Variability and Trends of Temperature and Rainfall Over Three Agro-Ecological Zones in North Shewa, Central Ethiopia

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Variability and Trends of Temperature and Rainfall Over Three Agro-Ecological Zones in North Shewa, Central Ethiopia

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Abstract

This study aims to analyze variability and trends of temperature and rainfall over three agro-ecological zones (AEZs) in Central Ethiopia. Gridded rainfall and temperature data, recorded on daily basis for 35 years (1979 - 2013) at 30 meteorological stations, were used for analysis. While Mann–Kendall test was applied to analyze the trends in rainfall and temperature, Sen’s slope estimator was used to determine the magnitude of change. The study detected an upward trend of 0.07°C/annum ($p < 0.001$) in mean annual maximum temperature at Kolla AEZ. It also showed an upward trend of 0.06/year ($p < 0.001$) for both Dega and Woina Dega AEZs. Mean annual minimum temperature exhibited an upward trend of 0.03°C/year at Kolla ($p < 0.001$), Woina Dega ($p < 0.05$), and Dega ($p < 0.01$), signifying a 1.05°C increase between 1979 and 2013. Results from precipitation concentration index (PCI) revealed highest percentage (97.1%) of irregular distributions in annual rainfall pattern at Kolla AEZ, followed by Woina Dega (82.9%). Standardized rainfall anomalies (SRA) computed in the study also showed higher percentage (28.6%) of drought in Kolla AEZ, which experienced drought once in every 3 or 4 years. The study revealed negative annual rainfall anomalies for 18 years in Kolla and 16 years in both Dega and Woina Dega AEZs. The reduced precipitation and rise in temperature could trigger wide-ranging influences on agricultural practices and crop production of smallholder farmers. Policymakers and stakeholders should give priority in designing and introducing pro-poor plus geographically differentiated adaptive strategies.

Key Words: Mann–Kendall, Sen’s Slope, PCI, SRA, Drought, Ethiopia

Introduction

Today’s global community is facing several critical issues. Climate change and/or variability are amongst the major issues of our time. They are manifested by the ever-increasing world average temperature, melting of glaciers, rising of sea levels, fluctuations in the amount of rainfall, changing weather patterns and the like. Observational records show that the global mean temperature increased by 0.78°C between 1850 and 2012. Based on the projections made, the global average temperature could rise between 1.5°C and 2°C by the end of the 21st century (Befikadu et al. 2019). It is widely observed in many areas of the world that changes in temperature and rainfall patterns are more likely to become hotter and drier under future climate scenarios (Longobardi and Villani 2010; Gebrehiwot and Veen 2013).

Various studies have investigated trends of climate change and variability in the continent of Africa (Kinyangi et al. 2009; Valli et al. 2013). It is reported that the climate of today’s Africa is warmer than it was 100 years ago and during the 20th century the continent has been warming at a rate of about 0.05°C/decade, with slightly larger warming from June to November than from December to May (Hulme et al. 2001). The region of East Africa is not an exception to this scenario. A very high temperature and rainfall variations and the associated adverse effects have been reported by scholars in the region (Valli et al. 2013; Easterling et al.

2007). The impact is primarily associated with higher instability in the inter-annual rainfall primarily affecting rain-fed Agriculture (Befikadu et al. 2019).

Ethiopia is one of the countries in East Africa exhibiting variable climatic conditions. It has diverse AEZs which are characterized by a dazzling variety of microclimates and corresponding weather patterns (Astawsegn 2014). Ethiopia has a tropical monsoon climate characterized by wide topographic induced variations. Mean annual rainfall distribution ranges in the country from more than 2000mm over the southwestern highlands to a minimum of below 300mm over the southeastern and northwestern lowlands (Abebe and Arega 2019). Rainfall distributions over the country are also strongly inconsistent among different seasons (Kew et al. 2017; Fekadu 2015). Moreover, mean annual temperature varies widely from less than 15°C over the highlands and above 25°C in the lowlands (Kew et al. 2017; Regassa et al. 2010).

It is reported that over the last 40-50 years, the mean annual temperature of Ethiopia has shown 0.2°C to 0.28°C rise/decade (McSweeney et al. 2010). A rise in average temperature of about 1.3°C has also been observed in the country between 1960 and 2006 (Asaminew and Diriba 2015). The rise in average temperature exhibited spatial and temporal variations over the country. Higher rise in temperature was noted in drier areas in the northeast and southeast part of the country (Abebe and Arega 2019). Notably the variability is higher in July-September. The number of “hot days” and “hot nights” has also shown increment (Asaminew and Diriba 2015). Consequently, the country’s minimum temperature has increased with 0.37°C to 0.4°C/decade (Astawsegn 2014). Ethiopia will experience, according to projections, a 1.7°C–2.1°C increase in the mean temperature by 2050 (Befikadu et al.2019).

Previous studies reported mixed findings on trends and variability of rainfall in Ethiopia. Asfaw et al. (2018), Wagesho et al. (2013), Gebrehiwot and Veen (2013), Conway (2000a and 2000b), and Abebe and Arega (2019) concluded that the amount and duration of annual and seasonal rainfall show decreasing trends in the country. Viste et al. (2013) and Meze-Hausken (2004), on the other hand, are not able to document a general decreasing trend of rainfall in Ethiopia. A non-significant trend in annual and seasonal rainfall amounts over the country was also reported by Suryabhagavan (2016) and McSweeney et al. (2008). Others such as Teyso and Anjulo (2016), Bewket and Conway (2007) and Rosell and Holmer (2007) indicated that the annual and seasonal rainfall show great space–time variations. There is a general consensus among most of the researchers that rainfall variability is increasing (and predictability is decreasing) in many parts of the country. This has strong implications for crop production, which becomes clear when assessing the change in areas that receive sufficient rain to support crop production (Kassahun 2011; Astawsegn 2014).

Many studies have been conducted to reveal the extent of climate variability at macro levels. There is, however, paucity of studies at local places and differentiated by AEZs (Befikadu et al. 2019). Easterling et al. (2007), Bewket and Conway (2007), Kebede and Bewket (2009), and Abebe and Arega (2019) clearly showed that trends and spatiotemporal variations in rainfall and temperature remain unknown in several localities of Ethiopia. Studies that scientifically investigate long-term and local scale fluctuations in these climate parameters are seriously lacking in many parts of the country. The previously conducted aggregate analyses do not reflect local conditions, which are extremely divergent and, where the negative upshots of climate variability are most felt. This makes it difficult to understand the extent to which climate parameters vary across periods and localities (Gebrehiwot and Veen 2013). North Shewa

Administrative Zone (NSAZ) of the Oromia National Regional State (ONRS) represents one of the localities within Ethiopia where trends in climate parameters remain largely unexamined and hence, only scanty of information is available here and there in bits and pieces. This study aims to analyze trends and spatiotemporal variations in rainfall and temperature disaggregating by AEZs in the area and attempts to fill the afore-indicated deficit.

