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Research article

Evidences of climate change presences in the wettest parts of southwest Ethiopia

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ABSTRACT

Climate change has been identified as a major challenge of rainfed agriculture. To contextualize whether there is climate change footprint, identification of rainfall and temperature trend at regional and local scale is helpful for designing long-term adaptation and mitigation strategies. The present study therefore aims to assess evidences of climate change presences in terms of, climate variability and trend in the wettest parts of Southwest Ethiopia. Daily and monthly historical gridded rainfall and temperature data (1983–2016) of ten stations were provided by Ethiopian National Metrological Agency. Moreover, long years historical recorded climate data of Nekemte and Bedele (1971–2020) and Sekoru (1981–2020) were used in the present study. Coefficient of variation, the Mann-Kendall non-parametric statistical test and Sen's slope estimator, linear regression analysis and the precipitation concentration index were applied to detect the presence of climate change in the southwest parts of Ethiopia. In this study, the trend package of open R software employed for trend identification and rate of change per year. The results indicate that the annual rainfall has declining trend at five stations with statistically significant at one station while the mean maximum and minimum temperature shows a statistically significant increasing trend at eight and six stations, respectively. At a seasonal scale, the amount of rainfall in the main rainy season (June to August) is dominated by a downward trend (eight out of ten stations) while, the autumn season (September to November) shows an increasing trend in all stations with statistically significant at one station. The precipitation concentration index analysis revealed that inconsistent and significantly irregular precipitation is observed at six stations (60%) of the ten stations. This study concludes that the climate of the wettest parts of Ethiopia is getting warmer and the amount of rainfall in the main rainy season has declined in the vast majority of the study area.

1. Introduction

Climate change is one of the critical global problems since the beginning of industrial revolution (Shakhashiri and Bell, 2014; Zandalinas et al., 2021) which has attributed to the increasing trend of carbon dioxide and other greenhouse gases (GHGs) in the atmosphere. The problem is particularly critical within the farming communities (Hein et al., 2019); whose livelihoods are heavily dependent on well-being of seasonal climatic conditions. Climate change has been considered as a major threat to smallholder farmers in Africa (Mubiru et al., 2018; Makate, 2019; Naab et al., 2019). For instance, drought severity, which is one of the indicators of climate change fundamentally influences the farming systems (Potopova et al., 2015). The impact of climate change in altering livelihood sustaining ecosystems has been clearly demonstrated (Nematchoua et al., 2019).

The 20th century has been recognized as the warmest of the millennium and the global surface temperature has risen by about 0.6 °C (Anastasiadis, 2005). Other scholars also confirmed that the 20th century was likely the warmest of the millennium and the global surface temperature rose by about 0.72 °C to 0.85 °C (Nyboer et al., 2019). The Intergovernmental Panel on Climate Change (IPCC) fifth assessment report (AR5), projected that the global surface temperature is likely exceed 1.5 °C by the end of the 21st century based on RCP4.5, RCP6.0 and RCP8.5 scenarios (IPCC, 2014). As reported by McMichael et al. (2006) and Hoegh-Guldberg and Bruno (2010) excess GHGs emissions will cause an increase in mean temperature by 1.4–5.8 °C by the end of the 21st century. Such increment in global temperature has adversely impacted food security globally (IPCC, 2014). It is projected that the global mean daily temperature will rise by 2.5–3.2 °C by 2100 (Adu et al., 2018). Recent global climate projections by Masroor et al. (2020) reported that

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the mean global mean temperature would increase by 4 °C by 2100. Recent study by Tan et al. (2020) indicates that both extreme and severe drought as well wet scenarios incidences is expected in the near future over east Africa.

The trend of rainfall in Ethiopia is not uniform throughout the country. Some studies reported a decreasing trend in seasonal and annual rainfall (Hill and Porter, 2017; Asfaw et al., 2018). Conversely, other studies have reported increasing trend in annual rainfall (Gemeda, 2019; Hundera et al., 2019; Tesfamariam et al., 2019; Wedajo et al., 2019). Other studies found both an increasing and decreasing rainfall trend in different areas (Cheung et al., 2008; Omondi et al., 2014; Eshetu et al., 2018; Gebrechorkos et al., 2018; Degefie et al., 2019). Moreover, the number of rainy months declined in southwestern parts of the country. Study by Fekadu et al. (2020) indicated that the number of rainy months in the coffee growing region of southwest has declined by 50%; from 9 to 5.5 months. Increasing temperature trend and fluctuation were also reported in different parts of Ethiopia (Kassie et al., 2015; Abebe, 2017; Ademe et al., 2020; Matewos, 2020). According to Abebe (2017), the mean annual temperature increased by 1.65 °C between 1955 and 2015. An increasing trend of temperature was projected in all regions of Ethiopia, with annual warming of 2.2 °C (with a range of 1.4–2.9 °C) by the 2050s (Conway and Schipper, 2011).

Climate change significantly affects the major cash crops in southwestern parts of Ethiopia. For instance, the yield of *Aframomum corrorima* (Braun), a native spice crop to Ethiopia was declined by 49% between 1988 and 2018 and is likely to decline further by 84% before 2050 (Fekadu et al., 2020). Declining of bioclimate suitability for indigenous Arabica coffee (*Coffea arabica* L.) in the wettest and coffee growing landscape of Ethiopia is another shocking and alerting climate change related impacts (Davis et al., 2012; Moat et al., 2017). Specifically, Davis et al. (2012) reported that climate suitability of the coffee growing landscape declined by 65% and projected to decline almost by 100% in 2080. Niang et al. (2014) indicates that the warming of the highland area of Arabic coffee producing regions becoming a serious threat by coffee berry borer (*Hypothenemus hampei*) pests. Yang et al. (2020) highlighted that increasing temperature trends across Ethiopia has had a negative effect on crop production. The calibrated crop model across Ethiopia over the past four decades shows that climate change has led to a decreasing trend in wheat production (Yang et al., 2020).

The significant impact of climate change on agricultural yield has been clearly documented (Kassie et al., 2015; Randell and Gray, 2016; Escarcha et al., 2018; Rahut and Ali, 2018; Aggarwal et al., 2019). This loss and decline in yield results in food insecurity (Kahiluoto et al., 2012; Thornton et al., 2014; Zhao et al., 2018; Aniah et al., 2019). Bryan et al. (2013) predicted that African key stable crops is likely declines by 8–22% by 2050 due to climate change. This is as a result of heavy dependency on rain-fed agriculture in Africa, which makes the continent more vulnerable to the impacts of climate change (Baarsch et al., 2020; Dumenu and Tiamgne, 2020). All sectors and individuals are not equally affected by climate change. The level of impact may be determined by the level of technological and institutional capacities and type of economy, which the people rely on. The level of climate change impacts varies across different social groups. According to Paul et al. (2019), the poor, young, elderly and marginalized people are highly vulnerable to climate change due to poor adaptive capacity.

There is a limited research studies concerning the existence of climate change in the highland areas of Ethiopia. In the past, climate change has been considered as a problem of pastoral and semi-pastoral areas around the lowland areas of the country. However, few studies (Davis et al., 2012; Ayal and Filho, 2017; Fekadu et al., 2020) revealed that climate change is happening over the highland areas in the southwestern parts of Ethiopia. Better understanding of climate change in the southwest part of Ethiopia, where there are presence of tropical rainforests (Korecha, 2014) is required to urgently put in place anticipatory adaptation strategies. This knowledge gap needs to be addressed by scholars and stakeholders. Substantial literature on climate change trends and its anticipated impacts has influenced scholars and decision makers to better understand the current and anticipated potential impacts of climate change. Moreover, climate change assessment is crucial to propose appropriate adaptation and mitigation strategies. This study presents the evidences of climate change presences in the wettest parts of southwest Ethiopia, which is expected to lay a scientific ground for policy makers to take new actions or adjusting the existing climate change adaptation or mitigation strategies.

