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Spatiotemporal variability and trends in rainfall and temperature in Alwero watershed, western Ethiopia

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Abstract

Climate analysis at relevant time scales is important for water resources management, agricultural planning, flood risk assessment, ecological modeling and climate change adaptation. This study analyses spatiotemporal variability and trends in rainfall and temperature in Alwero watershed, western Ethiopia. Our analysis is focused on describing spatial and temporal variability of rainfall in the study area including detection of trends, with no attempt at providing meteorological explanations to any of the patterns or trends. The study is based on gridded monthly rainfall and maximum and minimum temperature data series at a resolution of 4 × 4 km which were obtained from the National Meteorological Agency of Ethiopia for the period 1983–2016. The study area is represented by 558 points (each point representing 4 × 4 km area). Mean annual rainfall of the watershed is > 1600 mm. Annual, June–September (*Kiremt*), March–May (*Belg*) rainfall totals exhibit low inter-annual variability. Annual and October-February *(Bega)* rainfalls show statistically significant increasing trends at $p = 0.01$ level. May and November rainfall show statistically significant increasing trends at $p = 0.01$ level. March shows statistically significant decreasing trend at $p = 0.1$ level. The mean annual temperature of the watershed is 25 °C with standard deviation of 0.31 °C and coefficient of variation of 0.01 °C. Mean annual minimum and maximum temperatures show statistically non-significant decreasing trends. *Bega* season experienced statistically significant deceasing trend in the maximum temperature at $p = 0.01$ level. The year-to-year variability in the mean annual minimum and maximum temperatures showed that the 2000s is cooler than the preceding decades. Unlike our expectations, annual and seasonal rainfall totals showed increasing trends while maximum and minimum temperatures showed decreasing trends. Our results suggest that local level investigations such as this one are important in developing context-specific climate change adaptation and agricultural planning, instead of coarse-scale national level analysis guiding local level decisions.

Keywords: Rainfall and temperature trends, Climate variability, Alwero watershed, Ethiopia

Background

Climate change is increasing the occurrence and magnitude of rainfall extremes that cause increased drought and flood risks (Chen et al. 2014). The influence of current climate variability on crop production is large in developing countries like Ethiopia where agriculture is primarily dependent on rainfall (Alemayehu and Bewket 2016a). Rainfall in Ethiopia shows high variability across space and time owing to the complex topography varying from 120 mbsl to 4620 masl (Reda et al. 2015) and latitude of the country varying from 3 to 15 ºN and 33 ºE to 48 ºE (Gamachu 1988). Robust information on the seasonality of rainfall in the country is important to tackle its adverse economic and social consequences including on agriculture (Korecha 2013) and for local level climate change adaptation planning (Alemayehu and Bewket 2017a). The rainfall pattern in Ethiopia is strongly seasonal (World Bank 2006). It is characterized by wet and long rainy seasons on the one hand and long dry and

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short rainy seasons on the other hand (World Bank 2006; Korecha 2013). Consequently, the high and low rainfall phenomena can give rise respectively to flood and drought conditions with adverse economic and humanitarian crises (World Bank 2006). In Ethiopia, the performance of the agricultural sector and the rainfall pattern show strong correlations (Admassu 2004; Lemi 2005; World Bank 2006; Bewket 2009; Conway and Schipper 2011; Alemayehu and Bewket 2016a). Rainfall shortage often leads to famines (Alemayehu and Bewket 2017b).

There are three seasons in Ethiopia. These are (i) the June–September (main rainy season, locally known as *Kiremt*); (ii) the March–May (short rainy season, locally known as *Belg*); and the October – February (dry season, locally known as *Bega)* (Seleshi and Zanke 2004; Alemayehu and Bewket 2017a). Understanding the characteristics of *Kiremt* and *Belg* season rainfall is useful for improving agricultural productivity and mitigating food security challenges (Alemayehu and Bewket 2016a, a; Mulugeta et al. 2019) and water resource development of the country (Degefu and Bewket 2014; Suryabhagavan 2017). *Kiremt* rainfall which is the largest in terms of its amount and geographical coverage is less variable in most parts of the country compared to *Belg* and *Bega* season rainfall (Shankoa and Camberlin 1998). It supports the main cropping season production, locally known as *Meher*. *Kiremt* rainfall shortage or change impacted the agricultural productivity in the country (Mulugeta et al. 2019).

The *Belg* season rainfall is characterized by high temporal and spatial variability, which has implications on *Belg* season crops and food security of households (Alemayehu and Bewket 2016a; Bekele-Biratu et al. 2018). The change and shift in *Belg* season rainfall leads to devastating droughts affecting socioeconomic welfare and environmental resources (Haile et al. 2019).

Alemayehu and Bewket (2017a) summarized previous studies on rainfall and temperature variability and trends in Ethiopia covering different temporal and spatial scales. They concluded that studies on rainfall did not show clear trend for the country. The possible explanations to that are: (i) trends in annual and seasonal rainfalls are affected by topography (Bewket and Conway 2007; Mengistu et al. 2013); (ii) trend analysis is largely sensitive to quality of data, the choice of study periods and stations considered by the different studies (Seleshi and Zanke 2004; Bewket and Conway 2007; Mengistu et al. 2013); (iii) the north–south oscillation of the Inter Tropical Convergence Zone (ITCZ), the El Ni˜no-Southern Oscillation (ENSO) phenomena (Shanko and Camberlain 1998; Seleshi and Zanke 2004; Gleixner et al. 2017) and fluctuations in sea surface temperatures (SSTs) mask trends (Shanko and Camberlain 1998; Gissila et al. 2004; Segele and Lamb 2005; Viste et al 2012; Jury and Funk 2013); and (iv) previous studies on variability and trends in rainfall and temperature frequently takes place at large scale (Ademe et al. 2020) and contributed to mixed patterns of change.

Despite the discrepancies observed, a growing number of studies in Ethiopia reported downward trend in seasonal and annual rainfall totals (e.g., Shanko and Camberlin 1998; NMA 2007; Osman and Sauerborn 2002; Seleshi and Zanke 2004; Verdin et al. 2005; Cheung et al. 2008; Viste et al. 2012; Jury and Funk 2013; Urgessa 2013; Wagesho et al. 2013; Addisu et al. 2015; Alemayehu and Bewket 2017a; Asaminew et al. 2017; Asfaw et al. 2018; Haile et al. 2019; Ademe et al. 2020; Matewos and Tefera 2020). Available studies on temperature reported warming trend in the maximum and minimum temperatures (e.g., NMA 2007; McSweeney et al. 2008; Taye and Zewdu 2012; Ayalew et al. 2012; Mengistu et al. 2013; Mekasha et al. 2014; Addisu et al. 2015; Alemayehu and Bewket 2017a; Asaminew et al. 2017; Suryabhagavan 2017; Asfaw et al. 2018; Haile et al. 2019; Ademe et al. 2020; Matewos and Tefera 2020). Climate analysis at relevant time scales is important for agricultural planning, water resources management, flood risk management, ecological modeling and climate change adaptation (Engida and Esteves 2011; Alemayehu and Bewket 2017a; Sun et al. 2018).

The focus of this study is to investigate the spatiotemporal variability and trends in rainfall and temperature in Alwero watershed in the western part of Ethiopia using a dense network of 4×4 km gridded data (558 points) reconstructed from weather stations and meteorological satellite records which spatially covers the watershed. In countries like Ethiopia where a major underlying vulnerability factor is the heavy dependence of the economy on rain-fed smallholder agriculture (Conway and Schipper 2011; Alemayehu and Bewket 2016b), timely and accurate availability of climate information is useful for sustainable climate risk management (Alemayehu and Bewket 2017a). A better understanding of the changes in long-term annual and seasonal rainfall at local level is useful for adaptation intervention (Mulugeta et al. 2019). Local level investigations such as this one are important in developing context-specific climate change adaptation and agricultural planning, instead of coarse-scale national level analysis guiding local level decisions.

The study area in particular is the largest agricultural investment hub in the country where a detailed previous study does not exist. In the following section, we present a brief description of materials and methods of the study, and this is followed by the results and discussion section. Conclusions are presented in "Data and methods Section".

