowland, the observed minimum temperature is relatively goes down all the year round. In addition, mean minimum is at its maximum during all the seasons in the southeastern pocket parts of the lowland where the average temperature ranges from 19.82-21.61 ^{0}C for *Bega* and 19.03-20.49 ^{0}C for *Belg* seasons. Lowest mean minimum temperatures (12.36-13.74 ^{0}C) and (12.48-13.64 ^{0}C) were observed in the northern parts of the lowland during *Meher* and *Kiremt* seasons respectively. Unlike the mean maximum temperature, the mean minimum temperature shows a similar pattern in Borana lowland and there is no as such significant variation among the seasons.



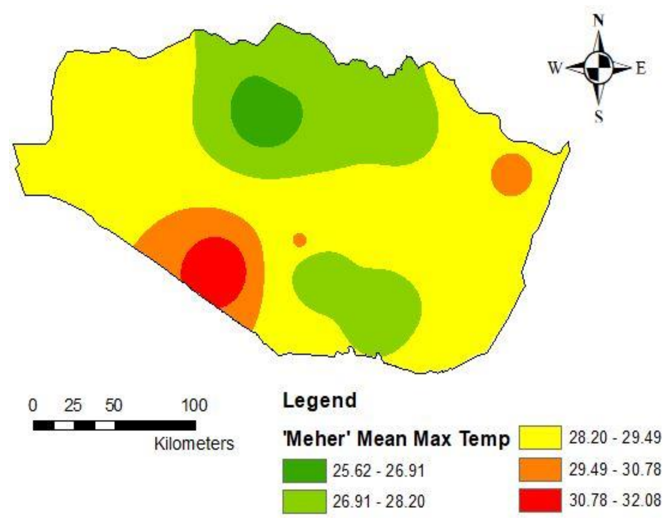
(i) 'Bega' season (DJF) mean maximum temp



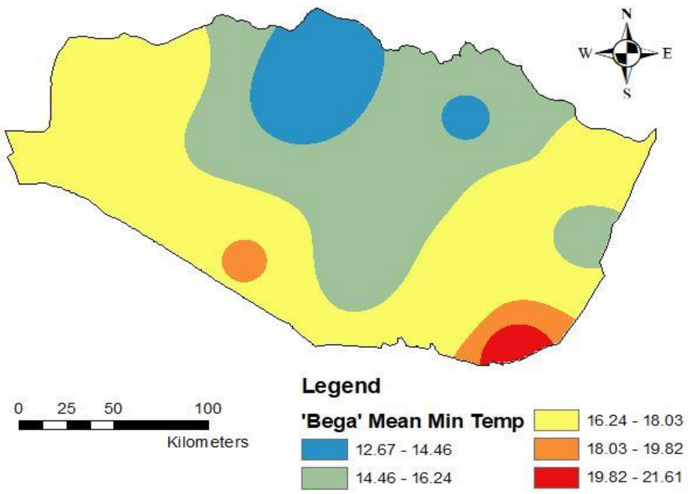
(ii) 'Belg' season (MAM) mean maximum temp



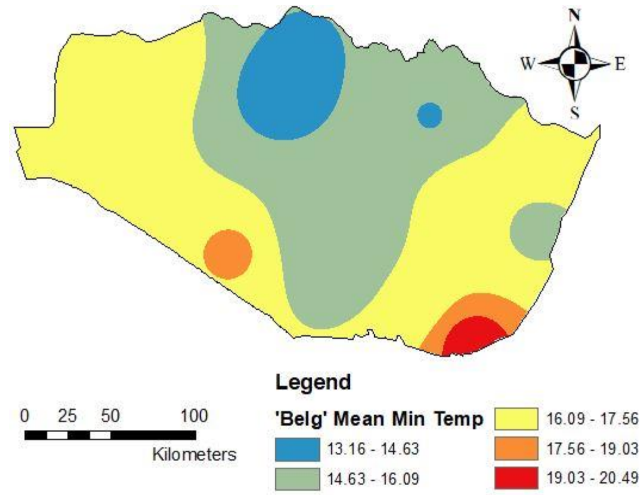
(iii) 'Kiremt' season (JJA) mean maximum temp



