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

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**A B S T R A C T**

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
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 coriimum (Braun), a native spice crop to Ethiopia was declined by 49% between 1998 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 Arabica coffee producing regions becoming a serious threat by coffee berry borer (Hypothememus 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 presence 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 7.25°N and 10.40°N and 34.35°E and 38.57°E.

The study area has a diversified landscape, which result in elevation varies between 702.5 to 3372.6 m.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 sub-humid 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 spatio-temporal distributions of annual rainfall, maximum and minimum temperature over the study area (Suryabhanagav, 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 Nekemte (1971–2020) and Sekoru (1981–2020). This test has been used by various researchers to analyze the trends of temperature and rainfall (Nyatuae 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.
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 < CV < 30, it is moderately variability, if CV > 30, it is strong variability (Hare, 2003).

Figure 1. Map of the study area.

Figure 2. Topography of the study area.
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 (PCI 11–15), irregular precipitation distribution (PCI 16–20), and strongly concentrated/strongly irregular distribution (PCI > 20). The annual PCI was computed as Eq. (1).

\[
PCI_j = 100 \frac{\sum_{i=1}^{12} p_{ij}^2}{P_j^2}
\]

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 analyze the climate trend and calculated using Eq. (2).

\[
S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(X_j - X_i)
\]

where \( S \) is the Mann-Kendall’s test statistics; \( X_j \) and \( X_i \) are sequential data values for the time series data of length n.

\[
\text{sgn} (X_j - X_k) = \begin{cases} +1, & \text{if } (X_j > X_k) > 0 \\ 0, & \text{if } (X_j > X_k) = 0 \\ -1, & \text{if } (X_j > X_k) < 0 \end{cases}
\]

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:

\[
f(t) = Qt + B
\]

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).

\[
Q = \frac{X_j - X_k}{j - k} \text{ where } j > k
\]
where $Q_i$ is Sen's slope estimator, $X_j$ and $X_k$ are the data values at times $j$ and $k$ ($j > k$), respectively. The median of these $N$ values $Q_i$ is represented as Sen's slope estimator and calculated as Eq. (7).

$$\text{Sen estimator} = \begin{cases} 
\frac{Q(R + 1)}{2} & \text{if } R \text{ is odd} \\
0.5 \times \left( \frac{QR}{2} + \frac{Q(R + 1)}{2} \right) & \text{if } R \text{ is even}
\end{cases} \quad (7)
$$

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 centigrade and 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

### 3. Results and discussion

#### 3.1. Spatial distribution of rainfall and temperature

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 | 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 | 28.8 | 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 |

#### 3.2. Temporal distribution and trends of rainfall and temperature

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     |
| Didesa Dildey | 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     |

#### 3.2. Temporal distribution and trends of rainfall and temperature

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   | 0.99          | 1.30 | 1.07    | -0.87 | -0.35     | -0.19| -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 $Z_s > 1.96 \ (\alpha = 0.05)$ at 5% level of significance.
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, Didessa Dildey, Arjo, Nekemte, and Gimbi stations. The annual rainfall trend results indicate that only Nekemte station showed a statistically significant trend at $Z_s > 1.96$ ($\alpha = 0.05$) 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 magnitude of the annual rainfall trend varied between 9.4 and -0.6 mm per year at Nekemte and Gedo station, respectively.

![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.](image-url)

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    |
| Didessa 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 $Z_s > 1.96$ ($\alpha = 0.05$) at 5% level of significance.
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    | 14.0–22.5 | 0                               | 3                                 | 29                                 | 2                                             |

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

| Attribute                          | M.k test | Sekoru | Serbo | Bedele | Didesa Sildey | Arjo | Nekemte | 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| <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 | 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 | 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 | 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  |        |
| Sekoru    | 1.80   | 0.07   | 0.02   |        |
| Serbo     | *3.00  | 0.00   | 0.04   |        |
| Bedele    | *2.16  | 0.03   | 0.02   |        |
| Didesa Sildey | *2.88  | 0.00   | 0.02   |        |
| Arjo      | *1.96  | 0.05   | 0.02   |        |
| Nekemte   | *3.44  | 0.00   | 0.04   |        |
| Gimbi     | *2.80  | 0.00   | 0.03   |        |
| Bako Tibe | *5.60  | <0.001 | 0.08   |        |
| Bako      | *5.31  | <0.001 | 0.07   |        |
| Gedo      | *4.48  | <0.001 | 0.07   |        |