Materials and methods

Description of the study area

Alwero watershed is found in the Abobo district of the Gambella National Regional State, western Ethiopia (Fig. 1). The Gambella Region is largely lowland (*Kolla*) agroecological zone with hot to warm humid climate. Mean annual rainfall is about 1200 mm. Mean annual temperature is 26.7 °C (Degife et al. 2019). The level of natural resource use is low due to sparse population density. The soil, topography and climate conditions have made the Region to be one of the most fertile parts of the country and highly suitable for growing various types of tropical crops. In the early 2000s, about 3.5 hectares of land from southwest part of the country which is also the present study area were leased to both domestic and foreign investors (Rahimato 2011). Since 2008, the Region was prioritized as one of the biggest destination for large scale agricultural investment. More than 1.2 hectares of land were transferred to both domestic and foreign investors (Rahimato 2011).

The altitude of Alwero watershed ranges from 385 to 2531 m asl (Fig. 1). About 58 and 40% of the watershed lies in altitude ranges of 385–500 m asl and 500–1837 m asl, respectively. Only about 2% of the watershed contains hills and escarpments located in the eastern edge of the watershed with an altitude range of 1837 to 2531 m asl. The eastern edge of the watershed is characterized by steep and very steep slopes whereas the central part is dominated by a mix of flat, gently sloping and sloping terrain. Alwero watershed has two sub-watersheds; upper (eastern) and lower (western). The altitude of the upper (eastern) sub-watershed ranges from 619 to 2531 m asl. The altitude of the lower (western) sub-watershed ranges from 385 to 619 m asl.

According to Zabel et al. (2014) Dystric and Eutric Plinthosols, Dystric and Chromic Cambisols, Eutric Vertisols and Planosols are the major soils of the district.

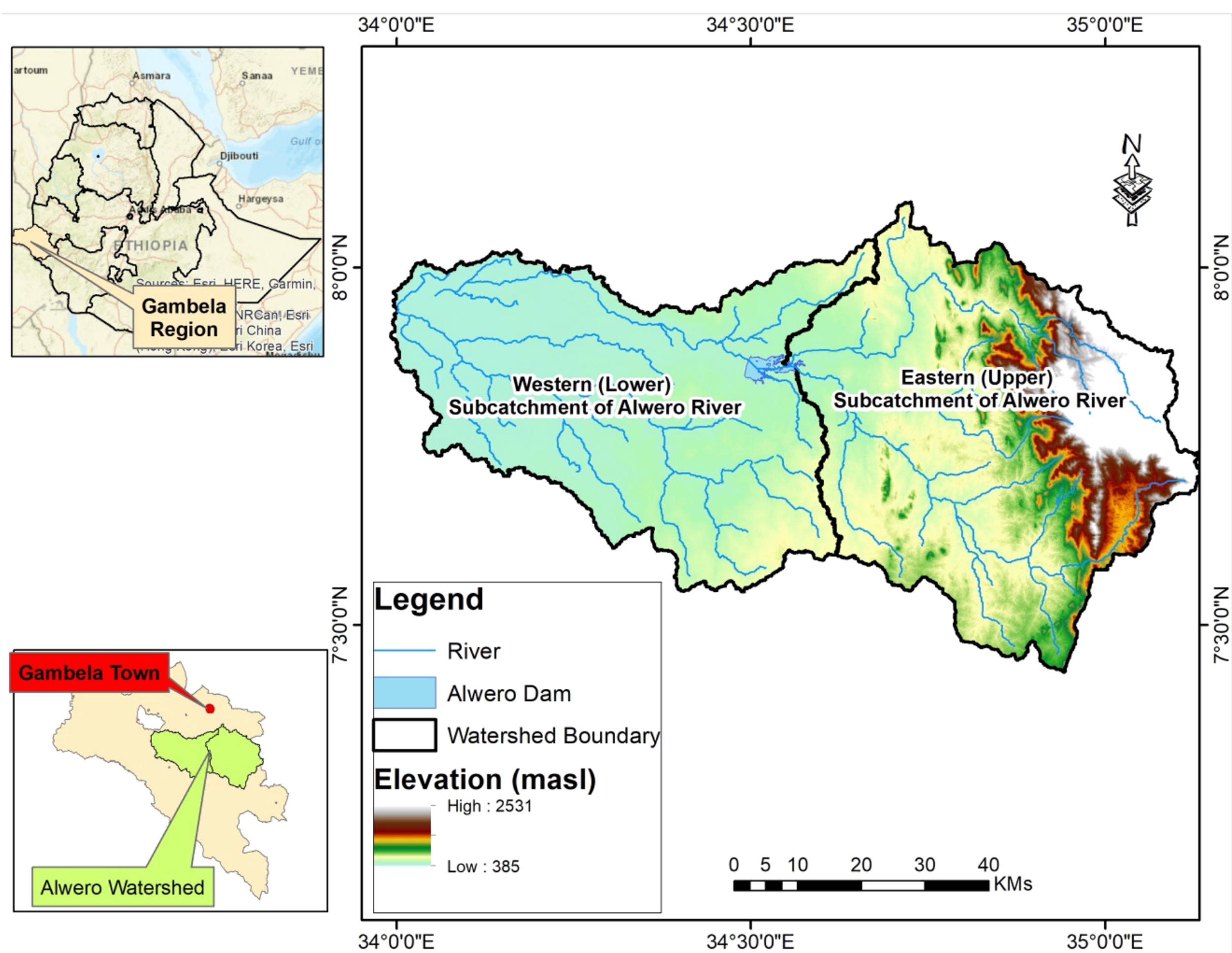

Fig. 1 Location of the study area

The major land use types of Abobo district include forest (143,086 ha), woodland (75,227 ha), shrub (5,793 ha), grass (62,997 ha) and cultivated lands (19,854 ha) (Yitbarek et al. 2017). Maize (*Zea mays L.*), sorghum (*Sorghum bicolor*), groundnut (*Arachis hypogae*), sesame (*Sesamum astivum*), cotton (*Gossypium sp.*) and rice (*Oryza sativa L.)* are major crops grown in the area (Yitbarek et al. 2017). From these, maize and sorghum are the dominant in terms of production (Degife et al. 2019) and consumption (Dorosh and Rashid 2013).

According to the Central Statistical Authority (CSA) (2013), the total population of Abobo district is 22,420 out of which 11,531 are males and 10,889 are females. Of the total, about 35% resides in urban area (Abobo town) and the remaining 65% lives in rural areas. The livelihood of the population in the watershed is largely dependent on small-scale farming, fishing, retailing and casual jobs in large-scale farms, construction and government and non-government offices.

Data and methods

The study is based on gridded monthly rainfall and temperature data series at a resolution of 4 × 4 km for the period 1983–2016. The study area is covered by 558 points (each representing 4 × 4 km area). The data are created by blending station records with meteorological satellite estimates and were obtained from the National Meteorological Agency of Ethiopia. This is the best available dataset for the country which is homogeneous and recommended for climate analysis (Dinku et al. 2014). In recent years, gridded rainfall and temperature datasets have been used in Ethiopia with different data sources and spatial resolutions (Mengistu et al. 2013; Dinku et al. 2014; Alemayehu and Bewket 2017a; Mulugeta et al. 2019; Gebrechorkos et al. 2020; Ademe et al. 2020; Matewos and Tefera 2020).

Coefficient of variation (CV), precipitation concentration index (PCI) and standardized rainfall anomaly (SRA) are used to examine inter-annual and intra-annual variability of rainfall. The CV measures year-to-year variation in the data series. According to NMA (1996) classification, CV less than 0.20 is less variable, CV between 0.20 and 0.30 is moderately variable and CV greater than 0.30 indicates high variability. The PCI values measure extent of seasonality of rainfall; and it is given as indicated in De Luis et al. (2000):

$$\mathrm{PCI} = 100 \times \left[\sum \mathrm{Pi}^2 / \left(\sum \mathrm{Pi}\right)^2\right] \quad (1)$$

where: Pi = the rainfall amount of the ith month; and $\Sigma\ \mathrm{Pi}^2$ = summation over the 12 months. PCI values of less than 10 indicate quite uniform monthly distribution of rainfall, values between 11 and 20 indicate moderate concentration, and values above 21 indicate high concentration.