Materials and Methods

Description of the Study Area

North Shewa Administrative Zone is located in the Oromia National Regional State of Ethiopia. Its latitudinal and longitudinal locations extend from 9°08'52"-10°35'17"N and 37°56'13"-39°34'47"E, respectively. NSAZ is characterized by varied topographic settings: plain features, highland and pocket lowland areas. It is dissected by high plateaus and mountains associated with hills, valleys and gorges. The altitude of NSAZ extends from about 1000 m.a.s.l., located in Abay gorge in Wara Jarso district to over 3500 m.a.s.l., located in Degem district (Asaminew and Diriba 2015). The study area's varied topographic features resulted in micro climatic variations in its several localities. Vertisols, Cambisols and Lithosols are major soils within the study area. The traditional agro-ecology of NSAZ ranges from highland (*Dega*) to lowland (*Kolla*). *Dega* occupies over 50% of the total area of the Zone. The second highest proportion of the area falls within midland (*Woina Dega*) agro-ecology. *Kolla* occupies small portion of the study area (Fig. 1).

Figure 1. Location of the Study Area

The area under study receives annual rainfall that ranges from about 532.4 to 1287.8mm (Table 3). It gets maximum rain in July and August. The area gets little rain from October to January. There are two distinct rainy seasons in the study area, namely; *Kirtemt* (summer) and *Belg* (spring). While the former extends from June to September, the latter extends from February to May. The monthly average temperature of the study area ranges from 15.6°C to 19.8°C (Table 2). The mean monthly minimum temperature ranges from 7.4°C to 11.2°C. The lowest mean monthly temperature is recorded on November. Similarly, the mean monthly maximum temperature of the area ranges from about 20.8°C to 28.5°C. The highest mean monthly temperature is recorded on March. The study area is characterized by mixed farming systems: crop and livestock production.

Research Design and Data Sources

The study employed a longitudinal research design to detect changes in rainfall and temperature events and to quantify the trends lasting over the study periods (1979-2013). The period of analysis was limited to three and half decades only because of the availability and accessibility of data. This study was conducted by exploiting both primary and secondary sources of data. Global Weather Data for SWAT were obtained from <https://globalweather.tamu.edu> and used as primary data for the study. It comprises gridded rainfall and temperature data recorded on daily basis for the period between 1979 and 2013 for 30 meteorological stations (Table 1). In this study, gridded data set were preferred over station based data due to high missing values, poor data quality and measurement errors that the latter suffers from.

Table 1. Latitude, Longitude, Altitude and Data Periods of the Meteorological Stations

Agro-ecological Zone	Stations	Longitude	Latitude	Elevation (m)	Period
Dega / Cool to Humid (2,300-3,200m)	weatherdata-86381	38.125	8.586290359	2588	1979-2013
	weatherdata-86384	38.4375	8.586290359	2430	1979-2013
	weatherdata-89378	37.8125	8.89852047	2420	1979-2013
	weatherdata-92381	38.125	9.210749626	2821	1979-2013
	weatherdata-92384	38.4375	9.210749626	2844	1979-2013
	weatherdata-92388	38.75	9.210749626	2498	1979-2013
	weatherdata-92391	39.0625	9.210749626	2748	1979-2013
	weatherdata-95388	38.75	9.522979736	2627	1979-2013
	weatherdata-95391	39.0625	9.522979736	2640	1979-2013
	weatherdata-98384	38.4375	9.835209846	2400	1979-2013
Woina Dega / Cool Sub Humid (1,500-2,300m)	weatherdata-86378	37.8125	8.586290359	2062	1979-2013
	weatherdata-86388	38.75	8.586290359	1837	1979-2013
	weatherdata-86391	39.0625	8.586290359	1812	1979-2013
	weatherdata-89381	38.125	8.89852047	2296	1979-2013
	weatherdata-89384	38.4375	8.89852047	2101	1979-2013
	weatherdata-89388	38.75	8.89852047	2138	1979-2013
	weatherdata-89391	39.0625	8.89852047	2245	1979-2013
	weatherdata-92378	37.8125	9.210749626	1884	1979-2013
	weatherdata-95378	37.8125	9.522979736	1731	1979-2013
	weatherdata-95384	38.4375	9.522979736	2067	1979-2013
	weatherdata-98378	37.8125	9.835209846	1602	1979-2013

	weatherdata-98388	38.75	9.835209846	1894	1979-2013
	weatherdata-98391	39.0625	9.835209846	1677	1979-2013
	weatherdata-101378	37.8125	10.1473999	2244	1979-2013
	weatherdata-101381	38.125	10.1473999	2268	1979-2013
	weatherdata-101388	38.75	10.1473999	1713	1979-2013
Kola / Warm Semi Arid (500-1,500m)	weatherdata-95381	38.1250	9.522979736	1272	1979-2013
	weatherdata-98381	38.1250	9.835209846	1357	1979-2013
	weatherdata-101384	38.4375	10.1473999	1295	1979-2013
	weatherdata-101391	39.0625	10.1473999	1372	1979-2013

Source: <https://globalweather.tamu.edu>

Method of Data Analysis

Non-Parametric Trend Tests and Change-Point Detection software packages in R (Version 1.1.1) along with Microsoft Excel spreadsheet were used to analyze the primary time series and long-term meteorological data records. The following indices and tests were conducted for analyzing the spatiotemporal variations in rainfall and temperature within the study area at different agro-ecological levels.

Coefficient of Variation (CV):- is a statistical measure of how the individual data value varies from the mean value. A greater value of CV is the indicator of larger spatial variability, and vice versa (Chakraborty et al. 2013). It is computed using the following equation:

$$CV = \frac{\sigma}{\bar{X}} * 100 \quad (1)$$

Where, CV is the coefficient of variation, σ is the standard deviation (SD) and $\bar{x}$ is the mean. Accordingly, CV values < 20% denotes less variable, between 20% and 30% denotes moderately variable and >30% denotes high variability of rainfall.

