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ORIGINAL ARTICLE

Spatiotemporal variability and trends of rainfall and temperature in the Northeastern Highlands of Ethiopia

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Abstract
The aim of the study was to examine the spatiotemporal variability and trends of rainfall and temperature in the northeast highlands of Ethiopia. To achieve this objective, long-term historical monthly rainfall and temperature data were recorded and analyzed for more than 100 years (1900–2016). Gridded rainfall and temperature data were gathered from CenTrends Great Horn of Africa v1 and CRU_TS 4.01 with a resolution of 0.1°×0.1° and 0.50×0.5°, respectively. The Mann–Kendall test was used to analyze the trends of rainfall data in different recording stations, and the Sen's slope estimator was used to determine the magnitude of change. The Inverse Distance Weighted spatial analysis tool was used to illustrate the spatial trends of rainfall and temperature. The results of the coefficient of variation revealed that the decadal, annual and seasonal rainfall distributions were varied though belg rainfall found to be more variable than the others. The MK test result demonstrated that belg and annual rainfall exhibit a decreasing trend as compared to kiremt rainfall. The distribution of kiremt, belg and annual rainfall demonstrated decreasing trends at a rate of 0.432, 0.335 and 0.595 mm/year, respectively. The decadal rainfall also showed a decreasing trend at the rate of 6.537 mm/decade. On the other hand, the averages of annual, maximum and minimum temperature were increased at the rate of 0.0034, 0.0028 and 0.0095 °C/year, respectively. The decadal minimum, maximum and average temperature has shown increasing trend at the rate of 0.098 °C, 0.041 °C and 0.069 °C, respectively. An abrupt declined rainfall and increased temperature were observed since the 1970s. Climate variability strongly affects rain-fed agriculture more than any other activities. Hence, policymakers and stakeholders have to give top priority in the designing and introduction of appropriate area-specific adaptive strategies to reduce the impacts on crop production over livelihood zones. Rainwater harvesting and the development of small-scale irrigation schemes could be taken as viable options where rainfall is scarce and more variable.

Keywords Livelihood zones · Spatiotemporal · CenTrends · Belg · Kiremt · South Wollo · Ethiopia

Background

In the present time, the aggravation of climatic change by global warming is a major concern to climate scientists and academicians across the world in recent years (Shahid 2009; Mearns et al. 1996; Zhang et al. 2009). Specifically, changes in temperature and rainfall patterns are more likely to become hotter and drier are widely observed in many areas of the world (Shahid 2009; Gebrehiwot and Veen 2013; Longobardi and Villani 2010). Such problems are severe in Africa where the rise of average temperature is faster than the global average. Rainfall is also unpredictable and more likely to continue in the future (Valli et al. 2013). Kinyangi et al. (2009) for example stated that Africa is distinguished as the most vulnerable to the adverse impacts of climate change and variability. In support of this idea, Kydd et al. (2004) explain that inconsistent rainfall patterns decrease the climate-sensitive like agriculture (farm yields), and also reduce national food availability and enhance rural poverty.

The Horn of Africa where Ethiopia is located is one of the most vulnerable regions to climate variability because of the dominance of rain-fed agriculture for food production (Blein et al. 2013; Easterling et al. 2007; Molua 2002). Kinyangi et al. (2009) also noted that the impacts of increased temperature and variable rainfall are expected to reduce agricultural

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production and lower crop yields in the Horn of Africa. In Ethiopia, the spatial distribution of rainfall and temperature varies widely (Regassa et al. 2010). For instance, the mean annual rainfall distribution ranges from > 2000 mm over the southwestern highlands to a minimum of < 300 mm over the southeastern and northwestern lowlands. The mean annual temperature also varies widely from < 15 °C over the highlands and above 25 °C in the lowlands (Kew et al. 2017; Regassa et al. 2010).

There are four seasons in Ethiopia locally known as K*iremt* (summer), *Meher* (autumn), *Bega* (winter)*, and Tseday* (spring). The big rainy season (k*iremt*/summer) extends from June to August. The harvesting season (*Meher*/autumn) extends from September to November. The dry season (B*ega*/winter) usually extends from December to February. The small rainy season (*Tseday*/spring) extends from March to May (Segele and Lamb 2005; Kew et al. 2017; Gissila et al. 2004; Riddle and Cook 2008; Regassa et al. 2010). However, rainfall distributions over Ethiopia are strongly inconsistent among different seasons (Kew et al. 2017; Riddle and Cook 2008; NMSA 1996; Beltrando and Camberlin 1993; Fekadu 2015). The overall agricultural activities in Ethiopia are affected by the amount and duration of the two rainy seasons of *belg* and *kiremt* (Rosell and Holmer 2007; Degefu 1987; Gissila et al. 2004; Korecha and Barnston 2007; Diro et al. 2008; NMSA 2005, 2009).

According to Degefu (1987), rain-fed agricultural activities are connected with the behavior of rainfall in *belg* and *kiremt* seasons. Crops fail mainly because the rain starts late and ceases early (World Bank 2007). In the same way, the north and eastern parts of Ethiopia experience a similar problem as a result of the insufficient amount of rainfall received. This could result in the loss of crop and livestock production ultimately exposes farm households for chronic food insecurity (Dinku 2011; EPCC 2015; Asfaw et al. 2015). Unpredictable rainfall and temperature events contribute much to the failure of crop production in many areas of the country (Regassa et al. 2010; Ndaruzaniye 2011). Smallholder farmers, in particular, are found to be the most vulnerable to climate variability resulting in crop failure and death of livestock (Aberra 2011; FDRE 2007; UNDP et al. 2010).

The north-central highland of Ethiopia where the present study is specifically located could be taken as the epicenter of climate variability. As high as 80% of the variability in agricultural production is caused by the disturbance of weather and related factors (Sumelius et al. 2009). The World Bank (2006) indicates that unpredictable rainfall costs 38% of the potential growth rate and increases poverty by 25%. Though the historical and recent literature shows a list of recorded crises in Ethiopia, the study area, south Wollo zone experiences the worst crises (Webb and Von Braun 1990). This could be the reason that the World Bank (2004) had classified this zone as one of the areas with high risk to climate variability. This pressing problem motivated the investigators to undertake this study.

Rainfall and temperature variability and trends were documented by many scholars in Ethiopia (Asfaw et al. 2018; Wagesho et al. 2013; Seleshi and Camberlin 2006; Gebrehiwot and Veen 2013; Conway 2000a, b). They conclude that the amount and duration of annual and seasonal rainfall show decreasing trends while temperature demonstrates an increasing trend. Viste et al. (2013) and Meze-Hausken (2004), on the other hand, are not able to document a general decreasing trend of rainfall in Ethiopia. A non-significant trend in annual and seasonal rainfall amounts over Ethiopia was also reported by Suryabhagavan (2016) and McSweeney et al. (2008). Others such as Teyso and Anjulo (2016), Bewket and Conway (2007) and Rosell and Holmer (2007) indicate that the annual and seasonal rainfall show great space–time variations. The variability might have originated from differences in spatial extent, study periods and geographic location. This study also believed that these differences might originate from the mountainous nature of the country that needs to investigate at local and/or micro-levels. In this regard, reports and scientific works such as IPCC (2001), Easterling et al. (2007), Bewket and Conway (2007), Kebede and Bewket (2009) and Gissila et al. (2004) evidently pointed that local scale spatiotemporal rainfall and temperature variability and trends in many parts of Ethiopia remain unknown and need scientific investigation at the local level for water management, food security analysis, and disaster risk management. The analysis of spatiotemporal variability of rainfall and temperature based on the livelihood zones is more appropriate. This is because livelihood zone-based climate variability and trends provide a geographical orientation of the livelihood system for food security analysis. Grillo (2009) supplements that administrative divisions such as districts, while important for political and governance purposes, are not useful for livelihood and food security analysis. The livelihood zone approach determines who might be vulnerable to the variations of rainfall and temperature. Hence, this study is appropriate and timely to investigate the spatiotemporal variability and trends of rainfall and temperature based on the livelihood zones and add knowledge to the existing literature. The general objective of the study was to examine spatiotemporal variability of rainfall and temperature in the northeastern highlands of Ethiopia using standard rainfall and temperature statistical descriptors.