2. Materials and methods

2.1. Study area

The study area is located in the wettest parts of Oromia National Regional State (Oromia), the largest national regional state in Ethiopia. In the present study, climate change, variability and trends in 5 zones of western Oromia; namely: Jimma, Buno Bedele, East Wollega, West Wollega, and West Shewa zone, were examined in this study (Figure 1). Oromia is the largest and most populous region in Ethiopia (Belcore et al., 2017), which consists of 20 administrative zones. The study area is located between 7.25ºN and 10.40ºN and 34.35ºE and 38.57ºE.

The study area has a diversified landscape, which result in elevation varies between 702.5 to 3372.6m.a.s.l (Figure 2). This topographic difference results in variations of rainfall and temperature across space and time. The study area is largely characterized by a tropical highland subhumid zone followed by tropical highland humid zone and sub-humid zone climate (Yang et al., 2020). The study area experiences a unimodal rainfall brought by wind from both Indian and Atlantic oceans and receives maximum rainfall between June and September (Korecha and Barnston, 2006). The study area is dominated by a single growing period [National Meteorological Services Agency (NMSA, 1996)]. Arabica coffee, the country main export crop grows naturally grows in the moist evergreen montane forests of southwest Ethiopia (Geeraert et al., 2019).

2.2. Data sources and analysis

Daily and monthly blended (gridded) rainfall and temperature data (1983–2016) of ten stations: Sekoru, Serbo, Bedele, Didesa Dildey, Arjo, Nekemte, Gimbi, Bako, Bako Tibe and Gedo were obtained from the National Meteorological Agency (NMA) of Ethiopia. In addition to gridded data, long years' historical recorded data from Bedele and Nekemte (1971–2020) and Sekoru (1981–2020) were used for linear regression analysis. In this study, both R software package version 4.0.3 and ArcGIS 10.3 were used for historical rainfall and temperature data analysis. The upward and downward tendency is calculated using the non-parametric Mann-Kendall test (Mann, 1945; Kendall, 1975) and its significance of change in both rainfall and temperature data was calculated using trend package of R software as previously used by Pohlert (2016), Gebrechorkos et al. (2018, 2019). ArcGIS application tool, the inverse distance weighted (IDW) spatial-interpolation method was used to demonstrate spatiotemporal distributions of annual rainfall, maximum and minimum temperature over the study area (Suryabhagavan, 2017; Umar et al., 2019).

In addition to Mann-Kendall and Sen's slope estimator, the linear regression analysis was used to quantify the trends of long-term historical recorded (rainfall and temperature) data for Bedele and Nekemete (1971–2020) and Sekoru (1981–2020). This test has been used by various researchers to analyze the trends of temperature and rainfall (Nyatuame et al., 2014; Jaiswal et al., 2015; Chepkoech et al., 2018; Tirkey et al., 2018; Asare-Nuamah and Botchway, 2019). To run the linear regression analysis test, a straight line was fitted to either rainfall or temperature data. In this test, the independent variable (X) was the year and the dependent variables (Y) were annual rainfall and annual mean temperature data. Furthermore, trends lines for annual and seasonal scale were calculated and the coefficient of determination (R^2) (Pallant, 2016) indicated the association between climate variables (rainfall and temperature) and year.

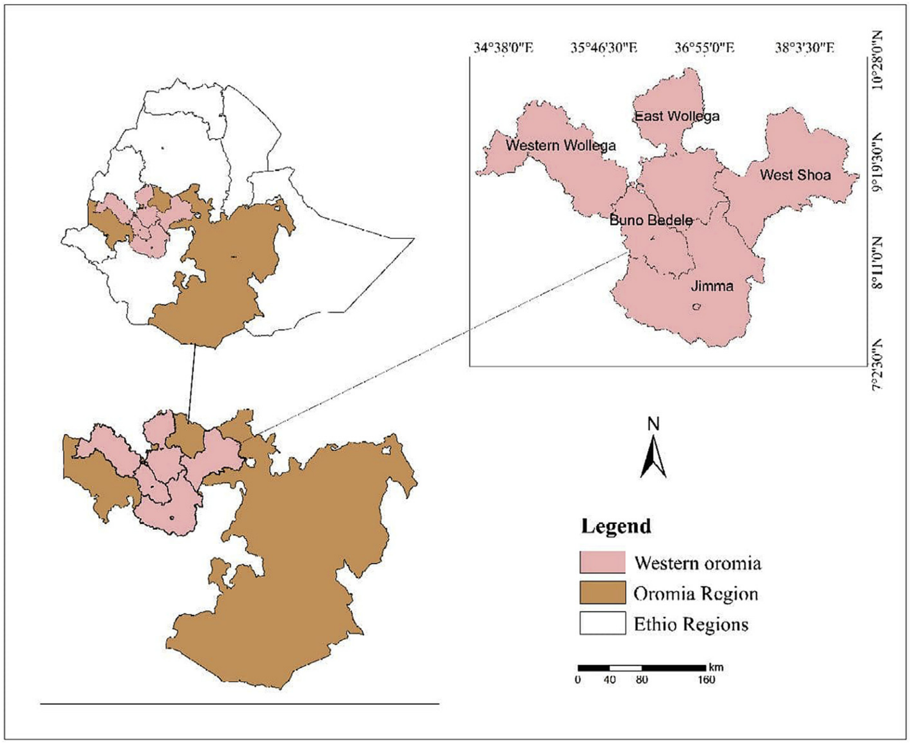

Figure 1. Map of the study area.

2.2.1. *Coefficient of variation*

The coefficient of variation (CV) was computed as the ratio of standard deviation (SD) to the mean in a given time-series as used by (Ademe et al., 2020) to quantify the extent of variability, which is expressed as a percentage. The CV values are classified as follows: if CV < 20 it is low variability, if $20 < \text{CV} < 30$, it is moderately variability, if CV > 30, it is strong variability (Hare, 2003).

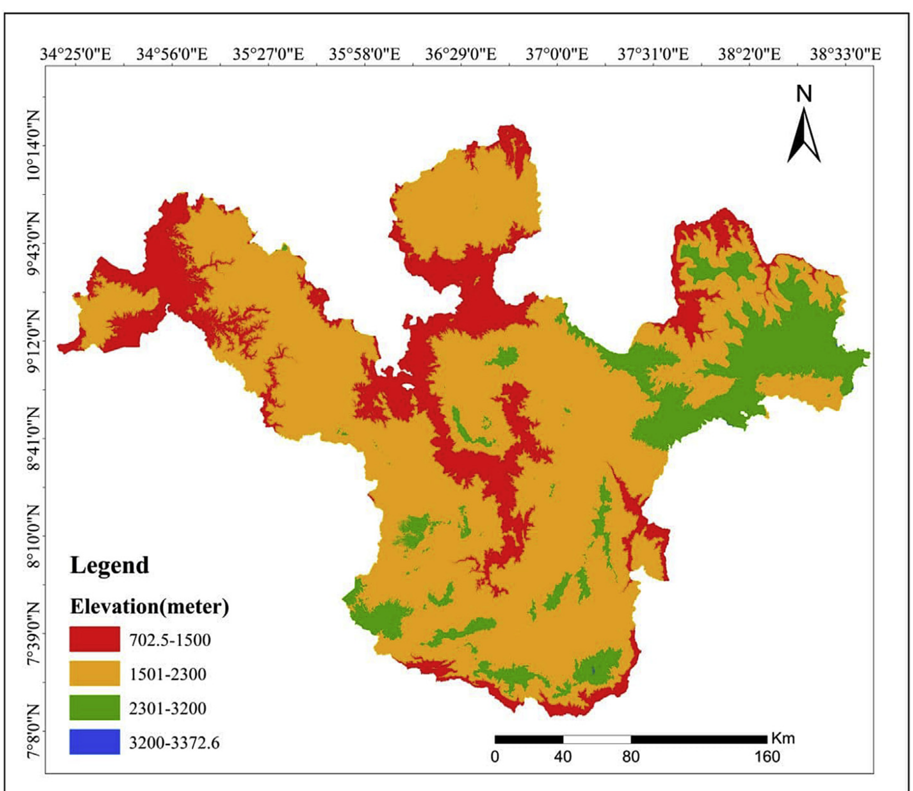

Figure 2. Topography of the study area.