Precipitation Concentration Index (PCI):- is a measure of relative distribution. It is a means to represent spatial variability of rainfall patterns. PCI signify rainfall concentration in terms of distribution and variability and is computed on annual and seasonal scale using the following equations, respectively.

$$PCI_{\text{Annual}} = \frac{\sum_{i=1}^{12} p_i^2}{\left(\sum_{i=1}^{12} p_i\right)^2} \times 100, \quad (2)$$

$$PCI_{\text{Seasonal}} = \frac{\sum_{i=1}^4 p_i^2}{\left(\sum_{i=1}^4 p_i\right)^2} * 33 \quad (3)$$

Where, p_i is the monthly precipitation in month i

According to scholars' categorization, PCI values of less than 10 signify a uniform precipitation distribution (low precipitation concentration); PCI values between 11 and 15 signify a moderate precipitation concentration; values from 16 to 20 signify irregular distribution and values greater than 20 signify a strong irregularity (high precipitation concentration) of precipitation distribution (De Luis et al. 2011; Valli et al. 2013; Al-Shamarti 2016)

Mann-Kendall Test: - is a non-parametric statistical test which is widely applied and most effective method to determine whether a time series has a monotonic upward or downward trend (Feng et al. 2016). This test is chosen over other statistical techniques (available to detect trends within time series data) for it does not require that the data be normally distributed or linear. It can test trends in a time series without requiring normality or linearity which is distribution-free test (Wang et al. 2008). It is also less sensitive to outliers or robust against the influence of extremes (Kendall 1975; Mann 1945; Poudel and Shaw 2016). Hence, it is highly recommended for general use by the World Meteorological Organization (Abebe and Arega 2019).

MK test is used to ascertain the existence of a statistically significant or non-significant trend in rainfall and temperature variability (Jain and Kumar 2012). It measures rainfall and temperature variability on both annual time scale (inter-annual variability) and seasonal scale (intra-annual variability, season to season) (Longobardi and Villani 2010). The null hypothesis (H_0) for this test is that there is no trend, and the alternative hypothesis (H_1), is that there is a trend in the two-sided test or that there is an upward trend (or downward trend) in the one-sided test. The Z score is computed and the confidence limits of the standard normal Z are equally determined. While positive (+) Z value signifies increasing trends over time, negative (-) Z value indicates decreasing trends (Suryabhagavan 2016).

It is acknowledged in Feng et al. (2016) and Longobardi and Villani (2010), the MK statistic S, the variance statistic Var (σ), and the interrelated standard normal test statistic Z, could be calculated as follows:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^N \text{sgn}(X_j - X_i), \quad (4)$$

Where, N is the number of data points; X_i and X_j are the time series observations. Assuming $(X_j - X_i) = \theta$, the value of $\text{sgn}(\theta)$ is computed from:

$$\text{Sgn}(\theta) = \begin{cases} +1 & \dots \theta > 0 \\ 0 & \dots \theta = 0 \\ -1 & \dots \theta < 0 \end{cases} \quad (5)$$

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

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

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

$$Z = \left. \begin{aligned} & \frac{S-1}{\sqrt{\text{Var}(S)}}, & \text{if } S > 0, \\ & = 0, & \text{if } S = 0, \\ & \frac{S+1}{\sqrt{\text{Var}(S)}}, & \text{if } S < 0. \end{aligned} \right\} \quad (7)$$

When Z value exceeds either of the confidence limit lines, it shows a significant trend at a given significance level. Hence, H_0 is rejected and in place H_1 is accepted.

Sen's Slope Estimator: - is non-parametric procedure used to quantify trend magnitude in time series data. It is more robust estimator than others due to its relative insensitivity to extreme values (Chattopadhyay and Edwards 2016). Sen's Slope estimator has been widely used for determining the trend magnitude in hydro-meteorological time series (Jain and Kumar 2012). To derive an estimate of the Slope b_i , the Slopes of all data pairs are computed as:

$$b_i = \frac{X_j - X_i}{j - i}, i = 1, 2, 3 \dots, N, j > i, \quad (8)$$

Where: x_j and x_i are data values at times j and i ; $j > i$ respectively. The Sen's estimator of the Slope is the median of these N values of b_i :

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

A positive value of b indicates an 'upward trend' (increasing values with time) while a negative value of b indicates a 'downward trend' (Chakraborty et al. 2013).

Standardized Rainfall Anomaly (SRA):- is the difference between the long-term average rainfall (sometimes called a reference value) and the annual rainfall in a given year, and divided by the standard deviation. SRA features have contributed to its acceptance for drought monitoring while enabling to identify the dry and wet years in the record (Svoboda et al. 2012). It is obtained using the following equation (Bewket and Conway 2007).

$$SRA = \frac{P_t - P_m}{\sigma}, \quad (10)$$

Where, SRA is standardized rainfall anomaly, P_t is annual rainfall in year t , P_m is long-term mean annual rainfall for the period 1979–2013, and σ is the standard deviation of annual rainfall for the period 1979–2013. According to Befikadu et al. (2019), the drought severity is categorized as: extreme drought ($SRA < -1.65$), severe drought ($1.28 > SRA > -1.65$), moderate drought ($-0.84 > SRA > -1.28$), and no drought ($SRA > -0.84$).

Results and Discussion

Variability and Trends of Rainfall and Temperature in NSAZ

Variability and Trends of Temperature

Table 2 illustrates the variability and trends of temperature in NSAZ between 1979 and 2013. It shows that the minimum temperature of the area was 9.5°C with a maximum of 25.6°C and annual average of 17.5°C. Mann–Kendall test statistics used in the study revealed a statistically significant increasing trend for all long-term average monthly temperature. The overall significant increasing trend that this study revealed for average monthly temperature was found to be more attributed to the increasing trend of mean monthly maximum temperature. The regression coefficient for annual average, maximum and minimum temperature showed an increasing trend at the rate of 0.039°C, 0.056°C and 0.022°C per annum, respectively (Fig. 2).

Thus, the rate of increase in the mean annual maximum temperature was faster than the minimum. Studies conducted in other parts of Ethiopia by Teyso and Anjulo (2016), Asfaw et al. (2018), Befikadu et al. (2019) and Abebe and Arega (2019) also found an increase in the long-run mean annual maximum, minimum and average temperature.

Table 2. M-K Test and Sen's Slope on Monthly Minimum, Maximum and Average Temperature (1979-2013)

Month	Tmin	Z(M-K)	P-Value	Slope	Tmax	Z(M-K)	P-Value	Slope	Tmean	Z(M-K)	P-Value	Slope
Jan.	8.4	1.363	0.173	0.021	26.3	3.522***	0.000	0.055	17.4	3.636***	0.000	0.040
Feb.	9.7	-0.057	0.955	-0.002	27.7	3.465***	0.001	0.076	18.7	2.613**	0.009	0.041
Mar.	10.8	0.937	0.349	0.016	28.5	3.124**	0.002	0.056	19.7	2.982**	0.003	0.039
Apr.	11.2	2.840**	0.005	0.031	28.3	2.272*	0.023	0.040	19.8	3.153**	0.002	0.040
May	10.5	2.272*	0.023	0.020	28.1	2.926**	0.003	0.065	19.3	3.522***	0.000	0.045
June	11.0	1.960	0.050	0.015	26.1	3.465***	0.001	0.073	18.5	4.033***	0.000	0.044
July	11.1	3.550***	0.000	0.024	21.2	2.272*	0.023	0.064	16.1	2.897**	0.004	0.045
Aug.	10.3	2.471*	0.013	0.023	20.8	2.556*	0.011	0.063	15.6	3.153**	0.002	0.045
Sept.	8.5	2.670**	0.008	0.024	23.6	3.068**	0.002	0.063	16.0	3.266**	0.001	0.045
Oct.	7.6	2.357*	0.018	0.034	24.7	2.045*	0.041	0.050	16.1	2.784**	0.005	0.044
Nov.	7.4	2.613**	0.009	0.038	25.7	1.562	0.118	0.027	16.6	2.613**	0.009	0.026
Dec.	7.5	1.136	0.256	0.024	25.7	2.869**	0.004	0.037	16.6	2.414*	0.016	0.027
Ave.	9.5	2.698**	0.007	0.027	25.6	3.806***	0.000	0.056	17.5	3.976***	0.000	0.037