SRA is commonly used as a simple index to characterize drought at different time scales, or to identify abnormal wetness or dryness (Guttman 1999). SRA values are given as;

$$\mathrm{SRA} = (\mathrm{Pt} - \mathrm{Pm})/\sigma \quad (2)$$

where SRA = standardized rainfall anomaly, Pt = annual rainfall in year t, Pm = is long-term mean annual rainfall over a period of observation and σ = standard deviation of annual rainfall over the period of observation. According to Agnew and Chappel (1999), SRA values indicate extreme drought (SRA < − 1.65), severe drought (− 1.28 > SRA > − 1.65), moderate drought (− 0.84 > SRA > − 1.28), and no drought (SRA > − 0.84). Linear regression was used to detect trends in rainfall. It is given as;

$$\mathrm{Y} = \mathrm{mx} + \mathrm{b} \quad (3)$$

where y is dependent variable, m is the slope, x is independent variable and b is the intercept. F-distribution test was applied to determine the statistical significance of the trends. The minimum and maximum temperatures were also analyzed using the above techniques. Surface data were generated from the gridded monthly rainfall and temperature data using kriging interpolation technique with the help of ArcGIS 10.1.

Results and discussion

Rainfall variability and trends in Alwero watershed

Annual and seasonal rainfall patterns

Mean annual rainfall of Alwero watershed is 1665.5 mm (Table 1), and its inter-annual variability is low with a CV of 8.7%. The *Kiremt* and *Belg* rainfall also show low inter-annual variability (CV, 9.2% and 19.7%, respectively). *Bega* rainfall shows moderate variability (CV, 24%). Previous studies on variability and trends of annual and seasonal rainfall reported moderate and high variability in their respective study areas (Bewket and Conway 2007; Ayalew et al. 2012; Alemayehu and Bewket 2017a, b; Hadgu et al. 2013; Urgessa 2013; Ademe et al. 2020).

As indicated by the PCI values, rainfall shows moderate concentration in few months of the year (10.8). It can be observed that above average mean monthly rainfall is recorded from May to October. These months have recorded above 130 mm rainfall (Fig. 2). About 80% of annual rainfall is concentrated in these six months which ranges from 11% (October) to 14.4% (August). August supplies the largest amount of rainfall in the watershed. July and September also represent high contributions to the annual totals. Our results corroborate the findings of (Alemayehu and Bewket 2017a).

Table 1 Trends of annual and seasonal rainfall in Alwero watershed

Parameter	Amount (mm)	Contribution (%)	CV	LT	Wettest year	Driest year	HMR	PCI
Annual	1665.5		0.087	66*	2011	1986	365.9	10.8
Kiremt	932.9	56	0.092	0.63	2003	1995		
Belg	410.8	25	0.197	20.27	2014	1987		
Bega	321.9	19	0.241	45.09**	2008	1984		

* Significant at 0.05 level; **Significant at 0.01 level; *LT* linear trend (mm/10 yr)

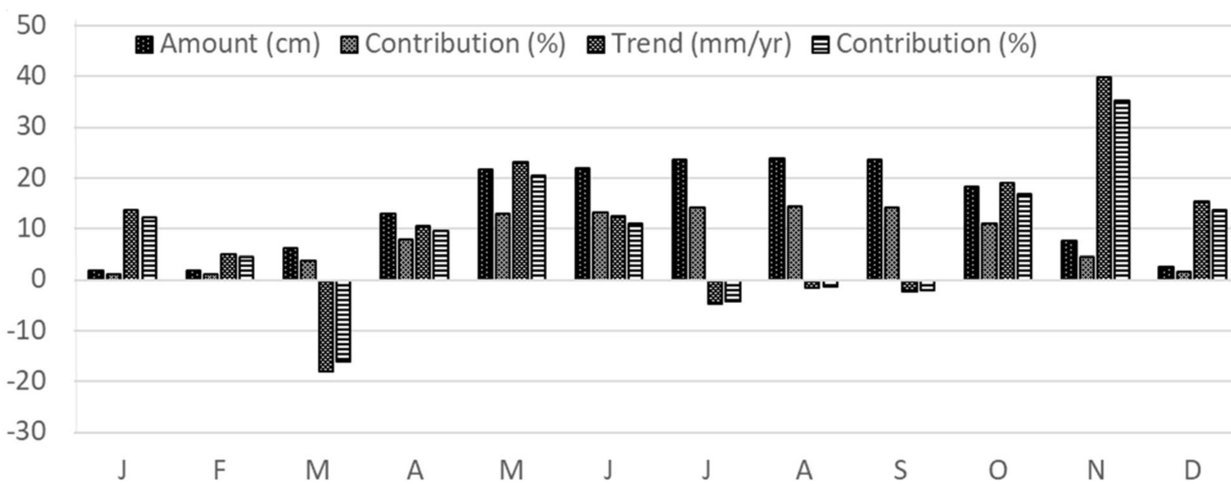

Fig. 2 Monthly rainfall (in cm), contribution to the annual total (in %), Monthly rainfall trends (mm/10 yr), and contribution to the annual rainfall trend (in %) left in Alwero watershed

As elsewhere in Ethiopia, *Kiremt* rainfall contributes the largest to the annual rainfall (56%), followed by *Belg* rainfall (25%). Unlike other parts of the country, the contribution of *Bega* rainfall is high (19%) as well. The highest monthly rainfall is 395.9 mm which accounted for 22% of the annual and 89% of *Belg* rainfall totals, respectively (Table 1). Unlike other areas of the country where high concentration of rainfall is recorded in the month of August followed by July, the highest monthly rainfall is recorded in May which is a dry month in most parts of the country. However, a recent study by Matewos and Tefera (2020) in the drought-prone districts of rural Sidama, central rift valley region of Ethiopia observed that April and May are the wettest months.

Annual and *Bega* rainfalls show statistically significant increasing trends at $p=0.1$ and $p=0.01$ levels, respectively. *Kiremt* and *Belg* rainfalls show no significant trends. These results contradict the findings of Shanko and Camberlin (1998), NMA (2007), Osman and Sauerborn (2002), Seleshi and Zanke (2004), Verdin et al. (2005), Cheung et al. (2008), Jury and Funk (2013), Urgessa (2013), Viste et al. (2012), Wagesho et al. (2013), Addisu et al. (2015), Alemayehu and Bewket (2017a), Asaminew et al. (2017), Haile et al. (2019), Ademe et al. (2020) and Matewos and Tefera (2020) who reported declining trends of annual and seasonal rainfall totals in their respective study areas in different parts of the country. The statistically significant increasing trend of *Bega* rainfall supports the findings of a recent study by Matewos and Tefera (2020) who reported a significant increasing trend of *Bega* rainfall in the drought-prone districts of rural Sidama, central rift valley region of Ethiopia.

Regarding monthly rainfall trends, November and May showed statistically significant increasing trends at $p=0.05$ level. October shows significant increasing trend at $p=0.1$ level, and March shows significant decreasing trend at $p=0.1$ level (Fig. 2). June to September show non-significant increasing trends. December, January and February showed statistically non-significant increasing trends. March contributes the highest to the overall declining trend of annual rainfall while November makes considerable contribution to the overall increasing trend of annual rainfall.

In Ethiopia the driest year is 1984, which is the well-known drought year. The wettest year is 2006, which is the major flood year. The country has witnessed large scale losses of life and property during those periods. However, the driest and wettest years for Alwero watershed are 1986 and 2011, respectively. The wettest year for *Kiremt* is 2003, which is a recovery period from the second major drought period affecting large parts of the country. The years 2008 and 2014 are wettest periods for *Bega and Belg* seasons, respectively, while the dry years for *Bega* and *Belg*, respectively, are 1984 and 1987 (Table 1).

Figure 3 shows standardized annual and seasonal rainfall anomalies. Since 1983, annual rainfall showed declining trend up to 1990 except for the year 1988. Conversely, standardized rainfall anomalies are positive from 1990–1999 except the years 1994 and 1995. Annual rainfall shows considerable inter-annual variations between 2000 and 2009. From 2010 to 2016 standardized rainfall anomalies are positive except the year 2013. In the watershed, positive and negative anomalies account for 53% and 47% of the total observations, respectively. About 29% of the total number of observations is under the different drought categories. The 1990s is wet compared with the 1980 and 2000s. The results of this study are consistent with Bewket and Conway (2007) and McSweeney et al. (2008) who concluded the 1980s was drier than its preceding decade and the decades following.