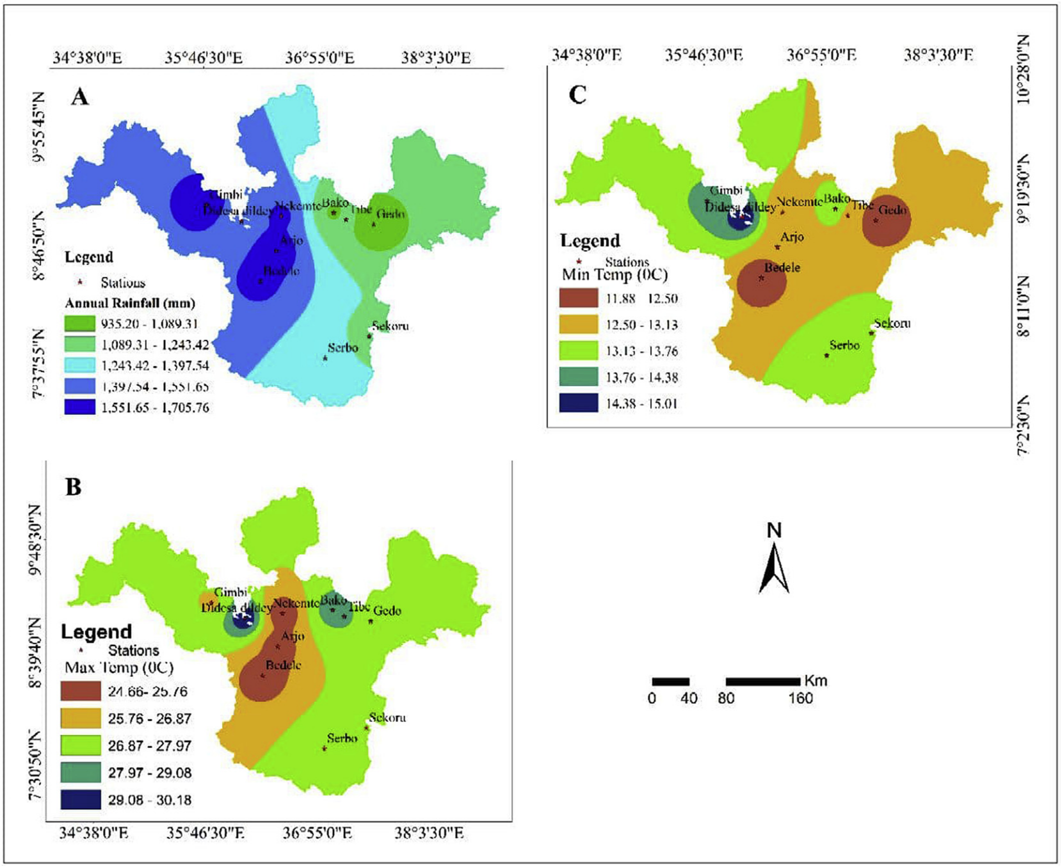

Figure 3. Spatial distribution of mean annual rainfall (A), mean maximum temperature (B) and mean minimum temperature (C) during 1983–2016.

2.2.2. *Precipitation concentration index (PCI)*

The PCI (Oliver, 1980) was adopted to quantify rainfall distribution and its heterogeneity pattern. Recently, this index is widely used (de Luis et al., 2011; Ademe et al., 2020; Guo et al., 2020; Shawul and Chakma, 2020). Michiels et al. (1992) classified the PCI values as low precipitation concentration or uniform (PCI≤10), moderate precipitation distribution (PCI11–15), irregular precipitation distribution (PCI16–20), and strongly concentrated/strongly irregular distribution (PCI>20). The annual PCI was computed as Eq. (1).

$$PCI_j = 100\,\frac{\sum_{i=1}^{12} Pij^2}{Pj^2} \tag{1}$$

where PCIj is the precipitation concentration index for year j, expressed as percent; P_{ij} is the precipitation of month i in the year j; and P_j is the annual precipitation in the year j.

2.2.3. *Mann-Kendall test*

The non-parametric Mann-Kendall test statistics 'S' developed by Mann (1945) and Kendall (1975) was adopted to analyzed the climate trend and calculated using Eq. (2).

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\left(X_j - X_k\right) \tag{2}$$

Where S is the Mann-Kendall's test statistics: X_i and X_k are sequential data values for the time series data of length n.

$$sgn\,(Xj - Xk) = \begin{cases} +1, \; if \; (Xj > Xk) > 0 \\ 0, \; if \; (Xj > Xk) = \; 0 \\ -1, \; if \; (Xj > Xk) < 0 \end{cases} \tag{3}$$

$$Zs = \begin{cases} \dfrac{S-1}{\sqrt{var\,(S)}} & , \; if \; S > 0 \\ 0, & if \; S = 0 \\ \dfrac{S+1}{\sqrt{var\,(S)}} & if \; S < 0 \end{cases} \tag{4}$$

A positive Zs value indicates an increasing trend, while a negative Zs value shows a decreasing trend (Shi et al., 2013; Deng et al., 2018; Adeyeri et al., 2019; Incoom et al., 2020), and 0 values indicate no trend. In the present study, both the null hypothesis (Ho) and the alternative hypothesis (H1) were used to check a trend in the time series. The Ho indicates that there is no trend (random variables) in the time-series, while the H1 states that, there is a possibility of bi-directional changes (Li et al., 2012). In the present study, Ho is rejected if Zs value is > 1.96 ($\alpha = 0.05$) at 5% significance level.

2.2.4. *Sen's method*

Sen's non-parametric method developed by Sen (1968) was adopted to quantify the change and the magnitude of a trend, and calculated as follows:

$$f(t) = Qt + B \tag{5}$$

where f(t), the estimated data at t year, Q is slope of trend line and, B is constant. Then the slope Q is estimated as Eq. (6).

$$Qi = \frac{Xj - Xk}{j - k} \; where \, j > k \tag{6}$$

Table 1. Statistics of annual rainfall and temperature series of 10 stations (1983–2016).

Station	Coordinate			Annual rainfall (mm)			Max. Temp (°C)			Min. Temp (°C)		
	Lat.	Long.	Altitude	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Sekoru	7.92	37.42	1910	1179	1455	877	27.7	29.0	26.6	13.5	14.3	12.0
Serbo	7.42	36.58	1793	1311	1686	879	27.6	29.1	26.3	13.5	14.4	11.9
Bedele	8.27	36.20	2016	1600	2101	1113	24.9	26.2	23.9	11.9	12.6	10.5
Didesa Dildey	9.10	36.06	1230	1426	1903	965	30.2	30.8	29.5	15.0	15.7	14.2
Arjo	8.45	36.30	2482	1702	2300	1177	25.0	25.9	23.8	12.6	13.2	11.2
Nekemte	9.09	36.54	2100	1591	1978	1117	24.6	25.5	23.4	12.5	13.1	11.8
Gimbi	9.17	35.78	1900	1638	2181	1257	26.7	27.3	25.3	13.8	14.6	13.0
Bako	9.07	37.03	1650	1066	1372	741	28.7	30.2	26.8	13.6	15.2	12.4
Bako Tibe	9.05	37.17	1706	1106	1487	733	28.0	29.7	25.9	12.9	14.3	11.5
Gedo	9.02	37.45	2500	935	1409	606	27.3	29.1	24.9	11.9	13.5	10.5

Table 2. Average annual and seasonal rainfall characteristics (1983–2016).