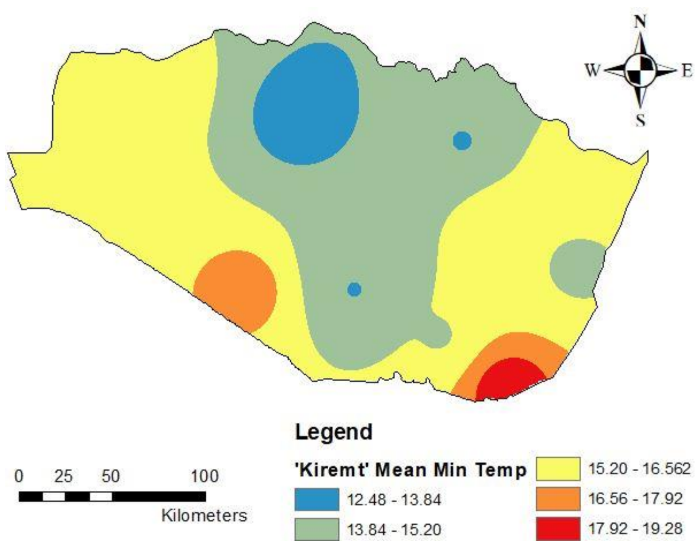
(iv) 'Meher' season (SON) mean maximum tem



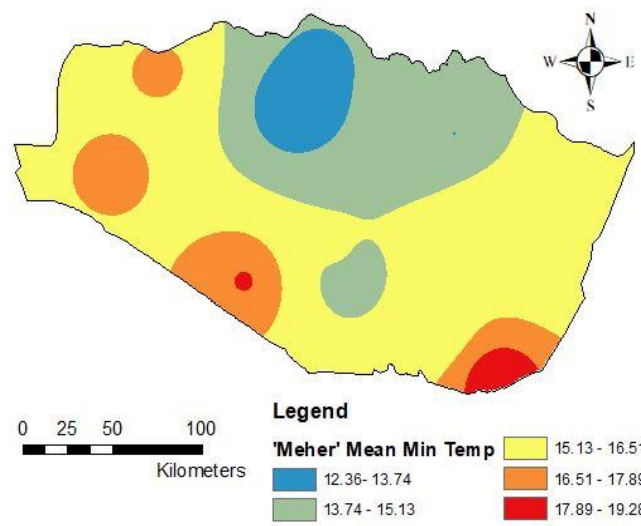
(v) 'Bega' season (DJF) mean minimum temp



(vi) 'Belg' season (MAM) mean minimum temp



(vii) 'Kiremt' season (JJA) mean minimum temp



(viii) 'Meher' season (SON) mean minimum temp

Figure 6: Spatial variation of maximum and minimum temperature across seasons (1981-2018)

Variability and trends of annual mean maximum and minimum temperature

The annual mean maximum temperature during the last 38 years was 29.66 ^{0}C, where the highest mean maximum was 30.49 ^{0}C (1994) and the lowest mean maximum was 28.68 ^{0}C (1985). On the other hand, the mean minimum temperature for the same period was 16.31 ^{0}C where the highest and lowest means observed were 16.93 ^{0}C (2016) and 15.73 ^{0}C (1985) respectively as shown in Table 3 and Figure 7. The range of temperature between the highest and lowest mean values over the studied periods were 1.81 ^{0}C for maximum and 1.2 ^{0}C for minimum temperature.

The test results also proved that, the trend of both annual mean maximum and minimum temperature shows an increasing trend but not statistically significant.