Negative anomalies in *Bega* rainfall were observed from 1983–1995 except the years 1988 and 1992. Similarly, negative anomalies are observed from 2002–2007 except the year 2006, which is the major flood year in the country. Positive anomalies are observed from 1996–2001 and 2008–2016 except the year 2013. The proportion of positive and negative anomalies is equal and represents 50% of the total observations. The 2000s is wetter than the preceding decades for *Bega*.

Kiremt rainfall shows considerable inter-annual variations throughout the period of observation. Large proportion of negative anomalies is observed in *Kiremt* rainfall (56% of the total observations). Relatively, the 1990s is wet compared with the 1980 and 2000s. Drier conditions for *Belg* rainfall were experienced for the period 1986–1992 except the years 1989 and 1991. Wetter conditions for *Belg* were experienced for the period 1993–2000 except the year 1995 and 1998. Since 2007, positive anomalies are observed except the years 2010 and 2012. Positive and negative anomalies account for 56% and 44% of the total observations, respectively. The 1980s is the driest decade for *Belg*.

Standardized monthly rainfall anomalies were also computed for the wettest and driest periods to assess extents of wetness and dryness in the watershed. As shown in Table 1, the driest and wettest years over the

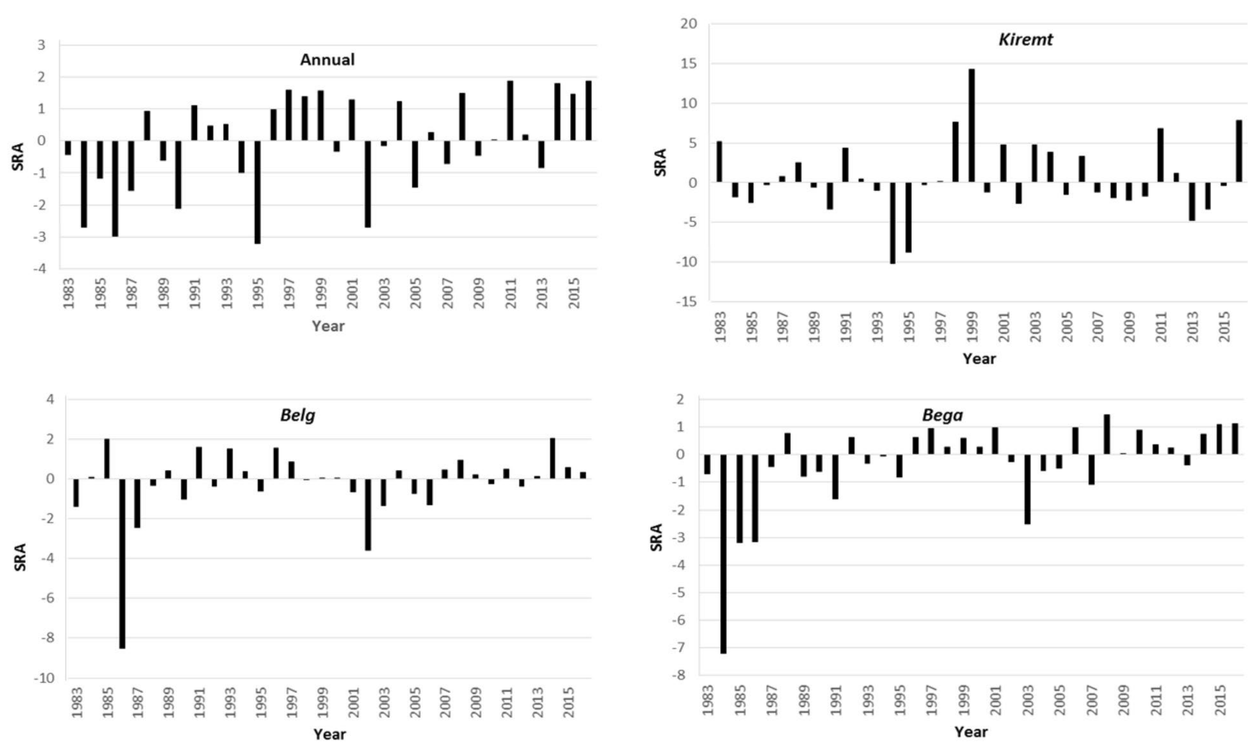

Fig. 3 Temporal variations in the seasonal and annual rainfall anomalies in Alwero watershed

period of observation are 1986 and 2011, respectively. In the driest period the highest and the lowest SRA values are 1.45 and − 1.25, respectively, while the highest and the lowest SRA values during the wettest period are 1.26 and − 1.19, respectively. The highest and the lowest SRA during driest years are observed during June and January, respectively. May and February observed the highest and the lowest SRA values during the wettest years. About 67% of observations showed below average rainfall during the driest period, but only 25% of the observations fall under the different drought categories. About 50% of the observations showed below average rainfall during the wettest period. From these, nearly 33% fall under the different drought categories. This shows that rainfall concentration is not uniform and few months remain dry even in years of good rain conditions.

Figure 4 and Table 2 show the spatial distribution of annual rainfall over the period of analysis. East and southeast part of the watershed receive high amount of annual rainfall. More than half of the watershed receives annual rainfall of 1550–1700 mm. Another large proportion of the watershed (26%) receives annual rainfall of between 1411 and 1550 mm. More than 20% of the watershed receives annual rainfall of between 1700 and 1850 mm. About 1% of the watershed receives annual rainfall of > 2000 mm. The spatial distribution of *Belg* and *Bega* seasons reveals similar pattern in which rainfall increases from west to east. Almost all parts of the lower sub watershed receive *Kiremt* rainfall > 950 mm over the period of observation. The northern part of the upper sub watershed receives *Kiremt* rainfall of 768–850 mm.

Trends in annual and seasonal rainfall in the upper (eastern) sub-watershed

Mean annual rainfall of upper sub-watershed is 1686.2 mm with coefficient of variation of 8.9% which