Station	Annual (mm)	CV (%)	Summer mm (%)	CV (%)	Autumn mm (%)	CV (%)	Winter mm (%)	CV (%)	Spring mm (%)	CV (%)
Sekoru	1179	14	620 (52)	16	222 (19)	33	58 (5)	86	279 (24)	33
Serbo	1311	15	537 (41)	18	332 (25)	33	73 (6)	61	370 (28)	22
Bedele	1600	15	828 (51.8)	12	407 (25.4)	30	32 (2)	88	333 (20.8)	30
Didesadildey	1426	17	800 (56)	15	356 (25)	32	8 (1)	134	262 (18)	42
Arjo	1702	15	866 (50.9)	12	433 (25.4)	29	39 (2.3)	80	363 (21.4)	33
Nekemte	1591	13	908 (57.1)	12	349 (21.9)	26	25 (1.6)	95	309 (19.4)	36
Gimbi	1638	14	945 (57.7)	12	408 (24.9)	31	10 (0.6)	176	275 (16.8)	43
Bako	1066	15	642 (60)	18	202 (19)	38	17 (2)	102	205 (19)	35
Bako Tibe	1106	16	666 (60)	13	211 (19)	38	19 (2)	103	210 (19)	42
Gedo	935	21	540 (58)	20	181 (19)	30	25 (3)	105	189 (20)	53

where Qi is Sen's slope estimator, Xj and Xk are the data values at times j and k (j > k), respectively. The median of these N values Qi is represented as Sen's slope estimator and calculated as Eq. (7).

$$Sen' sestimator = \begin{cases} \frac{Q(R+1)}{2} \text{ if } R \text{ is odd} \\ 0.5 * \left(\frac{QR}{2} + \frac{Q(R+2)}{2}\right) \text{if } R \text{ is even} \end{cases} \tag{7}$$

A negative and positive value of Sen's estimator indicates a downward and an upward trend in the time series analysis, respectively (Gao et al., 2020).

3. Results and discussion

3.1. Spatial distribution of rainfall and temperature

The average annual rainfall, maximum and minimum temperature over the past 34 years in the study area is presented. The annual rainfall decreases from the west to the eastern parts with a high concentration in the central and western parts of the study area (Figure 3A). The spatial distribution map shows that there is an inverse relationship between maximum annual rainfall and maximum temperature. The mean maximum temperature varied between 24.6 and 30.2 degree centigradeand higher mean maximum temperature was detected around Didesa Dildey (Figure 3B). The mean minimum temperature in the study area varies from 12 to 15 degree centigrade and lower mean minimum temperature was observed around Bedele and Gedo stations (Figure 3C).

3.2. Temporal distribution and trends of rainfall and temperature

Table 1 shows the mean annual rainfall, maximum and minimum temperature of ten stations from 1983 to 2016. The amount of annual rainfall varied from 1702 mm at Arjo station to 935 mm at Gedo station with an average of 1355.4 mm for the 10 stations. Local spatial variations of rainfall during the main rainy season are common across the country (Taye et al., 2021). Moreover, Suryabhagavan (2017) concluded that inter-annual rainfall variability is a common phenomenon in different parts of Ethiopia. Likewise, inter-annual variability of temperature is more persistent than rainfall variability. For instance, the mean maximum temperature varied from 30.2 °C at Didesa Dildey to 24.6 at Nekemte, while the mean minimum temperature varied between 15 °C at Didesa Dildey to 11.9 °C at Bedele and Gedo stations. These results show both maximum and minimum temperature were significantly varied across the region.

There was a low variability of annual rainfall over the study area (Table 2). With the exception of Gedo (CV = 21), Didesa Dildey (CV = 17), and Bako Tibe (CV = 16), the other stations showed a comparable CV. Studies conducted in different parts of the country show that the CV

Table 3. Annual rainfall trends: MK-test and Sen's slope estimator (1983–2016).

Trend	Sekoru	Serbo	Bedele	Didesa Dildey	Arjo	Nekemte	Gimbi	Bako Tibe	Bako	Gedo
Z_s	*-2.22	-1.35	1.79	0.09	1.30	*2.71	1.07	-0.87	-0.35	-0.19
P	0.02	0.17	0.07	0.93	0.19	0.01	0.29	0.38	0.72	0.85
Sen's	-6.6	-4.7	8.6	0.4	4.9	9.4	5.2	-2.1	-1.1	-0.6

Note: *statistically significant at Zs > 1.96 (α = 0.05) at 5% level of significance.

Table 4. Seasonal rainfall trend (1983–2016).

Site name	Summer			Autumn			Winter			Spring		
	Zs	*P*	Sen's	Zs	*P*	Sen's	Zs	*P*	Sen's	Zs	*P*	Sen's
Sekoru	*-2.22	0.02	-4.0	0.28	0.77	0.4	-1.91	0.05	-1.2	-0.56	0.57	-1.1
Serbo	-1.53	0.13	-2.5	0.50	0.61	1.3	-1.36	0.17	-1.4	-0.93	0.35	-1.4
Bedele	1.02	0.30	2.2	0.90	0.36	2.8	-0.60	0.54	-0.1	*2.12	0.03	2.9
Didesa Dildey	-0.85	0.40	-2.4	0.90	0.37	1.6	-0.88	0.38	0.0	0.87	0.38	2.2
Arjo	-0.30	0.77	0.8	1.41	0.16	3.3	-0.47	0.64	-0.3	1.65	0.10	3.2
Nekemte	0.71	0.48	1.3	*2.13	0.03	4.0	-0.50	0.58	-0.1	1.78	0.07	2.9
Gimbi	-0.56	0.57	-1.0	1.19	0.24	2.9	0.62	0.54	0.0	1.65	0.10	3.1
Bako Tibe	-1.04	0.30	-1.8	0.15	0.88	0.2	-1.12	0.26	-0.3	-0.64	0.52	-0.9
Bako	-0.35	0.72	-0.7	0.07	0.94	0.1	*-2.12	0.03	-0.4	-0.91	0.36	-1.2
Gedo	-0.06	0.95	-0.2	0.71	0.47	0.6	*-2.47	0.01	-0.9	-0.34	0.73	-0.5

Note: *statistically significant at Zs > 1.96 (α = 0.05) at 5% level of significance.

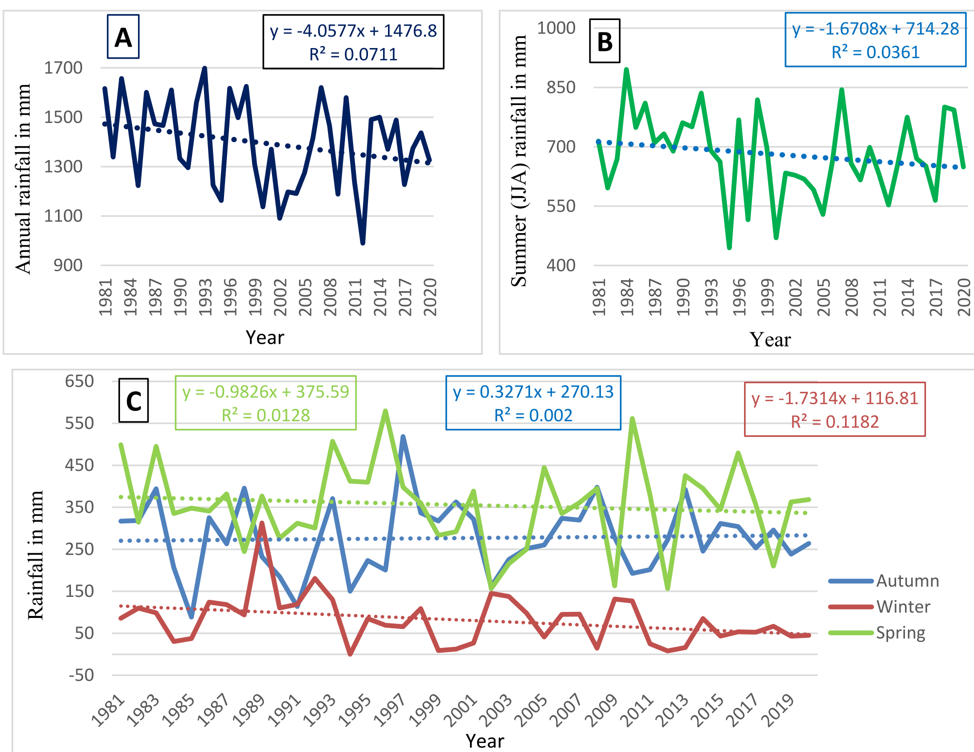

Figure 4. Local climate change evidences: (A) annual rainfall trend (B) summer rainfall trend and (C) autumn, winter & spring rainfall trend observed in Sekoru from 1981-2020.

values for annual rainfall is less than 20 (Ayal and Filho, 2017; Asfaw et al., 2018; Ademe et al., 2020; Gemeda et al., 2020). The results showed that the main rainy season (June to August: JJA) contributed the most to the total annual rainfall. It accounted for more than 50% of the annual rainfall for all the stations except at Serbo where the main rainy season contributed only 41% of the total annual rainfall. In addition to JJA, the study area received a substantial amount of rainfall in autumn (SON) and spring (MAM), while the amount of rainfall in winter season (DJF) is very small, which is consistent with the results of Gemeda et al. (2020) and Dessu et al. (2020). In winter season (DJF), the CV varies from 61 at Serbo to 176 at Gimbi, whereas, in spring season the CV varied between 22 at Serbo and 53 at Gedo. During autumn, the CV ranged from 26 to 38.