*, Is statistically significant at $P < 0.05$ **, Is statistically significant at $P < 0.01$ ***, Is statistically significant at $P < 0.001$

Figure 2. Trends in Long-Term Mean Annual Maximum, Minimum and Average Temperature

Variability and Trends of Rainfall

Table 3 shows the monthly, seasonal and annual trends of rainfall within the study area for the years extending from 1979 to 2013. As shown in the table, the long-term mean annual rainfall of the area was 940.2 mm with a SD of 157.8 and a CV of 16.8%. The highest (1287.8 mm) and the lowest (532.4 mm) mean annual rainfall was recorded in 1998 and 2002, respectively. The total annual rainfall of the area heavily concentrated in four months: June, July, August and September (*Kiremt* season). About 81.6% of the total rainfall was gained in these months. A considerable amount of rainfall was received during the four months of *belg* season (i.e February, March, April and May) accounting for about 14.2% of the annual total rainfall. Thus, *kiremt* season contributed the highest share of the total annual rainfall of the study area. Similar results were obtained by many other studies conducted in Ethiopia (Asfaw et al. 2018; Ayalew et al. 2012; Suryabhadgavan 2016; Gebrehiwot and Veen 2013).

Table 3. Monthly, Seasonal and Annual Rainfall Trend Analysis (1979–2013)

Month	Min	Max	Mean	%	Std.D	CV	Z(M-K)	P-Value	Slope
Jan.	0.00	30.37	8.38	0.89	8.09	0.9656	-0.8521	0.3942	-0.0797
Feb.	0.01	56.29	14.50	1.54	16.46	1.1356	-2.5563**	0.01058	-0.5569
March	0.16	139.41	37.03	3.94	28.55	0.7710	-0.8521	0.3942	-0.3542
April	3.89	99.50	42.92	4.56	27.90	0.6500	0	1	-0.0067
May	0.83	125.96	39.32	4.18	35.49	0.9027	-0.2556	0.7982	-0.1218
June	25.05	266.33	117.35	12.48	52.08	0.4438	-2.0734**	0.03813	-1.4552
July	112.80	381.86	274.65	29.21	50.83	0.1851	1.1361	0.2559	0.79237
Aug.	188.78	402.78	265.01	28.19	48.14	0.1816	-0.2556	0.7982	-0.1695
Sep.	37.99	174.85	109.68	11.67	33.21	0.3027	-0.5397	0.5894	-0.4428
Oct.	0.05	100.03	22.28	2.37	24.00	1.0773	-0.8521	0.3942	-0.1716
Nov.	0.06	30.27	5.20	0.55	8.14	1.5647	0.90889	0.3634	0.02682
Dec.	0.00	15.73	3.89	0.41	4.37	1.1243	-0.1136	0.9095	-0.0022
<i>Belg</i>	45.71	281.24	133.77	14.23	61.56	0.4602	-1.5622	0.1183	-1.7611
<i>Kiremt</i>	453.01	1001.16	766.69	81.55	117.26	0.1529	-0.5681	0.57	-0.9928
Annual	532.40	1287.75	940.20	100	157.78	0.1678	-1.2781	0.2012	-2.8284

***. Is statistically significant at $P < 0.05$*

Table 3 indicates that the CV of *belg* season was much higher (46%) and more variable than *kiremt* season (15%). Studies made in other parts of Ethiopia by Rosell and Holmer (2007), Ayalew et al. (2012), Bewket (2009), and Bewket and Conway (2007) documented similar results. Results from Mann–Kendall test revealed a decreasing, but non-significant trend for annual and seasonal (*kiremt* and *belg*) rainfall. Statistically significant decreasing trend of rainfall was observed for only two months: February ($p < 0.05$) and June ($p < 0.05$). The regression coefficients for annual, *kiremt* and *belg* rainfall showed decreasing trends at the rate of 3.104mm, 1.707mm and 1.431mm per year, respectively (Fig. 3). Rainfall reduction showed variations between years and amongst *kiremt* and *belg* seasons at a rate of 3.104mm, 1.707mm and 1.431mm, respectively. This result of the study negates with the work of Wagesho et al. (2013), Asfaw et al. (2018), and Abebe and Arega (2019) who found significant decreasing trends of annual and *kiremt* rainfall. The result obtained is, however, similar to the findings of Conway (2000a and 2000b), Viste et al. (2013), McSweeney et al. (2008), Suryabhadgavan, (2016), Conway et al. (2004), and Befikadu et al. (2019), who reported statistically non-significant trend results.

Table 4 indicates high (28.6%) and very high (71.4%) annual rainfall concentration (irregular rainfall distribution) in the period between 1979 and 2013. The table, on the other hand, shows

moderate (42.9%) and uniform (57.1%) rainfall distribution for *Kiremt* season during the indicated period. *Belg* season was mainly (65.7%) characterized by moderate rainfall distribution. Abebe and Arega (2019), Bewket (2009), Asfaw et al. (2018), Bewket and Conway (2007) and Ayalew et al. (2012) report similar results in which rainfall concentration is higher for *kiremt* season.

Figure 3. Trends in Mean Annual, *Kiremt* and *Belg* Rainfall (1979 - 2013)

Table 4. Annual, *Kiremt* and *Belg* Precipitation Concentration Index (PCI) for 1979–2013

PCI (%)	Description	Observation Years (%)		
		Annual	<i>Kiremt</i>	<i>Belg</i>
≤10	Uniform rainfall distribution/low concentration	-	57.1	11.4
(10-15]	Moderate rainfall distribution	-	42.9	65.7
(15-20]	High concentration/irregular rainfall distribution	28.6	-	20
>20	Very high concentration/irregular rainfall distribution	71.4	-	2.8

Variability and Trends in Rainfall and Temperature by AEZs

Variability and Trends in Temperature by AEZs

Variability and Trends in Mean Annual Maximum Temperature

The annual average maximum temperature for *Dega*, *Woina Dega* and *Kolla* AEZs varies between 22-25°C, 25-29°C and 28-31°C, respectively (Table 5). In this study, approximately equal CV was found for *Woina Dega* and *Kolla* AEZs in mean annual maximum temperature over the 35 years (1979-2013) considered. For highland area (*Dega* AEZ), however, a higher CV

was found. This suggests existence of variability in mean annual maximum temperature over those years between AEZ. The year 2002 was observed as the hottest year in all AEZs during the period (1979-2013). The coldest year for *Dega*, *Woina Dega* and *Kolla* AEZs was 1982, 1985 and 1986, respectively. The hottest and coldest years are consistent with a study by Mengistu et al. (2014), which reported that AEZs in the Upper Nile basin experienced relatively cold years in the 1980s and warm years from the early 1990s to the 2000s. Results obtained in the present study also go in line with the finding by Befikadu et al. (2019).