Materials and methods

Description of the study area

South Wollo zone is one of the eleven administrative zones of the Amhara National Regional State. The zone is located in between 10°10′N and 11°41′N and 38°28′E and 40°5′E (Fig. 1). Of the total area, 36.3%, 13.5%, 18.3%, and 31.9% are covered by arable land, forest and bush, grazing land and others, respectively (SWAD 2018; ANRSPC 2017). The landscape of the zone experiences diversified and dissected topography. Arabat (927 m asl) is the lowest altitude located in the east, while the highest altitude, Mount Degat (4261 m asl), is situated in the west (SWAD 2018; Little et al. 2006). The zone is composed of six livelihood zones, namely Abay-Beshilo Basin (ABB), South Wollo and eastern lowland sorghum and cattle zone (SWS), Chefa Valley zone (CHV), *Meher-Belg*, *Belg*, and *Meher* which are the six major livelihood zones of the study area. The study area is dominated by two distinct rainfall regimes: *Kiremt* (big rainy season) and *Belg (*small rainy season) (NMSA 1996; Conway 2000a, b). The agricultural activities of the zone follow these rainfall regimes; however, there are variations among livelihood zones. Accordingly, the livelihood zones of ABB and SWS experiences *belg* and CHV are dependent on the *kiremt* rainfall season for the cultivation of crop production (USAID 2009). The agricultural activities are entirely rainfed. However, small-scale irrigation and water harvesting are practiced in some pocket areas by a small number of farmers (Kahsay 2013; SWAD 2018). The selected gauge stations and the livelihood zones of the study are described in Fig. 1 and Table 1.

Research design and data collection techniques

The study employed a longitudinal research design to detect changes in rainfall and temperature events and to quantify the trends lasting many years from repeated observations. A complete and accurate set of gridded monthly rainfall data were obtained from CenTrends Greater Horn of Africa precipitation with 0.1°×0.1° resolutions. The temperature data, on the other hand, were gathered from the Climate Research Unit (CRU) TS with 0.5°×0.5° resolution. Both the CenTrends and CRU data were obtained from KNMI climate explorer (https://climexp.knmi.nl/start.cgi). Long-term historical monthly meteorological recorded data for the

Fig. 1 Geographic location of livelihood zones of South Wollo and Metrological stations Source: USAID (2009)

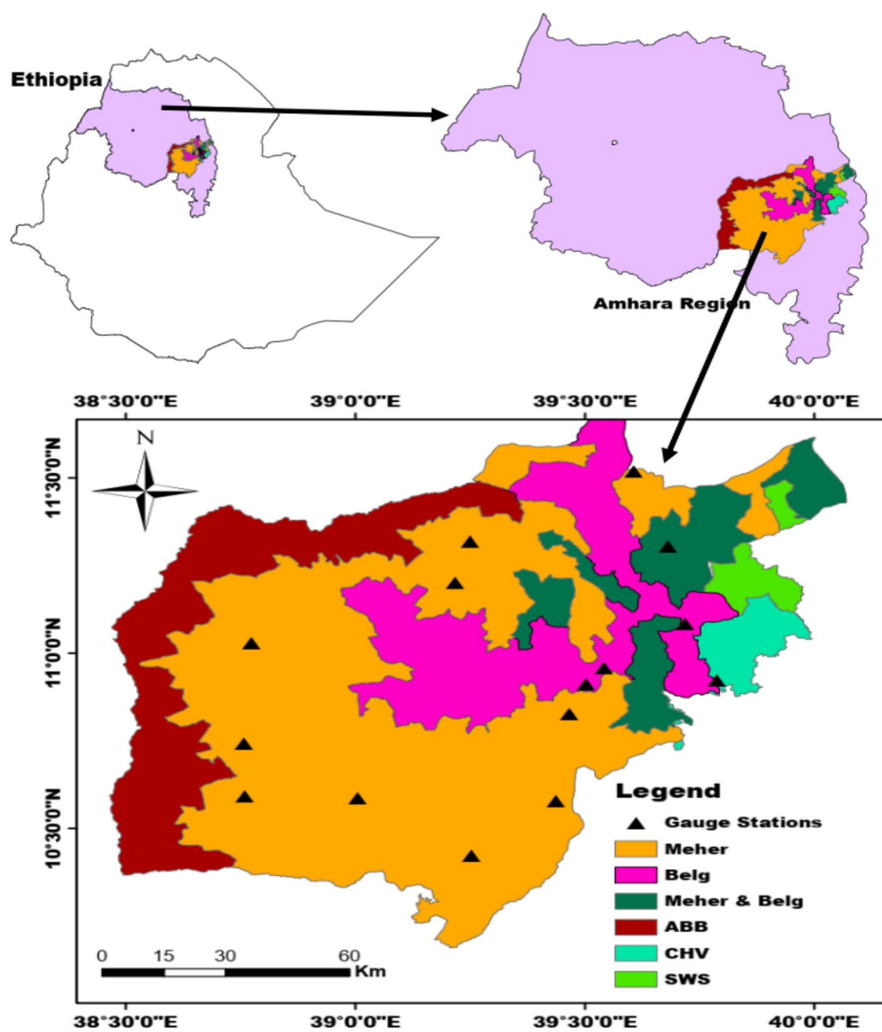

Table 1 The latitude, longitude, altitude and the periods of the meteorological stations

Stations	Latitude	Longitude	Altitude (m)	Period
South Wollo[a]	10°10′ N–11°41′ N	38°28′ E–40°5′ E	927–4261	1900–2016
Ambamariam	11.20° N	39.22° E	2990	1988–2017
Kombolcha	11.09° N	39.72° E	1857	1953–2017
Guguftu	10.91° N	39.50° E	3829	1987–2013
Haik	11.31° N	39.68° E	1985	1968–2017
Harbu	10.92° N	39.79° E	1507	1972–2017
Jamma	10.42° N	39.25° E	2601	1978–2017
Kabie	10.83° N	39.47° E	2810	1981–2015
Kelela	10.58°N	39.0° E	2580	1981–2008
M/selam	10.74° N	38.76° E	2607	1982–2011
Saynt	11.03° N	38.77° E	2844	1995–2017
Tebasit	10.96° N	39.54° E	3302	1984–2017
Tenta	10.32° N	39.25° E	2910	1978–2010
Wogidi	10.59° N	38.76° E	2405	1995–2015
Wereilu	10.58° N	39.43° E	2708	1963–2012
Wuchalle	11.52° N	39.61° E	1948	1962–2011

[a]Gridded data of rainfall and temperature have been taken from CenTrends v1and CRU_TS Version 4.01, respectively

period 1953–2017 were also documented for 15-gauge stations from the Ethiopian National Meteorological Agency, ENMA–East Amhara Meteorological Service Center (Kombolcha) (Fig. 1). Gauge stations data with better quality, the longer time recorded and spatially distributed were documented for the study.