3.2.1. Annual rainfall trend and rate of change

The Mann-Kendall test results indicates that the annual rainfall has a declining trend at five out of ten stations, namely: Sekoru, Serbo, Bako Tibe, Bako and Gedo (Table 3). An increasing trend has been observed at Bedele, Didesa Dildey, Arjo, Nekemte, and Gimbi stations. The annual rainfall trend results indicate that only Nekemte station showed a positive statistically significant trend at Zs > 1.96 (α = 0.05) while Sekoru showed a statistically significant decreasing trend. These results contrasted with the findings of Suryabhagavan (2017), who reported that there was no significant change in annual rainfall in Ethiopia during 1983–2012. Only 10% of the annual time series has a positive significant trend, while 10% showed a downward trend with statistically significant. The annual rainfall has decreased by 6.6 mm, 4.7 mm, 2.1 mm, 1.1 mm and 0.6 mm per year at Sekoru, Serbo, Bako Tibe, Bako, and Gedo stations, respectively. In contrast, five stations (Bedele, Didesa Dildey, Arjo, Nekemte and Gimbi) showed that the amount of annual rainfall increased by 8.6 mm, 0.4 mm, 4.9 mm, 9.4 mm, and 5.2 mm per year, respectively. The magnitude of the annual rainfall trend varied between 9.4 and -0.6 mm per year at Nekemte and Gedo station, respectively.

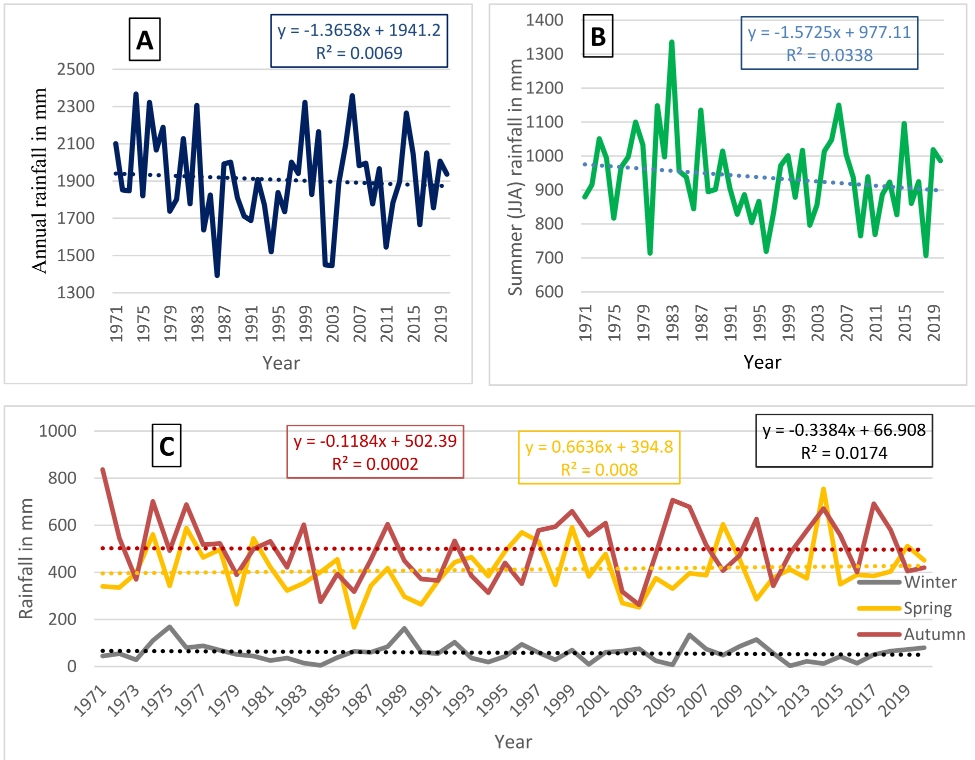

Figure 5. Local climate change evidences: (A) annual rainfall trend (B) summer rainfall trend and (C) autumn, winter & spring rainfall trend observed in Bedele from 1971-2020.

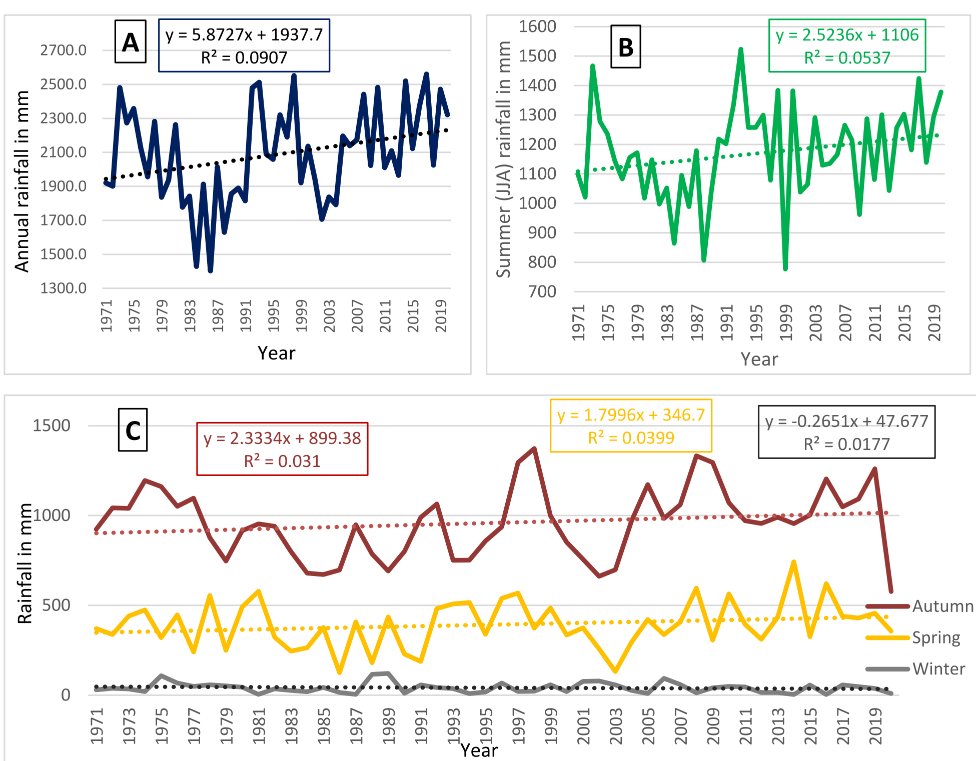

Figure 6. Local climate change evidences: (A) annual rainfall trend (B) summer rainfall trend and (C) autumn, winter & spring rainfall trend observed in Nekemte from 1971-2020.

Table 5. Precipitation concentration index of 10 stations and number of years (1983–2016).

Station	PCI range	Uniform precipitation (PCI<10)	Moderate precipitation (PCI 11–15)	Irregular precipitation (PCI 15–20)	Significantly irregular precipitation (PCI≥20)
Sekoru	11.1–19.5	0	17	17	0
Serbo	10.7–15.3	0	32	2	0
Bedele	13.0–19.0	0	16	18	0
Didesa Dildey	14.0–22.5	0	3	29	2
Arjo	12.1–19.9	0	14	20	0
Nekemte	13.7–21.0	0	9	23	2
Gimbi	13.8–24.7	0	2	28	4
Bako	13.7–22.1	0	3	28	3
Bako Tibe	13.3–22.8	0	3	25	6
Gedo	13.5–23.3	0	5	24	5

Table 6. Mean maximum and minimum temperature trend (1983–2016).