Table 5. Annual Maximum Temperature Variability by AEZs (1979 - 2013)

AEZs	Mean	Std. deviation	Max (°C)	Year	Min (°C)	Year	CV (%)
<i>Dega</i>	25.06	0.95	25.06	2002	21.49	1982	4.18
<i>Woina-Dega</i>	26.39	0.89	28.50	2002	25.24	1985	3.37
<i>Kolla</i>	29.19	0.97	31.09	2002	27.74	1986	3.34

Figure 4. Trends in Mean Annual Maximum Temperatures by AEZs (1979 - 2013)

Fig. 4 and Table 6 show the temporal and spatial variability and trend of mean annual maximum temperature by AEZs. The mean annual maximum temperature showed an increase over the years considered in all AEZs. It exhibited an upward trend of $0.07^{\circ}\text{C}/\text{year}$ ($p < 0.001$) for *Kolla* AEZ, signifying a 0.7°C increase per decade between 1979 and 2013. It also showed an upward trend of $0.06/\text{year}$ ($p < 0.001$) for both *Dega* and *Woina Dega* AEZs, signifying a 0.6°C increase per decade between the afore-indicated years. The warming trend observed in the study area is relatively higher than the historical trend reported at national and sub-national levels. For instance, a warming trend of $0.1^{\circ}\text{C}/\text{decade}$ was observed in Ethiopia between 1953 and 1999 (NMA 2007) while it was $0.2^{\circ}\text{C}/\text{decade}$ for Addis Ababa from 1951 to 2002 (Conway et

al.2004). Mengistu et al. (2014) also reported warming of 1.28°C and 0.64°C over three decades in highland and lowland AEZs implying some possible negative impacts on the lives and livelihoods of smallholder farmers. Despite the difference in the magnitude of increase in the annual average maximum temperature, the general warming trend matches with studies reported both at national level (NMA 2007) and local level (Mengistu et al. 2014).

Table 6. M-K Test and Sen's Slope on Monthly and Annual Maximum Temperature by AEZs

Month	<i>Dega</i>			<i>Woina Dega</i>			<i>Kolla</i>		
	Z(M-K)	P-Value	Slope	Z(M-K)	P-Value	Slope	Z(M-K)	P-Value	Slope
Jan.	3.1243**	0.0018	0.0588	3.4083***	0.0007	0.0509	4.4877***	0.0000	0.0597
Feb.	3.664***	0.0002	0.0967	3.1811**	0.0015	0.0629	4.1184***	0.0000	0.0673
Mar.	2.9539**	0.0031	0.0576	3.2379	0.0012	0.0549	3.4083***	0.0007	0.0491
Apr.	1.4769	0.1397	0.0397	2.4142*	0.0158	0.0441	3.5504***	0.0004	0.0534
May	2.1018*	0.0356	0.0664	2.9823**	0.0029	0.0633	4.4308***	0.0000	0.0748
June	3.0107**	0.0026	0.0685	3.3799***	0.0007	0.0694	4.2604***	0.0000	0.0977
July	1.6758	0.0938	0.0446	2.4142*	0.0158	0.0665	2.9255**	0.0034	0.1029
Aug.	1.5906	0.1117	0.0415	2.6983**	0.0070	0.0713	3.3231***	0.0009	0.1084
Sept.	2.1018*	0.0356	0.0476	3.1243**	0.0018	0.0619	3.7776***	0.0002	0.1129
Oct.	1.8746	0.0609	0.0446	2.1302*	0.0332	0.0508	3.0959**	0.0020	0.0708
Nov.	1.0225	0.3065	0.0186	1.7042	0.0884	0.0285	2.9255**	0.0034	0.0449
Dec.	2.7551**	0.0059	0.0393	2.6415**	0.0083	0.0343	3.806***	0.0001	0.0471
Annual	3.4936***	0.0005	0.0546	3.4936***	0.0005	0.0546	4.4877***	0.0000	0.0740

*, Is statistically significant at $P < 0.05$ **, Is statistically significant at $P < 0.01$ ***, Is statistically significant at $P < 0.001$

Variability and Trends in Mean Annual Minimum Temperature

The annual average minimum temperature was 8.46°C (CV=6.12), 9.81°C (CV=5.18) and 10.86°C (CV=4.49) for *Dega*, *Woina Dega* and *Kolla*, respectively (Table 7). It shows relatively high variability in the highland (*Dega*) area than the other AEZs. The coldest year, during the period ranging from 1979 to 2013, was 1984 in all AEZs. This result goes in line with the finding by Befikadu et al. (2019). It also agrees with the cold and warm years reported among AEZs of the Upper Nile basin (Mengistu et al. 2014). Table 8 and Fig. 5 show an increasing in mean annual minimum temperature in all AEZs over the years stretching from 1979 to 2013. Mean annual minimum temperature exhibited an upward trend of 0.03°C/year for *Kolla* ($p < 0.001$), *Woina Dega* ($p < 0.05$), and *Dega* ($p < 0.01$) agro-ecologies, signifying a 1.05°C increase between the indicated years. Earlier studies have also shown significant increasing trend for annual average minimum temperature. For instance, Bewket et al. (2014) reported a 0.05°C increase per annum in mean annual minimum temperature in lowland and midland AEZs. Conway et al. (2004) also observed an increasing trend of 0.4°C/decade in annual average minimum temperature from 1951 to 2002 for Addis Ababa. Besides, a study by Mengistu et al. (2014) found a 0.15°C increase per decade in the Upper Nile basin. In addition, mean annual minimum temperature increased by about 0.37°C/decade between 1951 and 2006 in a study conducted by McSweeney et al. (2008). Tekleab et al. (2013) also reported significant increases for many stations studied in the Abay basin. This finding shows that the rate with which mean annual maximum temperature increase was far higher than the rate with which mean annual minimum temperature increase in all AEZs over the period considered in the study. This negates

the result obtained by Befikadu et al. (2019), who reported that the rate of change for mean annual minimum temperature is faster than the mean annual maximum temperature both in time and space.