Data analysis techniques

Different indices and tests were employed to analyze the spatiotemporal variability and trends of rainfall and temperature as shown in the succeeding discussions. Coefficient of variation (CV) and the Precipitation Concentration Index (PCI) were computed to analyse temporal variability of rainfall as shown below:

i. *Coefficient of Variation* was used to show temporal variability of rainfall.

$$\mathrm{CV} = \frac{\sigma}{X} \times 100, \tag{1}$$

where *CV* is the coefficient of variation, σ is the standard deviation and $\bar{x}$ is the mean. Accordingly, the result of the coefficient of variation less than 20 (less variable) in between 20 and 30% (moderately variable) and greater than 30% exhibits high variability of rainfall (Chakraborty et al. 2013).

ii. *Precipitation Concentration Index (PCI)* was employed to show the concentration of annual and seasonal rainfall.

$$\mathrm{PCI}_{\mathrm{Annual}} = \frac{\sum_{i=1}^{12} \mathrm{pi}^2}{\left(\sum_{i=1pi}^{12}\right)^2} \times 100, \tag{2}$$

$$\mathrm{PCI}_{\mathrm{Seasnal}} = \frac{\sum_{i=1}^{12} \mathrm{pi}^2}{\left(\sum_{i=1\mathrm{pi}}^{4}\right)^2} \times 33.3, \tag{3}$$

where *pi* is the monthly rainfall in *i*th month.

For this study, the annual and seasonal concentration of rainfall was calculated using PCI. Scholars (Oliver 1980; De Luis et al. 2011; Valli et al. 2013; Al-Shamarti 2016; Michiels et al. 1992) classified precipitation concentration index as uniform concentration (PCI < 10), moderate rainfall concentration (11–15), irregular concentration (16–20) and very high concentration (PCI > 20).

iii. *Mann–Kendall (MK) test and Sen's slope estimator*: The non-parametric Mann–Kendall (MK) test and Sen's Slope estimator were applied for trends and magnitude of rainfall and temperature. The non-parametric MK trend test was computed to analysis the annual and seasonal based (*belg* and *kiremt*) rainfall and temperature. The MK test is widely applied to the most effective method in favor of statistically significant trend test detection in different climatological and hydrological time series applications (Feng et al. 2016; Paulin and Xiaogang 2005; Al-Houri 2014; Ahmed et al. 2014). Moreover, the choice of MK test over others including the methods is less sensitive to outliers or robust against the influence of extremes (Kendall 1975; Mann 1945; Poudel and Shaw 2016); can test trends in a time series without requiring normality or linearity which is distribution-free test (Wang et al. 2008). Hence, it is highly recommended for general use by the World Meteorological Organization (Mitchell et al. 1966). MK test is used to ascertain the existence of a statistically significant or non-significant trend in rainfall and temperature variability (Jain and Kumar 2012). A positive value indicates an increasing trend and a negative value indicates a decreasing trend over time (Suryabhagavan 2016. The MK statistic S, the variance and the interrelated standard normal test statistic Z were calculated as:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \operatorname{sgn}(Xj - Xi), \tag{4}$$

where N is the number of data points, and X_i and X_j are the time series observations.

Assuming $(x_j - x_i) = \theta$, the value of sgn (θ) is computed from

$$Sgn(\theta) = \begin{cases} +1 \ldots \theta > 0 \\ 0 \ldots \theta = 0 \\ -1 \ldots \theta < 0 \end{cases}. \tag{5}$$

Under the hypothesis of independent and randomly distributed variables, for large samples ($n \geq 10$), the σ statistic is approximately normally distributed, with zero mean and variance as

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18}. \tag{6}$$

As a consequence, the standardized normal deviate (Z-statistics) distribution will be then calculated as

$$Z = \begin{cases} \frac{S-1}{\sigma} \text{ if } S > 0 \\ 0 \quad \text{if } S = 0 \\ \frac{S+1}{\sigma} \quad \text{if } S < 0 \end{cases}. \tag{7}$$

As indicated, the positive Z value signifies increasing trends and negative Z value signifies decreasing trends. Similarly, to evaluate the relative strength of the MK trend test in time series data, trend magnitude has been quantified using the non-parametric procedures of Sen's (1968) slope estimator. As noted by Jain and Kumar (2012), Sen's slope estimator is commonly used for determining the trend magnitude in hydro-meteorological time series. It is a robust estimator due to its relative non-sensitivity to extreme values (Chattopadhyay and Edwards 2016). To derive an estimate of the slope b_i, the slopes of all data pairs are computed based on Chakraborty et al. (2013) as shown below:

$$b_i = \frac{Xj - Xi}{j - i}, i = 1, 2, 3 \ldots, N, j > i, \tag{8}$$

where xj and xi are data values at times j and i. The Sen's estimator of the slope is the median N values of bi

$$b = \begin{cases} b_{\frac{(N+1)}{2}} \quad \text{if } N \text{ is odd} \\ 0.5[b_{\frac{N}{2}} + b_{\frac{(N+2)}{2}}] \quad \text{if } N \text{ is even} \end{cases}. \tag{9}$$

A positive value of b indicates an increasing value with time while a negative value of b indicates a decreasing value with time.

iv. *Inverse distance weighted (IDW)*: It is a spatial analysis tool used to illustrate the spatial trends of observed rainfall and temperature data. The IDW is a measure between neighbored stations for time series. It is more robust, especially close to mountainous terrain where complex rain–orography interactions are considered (Ahrens 2005; Suhaila et al. 2008). The annual and seasonal (*kiremt* and *belg*) spatial rainfall and temperature distribution were mapped using IDW interpolation. The XLSTAT 2014 software and excel spreadsheet for detecting and estimating variability and trends (time series) of annual and seasonal rainfall and temperature values were employed. Sen's method for the magnitude of the trend was also employed. Geographic Information Systems (GIS version 10.3) was used for spatial trend analysis of rainfall and temperature data.

Results and discussion

Temporal variability and trends of rainfall and temperature

Temporal variability of rainfall

As shown in Table 2, the long-term mean annual rainfall of the study area was 1000.9 mm with a standard deviation of 87.2 and a coefficient of variation of 8.7%. The decadal mean rainfall was 998.48 mm with a standard deviation of 32.77 and a coefficient of variation of 3.28%. The lowest (674.1 mm) and the highest (1251.9 mm) mean annual rainfall was recorded in 1984 and 1916, respectively. *Kiremt* had contributed about 68.4% of the total annual rainfall, while *belg* contributed 23% of the annual total rainfall. A similar study was reported by Asfaw et al. (2018) in the Woleka sub-basin of south Wollo indicates that *kiremt* and

Table 2 Monthly, seasonal and decadal statistical and MK test trend analysis of rainfall (1900–2014)