Attribute	Mk test	Sekoru	Serbo	Bedele	Didesa Sildey	Arjo	Nekmte	Gimbi	Bako Tibe	Bako	Gedo
Mean Maximum Temperature	Z_s	*2.55	*4.60	1.57	*3.42	1.04	*2.55	*3.57	*6.02	*5.33	*5.51
	P	0.01	<0.001	0.12	0.00	0.30	0.01	0.00	<0.001	<0.001	<0.001
	Sen's slope	0.02	0.05	0.02	0.04	0.01	0.02	0.05	0.09	0.07	0.09
Mean minimum Temperature	Z_s	0.95	0.83	*2.49	*2.74	0.92	*2.78	*3.49	*4.18	*4.24	1.84
	P	0.34	0.41	0.01	0.01	0.36	0.01	0.00	<0.001	<0.001	0.06
	Sen's slope	0.01	0.01	0.02	0.02	0.01	0.02	0.03	0.06	0.05	0.03

Note: *statistically significant at Zs > 1.96 (α = 0.05) at 5% level of significance.

Table 7. Mean maximum temperature at seasonal scale (1983–2016).

Site name	Summer			Autumn			Winter			Spring		
	Zs	*P*	Sen's	Zs	*P*	Sen's	Zs	*P*	Sen's	Zs	*P*	Sen's
Sekoru	1.80	0.07	0.02	*2.07	0.04	0.02	*2.37	0.02	0.04	*2.31	0.02	0.03
Serbo	*3.00	0.00	0.04	*3.47	0.00	0.05	*4.03	<0.001	0.06	*3.97	<0.001	0.05
Bedele	*2.16	0.03	0.02	0.89	0.37	0.01	1.42	0.15	0.02	1.30	0.19	0.02
Didesa Dildey	*2.88	0.00	0.02	*2.46	0.01	0.02	*2.98	0.00	0.05	*3.08	0.00	0.07
Arjo	*1.96	0.05	0.02	0.65	0.51	0.00	0.86	0.39	0.01	0.53	0.59	0.01
Nekemte	*3.44	0.00	0.04	0.59	0.55	0.00	1.69	0.09	0.02	1.81	0.07	0.03
Gimbi	*2.80	0.00	0.03	*2.82	0.00	0.03	*3.28	0.00	0.08	*3.23	0.00	0.09
Bako Tibe	*5.60	<0.001	0.08	*4.06	<0.001	0.06	*5.96	<0.001	0.09	*5.34	<0.001	0.11
Bako	*5.31	<0.001	0.07	*3.08	0.00	0.04	*4.71	<0.001	0.07	*5.31	<0.001	0.10
Gedo	*4.48	<0.001	0.07	*4.86	<0.001	0.10	*5.48	<0.001	1.10	*4.59	<0.001	0.09

Note: *statistically significant at Zs > 1.96 (α = 0.05) at 5% significance level.

Table 8. Mean minimum temperature at seasonal scale (1983–2016).

Site name	Summer			Autumn			Winter			Spring		
	Zs	*P*	Sen's	Zs	*P*	Sen's	Zs	*P*	Sen's	Zs	*P*	Sen's
Sekoru	0.62	0.53	0.01	1.84	0.06	0.02	0.89	0.37	0.01	0.62	0.53	0.01
Serbo	*2.10	0.03	0.02	0.18	0.86	0.00	0.35	0.72	0.00	0.03	0.97	0.00
Bedele	*2.55	0.01	0.03	*2.05	0.04	0.03	*2.31	0.02	0.02	*2.05	0.04	0.02
Didesadildey	*2.65	0.01	0.01	*2.74	0.01	0.03	1.27	0.20	0.02	*2.79	0.01	0.02
Arjo	1.27	0.20	0.01	*1.84	0.06	0.02	1.69	0.09	0.02	1.16	0.25	0.02
Nekemte	*2.11	0.04	0.02	*4.42	<0.001	0.03	*2.87	0.00	0.03	0.18	0.86	0.00
Gimbi	*2.86	0.00	0.02	*2.73	0.01	0.03	*2.09	0.04	0.03	*3.60	0.00	0.03
Bako Tibe	*4.51	<0.001	0.06	*4.39	<0.001	0.07	*3.14	0.00	0.05	*3.44	0.00	0.06
Bako	*4.12	<0.001	0.05	*4.65	<0.001	0.05	*2.61	0.00	0.03	*3.38	0.00	0.05
Gedo	*1.99	0.05	0.03	1.13	0.26	0.01	0.30	0.77	0.01	1.69	0.09	0.03

Note: *statistically significant at Zs > 1.96 (α = 0.05) at 5% significance level.

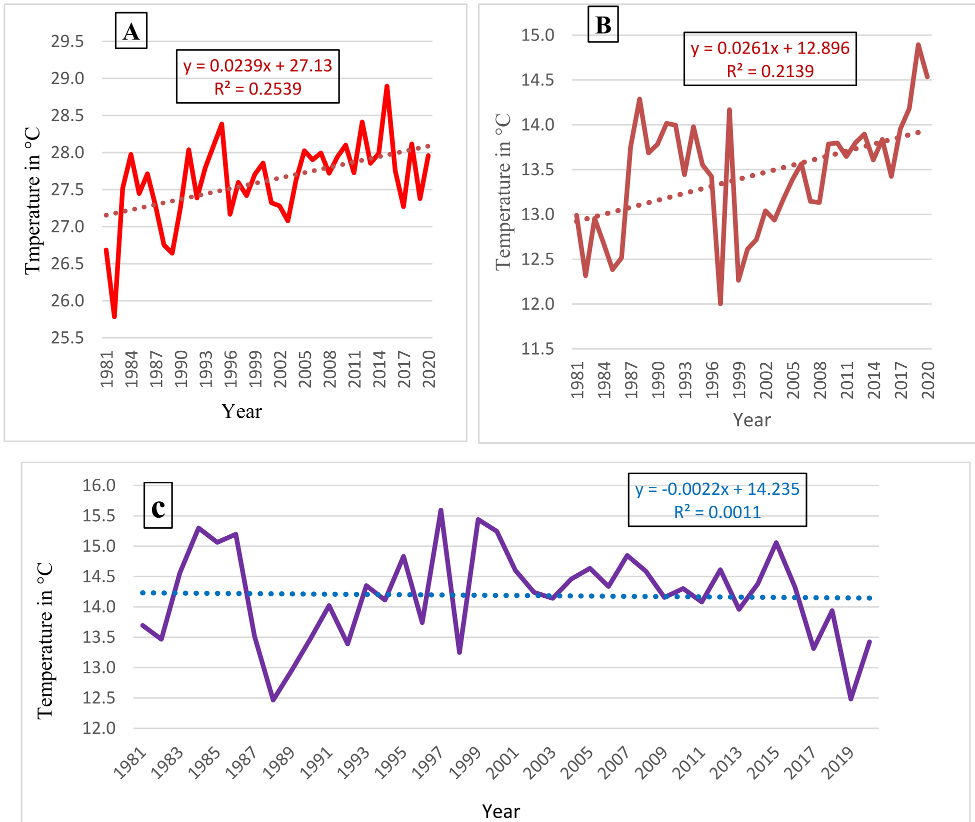

Figure 7. Local climate change evidences: (A) Annual Mean Maximum Temperature Trend (B) Annual Mean Minimum Temperature and (C) Annual Temperature Range Trend observed in Sekoru from 1981-2020.