Table 3: 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	0.8406	0.001	16.31	0.29	1.74	0.83	0.4067	0.0042

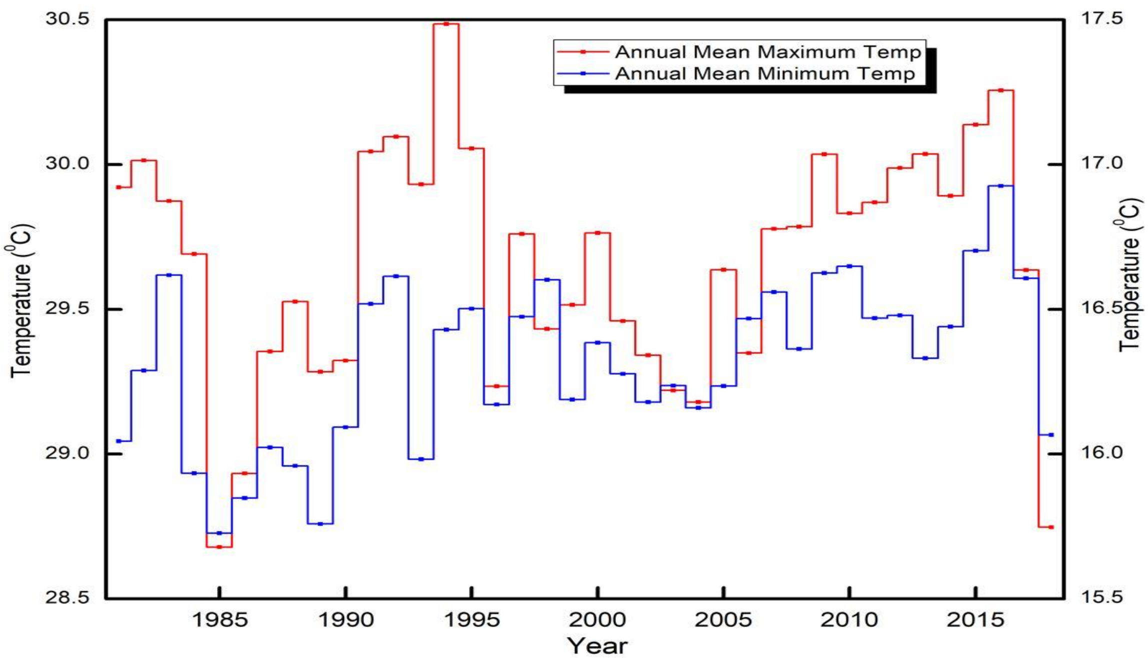
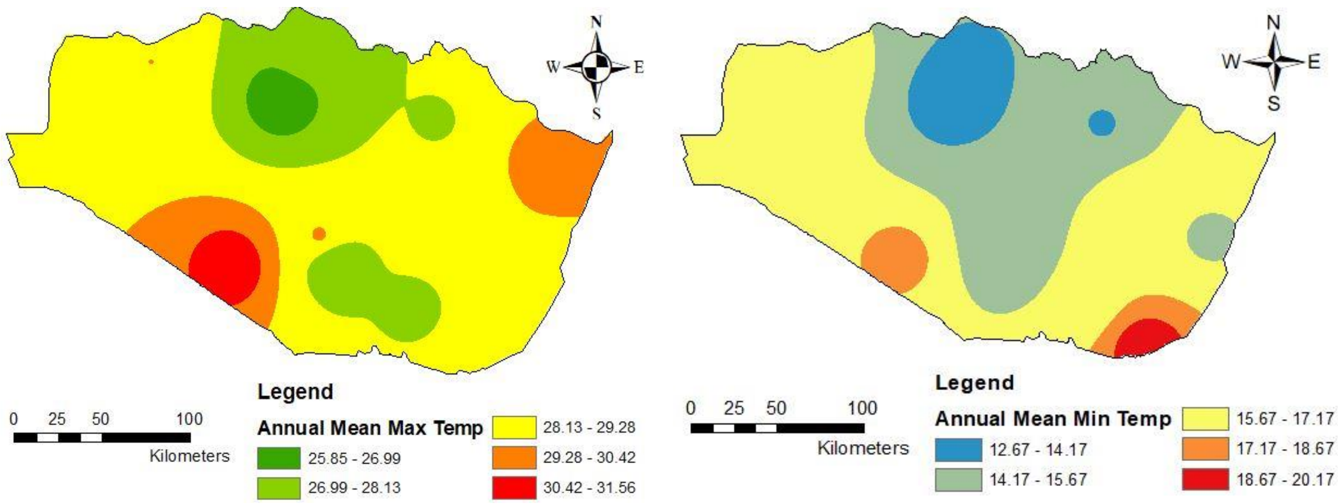