Table 7. Annual Minimum Temperature Variability by AEZs (1979 - 2013)

Agro-Ecology	Mean	Std. deviation	Max (°C)	Year	Min (°C)	Year	CV (%)
<i>Dega</i>	8.46	0.52	9.52	2010	7.41	1984	6.12
<i>Woina-Dega</i>	9.81	0.51	10.93	2010	8.84	1984	5.18
<i>Kolla</i>	10.86	0.49	11.66	2010	9.84	1984	4.49

Figure 5. Trends in Mean Annual Minimum Temperatures by AEZs (1979 - 2013)

Table 8. M-K Test and Sen's Slope on Monthly and Annual Minimum Temperature by AEZs

Month	<i>Dega</i>			<i>Woina Dega</i>			<i>Kolla</i>		
	Z(M-K)	P-Value	Slope	Z(M-K)	P-Value	Slope	Z(M-K)	P-Value	Slope
Jan.	1.4769	0.140	0.0272	1.1077	0.2680	0.0158	2.329*	0.0199	0.0347
Feb.	0	1.000	0.0001	-0.25563	0.7982	-0.0050	0.53965	0.5894	0.0119
Mar.	1.3349	0.182	0.0242	0.65327	0.5136	0.0117	1.1645	0.2442	0.0191
Apr.	3.0959**	0.002	0.0366	2.4995*	0.0124	0.0285	3.5504***	0.0004	0.0379
May	1.7326	0.083	0.0212	2.1302*	0.0332	0.0186	2.9823**	0.0029	0.0267
June	1.3633	0.173	0.0111	2.0166*	0.0437	0.0158	2.6699**	0.0076	0.0262
July	3.6924***	0.000	0.0221	3.3515***	0.0008	0.0220	3.8628***	0.0001	0.0397
Aug.	2.045*	0.041	0.0205	2.2438*	0.0248	0.0219	3.5788***	0.0003	0.0358
Sept.	2.1586*	0.031	0.0211	2.8119**	0.0049	0.0258	2.6699**	0.0076	0.0267
Oct.	2.045*	0.041	0.0328	2.4995*	0.0124	0.0324	2.8119**	0.0049	0.0417
Nov.	2.5847**	0.010	0.0412	2.3858*	0.0170	0.0344	3.2379**	0.0012	0.0466

Dec.	1.1929	0.233	0.0252	0.93729	0.3486	0.0195	2.1018*	0.0356	0.0455
Annual	2.8119**	0.005	0.0282	2.4995*	0.0124	0.0259	3.8912***	0.0001	0.0304

*, Is statistically significant at $P < 0.05$

**, Is statistically significant at $P < 0.01$

***, Is statistically significant at $P < 0.001$

Variability and Trends in Rainfall by AEZs

The mean annual, seasonal and monthly rainfall for 35 years (1979-2013) at highland, midland and lowland AEZs of NSAZ is shown in Table 8 and 9. The annual rainfall performance was very much variable from year to year in the three AEZs. The yearly rainfall amount varies between 186.0-584.1mm, 375.8-1006.5mm and 921.6-2019.2mm over *Kolla*, *Woina Dega* and *Dega* AEZs, respectively. The mean annual rainfall was 1520.4mm, 710.6mm and 407.9mm for highland, midland and lowland AEZs, respectively. The CV ranges from 15.95% in the *Dega* AEZ to 20.8% in the *Kolla* AEZ, suggesting high inner-annual rainfall variability in the latter AEZ. All the three AEZs received their maximum annual rainfall in 1998 and minimum in 2002 (Table 8). These were, therefore, the wettest and the driest years.

Table 8. Annual Rainfall Variability by AEZs (1979-2013)

Agro-ecology	Mean (mm)	Std. D	Max (mm)	Year	Min (mm)	Year	CV (%)
<i>Dega</i>	1520.4	242.5	2019.2	1998	921.6	2002	15.9465
<i>Woina Dega</i>	710.6	128.5	1006.5	1998	375.8	2002	18.0792
<i>Kolla</i>	407.9	84.9	584.1	1998	186.0	2002	20.8032

Figure 6. Trends in Mean Annual Rainfall by AEZs (1979 - 2013)

Table 9. Monthly, Seasonal and Annual Rainfall Variability by AEZs (1979-2013)

Month	<i>Dega</i>						<i>Woina Dega</i>						<i>Kolla</i>					
	Min (mm)	Max (mm)	Mean (mm)	%	Std.D	CV (%)	Min (mm)	Max (mm)	Mean (mm)	%	Std.D	CV (%)	Min (mm)	Max (mm)	Mean (mm)	%	Std.D	CV (%)
Jan.	0.0	71.1	17.3	1.1	17.3	100	0.0	15.3	4.7	0.7	4.4	94	0.0	3.6	0.8	0.2	1.1	128
Feb.	0.0	124.0	29.9	2.0	33.6	112	0.0	37.5	7.9	1.1	9.5	121	0.0	16.6	2.4	0.6	3.8	161
Mar.	0.3	246.0	68.9	4.5	52.0	75	0.1	95.0	23.6	3.3	19.7	84	0.0	55.3	10.9	2.7	13.7	126
Apr.	8.0	195.3	85.2	5.6	54.0	63	1.9	57.3	24.9	3.5	17.5	70	0.0	35.4	9.4	2.3	10.4	112
May	1.9	193.9	67.8	4.5	56.5	83	0.3	95.2	28.2	4.0	27.5	97	0.0	79.0	12.5	3.1	19.2	154
Jun.	44.5	421.2	195.6	12.9	81.2	42	18.2	204.8	88.4	12.4	42.0	48	3.6	125.1	37.7	9.2	24.6	65
July	199.1	604.8	423.6	27.9	73.8	17	76.7	288.0	214.9	30.2	42.5	20	41.2	223.2	141.0	34.6	37.1	26
Aug.	299.5	583.1	400.5	26.3	68.6	17	145.2	331.5	210.1	29.6	42.3	20	77.0	237.2	145.9	35.8	32.5	22
Sept.	72.4	276.9	178.0	11.7	50.2	28	22.8	134.5	84.5	11.9	27.4	32	7.2	81.3	39.7	9.7	17.6	44
Oct.	0.1	158.6	36.4	2.4	37.9	104	0.0	81.6	17.5	2.5	19.4	111	0.0	32.8	6.3	1.5	8.7	138
Nov.	0.1	55.2	9.5	0.6	14.8	156	0.0	20.6	3.6	0.5	5.6	156	0.0	7.2	1.0	0.2	2.1	209
Dec.	0.0	31.6	7.8	0.5	8.9	115	0.0	9.7	2.3	0.3	2.6	111	0.0	2.3	0.4	0.1	0.6	147
<i>Belg</i>	82.3	535.1	251.8	16.6	111.7	44	28.9	190.9	84.7	11.9	42.4	50	3.5	114.5	35.1	8.6	27.6	79
<i>Kiremt</i>	761.7	1513.8	1197.7	78.8	172.0	14	330.7	823.3	597.9	84.1	99.6	17	170.5	494.6	364.3	89.3	68.2	19
Annual	921.6	2019.2	1520.4	100	242.5	16	375.7	1006.5	710.6	100	128.5	18	186.0	584.1	407.9	100	84.9	21