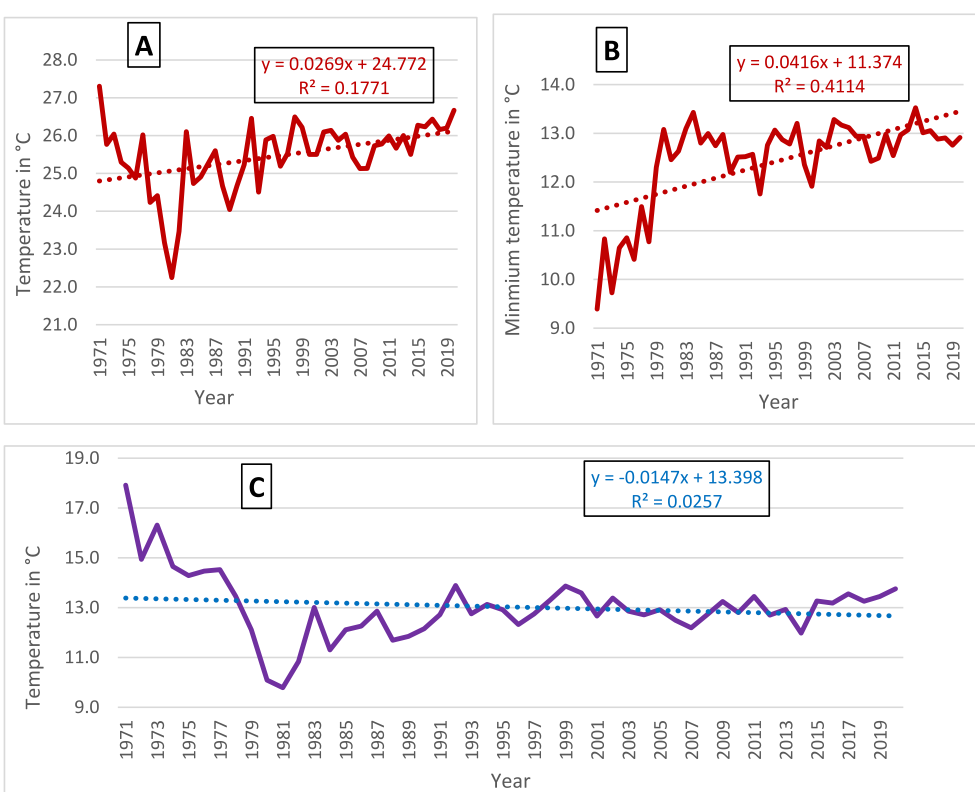

Figure 8. Local climate change evidences: (A) Annual Mean Maximum Temperature Trend (B) Annual Mean Minimum Temperature Trend and (C) Annual Temperature Range Trend observed in Bedele from 1971-2020.

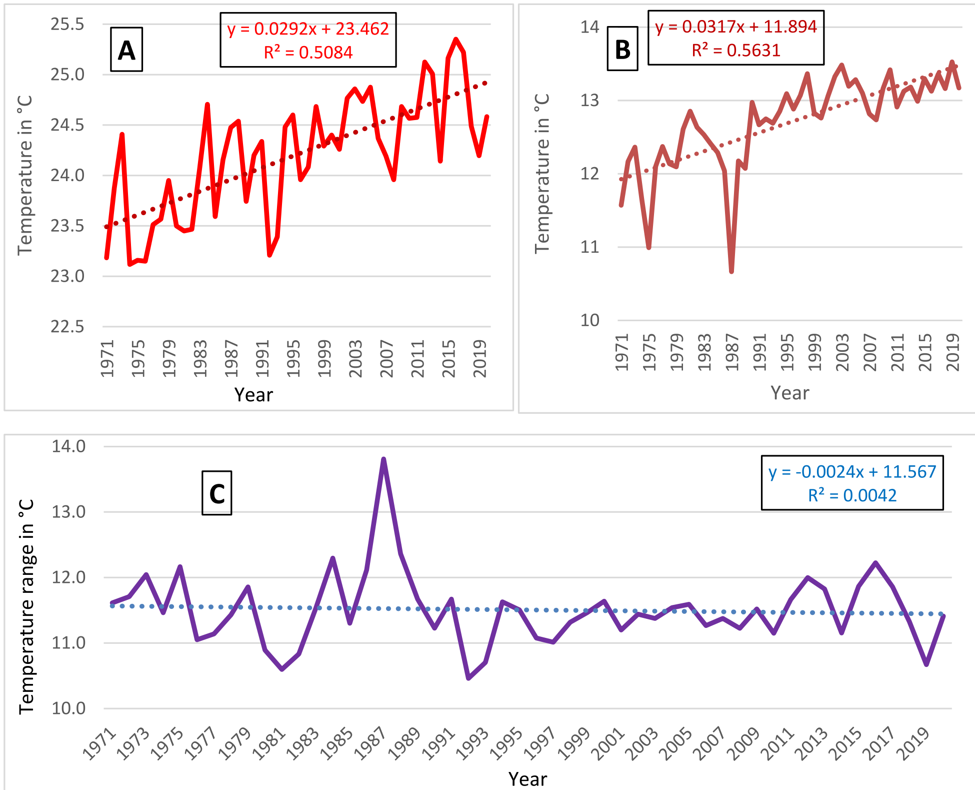

Figure 9. Local climate change evidences: (A) Annual Mean Maximum Temperature Trend (B) Annual Mean Minimum Temperature Trend and (C) Annual Temperature Range Trend observed in Nekemte from 1971-2020.

3.2.2. Seasonal rainfall trend analysis

The amount of rainfall in the main rainy season (June–August) is dominated by a downward trend (80%), with the exception of Bedele and Nekemte, which are the only two stations that had a positive trend without statistically significant (Table 4). This agrees with the results of Omondi et al. (2014), who observed decreasing trend of total precipitation in the wet season in western parts of Ethiopia. Although, the main rainy season is dominated by a downward trend (eight out of ten stations), only one station (Sekoru) showed a statistically significant decreasing trend at Zs > 1.96 ($\alpha = 0.05$). Unlike the main rainy season, there is a tendency of increasing trend of rainfall in the autumn season (SON) across the study sites with a statistically significant at Nekemte station. The average rainfall during the winter season (NDJ) is dominated by the downward trend (nine out of ten stations) in the time series of 1983–2016 with statistically significant trend at Bako and Gedo stations. Whereas, the spring season, which is a small rainy season in the study area, has both a declining (50%) and increasing (50%) rainfall trend. Three stations, namely Arjo, Nekemte and Gimbi stations showed but not statistically significant trend while Bedele station showed a statistically significant increasing trend. The magnitude of rainfall during the rainy season varied from 2.2 mm per year at Bedele to -4.0 mm per year at Sekoru station. Whereas, the trend slope in autumn season varied from 4.0-0.1 mm per year, while the slope trend for winter season ranged from -1.4 to -0.1 mm per year. In spring season, the slope of the trend ranged from 3.2 mm to -0.5 mm per year.

The annual and seasonal linear regression results of long historical record data of three stations were presented (Figures 4, 5, 6). The annual and seasonal linear regression results showed a significant downward trend of annual rainfall and main-rainy season (JJA) at Sekoru (Figure 4) and Bedele (Figure 5) over the study period 1981–2020 and 1971–2020, respectively while a significant upward trend of both annual and main rainy season at Nekemte station (Figure 6). These findings support the work of Ademe et al. (2020) for Choke Mountains watershed that clearly reported the declining trend of rainfall in the main rainy season. Besides the main rainy season, the small rainy season also shows both an increasing and decreasing trend in these three long years record rainfall and temperature data. There are two small rainy seasons in the study area (1) Autumn (September–November) and (2) Spring (March–May). The Autumn season (SON) experienced an upward trend at Sekoru and Nekemte stations while Bedele experienced a decreasing trend. The spring season (MAM) showed upward trends at Bedele and Nekemte stations. Since the winter season (December–February) is the dry season in the study area all sites showed a declining trend.