Figure 7: Trends of annual mean maximum and minimum temperature (1981-2018)

As shown in Figure 8 (a) the annual mean maximum temperature of Borana lowland ranges between 25.85 – 31.56 ^{0}C during the studied period. The northern and north central parts of the lowland were areas of lowest mean maximum temperature. The southwestern areas of the lowland on the Ethio-Kenyan border were known for highest mean maximum temperature which ranges between 29.28 ^{0}C and 31.56 ^{0}C. The remaining portions of the lowland were characterized by moderate mean maximum temperature. On the other hand, the annual mean minimum temperature shows similarity with the seasonal variation spatially. For this parameter, a smaller area in the southeastern part of the lowland shows the highest mean minimum temperature of 18.67 ^{0}C but below 20.17 ^{0}C for the entire studied period as observed from Figure 8(b). Most of the areas covering the eastern, central and western sections of the lowland show moderate mean minimum temperature that ranges between 14.17-17.17 ^{0}C. Overall, the hotspot areas for mean maximum and minimum temperature were observed in the southwestern and southeastern parts of the lowland respectively whereas relatively cooler conditions were observed for both maximum and minimum temperature in the north and northcentral areas of the study area.



(a) Annual mean maximum temperature *(b) Annual mean minimum temperature*

Figure 8: Spatial distribution of annual temperature (1981-2018)

Decadal variability in maximum and minimum temperature (1981-2018)

The results show that the mean maximum temperature at decadal scale was 29.46 ^{0}C (1981-1990), 29.83 ^{0}C (1991-2000), 29.56 ^{0}C (2001-2010) and 29.82 ^{0}C (2011-2018) and the overall average was 29.67 ^{0}C for the entire period. The first decade was slightly warmer and followed by the last decade than the rest in the study area. Concerning the mean minimum temperature at decadal scale, there was no significant variation and minimum temperature ranges between 16.03 ^{0}C (1981-1990) and 16.50 ^{0}C (2011-2018). The decadal average minimum and maximum temperature shows a significant warming trend during 2001-2010 time period; but for the later decade, 2011-2018 shows not significant warming trend only for minimum temperature. Therefore, the recent decade was a bit warmer than the preceding as graphically presented in Figure 9.

Table 4: Decadal maximum and minimum temperature (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	0.074	-0.08	16.03	0.26	1.65	-0.72	0.4743	-0.035
1991-2000	29.83	0.37	1.24	-1.43	0.15	-0.07	16.39	0.21	1.27	-0.54	0.5915	-0.007
2001-2010	29.56	0.29	0.99	2.33	0.02	0.072	16.38	0.19	1.14	2.33	0.02004	0.051
2011-2018	29.82	0.47	1.58	-0.124	0.90	-0.044	16.50	0.26	1.55	0.124	0.9015	0.016