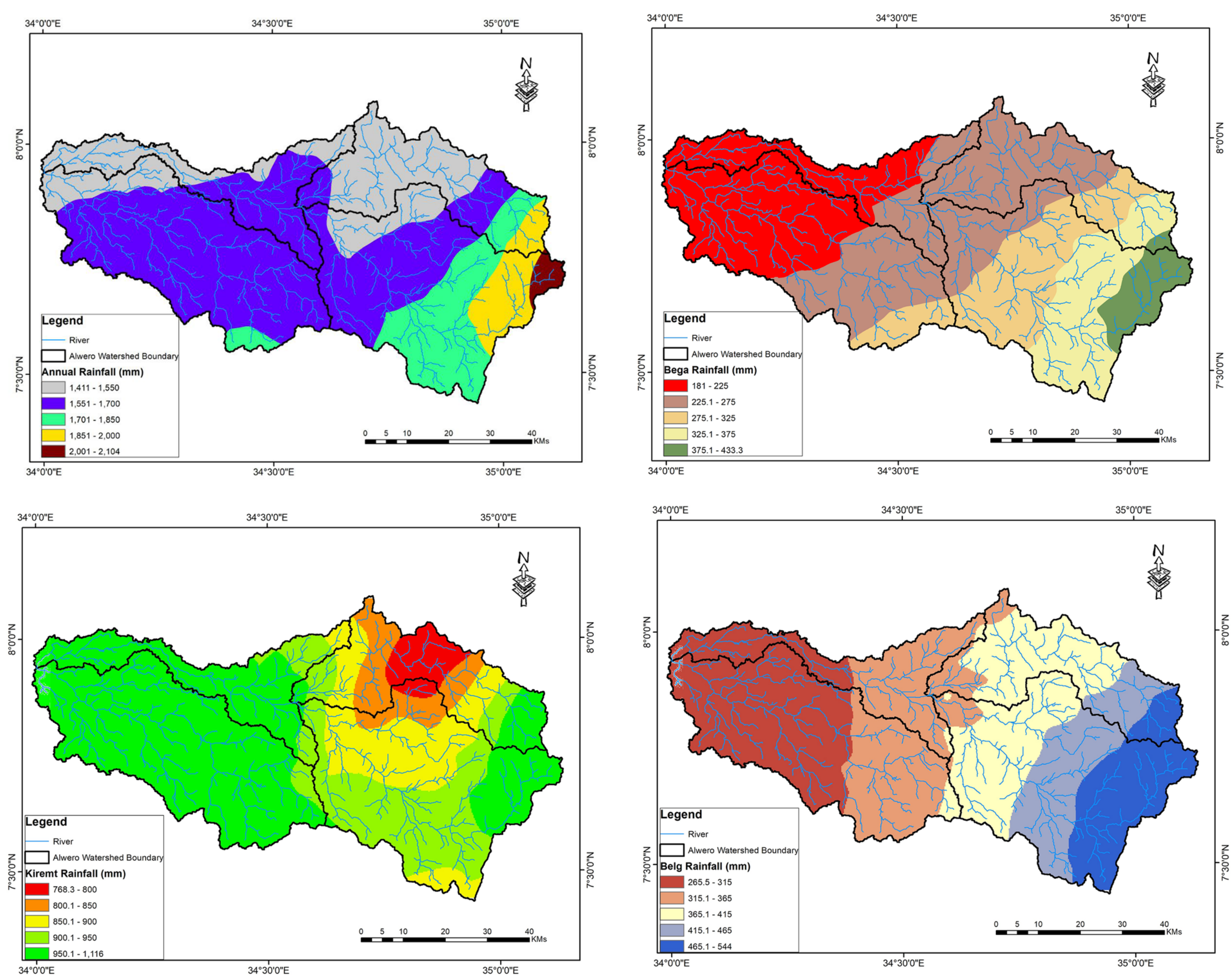

Fig. 4 Spatial distribution of annual and seasonal rainfall in Alwero watershed

Table 2 Rainfall distribution in Alwero watershed

Rainfall Class	Upper (eastern) sub-watershed		Lower (western) subwatershed		Alwero watershed	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
1411–1550 mm	77,962.5	28.6	54,650.0	22.7	132,612.5	25.8
1550–1700 mm	87,243.8	32.0	180,487.5	75.0	267,731.3	52.2
1700–1850 mm	68,800.0	25.3	5431.3	2.3	74,231.3	14.5
1850–2000 mm	32,131.3	11.8	0.0	0.0	32,131.3	6.3
2000–2104 mm	6318.8	2.3	0.0	0.0	6318.8	1.2
Total	272,456.3	100.0	240,568.8	100.0	513,025.0	100.0

shows low inter-annual variability. *Kiremt* and *Belg* rainfalls show low inter-annual variability of 9% and 19%, respectively. Only *Bega* rainfall shows moderate inter-annual variability with coefficient of variation of 24%. *Kiremt* rainfall contributes the largest to the annual rainfall (55%), which is followed by *Belg* (26%) and *Bega* (19%), respectively. The driest and wettest periods over the period of observation are 1986 (1419.3 mm) and 2016 (1987 mm), respectively. Annual rainfall shows statistically significant increasing trend at $p = 0.05$ level, while *Bega* rainfall also shows statistically significant increasing trend at $p = 0.01$ level. *Belg* and *Kiremt* rainfalls show statistically non-significant increasing and decreasing tendencies, respectively (Fig. 5).

More than 85% of the upper sub-watershed receives annual rainfall of between 1411 and 1850 mm. The other 12% of the upper sub-watershed receives annual rainfall of between 1850 and 2000 mm. The remaining 2% of the upper sub-watershed receives annual rainfall of > 2000 mm (Fig. 4 and Table 2).

Annual rainfall shows considerable inter-annual variations since 2000. Positive annual rainfall anomalies accounts for 50% of the total observations for the period 1983–2016. The 1980s is the driest decade. *Bega* rainfall anomalies show similar pattern with annual rainfall anomalies. Positive *Bega* rainfall anomalies accounts for 50% of the total observations. *Kiremt* rainfall shows considerable inter-annual variations throughout the period of observation. *Kiremt* rainfall has the smallest proportion of positive anomalies (44%). The 2000s is the driest decade. *Belg* rainfall shows considerable inter-annual variations. However, large proportion of positive rainfall anomalies is observed (56%). Since 2007 positive rainfall anomalies are observed except the years 2010 and 2012.

Trends in annual and seasonal rainfall in the lower (western) sub-watershed

Mean annual rainfall of the lower sub-watershed is 1600.6 mm. Annual rainfall shows low inter-annual variability (10.9%). *Kiremt* rainfall also shows low inter-annual variability (12.5%). *Belg* and *Bega* rainfalls show moderate inter-annual variability with coefficient of variation of 29 and 32%, respectively. *Kiremt* rainfall contributes the largest to the annual rainfall (67%). *Belg* and *Bega* contribute the remaining 19 and 14% of annual rainfall, respectively. The driest and wettest periods over the period of observation are 1995 (1179 mm) and 1991 (1857 mm), respectively. Annual and *Kiremt* rainfalls show statistically non-significant increasing trend, while *Bega* rainfall shows statistically significant increasing trend at $p = 0.01$ level (Fig. 5).

Large part of the lower sub-watershed (75%) receives annual rainfall of between 1411 and 1550 mm, and about 23% receives annual rainfall of between 1550 and 1700 mm. A small portion of the lower sub-watershed receives annual rainfall of between 1700 and 1850 mm (Fig. 4 and Table 2).

Annual rainfall shows considerable inter-annual variations from 1983–2009. Positive annual rainfall anomalies accounts for 59% of observations. The 2000s is the wettest decade. Positive anomalies are observed since 2007 except the year 2009. The 2000s is the driest decade for *Belg* and *Bega* rainfall. The proportion of positive and negative anomalies for *Belg* and *Bega* rainfalls are 44% and 56% of the observations, respectively. Positive anomalies for *Kiremt* rainfall account for 53% of observations. The 1990s is the wettest decade.

Temperature trends in Alwero watershed

In the watershed, the mean annual temperature is 25.0 °C. Over the study period, the lowest and highest mean annual temperatures are experienced in 2016. The lowest temperature is 14.5 °C (January) with standard deviation of 0.096 and coefficient of variation of 0.05. The highest temperature is 39.3 °C (March) with standard deviation of 0.1 and coefficient of variation of 0.03. Mean annual minimum temperature ranges from 16.7 °C (2001) to 18.5 °C (1984), and the long term mean is 17.5 °C with standard deviation of 0. 4 and coefficient of variation of 0.03. Mean annual maximum temperature ranges from