Month	Min	Max	Mean	%	Std. D.	CV (%)	MK test	Sen's slope
January	2.39	88.48	18.05	1.8	13.37	74.11	−0.0304	−0.013
February	0.79	97.81	24.46	2.44	17.6	71.97	**−0.1808****	−0.118
March	16.74	171.09	63.53	6.35	26.71	42.05	−0.0529	−0.046
April	19.69	175.16	82.16	8.21	27.8	33.84	−0.078	−0.091
May	1.95	155.67	60.31	6.03	31.84	52.8	**−0.1243****	−0.185
June	5.54	130.11	51.72	5.17	23.87	46.16	−0.0715	−0.08
July	101.52	391.87	264.78	26.48	44.77	16.91	−0.0047	−0.004
August	138.35	342.12	270.5	27.03	32.64	12.07	−0.0612	−0.075
September	35.75	159.95	98.82	9.87	26.9	27.22	**−0.1683****	−0.205
October	3.42	151.55	32.66	3.26	24.81	75.95	−0.0392	−0.038
November	1.25	80.49	18.78	1.88	16.41	87.37	0.0182	0.009
December	0.87	81.02	15.13	1.51	12.48	82.51	−0.0682	−0.023
Belg (FMAM)	80.61	394.77	230.47	23.03	55.59	24.12	**−0.1616****	−0.367
Kiremt (JJAS)	427.8	875.5	685.82	68.44	80.15	11.69	−0.0859	−0.32
Annual	674.07	1251.9	1000.92	100	87.2	8.71	**−0.1262****	−0.467
Decadal	941.49	1033.44	998.48		32.77	3.28	**−0.4848****	−6.3232

**Is statistically significant at $P < 0.05$

belg seasons contribute 74.4% and 13%, of rainfall, respectively. Likewise, a study conducted by Ayalew et al. (2012) in the Amhara Region and Abtew et al. (2009) in the Upper Blue Nile basin of the Amhara Region concluded that *kiremt* season contributes the highest share of the total annual rainfall. Many other studies (Suryabhagavan 2016; Gebrehiwot and Veen 2013; Bewket 2009; Bewket and Conway 2007; NMSA 2005, 2009) revealed that *kiremt* season contributes the highest (64–85%) while *belg* season contributes much lower (5–30%) of the total annual rainfall across many parts of Ethiopia.

The results of the Coefficient of Variation (CV) demonstrate that the *belg* season (February-May) was much higher (24.1%) than *kiremt* season (June–September) with a CV of 11.7%. Studies made in the Amhara Region of Ethiopia (Rosell and Holmer 2007; Ayalew et al. 2012; Bewket 2009; Bewket and Conway 2007) documented similar results in that CV of *belg* season was higher and more variable than *kiremt* season. As can be seen in Table 3, the annual PCI in the period between 1900 and 2014 is largely characterized by high and irregular concentration (77.4%). Very high irregular concentration (14.8%) with a moderate concentration (about 7.8%) of the observation years was also observed. K*iremt* season belongs to moderate concentration (92.2%), while *belg* season shows low rainfall concentration (41%) of the years. Bewket (2009), Asfaw et al. (2018), Bewket and Conway (2007) and Ayalew et al. (2012) report similar results in which rainfall concentration is higher for *kiremt* season.

Trends of rainfall

As presented in Table 2, the Mann–Kendall test result revealed a statistically significant decreasing trend of rainfall for February, May, and September. The result also indicated that *belg*, annual and decadal rainfall showed a significant decreasing trend, while a non-significant decreasing trend was observed for *kiremt* rainfall. Wagesho et al. (2013), Asfaw et al. (2018), Tesemma et al. (2010), and Moreda and Bauwens (1998) exhibited significant decreasing trends of annual and *kiremt* rainfall. On the other hand, many scholars (Conway 2000a, b; Viste et al. 2013; McSweeney et al. 2008; Suryabhagavan, 2016; Conway et al. 2004; Seleshi and Zanke 2004) report statistically non-significant trend results. The regression coefficients also illustrated decreasing trends at the rate of −0.432 mm/year, −0.335 mm/year,

Table 3 Annual, *kiremt* and *belg* precipitation Concentration Index (PCI) for 1900–2014

PCI Index (%)	Description	Observation years (%)		
		Annual	*Kiremt*	*Belg*
< 10	Uniform rainfall distribution/low concentration	–	7.8	41
15–16	Moderate rainfall distribution	7.8	92.2	55.5
16–20	High concentration/irregular rainfall distribution	77.4	–	3.5
> 20	Very high concentration/irregular rainfall distribution	14.8	–	–

− 0.595 mm/year and − 6.537 mm/decade for *kiremt, belg*, annual and decadal rainfall, respectively (Fig. 2). Rainfall reduction showed variations among *belg, kiremt*, annual and decadal at a rate of 0.432 mm, 0.335 mm, 6.537 m and m 0.595 mm, respectively. However, *kiremt* rainfall reduction is found to be non-significant. In the decline of annual rainfall, a similar result was reported by Jury and Funk (2013) at a rate of − 0.4 mm/year.

Temporal variability and trends of temperature

The mean monthly minimum, maximum, annual and decadal temperature data for the period 1901–2016 were presented to examine the temporal variabilities and trends (Table 4 and Figs. 3, 4). The minimum temperature of the study area was 9.7 °C with a maximum of 24.3 °C and annual average of 17 °C (Table 4). The regression coefficient for annual average, maximum and minimum temperature showed an increasing trend at the rate of 0.034 °C, 0.028 °C and 0.095 °C per decade, respectively (Fig. 3). The decadal regression coefficient results showed that the minimum, maximum and average temperature showed an increasing trend at the rate of 0.098 °C, 0.041 °C and 0.069 °C per decade, respectively (Fig. 4). Specifically, an abrupt increased temperature was observed since the 1970s. Here, the rate of increase in the minimum temperature was found to be faster than the maximum. Accordingly, for the last hundred sixteen years (1901–2016) the rate of annual average, maximum and minimum temperature has