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  |        |
| Sekoru    | 0.62   | 0.53   | 0.01   | 1.84   |
| Serbo     | *2.10  | 0.03   | 0.02   | 0.18   |
| Bedele    | *2.55  | 0.01   | 0.03   | *2.05  |
| Didesa Sildey | *2.65  | 0.01   | 0.01   | *2.74  |
| Arjo      | 1.27   | 0.20   | 0.01   | *1.84  |
| Nekemte   | *2.11  | 0.04   | 0.02   | *4.42  |
| Gimbi     | *2.86  | 0.00   | 0.02   | *2.73  |
| Bako Tibe | *4.51  | <0.001 | 0.06   | *4.39  |
| Bako      | *4.12  | <0.001 | 0.05   | *4.65  |
| Gedo      | *1.99  | 0.05   | 0.03   | 1.13   |

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.
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 $Z > 1.96$ ($\alpha = 0.05$). 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.

3.2.2. 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 range 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).
The occurrence of significant timescales (Table 8). The results of the mean minimum temperature in Ethiopia was found to be more or less comparable to NMSA (2007), which documented that the mean maximum temperature over the vast majority 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 Obse Gmeda: 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 Gareedew: 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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References

Abebe, G., 2017. Long-term climate data descriptions in Ethiopia. Data brief 14, 371–392.
Ademe, D., Ziatchik, B.F., Tesfaye, K., Simane, B., Alemayehu, G., Adgo, E., 2020. Climate trends and variability at adaptation scale: patterns and perceptions in an agricultural region of the Ethiopian Highlands. Weather. Clim. Extremes. 29, 100263.
Aderetey, O.E., Lawin, A.E., Laux, P., Ishola, K.A., Ige, S.O., 2019. Analysis of climate occurrence in the Komadugu-Yobe basin, Lake Chad region: past and future occurrences. Weather. Clim. Extremes. 23, 100194.
Adu, D.T., Koworma, J.K.M., Anim-Somuah, H., Sanaki, N., 2018. Application of livelihood vulnerability index in assessing smallholder maize farming households’ vulnerability to climate change in Brong-Ahafo region of Ghana. Weather. Clim. Extremes. 26, 100230.
Anastasiadis, S., 2005. The big problem in understanding climate change, peace review. J. Soc. Justice. 17 (2-3), 299-306.
Aniah, P., Kaunza-Nu-Dem, M.K., Ayembilla, J.A., 2019. Smallholder farmers’ perception of climate change in Kenya: household strategies and determinants. J. Environ. Manag. 114, 16–25.
Barreto-Martin, C., Sierra-Parada, R., Calderon-Rivera, D., Jaramillo-Llondo, A., Mesa-Fernandez, D., 2021. Spatio-temporal analysis of the hydrological response to land cover changes in the sub-basin of the Guian river, Colombia. Heliyon 7 (7), e07358.
Belcore, E., Calvo, A., Canessa, C., Pezzoli, A., 2017. A methodology for the vulnerability analysis of the climate change in the Oromia region, Ethiopia. In: Tiepolo, M., Pezzoli, A., Tarchiani, V. (Eds.), Renewing Local Planning to Face Climate Change in the Tropics. Green Energy and Technology. Springer, Cham.
Bryan, E., Ringler, C., Okoba, B., Roncollet, a.l., 2013. Adapting agriculture to climate change in Kenya: household strategies and determinants. J. Environ. Manag. 114, 16–25.
Chepkoech, W., Munag, N.W., Stober, S., Bett, H.K., Lotze-campen, H., 2018. Farmers Perspectives: impact of climate change on African indigenous vegetable production in Kenya. Int. J. Clim. Change. Manag. 10, 551–579.
Cheung, H.H., Senay, G.B., Singh, A., 2008. Trends and spatial distribution of annual and seasonal rainfall in Ethiopia. Int. J. Climatol. 28, 1723–1734.
Conway, D., Schipper, E.L.F., 2011. Adaptation to climate change in Africa: challenges and opportunities identified from Ethiopia. Global Environ. Change 21 (1), 227–237.
Davis, A.P., Gole, T.W., Barna, S., Moat, J., 2012. The impact of climate change on indigenous arabica coffee (coffee arabica): predicting future trends and identifying priorities. Plos One 7 (11), e47981.
de Luis, M., Gonzalez-Hidalgo, J.C., Brunetti, M., Longares, L.A., 2011. Precipitation concentration changes in Spain 1946–2005. Nat. Hazards Earth Syst. Sci. 11 (5), 1259–1265.