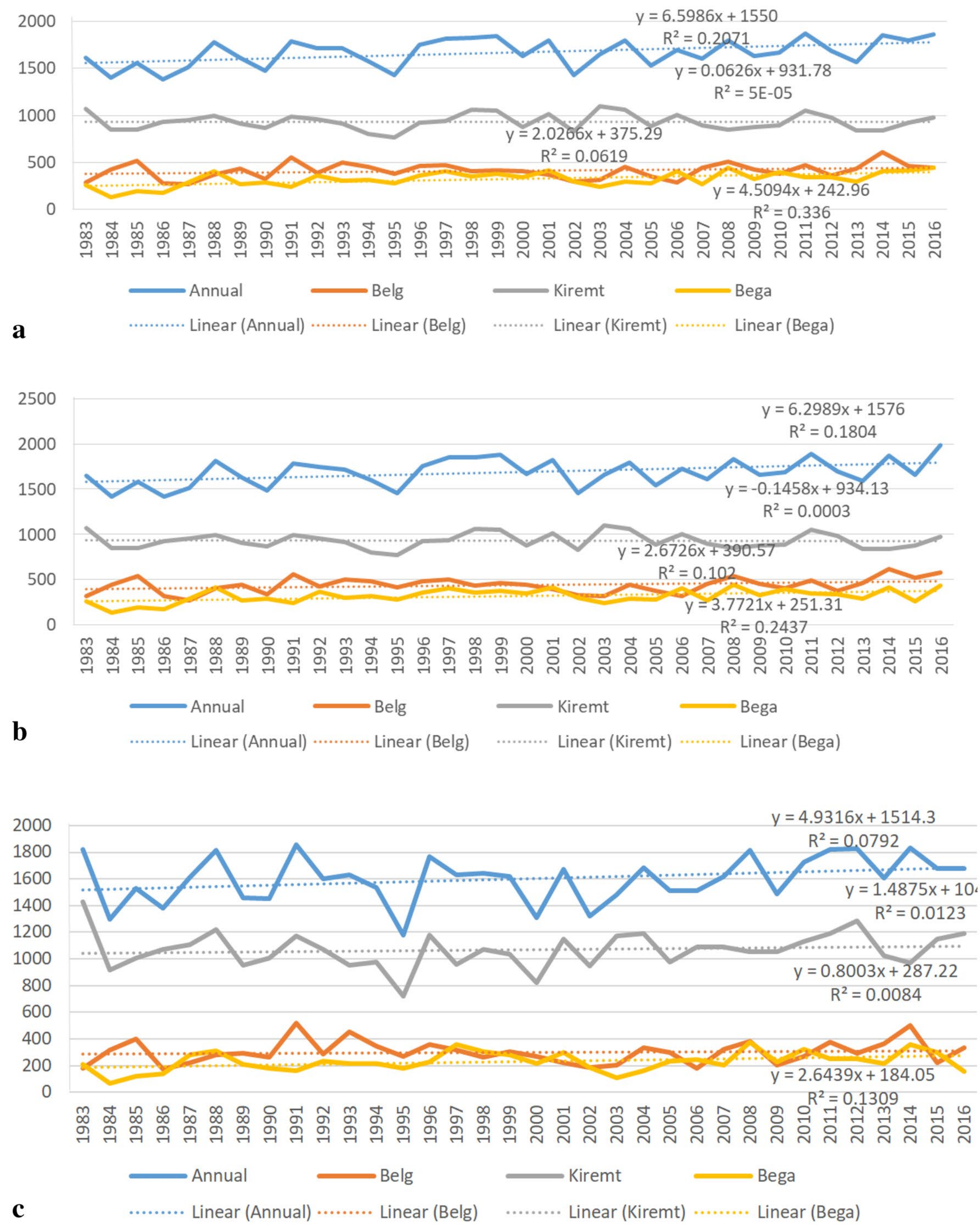

Fig. 5 **a** Trends of annual and seasonal rainfall in Alwero watershed. **b** Trends of annual and seasonal rainfall in the lower sub watershed. **c** The Trends of annual and seasonal rainfall in the upper sub watershed

31.4 °C (2008) to 33.2 °C (1999), and the long term mean is 32.5 °C with standard deviation of 0.46 and coefficient of variation of 0.01.

Unexpectedly, the mean annual minimum and maximum temperatures show statistically non-significant declining trends. Statistically non-significant but decreasing trends in all seasons are also observed in the minimum temperature. *Bega* season experienced statistically significant deceasing trend in the maximum temperature at $p = 0.01$ level. *Belg* season experienced statistically non-significant but decreasing trend in the maximum temperature. Statistically non-significant but increasing trend is also observed for the *Kiremt* (Table 3).

Our finding of declining trends in the mean maximum and minimum temperatures contradicts the results reported by NMA (2007), McSweeney et al. (2008), Taye and Zewdu (2012), Ayalew et al. (2012), Mengistu et al. (2013), Mekasha et al. (2014), Addisu et al. (2015), Alemayehu and Bewket (2017a), Asaminew et al. (2017), Suryabhagavan (2017), Haile et al. (2019) and Matewos and Tefera (2020) who reported warming trends in the minimum and maximum temperatures in different parts of the country. Our research is unable to explain this result.

Figure 6 shows the year-to-year variability in the mean annual minimum temperature. The 1980s was the warmest decade compared to the 1990 and 2000s. Positive and negative anomalies account for 38% and 62% of the total observations, respectively. Seasonal anomalies in the minimum temperature have similar patterns to anomalies in the annual minimum temperature. *Kiremt* season anomalies are positive since 2005 except the years 2008 and 2011. The maximum number of negative anomalies is observed in *Bega* season (59%).

The year-to-year variability in the mean annual maximum temperature is shown in Fig. 7. From 1998–2005 standardized anomalies are positive, and then negative

Table 3 Trends in annual and seasonal maximum and minimum temperatures in Alwero watershed

	Temperature (˚C)							
	Annual	**LT**	***Belg***	**LT**	***Bega***	**LT**	***Kiremt***	**LT**
Minimum	17.51	− 0.06	18.50	− 0.17	17.05	− 0.014	17.3	− 0.04
Maximum	32.46	− 0.01	34.45	− 0.09	33.17	− 0.24**	30.07	0.06