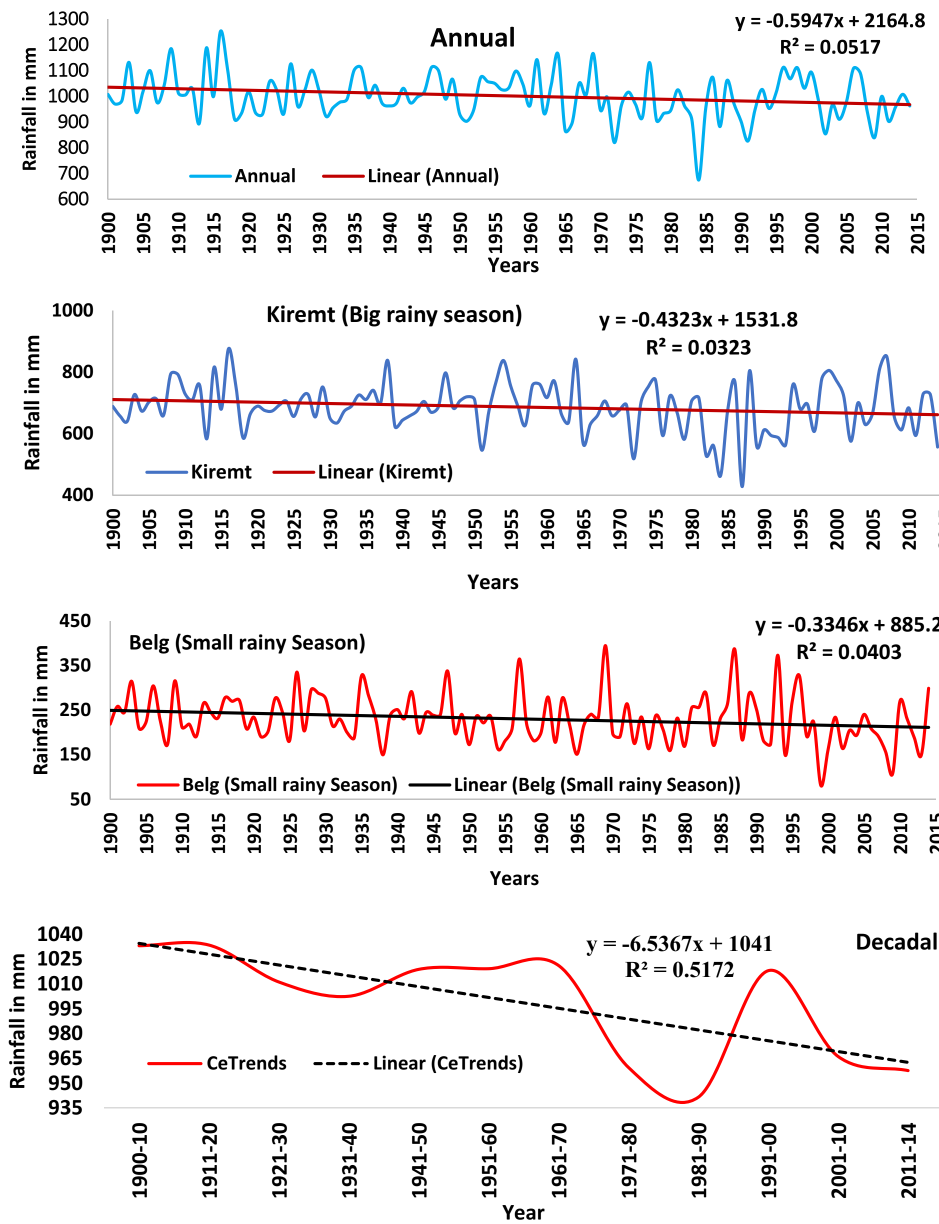

Fig. 2 Kiremt, belg, annual and decadal Rainfall trends

Table 4 Monthly, annual and decadal MK trend test of temperature (1901–2016)

Month	Tminimum				Tmaximum				Tmean			
	Mean-Min	ZMK	*P* value	Slope	Mean-Max	ZMK	*P*-value	Slope	Mean	ZMK	*P*-value	Slope
Jan	7.12	0.145	**0.021**	0.009	23.6	−0.045	0.471	−0.003	15.36	0.085	0.175	0.004
Feb	8.9	0.163	0.**009**	0.011	24.5	0.013	0.843	−0.0008	16.70	0.139	0.**027**	0.007
Mar	10.31	0.300	**0.000**	0.016	25.35	0.041	0.512	0.003	17.83	0.221	**0.000**	0.009
Apr	11.35	0.349	**0.000**	0.017	25.5	0.180	0.**004**	0.01	18.43	0.314	**0.000**	0.014
May	11.51	0.391	**0.000**	0.017	26.49	0.094	0.137	0.005	19.00	0.294	**0.000**	0.012
Jun	11.82	0.313	**0.000**	0.011	26.61	−0.06	0.32	−0.003	19.22	0.119	0.058	0.004
Jul	11.79	0.070	0.269	0.002	23.82	0.065	0.305	0.003	17.80	0.094	0.137	0.004
Aug	11.19	0.200	**0.000**	0.007	22.93	0.165	**0.009**	0.007	17.06	0.214	**0.001**	0.009
Sept	10.51	0.212	**0.000**	0.006	23.37	0.145	**0.021**	0.006	16.94	0.214	**0.001**	0.007
Oct	8.54	0.170	**0.007**	0.006	23.26	0.097	0.124	0.004	15.90	0.199	**0.002**	0.005
Nov	7.13	0.179	**0.000**	0.008	22.99	0.130	**0.039**	0.006	15.06	0.184	**0.003**	0.006
Dec	6.43	0.159	**0.012**	0.008	22.93	0.016	0.806	0.001	14.68	0.116	0.066	0.004
Average	9.72	0.356	**0.000**	0.01	24.28	0.091	0.150	0.003	17.00	0.283	**0.000**	0.007
Decadal	9.74	0.667	**0.002**	0.11	24.31	0.182	0.452	0.058	17.03	0.394	**0.086**	0.075

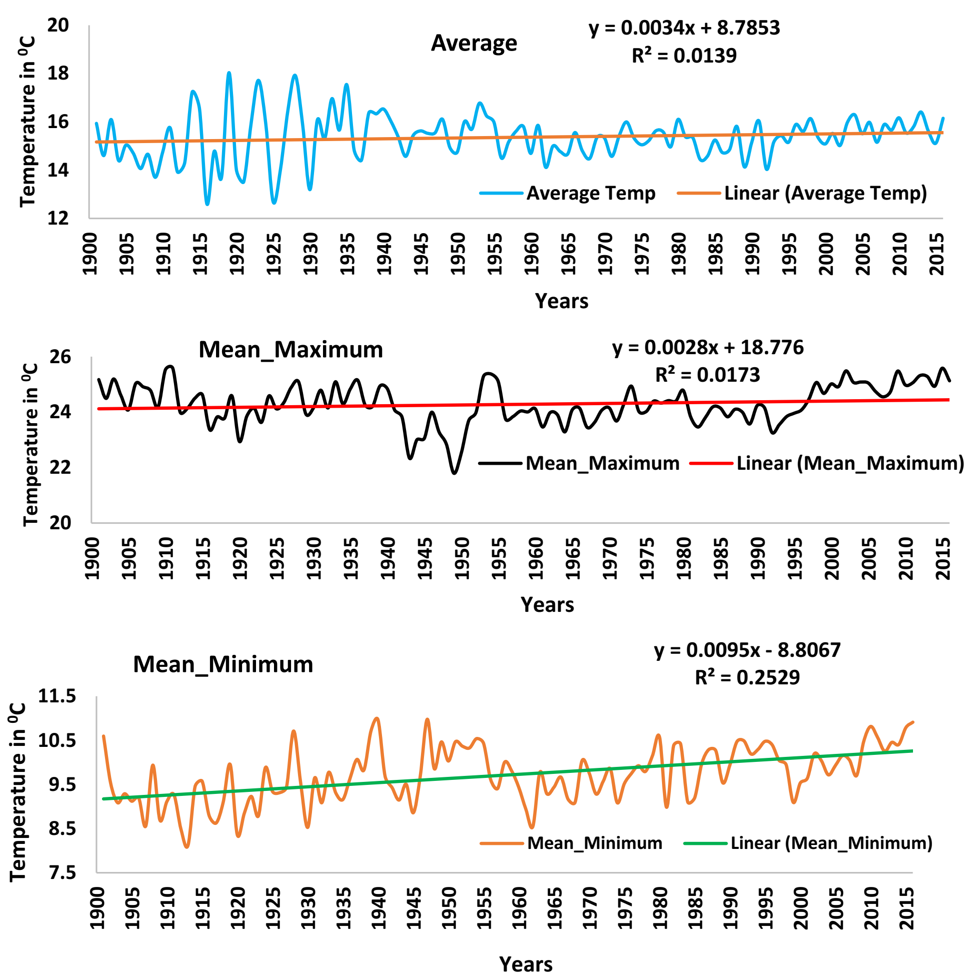

Fig. 3 Temporal trends of annual total, maximum and minimum temperature (1900–2016)