All AEZs of the study area, as with most other places in Ethiopia, receive large amount of rainfall during summer (*Kiremt*) season, which contributes 78.8%, 84.1% and 89.3% of rainfall for *Dega*, *Woina Dega* and *Kolla* AEZs, respectively. *Belg* also contributes 16.6%, 11.9% and 8.6% of rainfall for each, respectively. While rainfall was more concentrated in *Kiremt* season at lowland AEZ than others, *Belg* contributed more amount of rain for highland AEZ than for others. The mean monthly maximum rainfall was 423.6mm, 214.9mm and 145.9mm at *Dega*, *Woina Dega* and *Kolla* AEZs, respectively. While highland and midland AEZs get their maximum amount of rainfall on July, lowland receives its maximum amount of rainfall on August. All AEZs of the study receive limited/ minimum amount of rain on December (Table 9). Figure 6 and Table 10 show the trend test results of rainfall on the annual time scale. Though not statistically significant, a decreasing trend was observed at all AEZs. The rate of decline was 4.695 mm/year, 2.55 mm/year and 1.342 mm/year in *Dega*, *Woina Dega* and *Kolla* AEZs, respectively. This result partly goes in line with the finding by Befikadu et al. (2019).

Table 10. M-K Test and Sen's Slope on Monthly, Seasonal and Annual Rainfall by AEZs (1979-2013)

Month	<i>Dega</i>			<i>Woina Dega</i>			<i>Kolla</i>		
	Z(M-K)	P-Value	Slope	Z(M-K)	P-Value	Slope	Z(M-K)	P-Value	Slope
Jan.	-0.8521	0.3942	-0.1535	-0.5397	0.5894	-0.0235	-1.3496	0.1771	-0.0104
Feb.	-2.5847**	0.0098	-1.2546	-2.7267**	0.0064	-0.2968	-2.0468**	0.0407	-0.0203
Mar.	-1.1645	0.2442	-0.8473	-0.426	0.6701	-0.1116	-0.7385	0.4602	-0.0752
Apr.	0.08521	0.9321	0.0588	-0.1136	0.9095	-0.0261	-0.3976	0.6909	-0.0501
May	-0.284	0.7764	-0.2453	-0.142	0.8871	-0.0155	0.14201	0.8871	0.0149
June	-2.329**	0.0199	-2.6004	-1.903	0.0570	-1.0714	-1.3349	0.1819	-0.5467
July	0.65327	0.5136	0.9351	0.85209	0.3942	0.6685	1.1361	0.2559	0.5927
Aug.	0.68167	0.4954	0.9781	-0.9941	0.3202	-0.8087	-1.6758	0.0938	-0.9650
Sept.	-0.6249	0.5321	-0.5528	-0.7385	0.4602	-0.3630	-1.1645	0.2442	-0.2267
Oct.	-0.9373	0.3486	-0.2674	-0.7385	0.4602	-0.1258	-0.412	0.6803	-0.0273
Nov.	0.9657	0.3342	0.0479	0.76688	0.4432	0.0187	1.0112	0.3119	0.0012
Dec.	-0.0284	0.9773	-0.0023	0	1.0000	-0.0001	-0.3276	0.7432	-0.0002
<i>Belg</i>	-1.6474	0.0995	-3.5381	-1.2781	0.2012	-0.6940	-1.3633	0.1728	-0.5819
<i>Kiremt</i>	-0.2556	0.7982	-0.6531	-0.8805	0.3786	-1.0811	-0.9373	0.3486	-1.3955
Annual	-1.1077	0.2680	-4.7715	-1.2497	0.2114	-2.3478	-1.1929	0.2329	-2.2691

***: Is statistically significant at P < 0.05*

Table 11 depicts frequency and percentage of annual and seasonal PCI values by agro-ecology for the years ranging from 1979 to 2013. It shows irregular distributions in the annual rainfall patter at all AEZs. While higher frequency of irregular distributions in the annual rainfall patter was seen at *Dega* agro-ecology (48.6%), more strong irregularity was observed at *Woina Dega* (82.9%) and *Kolla* (97.1%). Table 11 also illustrates a more or less uniform and moderate pattern in *Kiremt* rainfall at all agro-ecologies. It further shows that an increase in the irregularity of *Belg* rainfall pattern as on moves from *Dega* down to *Kolla* AEZs.

Table 11. Percentage of Annual and Seasonal PCI Values by AEZs (1979-2013)

PCI	<i>Dega</i>			<i>Woina Dega</i>			<i>Kolla</i>		
	Annual	<i>Kiremt</i>	<i>Belg</i>	Annual	<i>Kiremt</i>	<i>Belg</i>	Annual	<i>Kiremt</i>	<i>Belg</i>
≤10	-	62.9%	20%	-	51.4%	8.6%	-	11.4%	-
(10-15]	2.9%	37.1%	51.4%	-	48.6%	62.9%	-	82.9%	37.1%
(15-20]	48.6%	-	20%	17.1%	-	25.7%	2.9%	5.7%	40%
>20	48.6%	-	8.6%	82.9%	-	2.9%	97.1%	-	22.9%

Figure 7 shows SRA computed for mean annual rainfall in three agro-ecological belts in NSAZ. The upward bar shows positive anomalies and the downward bar shows negative anomalies during the 35 years (1979-2013) of the study. Figure 7 reveals negative rainfall anomalies for 16 years in both *Dega* and *Woina Dega* AEZs and for 18 years in *Kolla* AEZ between 1979 and 2013. During those years annual rainfall was below average. The reduced precipitation, shown in the aforementioned figure as negative rainfall anomalies, has a critical implication on rural livelihoods in general and food security in particular. Figure 7 also illustrates positive rainfall anomaly for 19 years in both *Dega* and *Woina Dega* AEZs and for 17 years in *Kolla* AEZ during the study period and this implies that during those years their respective annual rainfall was above average in each belts.

Figure 7. Mean Annual Rainfall Anomalies by AEZs (1979-2013)

SRA, apart from enabling to identify the dry and wet years in the record, is important for drought monitoring. Using SRA, as Befikadu et al. (2019) plainly indicated, severity of drought is categorized as: extreme drought ($SRA < -1.65$), severe drought ($-1.28 > SRA > -1.65$), moderate drought ($-0.84 > SRA > -1.28$), and no drought ($SRA > -0.84$) Table 12 summarizes the frequency and severity of droughts in the study area for the years between 1979 and 2013. It shows high frequency of drought in *Kolla* agro-ecology (28.6%), which experienced drought once in every three or four years between 1979 and 2013. *Dega* and *Woina Dega* experienced drought less frequently ($\leq 17.1\%$) than *Kolla*.