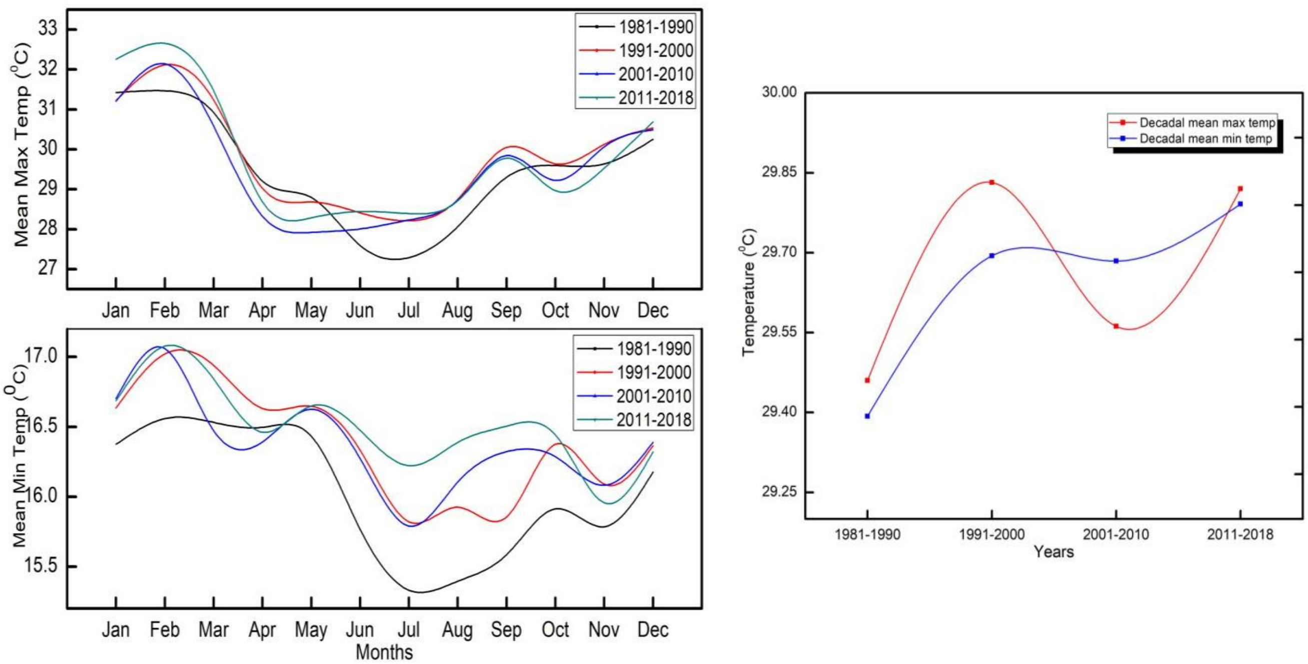


Figure 9: Decadal mean maximum and minimum temperatures (1981-2018)

Discussion

Both mean maximum and minimum temperature were studied at various temporal scales covering monthly, seasonal, annual and decadal timescales as well as spatially covering the entire semi-arid Borana zone in this paper. The highest average maximum temperature was observed in February while the lowest was in July. The mean monthly maximum temperature during the study period was 29.66 ^{0}C and it showed an increasing trend for most of the months where the increase was statistically significant only for August *(P-value = 0.003)*. April, May and October showed not significant decreasing trend during the studied period. The mean monthly minimum temperature in Borana was 16.31 ^{0}C, where the highest value was observed in February followed by March for the studied period. Apart from this, the lowest mean minimum temperature was recorded in July and August. The same months revealed the highest and the lowest values for both mean maximum and minimum temperature and these months were February and July. The range of temperature between the highest and lowest mean minimum temperature was estimated to 1.15 ^{0}C, which is by far smaller than the value for mean maximum temperature. The mean minimum temperature shows a significant increasing trend for January, February, August and September but in April, the trend was decreasing and also not statistically significant. From this it can be concluded that, the trend of both maximum and minimum temperature at monthly timescale is increasing in Borana lowland. The result obtained is consistent with the works of Tesfamariam et al. (2019) who 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, maximum temperature exhibited non-significant increasing trend while a significant increasing trend for minimum temperature was obtained for all months in the northern central Ethiopia (Asfaw et al. 2018).

Seasonally, *Bega* exhibited the highest mean value for both maximum and minimum temperature while the lowest was observed during *Kiremt*. Although the variability among seasons was not as such significant in Borana lowland, slight variation was observed in mean maximum than the minimum temperature. When it comes trend, Bega and *Kiremt* seasons show a non-significant increasing trend for maximum as well as minimum temperature. *Belg* and *Meher* seasons showed non-significant decreasing trend for maximum but increasing trend for minimum temperature and the increase was significant only for *Meher* season. Therefore, mean minimum temperature showed a warming trend during all the seasons where it was statistically significant for *Kiremt* and *Meher*. Therefore, there found to be inter-annual variability of temperature in the Borana lowland. 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 lowland which is characterized by warm and semi-arid climate.