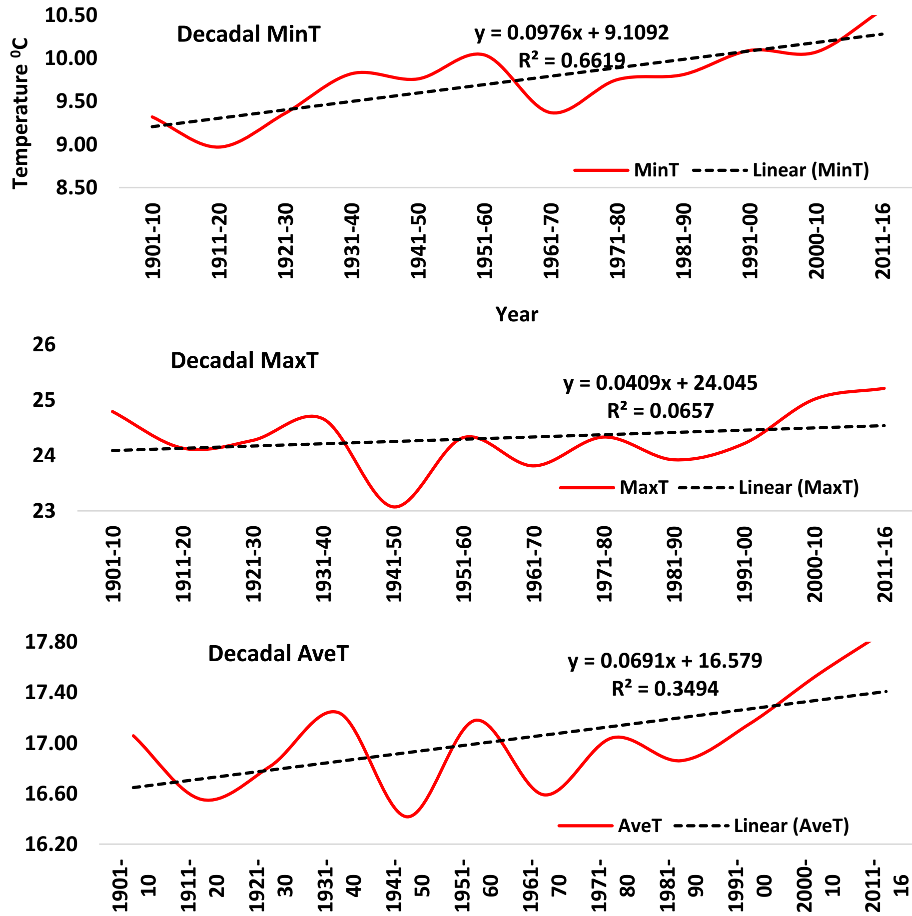

Fig. 4 Decadal trends of average, maximum and minimum temperature (1901–2016)

increased by 0.4 °C, 0.3 °C, and 1.1 °C, respectively. These results were substantiated by Asfaw et al. (2018), Teyso and Anjulo (2016), NMSA (2001), McSweeney et al. (2008), Jury and Funk (2013), Gebrehiwot and Veen (2013), Conway et al. (2004) and Mengistu et al. (2014). They concluded that an increasing rate of annual, maximum and minimum temperature was observed in many parts of Ethiopia.

The result of the Mann–Kendall test revealed that the trend of monthly minimum temperature showed a significant increasing trend except for July. Nevertheless, a non-significant increasing trend had been observed for the monthly maximum temperature except for April, August, September, and November (Table 4). The monthly mean temperature showed a significant increasing trend except for January, June, July, and December. The overall significant increasing trend of average temperature was found to be more attributed to the increasing trend of minimum temperature (Table 4).

Spatial variability and trends of rainfall and temperature

Spatial variability and trend of rainfall

The long-term spatial variability and trends of mean annual, *kiremt* and *belg* rainfalls were demonstrated (Table 5 and Fig. 5). The spatial distribution of the long-term mean annual rainfall ranges from 834 mm in Harbu to 1387 mm in Guguftu. Eight gauge stations (Haik, Saynt, Kombolcha, Amba Mariam, Wereillu, Guguftu, Wuchalle, and Kelala) receive rainfall in between 1005 mm and 1388 mm per year. The remaining seven stations receive on average less than 1000 mm rainfall per year. Spatial rainfall distribution also varies within the season. For instance, *kiremt* rainfall varies from 564 mm in Harbu to 1065 mm in Guguftu, while *belg* rainfall varies from 164 mm in Saynt to 360 mm in

Table 5 Gauge stations' spatial variability and trends of the mean annual, kiremt and belg season rainfall

Variable	Seasons	Attributes		Haik	Saynt	Harbu	Tebasit	K/cha	Jamma	Amba Mariam	Wereillu	Guguftu	Kabie	Wuchalle	M/selam	Tenta	Wogidi	Kelala
Rainfall	Belg	Mean		342	164	228	163	260	170	222	183	233	174	360	221	198	266	215
		%		29.1	15.5	27.4	16.8	24.9	18.2	22.1	18	16.8	20.4	28	24.9	22.6	27	19.4
		CV (%)		37.4	54.7	48.9	62.4	38.9	54.1	71.2	82.2	39.5	49.6	39.4	38.5	55.7	44.8	61
		MK test	Total	−0.13	0.08	−0.08	0.12	−0.1	**−0.33****	−0.02	−0.18	−0.1	−0.18	−0.06	**−0.28****	−0.18	**−0.40****	−0.23
	Kiremt	Mean		719	816	564	753	678	725	705	786	1065	637	730	594	642	602	837
		%		61	77.8	67.7	77.6	65.2	77.6	70.2	77.3	76.8	74.8	56.9	66.8	73.1	61	75.6
		CV (%)		23.8	22.8	38.8	41.9	21.7	28.2	28.2	45.9	22.1	25.1	30.6	18.4	29.1	25.8	41
		MK test	Total	0.19	−0.02	0.06	**0.53****	0.02	0.17	0.05	0.04	**−0.42****	0.22	**0.25****	0.2	0.2	**0.23****	**−0.43****
	Annual	Mean		1178	1048	834	971	1041	935	1005	1018	1388	851	1283	888	877	987	1106
		PCI (%)		18.2	24.7	20.4	24.1	18.9	24.5	25	26.4	24.1	24.5	16.5	17.3	25.3	18	22.1
		CV (%)		16.8	21.3	37.9	40.6	16.1	19.8	37.8	43.7	19.5	19.1	23	17.9	19.9	17.6	41.2
		MK Test	Total	−0.01	−0.1	−0.04	**0.50****	−0.12	0.08	0.05	−0.05	**−0.37****	0.2	**0.25****	−0.01	0.12	−0.13	**−0.36****

Wuchalle. The mean annual spatial coefficient of variation showed that Kombolcha (CV = 16.1%) was lower than Wereillu (43.7%). *Kiremt* season coefficient of variation exhibited a similar trend to the mean annual in which Mekaneselam (18.4%) was lower than Wereillu (45.9%). However, in all the cases, the *belg* coefficient of variation is by far the highest that ranges from 37.4% in Haik to 82.2% in Wereillu. The PCI showed that rainfall concentration was largely varied spatially from high concentration (16.5%) in Wuchalle to very high concentration (26.4%) in Wereillu. Similar results were reported by Seleshi and Zanke (2004), Urgessa (2013), Rosell and Holmer (2007), Game and Korecha (2015), Gebrehiwot and Veen (2013), Bewket and Conway (2007), Asfaw et al. (2018), Ayalew et al. (2012) Bewket (2009), and Viste et al. (2013).