3.2.3. Precipitation concentration index

This study analyzed the heterogeneity of precipitation using a precipitation concentration index, which is widely used across the world for more than four decades. Monitoring rainfall distribution is a crucial part of analyzing heterogeneity of precipitation (Oliver, 1980). Our results indicate inconsistent rainfall distribution and none of the stations in the study area showed a uniform precipitation (Table 5). Therefore, the study area falls under the three classes of precipitation patterns: moderate, irregular and significantly irregular. A previous study in the western highlands of Ethiopia by Ademe et al. (2020) confirmed that the PCI values ranges from moderate to strong irregular or significantly irregular precipitation. The highest PCI was recorded at Gimbi (PCI = 24.7), followed by Gedo (PCI = 23.3) and Bako Tibe (PCI = 22.8). Six stations, namely: Didesa Dildey, Nekemte, Gimbi, Bako, Bako Tibe and Gedo stations, experienced significantly irregular precipitation distribution. The lowest PCI was found at Serbo station, with a value between 10.7 and 15.3. Specifically, at Serbo, out of 34 years, 32(94%) indicates a moderate precipitation distribution. A recent study by Taye et al. (2021) concluded that rainfall in Ethiopia is heterogeneous in nature.

3.2.4. Mean maximum and minimum temperature trend

Results showed that all stations had experienced an increasing trend in mean maximum temperature with statistically significant positive trend at eight stations over the study period 1983–2016 (Table 6). This study indicates that all stations in the study area showed a positive trend in mean maximum temperature over the study period, which is in line with increasing global mean temperature and increasing number of warm days and warm nights in Ethiopia (Mekasha et al., 2013; Gebrechorkos et al., 2018). The increasing of warm days and nights increase the earth's water cycle that leads to increasing evaporation. The rate of hydrological response is determined by land use and land cover dynamics (Barreto-Martin et al., 2021). There is a direct relationship between global temperature and storm events. As global temperature increase, more concentrated spatial storm events could be expected with higher temperatures (Wasko et al., 2016). At temporal scale, the mean annual maximum temperature showed an increasing linear trend with the rate between 0.01 °C and 0.09ºC/year. The annual maximum temperature change over Ethiopia is about 0.1ºC/decade (0.01ºC/year) over the past 50 years (NMSA, 2001). Change in land use land cover, and over-exploitation of natural resources to feed the rapid population growth are the major driving forces for the current trends of maximum temperature over the study area.

Similar to mean maximum temperature, the minimum temperature shows a positive increasing trend across the study area. Our results from the mean minimum temperature across the study area showed positive increasing trend with statistically significant trend at six out of ten stations. This finding is in agreement with the results of Suryabhagavan (2017) who reported that the vast majority of Ethiopia weather stations experienced a significant increasing trend in minimum temperature. This finding requires policy intervention and public awareness to minimize the adverse impacts of climate change. Both the Mann-Kendall's test and Sen slope statistics results showed a positive minimum temperature trend across the vast majority of the study area. The magnitude of change in mean minimum temperature varied between 0.06 °C and 0.01ºC/year.

The Mann-Kendall's test statistics results at seasonal scale showed that the mean maximum temperature over the vast majority of the study area is increasing with a statistically significant trend. Except Sekoru station, the remaining nine stations showed a statistically significant increasing trend of mean maximum temperature at $Zs > 1.96$ ($\alpha = 0.05$) in the main rainy and growing season (JJA). This result is consistent with the works of Ademe et al. (2020), who reported a significant increasing trend of maximum temperature during the main rainy season. The magnitude of trends (changes per year) during the main rainy season varied between 0.08°C and 0.02 °C (Table 7). With the exception of Arjo, Bedele and Nekemte, all stations showed a statistically significant increasing trend in autumn (SON), winter (DJF) and spring (MAM) seasons. This result is consistent previous studies (Conway and Schipper, 2011; Kassie et al., 2015; Suryabhagavan, 2017; Matewos, 2020) which reported an increasing trend of mean maximum temperature in Ethiopia. Likewise, IPCC (2013) also reported the occurrence of significant increasing trends of temperature in all sub-Saharan regions.

The mean minimum temperature trend was also analyzed at seasonal timescales (Table 8). The results of the mean minimum temperature across the four seasons showed that some trends are positive and some negative. The mean minimum temperature across the study area showed a positive trend. This result is in strong agreement with Suryabhagavan (2017) who reported that the mean minimum temperature showed an increasing trend over most parts of Ethiopia. In the main growing season eight stations showed a statistically significant increasing trend. The mean minimum temperature trend was statistically significant across all seasons at four stations (Bedele, Gimbi, Bako Tibe, and Bako). The magnitude of change in average minimum temperature during the rainy season (JJA) varied between 0.6 °C and 0.1ºC/decade (0.06 °C and 0.01 °C/year) while the magnitude of change during the winter season (JFM) ranged from 0.5 °C to 0.1ºC/decade (0.05–0.01 °C/year). These findings are more or less comparable to NMSA (2007), which documented that the change in mean temperature over Ethiopia was found to be 0.36ºC/decade, which is more or less similar to the global mean surface temperature (IPCC 2007, 2013).

The linear regression analysis results showed that both maximum and minimum temperature have increased by 0.2 and 0.3/decade, respectively at Sekoru with overall increment of 0.25/decade over the study period 1981–2020 (Figure 7A and B). This is, more or less comparable with the global standards on average. The linear regression model for Bedele showed that the mean maximum and minimum temperature have increased by 0.03 and 0.04 °C/year (0.3 and 0.4°C/decade) over the study period 1971–2020 (Figure 8A and B). The increment is more noticeable in minimum temperature. The rate of change for both maximum and minimum temperature at Nekemte is about 0.03/year or 0.3/decade (Figure 9A and B). Temperature range for the three long record climate data showed a declining trend (Figures 7C, 8C and 9C). This is mainly due to the increment of the mean minimum temperature over the study period.

4. Conclusions

Results of historical rainfall and temperature data showed that the climate in the study area varies both spatially and temporally. Annual rainfall distributions and amount is not uniform, and 50% of the stations showed a positive trend, with statistically significant increasing trend at Nekemte while a statistically significant declining trend was observed at Sekoru station over the study period 1983–2016. The trend analysis of rainfall during the main rainy and crop growing season (JJA) showed a negative trend in most stations (80%) in the study area. However, a statistically significant negative trend was detected at Sekoru station only. In contrast, the mean maximum and minimum temperature show a statistically significant increasing trend over a large portion of the study area. Under business as usual more severe warming and drought that may affect agricultural yield and food security. This study concludes that the climate of the wettest parts of Ethiopia is getting warmer and the amount of rainfall in the main rainy season has declined in the vast majority of the study area. The main growing season is dominated by a downward trend and only two stations (Bedele and Nekemte) experienced a positive trend. However, the long record years (1971–2020) clearly indicates that the main rainy season is increasing at the rate of 2.52mm/year or 25.2mm/decade at Nekemte. The PCI results revealed that the annual rainfall is significantly irregular (inconsistent) at six of the ten stations and no station showed a uniform precipitation.

The Mann-Kendall trend test statistics and Sen's slope estimator results for the mean maximum and minimum temperatures at annual and seasonal scales showed a positive trend. The results of the satellite blended/gridded monthly temperature data of ten station in the wettest parts of southwestern Ethiopia proved that all stations experienced an upward trend and no stations experienced a declining trend both in maximum and minimum temperature. The long historical record data indicates that the maximum temperature have increased by 0.3°C/decade at Bedele and Nekemte stations while 0.2°C/decade at Sekoru. Moreover, the average minimum temperature has increased by 0.04°C/year (0.4/decade) at Bedele and 0.03°C/year (0.3°C/decade) both at Sekoru and Nekemte stations. Moreover, the average minimum temperature has increased by 0.04°C/year (0.4/decade) at Bedele and 0.03°C/year (0.3°C/decade) both at Sekoru and Nekemte stations. Rainfall and temperature fluctuations as well as uneven distributions of rain will likely influence the farming communities and affect agricultural production. The declining of rainfall during the main crop growing season and an increasing temperature trend have considerable impact on agricultural productions and results in food insecurity. This implies that climate change can influence agricultural practices in the region under business as usual. The study area is one of the major cash crops growing areas like coffee, and tea, an urgent policy intervention is vital to prevent disasters in social and economic impacts.

Declarations

Author contribution statement

Dessalegn Obsi Gemeda: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Diriba Korecha, Weyessa Garedew: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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