The annual mean maximum temperature in Borana lowland for the period 1981-2018 was 29.66 ^{0}C (28.68-30.49 ^{0}C). Concerning the minimum temperature, for the same period, the observed annual mean was 16.31 ^{0}C (15.73-16.93 ^{0}C). Both annual maximum and minimum temperatures show a not significant increasing trend in Borana lowland. Asfaw et al. (2018) observed non-significant increase in the trend of maximum temperature but significant increase in minimum temperature. Positive trends were observed in the annual maximum temperature in lowlands and highlands of southern Ethiopia and there was observed significant positive trend of annual minimum temperature, consistent in all agroecological zones (Esayas et al. 2019). Upward trends of mean temperature have 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.

The decadal mean maximum and minimum temperatures in Borana lowland were 29.67 ^{0}C (29.46 - 29.83 ^{0}C) and 16.33 ^{0}C (16.03 - 16.50 ^{0}C) respectively. The temperature variability between relatively warmest decades was calculated to 0.37 ^{0}C for mean maximum while it was 0.47 ^{0}C for mean minimum. The 1990s decade was warmest for maximum temperature and for minimum temperature, the recent decade (2011-2018) was the warmest. 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 minimum and maximum temperature shows a significant warming trend during 2001-2010 time period; but the period from 2011-2018 shows not significant warming trend only for minimum temperature. Therefore, the later periods are warmer than the previous time periods. In general, temperature shows a slight variation at shorter timescales (months and seasons) than longer timescales (annual and decadal) and the later period show warmer condition than the previous in Borana lowland. Mekonnen and Berlie (2020) also observed the increasing trend of decadal minimum (0.098 ^{0}C), maximum (0.041 ^{0}C) and average (0.069 ^{0}C) temperatures in the northeastern highlands. Asfaw et al. (2018) found the change of temperature to be 0.046, 0.067 and 0.026 ^{0}C per decade for mean, minimum and maximum respectively during the period of 1901-2014 in the north central Ethiopia.

The spatial distribution of temperature during the various seasons shows similarity across the lowland for mean minimum temperature than maximum temperature. In the case of maximum temperature, *Meher* and *Bega* seasons for months September through February shows less variability as well as *Belg* and *Kiremt* (March to August) shows uniformity across the lowland. From this it can be concluded that, temperature is not uniformly distributed across the Borana lowland. The mean distribution of mean maximum and minimum temperature shows that, warmer conditions were observed over the southwestern and the southeastern areas of the lowland respectively. In addition, relatively cooler conditions were observed for both maximum and minimum temperature in the north and northcentral areas of the study area whereas moderate temperature was observed in so many areas including eastern central and western parts of the Borana lowland.

Conclusion

This study presented the variability and time series trend analysis of observed maximum and minimum temperature for the time period extending from 1981-2018 in semi-arid Borana zone of southern Ethiopia. The observed monthly mean maximum and minimum temperature in the study area were 29.66 ^{0}C and 16.31 ^{0}C respectively. February and July were the warmest and coldest months respectively for maximum as well as minimum temperature. Most of the months have shown an increasing trend for both maximum and minimum temperature. *Bega* season was the warmest for both maximum and minimum temperature. All seasons have shown a non-significant increasing trend for minimum temperature than maximum temperature whereas *Meher* season shows a significant increasing trend for minimum temperature. The year 1994 and 2016 the warmest years for the respective mean maximum and minimum temperatures. The annual timescale has shown a not increasing trend for both maximum and minimum temperature in the study area. Temperature is less variable at decadal scale where the decade (2001-2010) has shown a significant warming trend for both maximum and minimum temperatures. Prior to that temperature showed a non-significant decreasing trend. It can be concluded that, temperature is highly variable at shorter timescales (monthly and seasonally) than at longer timescales (annual and decadal) in the study area. The minimum temperature pronounced more warming trend than maximum temperature. Temperature also varies across the semi-arid Borana where temperature have shown an increment from northcentral parts to the southwestern for maximum temperature and southeastern for minimum temperature. This spatial variability is attributed to the nature of topography in the study area which could modify the local climate. Therefore, any intervention measure such as adaptation planning in response to local climate variability should take in to account the temporal and spatial variability at microscale.

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; ^{0}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.

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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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