The spatial trends of annual, *kiremt* and *belg* rainfalls were also shown (Fig. 5). Accordingly, all the livelihood zones (81%) of the *belg* season exhibited a non-significant decreasing trend of rainfall. The northeastern and southwest livelihood zones such as ABB, *Belg*, *Meher*-*belg*, SWS, and *Meher* had shown a significant increasing trend during the *kiremt* season. At the annual level, the southwest of M*eher* and part of northwest ABB livelihood zones (38%) illustrated non-significant decreasing trends. The overall annual, *kiremt* and *belg* seasons spatial trends of rainfall in the northeastern and northern part experienced a non-significant decreasing trend. Mengistu et al. (2014) also identified significant increasing trends at the annual and *kiremt* season. In contrast, there was a significant decreasing trend in the eastern and northeastern part of the upper Blue Nile Basin of the Amhara Region in the *belg* season where the present study is located.

Spatial variability and trend of temperature

The long-term average temperature distribution found to be spatially varied from 9.4 °C in Guguftu to 22.2 °C in Harbu. The MK trend analysis of the mean, maximum and minimum temperature among gauged stations exhibited a statistically significant increasing and decreasing, and a significant and non-significant decreasing trend (Fig. 6). These results were in agreement with the works of Asfaw et al. (2018), Suryabhagavan (2016), and Teyso and Anjulo (2016), where the average, minimum and maximum temperature of the larger gauged data exhibits spatially significant increasing and decreasing trends overtime in many parts of Ethiopia.

As illustrated (Fig. 6), the spatial trend of minimum temperature in the M*eher*-B*elg, Meher, Belg*, ABB, and SWS livelihood zones (65%) shows a non-significant increasing trend. Nevertheless, the maximum temperature in almost all the livelihood zones experienced a significant increasing trend. The southern and southeastern parts

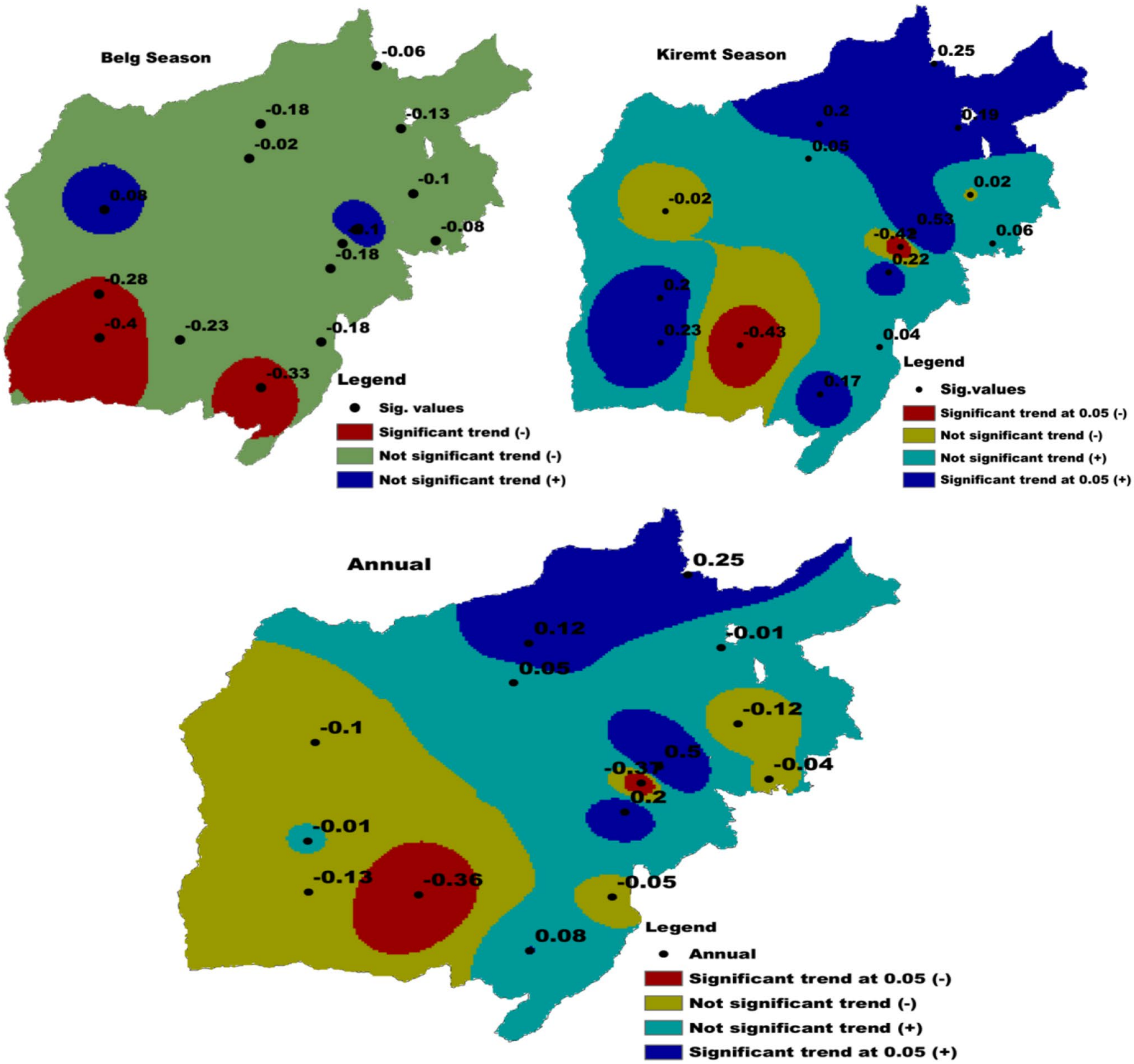

Fig. 5 Spatial trends of *belg*, *kiremt* and annual level rainfall at $P < 0.05$

of the M*eher* livelihood zone (33%) show a significant increasing trend of mean temperature. But the western and northeastern parts of the rest livelihood zones (51%) show a non-significant increasing trend. The influence of minimum temperature was distinctly observed over the mean temperature. Mengistu et al. (2014) spatially illustrated a non-significant trend for maximum temperature unlike this finding. However, a mix of both significant decreasing and non-significant trends was observed for minimum temperature in the eastern and northeastern parts of the upper Blue Nile Basin.

Potential influence of rainfall and temperature variability

The detected spatial and temporal rainfall and temperature variability could trigger wide-ranging influences on agricultural practices and crop production of smallholder farmers. Sufficient and timely available rainfall amounts and duration during *belg* and *kiremt* seasons are imperative for agricultural practices. However, the inconsistancy and variability of rainfall during *belg* (Feb-to-May) and *kiremt* (June-to-Sept) seasons discouraging the farming practices and decreasing produtions over the livelihood zones. Yet, the decline in the