** Significant at 0.01 level; *LT* linear trend (˚C /10 yr)

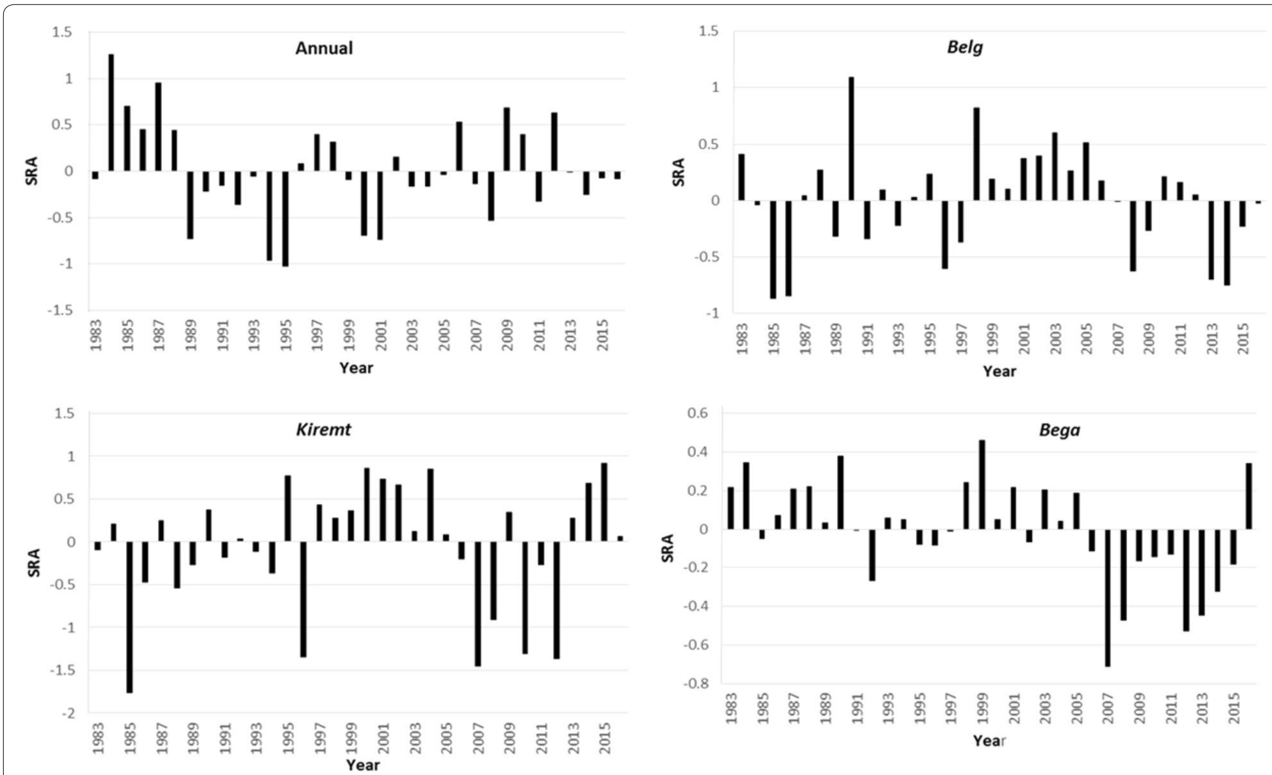

Fig. 6 Anomalies in the mean minimum temperature in Alwero watershed

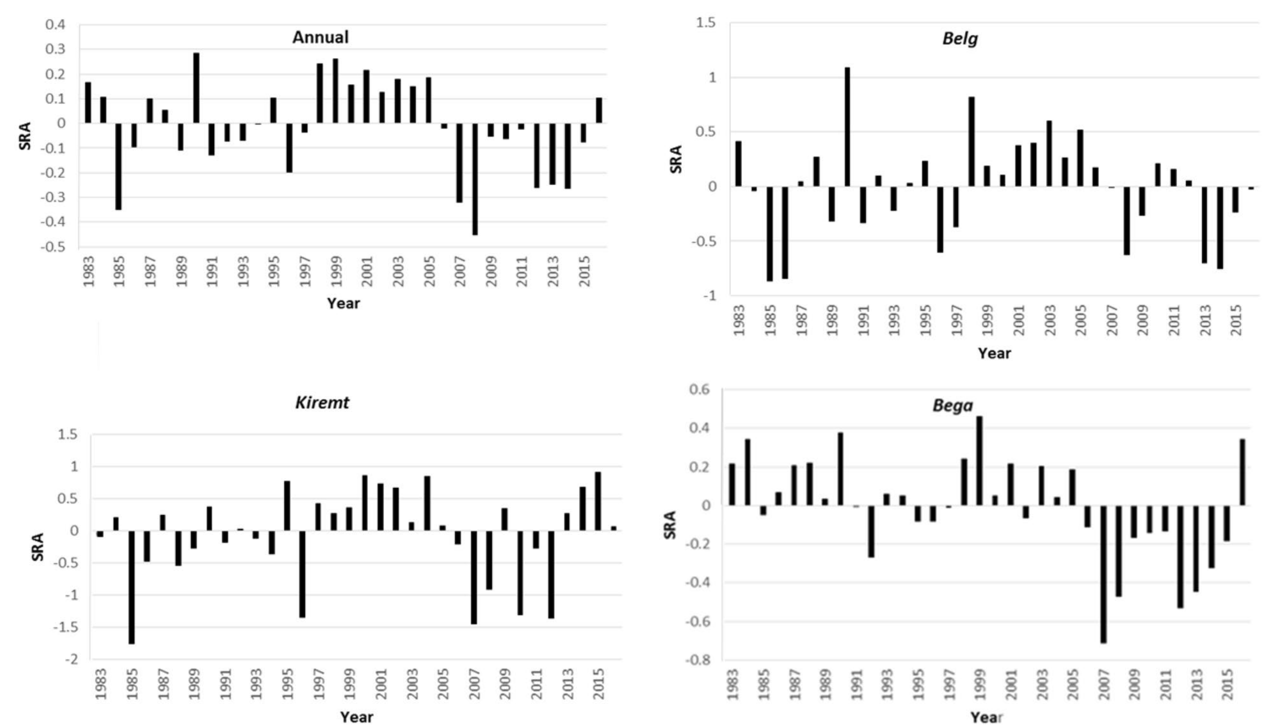

Fig. 7 Anomalies in the mean maximum temperature in Alwero watershed

since 2006 except 2016. Positive and negative anomalies account for 44 and 56% of the total observations, respectively. The 2000s are cooler than the preceding decade. Seasonal anomalies in the maximum temperatures have similar patterns to mean annual maximum temperatures. Seasonal negative temperature anomalies range from 44% (*Belg*) to 53% (*Bega*). Cooling conditions are observed for *Bega* season from 2006–2015.

Spatial patterns of temperature

Figure 8 shows the spatial distribution of mean maximum and minimum temperatures. The mean maximum and minimum temperatures decrease from west to east.

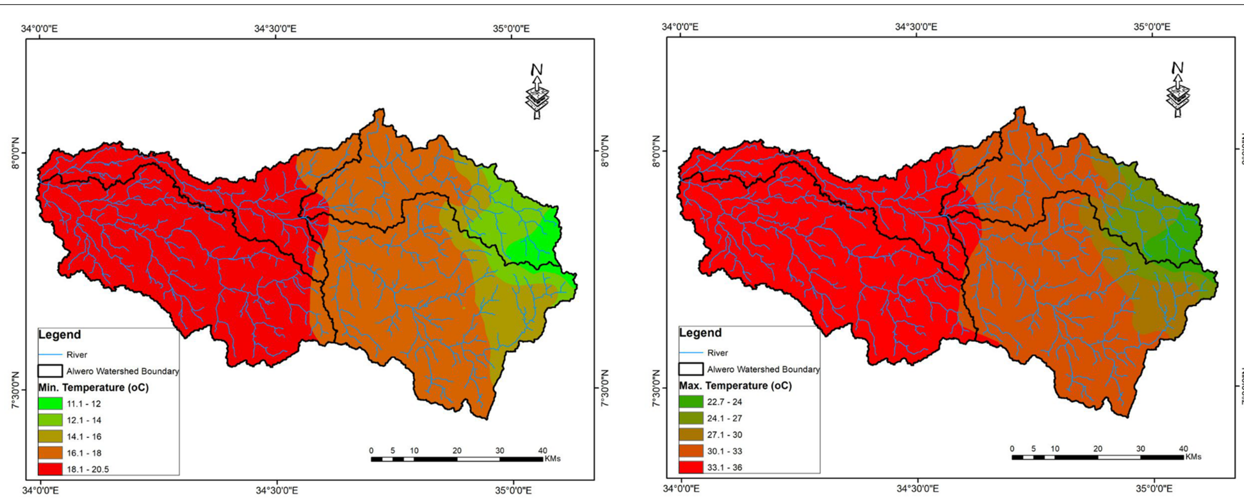

Fig. 8 Spatial distribution of maximum (left) and minimum (right) temperatures in Alwero watershed

Large proportion of Alwero watershed (44.5%) experiences mean minimum temperature of 18.1–20.5 °C. About 39.4% of the area experiences mean minimum temperature of 16.1–18 °C. A small proportion of the watershed (2.4%) experiences mean minimum temperature of 11.1–12 °C. About 47% of the watershed experiences mean maximum temperature of 33.1–36 °C. Another large proportion of the watershed (38%) experiences mean maximum temperature of 30.1–33 °C. Less than 3% of the watershed experiences maximum temperature of 22.7–24 °C.

Temperature trends in the upper (eastern) sub watershed

The mean annual temperature in the upper sub watershed varies from 22.53 °C (2008) to 23.81 °C (1984). The mean annual temperature over the period of observation is 23.25 °C with standard deviation of 0.31 °C and coefficient of variation of 0.01 °C. The highest mean maximum temperature is 31.04 °C (2016). Conversely, the lowest mean minimum temperature over the period of observation is 15.33 °C (1994). The mean annual and seasonal maximum temperatures show statistically significant declining trends except *Kiremt* season which shows statistically non-significant but increasing trend. The decreasing trend in *Bega* season is statistically significant at $p=0.05$ level. The deceasing trends in *Belg* season and annual maximum temperatures are significant at $p=0.1$ level. The mean annual and seasonal minimum temperatures show statistically non-significant declining trends except *Belg* season which shows statistically significant declining trend at $p=0.05$ level. Large part of the upper sub watershed (98%) experiences mean minimum temperature of 11–18 °C. The remaining 2% of the area experiences mean minimum temperature of 18.1–21 °C. Over 70% of the sub watershed experiences mean maximum temperature of 30–36 °C. The remaining part of the sub watershed experiences maximum temperature of 23–30 °C (Tables 4 and 5 and Fig. 9). Seasonal anomalies in the maximum and minimum temperatures have similar patterns to mean annual maximum and minimum temperatures of the respective watersheds.