Degefere, D.T., Seid, J., Gesesse, B., Bedada, T.B., 2019. In: Melse, A.M., Abtew, W., Senay, G. (Eds.), Chapter 24-Agricultural Drought Projection in Ethiopia from 1981 to 2050: Using Coordinated Regional Climate Downscaling experiment Climate Data for Africa. Extreme Hydrology and Climate Variability. Elsevier, pp. 311–323.
Deng, S., Chen, T., Yang, N., Qu, L., Li, M., Chen, D., 2018. Spatial and temporal distribution of rainfall and drought characteristics across the Pearl River basin. Sci. Total Environ. 619–620, 28–41.
Desu, T., Korecha, D., Hunde, D., Worku, A., 2020. Long-term land use land cover change in urban centers of southwest Ethiopia from a climate change perspective. Frontiers Climatol 2, 577169.
Dumenu, W.K., Tiamgne, X.T., 2020. Social vulnerability of smallholder farmers to climate change in Zamb: the applicability of social vulnerability index. SN Appl.Sci. 2, 436.
Edwards, J.F., Lassa, J.A., Palpacuc, E.P., Zander, K.K., 2018. Understanding climate change impacts on water buffaloes production through farmers’ perceptions. Clim. Risk Manag. 20, 50–63.
Eshetu, G., Johannson, T., Gareedew, W., Yisahak, T., 2018. Climate variability and small-scale farmer adaptation strategies in the Western Highlands of Ethiopia: the applicability of social vulnerability index. J. Agric. Biol. Environ. Stat. 4 (1), 1–9.
Fekadu, A., Soromessa, T., Dullo, B.W., 2020. GIS-based assessment of climate change impacts forseto habulamromonum coriaria (Bruna) in Southwest Ethiopia coffee forest. J. Mt. Sci. 17 (10).
Gao, F., Wang, Y., Chen, X., Yang, W., 2020. Trend analysis of rainfall time series in Shanzxi province, Northern China (1957-2019). Water 12, 2335.
Gebrechorkos, S.H., Hulsmann, S., Bernhofer, C., 2018. Changes in temperature and precipitation extremes in Ethiopia, Kenya, and Tanzania. Int. J. Climatol. 39, 18–30.
Gebrechorkos, S.H., Hulsmann, S., Bernhofer, C., 2019. Long-term trends in rainfall and temperature using high-resolution climate datasets in East Africa. Sci. Rep. 9, 11376.
Geerdes, B., Berech, G., Homeny, O., Aerts, R., 2019. Understanding the quality of Ethiopian Arabica coffee deteriorates with increasing intensity of coffee forest management. J. Environ. Manag. 231, 288–288.
Gmeda, D.O., 2019. Climate change variability analysis in and around Jinka, southern Ethiopia. With special emphasis on temperature and rainfall. JAS-Sl. 14 (3), 145–153.
Gmeda, D.O., Feyisa, D.H., Gareedew, W., 2020. Meteorological data trend analysis and local community perception towards climate change: a case study of Jimma city, Southwestern Ethiopia. Environ. Dev. Sustain. 23, 5885–5903.
Guo, E., Wang, Y., Jirigala, B., Jin, E., 2020. Spatiotemporal variations of precipitation concentration and their potential links to drought in mainland China. J. Clean. Prod. 122004.
Hare, W., 2003. Assessment of Knowledge on Impacts of Climate Change, Contribution to the Specification of Art, 2 of the UNFCCC WBGU. Postdam, Berlin.http://www.wbgu.de/wbgu_sn2003_ex01.pdf.
Hein, Y., Vrijiskamol, K., Attavanch, W., Janezardij, P., 2019. Do farmers perceive the trends of local climate variability accurately? An analysis of farmers’ perceptions and meteorological data in Myanmar. Climate 5 (5), 64.
Hill, R.V., Porter, C., 2017. Vulnerability to drought and food price shocks: evidence from Ethiopia. World Dev. 96 (C), 65–77.
Hoeogh-Guldberg, O., Bruno, J.F., Pezzoli, A., 2010. The impact of climate change on the world’s marine ecosystems. Science 328, 1523–1528.
Hundera, H., Mpandeli, S., Bustander, A., 2019. Stallholder farmers’ awareness and perceptions of climate change in Adama district, central rift valley of Ethiopia. Weather. Clim. Extremes. 20, 100230.
Incoom, A.B.M., Adeji, K.A., Odi, S.N., 2020. Rainfall variabilities and drought in the Savannah zone of Ghana from 1960-2015. Scientiﬁc African 10, e00571.
Intergovernmental Panel on Climate Change (IPCC), 2007. In: Core Writing Team, 2007. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, p. 104.
IPCC, 2013. The physical science basis. In: Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Contribution of Working Groups I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Cambridge University Press, pp. 1–143.
IPCC, 2001. Contribution of Working Groups I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, p. 476.