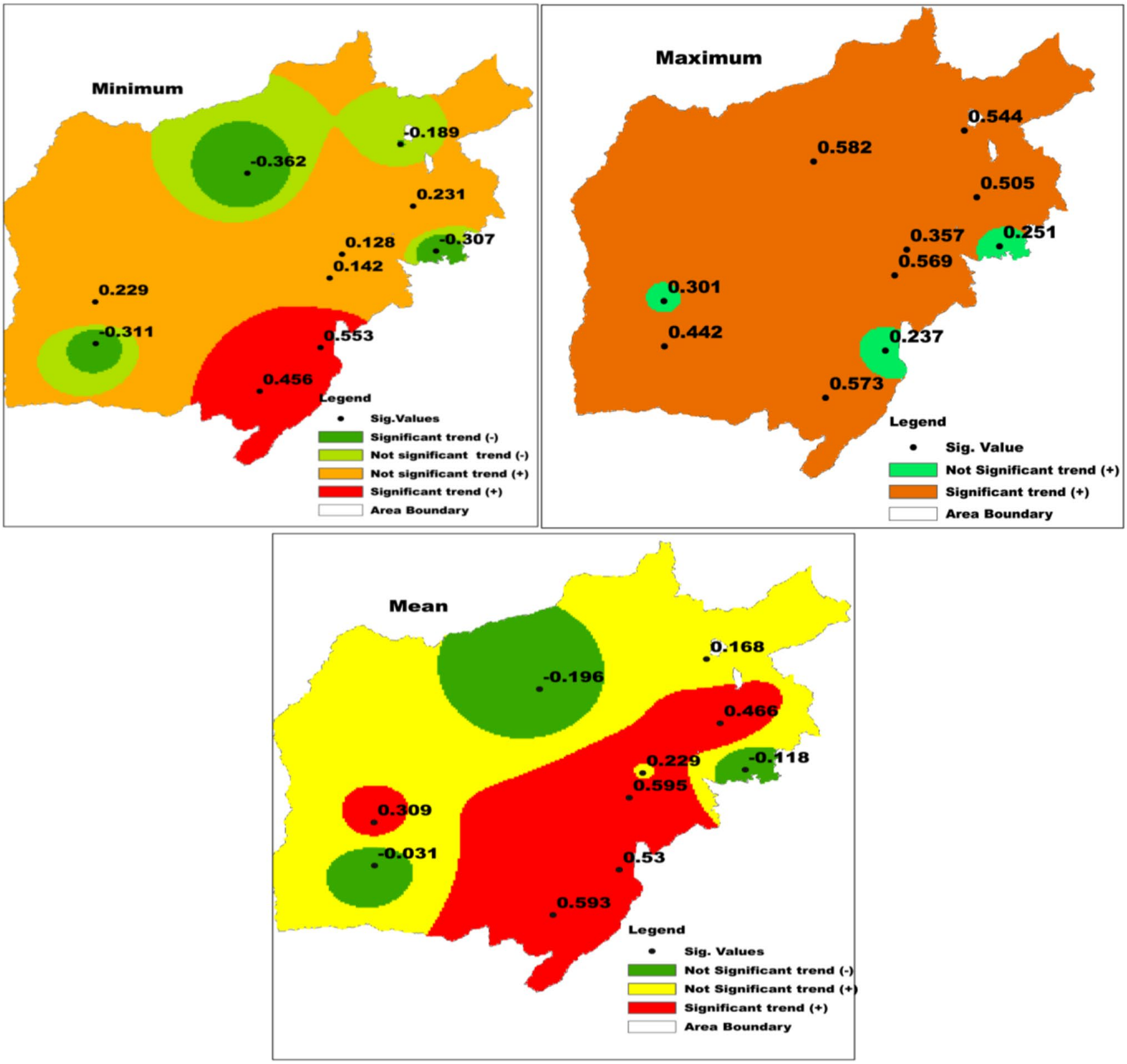

Fig. 6 Spatial trends of minimum, maximum and annual average temperature (1900–2016)

onset of rainfall in February and cessation of rainfall in September influenced the liftoff farmers for early and timely planting, active growing and maturation of different crops. This eventually impacted agricultural production through the uncertainty of the cropping calendar. For instance, authors such as Dinku (2011), EPCC (2015), Negatu (2004), and Asfaw et al. (2015) indicated that the variability in the amount and duration of rainfall in both *kiremt* and *belg* seasons brought a loss of crop and livestock production leading households to chronic food insecurity. Regassa et al. (2010) also indicated that *belg* rains may impact long cycle crop production with crippling consequences for agricultural production. Von Braun (1991) and Valli et al. (2013) estimated that a 10% variation in seasonal rainfall below the long-term average resulted in a 4.4% reduction in the country's food production. Likewise, the World Bank (2006) further projected that variable rainfall costs 38% of the country's potential growth rate and increases poverty by 25%. Bewket (2009) complemented that extreme variability of rainfall is a major cause of variations in crop production making smallholder farmers susceptible to food insecurity.

The increasing trend of annual and seasonal temperature over the study period could have also an overwhelming influence on the crop production process of the smallholder farmers (Parry et al. 2007). For instance, Funk et al. (2012) reported that warming will increase the influence of droughts, reducing the moisture availability of the soil affecting the productivity of the cropland. Gebreegziabher et al. (2013) also estimated that an increase in annual and seasonal temperature decreases crop yields per hectare. According to the aforementioned authors, a 1 °C rise in annual temperature will lead to a reduction of yields that costs about 1577.00 Ethiopian Birr from crop production. Scientific documents (EPCC 2015; Pachauri et al. 2014) differently indicate that an increase in temperature could result in the potential influence on crop production. This could be through the occurrences of crop pests such as insects, migratory birds, and rodents, and invasive weeds that occur at some stage in the agricultural calendar.

Generally, the potential influence of climate variability on crop production would be its sensitivity mainly to the variability of rainfall and temperature. This is because crop productions have very limited optimal and tolerable rainfall and temperature range to grow well (Gebreegziabher et al. 2013). The occurrences of temperature and rainfall variability would drastically reduce crop production and in certain circumstances cause overall crop failure (Funk et al. 2015; Mahoo et al. 2013). From the discussions, it can be concluded that temperature and rainfall variability reduce crop production in particular and affect the overall success of the agricultural sector in general. At times when climate variability becomes the worst, it results in total crop failure leading to hunger and death of people and animals. These scenarios frequently occur in the north, northeastern and southeastern parts of Ethiopia.

Conclusions

Long-term rainfall and temperature data (1900–2016) were documented and analyzed using different meteorological indices to show spatiotemporal variations and their potential influences. The results showed that rainfall and temperature vary in space and time. More variability of rainfall and temperature was observed in the recent period. The rainfall distribution is distinguished by a high coefficient of variation and increasing high irregular distribution, particularly in the recent period. It was found out that the decadal, annual and *belg* rainfall declined significantly but the non-significant trend was observed for *kiremt* rainfall. Moreover, the observed significant decline of February and September rainfall over the livelihood zones was making the planting and growing of crops unpredictable. This happens associated with the late-onset and early cessation of *belg* and *kirem*t rains. Increased frequency of negative rainfall anomalies and positive temperature anomalies in the last three and half decades has been another manifestation of declined rainfall and increased temperature. The discrepancy in the decline of rainfall amount at the decadal, annual, *kiremt* and *belg* timescales over the livelihood zones strongly influence the agricultural activities through the uncertainty of the cropping calendar. The average, maximum and minimum temperatures also showed an increasing trend. The decreasing trend of rainfall and the increasing trend of temperature were the potential threat to the agricultural sector through pest intensification. Therefore, it is essential to design applicable adaptation and mitigation approaches to reduce the impacts of climate variability that suit agricultural activities in the livelihood zones. The study recommended that designing and implementing area-specific adaptation and mitigation strategies to reduce the impacts of climate variability on crop production over the livelihood zones of the study area and similar environments across the country have paramount importance for policymakers. Rainwater harvesting and the development of small-scale irrigation schemes could be taken as viable options where rainfall is scarce and more variable for the growth of crops.

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