Temperature trends in the lower (western) sub watershed

The mean annual temperature in the lower sub watershed ranges from 26.6 °C (2009) to 28.13 °C (1985). The mean annual temperature over the period of observation is 27.39 °C with standard deviation of 0.38 °C and coefficient of variation of 0.01 °C. The highest mean maximum temperature is 36.59 °C (1991). Conversely, the lowest mean minimum temperature in the lower sub watershed over the period of observation is 18.61 °C (1990). The mean annual and seasonal maximum temperatures show decreasing trends. The decreasing trends in *Bega* season and annual maximum temperatures are statistically significant at $p=0$ 01 and $p=0.05$ levels, respectively. The mean annual

Table 4 Minimum temperature distribution in Alwero watershed

Min temp class	Upper (eastern) sub watershed		Lower (western) sub watershed		Alwero watershed	
	Ha	%	Ha	%	Ha	%
11.1–12 °C	12,281.3	4.5	0.0	0.0	12,281.3	2.4
12.1–14 °C	28,681.3	10.5	0.0	0.0	28,681.3	5.6
14.1–16 °C	41,743.8	15.3	0.0	0.0	41,743.8	8.1
16.1–18 °C	184,081.3	67.6	17,887.5	7.4	201,968.8	39.4
18.1–20.5 °C	5668.8	2.1	222,681.3	92.6	228,350.0	44.5
Total	272,456.3	100.0	240,568.8	100.0	513,025.0	100.0

Table 5 Maximum temperature distribution in Alwero watershed

Max temp class	Upper (eastern) sub watershed		Lower (Western) sub watershed		Alwero watershed	
	Ha	%	Ha	%	Ha	%
22.7–24 °C	14,525.0	5.3	0.0	0.0	14,525.0	2.8
24.1–27 °C	28,931.3	10.6	0.0	0.0	28,931.3	5.6
27.1–30 °C	34,900.0	12.8	0.0	0.0	34,900.0	6.8
30.1–33 °C	183,287.5	67.3	9243.8	3.8	192,531.3	37.5
33.1–36 °C	10,812.5	4.0	231,325.0	96.2	242,137.5	47.2
Total	272,456.3	100.0	240,568.8	100.0	513,025.0	100.0

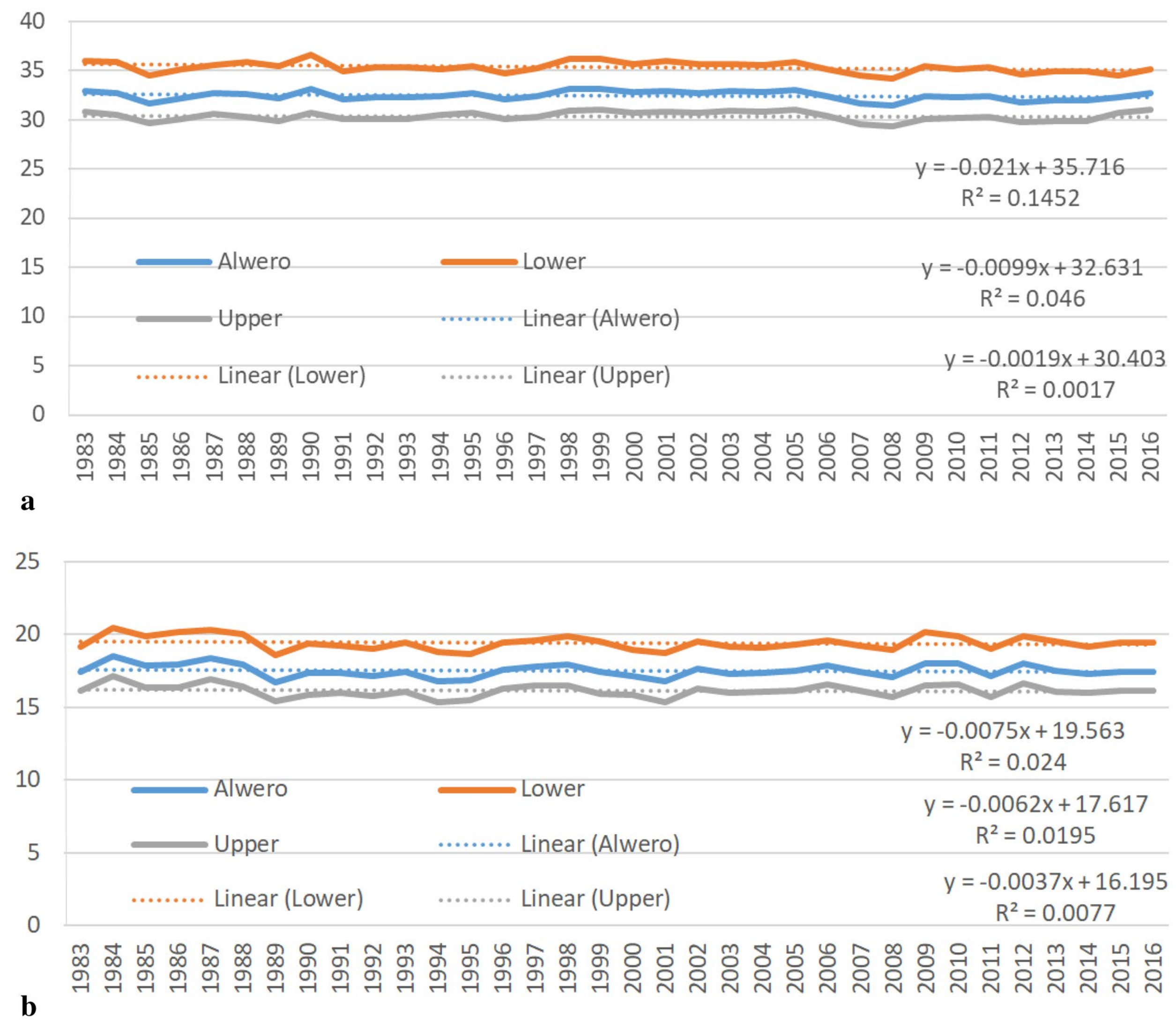

Fig. 9 **a** Annual trends in the mean minimum temperature. **b** Annual trends in the mean maximum temperature

and seasonal minimum temperatures show statistically non-significant declining trends except *Bega* season which shows statistically non-significant but increasing trend. Large proportion of the lower sub watershed (93%) experiences mean minimum temperature of 18–21 °C while the remaining 7% of the lower sub watershed experiences mean minimum temperature of 16–18 °C. Almost 96% of the area experiences mean maximum temperature of 33–36 °C. The remaining 4% of the lower sub watershed experiences mean maximum temperature of 30–33 °C (Tables 4 and 5 and Fig. 9).

The innovative element of this study is the use of gridded monthly rainfall and maximum and minimum temperature data series at a resolution of 4 × 4 km which are created by blending station records with meteorological satellite estimates. This is the best available dataset for the country recommended for climate analysis. The methodology used is well established, standard, proven, and widely used by many researchers. It has the advantage of making good results. However, the methodology and results are new to the study area. Our analysis focuses on local scale climatology and the findings are useful for climate risk management. The findings can be applicable to other parts of rural Ethiopia as well. In particular, the analysis is useful for irrigation and investment as the area is the largest agricultural investment hub in the country.

Conclusions

This study presents analysis of spatiotemporal variability and trends in rainfall and temperature in Alwero watershed, western Ethiopia. The key findings and conclusions are the following;

1. Mean annual rainfall of Alwero watershed is 1665.5 mm. More than half of the watershed receives annual rainfall of 1550–1700 mm. Annual and seasonal rainfall show low inter-annual variability except for *Bega* which shows moderate coefficient of variation. Annual and *Bega* rainfall shows statistically significant increasing trend at $p = 0.01$ level. *Belg* rainfall shows statistically non-significant increasing trend. There is no clear trend in *Kiremt* rainfall. Regarding monthly rainfall trends, May, November and October showed statistically significant increasing trends while March showed statistically significant decreasing trend. Positive and negative anomalies in annual rainfall account for 53% and 47% of the total observations, respectively. About 29% of the total observations is under the different drought categories. The 1990s is wet compared to the 1980 and 2000s.
2. The mean annual temperature of the watershed is 25 °C with a standard deviation of 0.31 and coefficient of variation of 0.01. In the watershed, mean annual minimum and maximum temperatures show statistically non-significant decreasing trends. The year-to-year variability in the mean annual minimum and maximum temperatures showed that the 2000s is cooler than the preceding decades. Seasonal anomalies in the mean minimum and maximum temperatures have similar patterns to mean annual minimum and maximum temperatures. The mean maximum and minimum temperatures decrease from west to east. Large proportion of Alwero watershed (44.5%) experiences mean minimum temperature of 18.1–20.5 °C. Another large proportion of the watershed (38%) experiences mean maximum temperature of 30.1–33 °C.
3. Overall, it is shown that climatic variability and trends are highly localized in the country; hence local level studies such as this are important for practical decision making in agriculture, water management, and climate change adaptation planning.

Abbreviation
NMA: National Meteorological Agency.

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Authors' contributions
MM has made substantial contributions in conception of the research, acquisition of data and preparation of maps. AA interpreted the results and drafted the manuscript. WB and MA reviewed, edited and shaped the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets used in the study are available in the National Meteorological Agency (NMA) of Ethiopia repository. Access to NMA data can be allowed based on justifiable request. However, the datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
No potential conflict of interest was reported by the authors.

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