Table 12. Percentage and Severity of Drought by AEZs (1979-2013)

Agro-Ecology	Extreme Drought (SRA < -1.65)	Severe Drought (-1.65 ≤ SRA ≤ -1.28)	Moderate Drought (-1.28 ≤ SRA ≤ -0.84)	No Drought (SRA > -0.84)
<i>Dega</i>	5.7%	8.6%	0	85.7%
<i>Woina Dega</i>	5.7%	2.9%	8.6%	82.9%
<i>Kolla</i>	2.9%	2.9%	22.9%	71.4%

Potential Impacts of Rainfall and Temperature Variability

The study area's economy mainly depends on rain-fed agricultural activities. It is intimately tied to the prevailing weather conditions. The occurrences of temperature and rainfall variability would compromise the productive performances of the agricultural sector and makes rural households at risk. Variations and fluctuations in rainfall and temperature repetitively bring devastating repercussions on livestock and crop productions of the area (Million 2007; Messay 2009; Meskerem 2011; Feleke 2018). The productivity of livestock is being adversely affected, among others, through shortages of rain. Deficiency of rain is usually associated with reduced pastures and limited pasture inturn is associated with death of cattle. Loss of livestock holding consequently exposes rural households, who depend on cattle for survival, to food insecurity. It more specifically makes income earning from livestock rearing very low and limits the purchasing capacity of the households to have access to food. Erratic rainfall is also responsible for crop failures and apparently reduces productions. The decline in agricultural yield slowly drains food stocks and increases the risk of hunger.

This study has shown prevalence of erratic climatic conditions within NSAZ. The area is prone to extreme climatic events particularly drought, flooding, water-logging and frost. *Kolla* AEZ of the area experienced drought once in every 3 or 4 years between 1979 and 2013. During extreme drought conditions, it is common that many smallholder farmers could not adequately feed their family members from own production. They depend on food aid (could be from the government or their relatives or NGOs) to sustain their lives or die due to hunger (Messay 2009). Million (2007) indicated that water-logging in *Woin Dega* and frost in *Dega* AEZs devastate 50 to 75 % of standing crops during their worst incidence. Kassahun (2011) showed that change of rainfall amount and pattern significantly reduce total crop yield through affecting planting time, growing stages, and harvesting periods. Sumelius et al. (2009) indicated that as high as 80% of the variability in agricultural production is caused by the disturbance of weather and related factors. Von Braun (1991) further showed that a 10% decrease in the amount of rainfall below the long run average leads to a 4.4% reduction in the production of food and makes rural households vulnerable to food insecurity. Bewket (2009) complemented that extreme variability of rainfall is a major cause of variations in crop production making smallholder farmers susceptible to food shortage.

The increasing trend of annual and seasonal temperature over the study period could also have an influence on smallholder farmers and their crop production processes (Parry et al. 2007). Feleke (2018) indicated extreme temperature as one of the principal factors behind crop production failure across *Dega*, *Woina Dega* and *Kolla* AEZs in Kuyu district of NSAZ. He also indicated that crop yield dropped when the threshold of temperature values for a crop in a given region is exceeded only. This indicated that crop production failed when temperature became above or below the potential of the crop in any AEZ. Funk et al. (2012) reported that warming would

increase the influence of droughts, reducing the moisture availability of the soil affecting the productivity of the cropland. Gebreegziabher et al. (2013) also indicated that an increase in annual and seasonal temperature decreases crop yields per hectare. It is estimated that a 1°C rise in annual temperature will lead to a reduction of yields that costs about 1577.00 Ethiopian Birr from crop production. EPCC (2015) and Pachauri et al. (2014) showed that an increase in temperature could have potential influence on crop production differently. This could be through the occurrences of crop pests such as insects, migratory birds, and rodents, and invasive weeds that occur at some stage in the agricultural calendar (Abebe and Arega 2019).

In a nut shell, the potential influence of climate variability on crop production would be its sensitivity mainly to the variability of rainfall and temperature. This is because crop productions have very limited optimal and tolerable rainfall and temperature range to grow well (Kassahun 2011; Gebreegziabher et al. 2013). The occurrences of temperature and rainfall variability would drastically reduce crop production and in certain circumstances cause overall crop failure (Funk et al. 2015). Temperature and rainfall variability reduce crop production in particular and affect the overall success of the agricultural sector in general. At times when climate variability becomes the worst, it results in total crop failure leading to hunger and death of people and animals (Abebe and Arega 2019).

Conclusion

This study has analyzed climate variability over three AEZs in Central Ethiopia. The analyzed historical long term climate data shows that there was variability in rainfall and temperature from year to year over the three AEZs of the study area. The detected rainfall and temperature variability has critical implications for rural livelihoods in general and, rain-fed agriculture and food security in particular. Variations and fluctuations in rainfall and temperature compromise, among others, the productive performances of the agricultural sector and makes rural households at risk. Rainfall and temperature variability will continually compromise the life of rural people if not halted. There is the need for an increased attention on adaptation and mitigation mechanisms. The impact of climate variability varies based on rural households' ability to respond for and mitigate its adverse effects. Variations in climate elements disproportionately affect poor rural households. Any effort to be exerted by the government or else any other concerned bodies should have to consider the magnified impact of climate variability on the most vulnerable group of the society. Rainfall and temperature variability and their resultant effect on rural livelihoods imply those poor farmers who are dependent on natural weather condition need protection through for example, irrigation scheme, introduction of drought resistant varieties of crops, livelihood diversifications and other services. This can help farmers to stabilize income during the period of low rain and poor output.

Abbreviations

AEZs: Agro-Ecological Zones; CV: Coefficient of Variation; IPCC: Intergovernmental Panel on Climate Change; MK: Mann Kendal; NMA: National Meteorological Service Agency; NSAZ: North Shewa Administrative Zone; ONRS: Oromia National Regional State; PCI: Precipitation Concentration Index; SD: Standard Deviation; SRA: Standardized Rainfall Anomalies.

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Authors' Contributions

The first author collected and analyzed the data, and wrote the manuscript. All authors read, edited and approved the manuscript.

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Availability of Data and Materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing Interests

The authors declare that they have no competing interests.

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Figures

Figure 1

Location of the Study Area

Figure 2

Trends in Long-Term Mean Annual Maximum, Minimum and Average Temperature

Figure 3

Trends in Mean Annual, Kiremt and Belg Rainfall (1979 - 2013)

Figure 4

Trends in Mean Annual Maximum Temperatures by AEZs (1979 - 2013)

Figure 5

Trends in Mean Annual Minimum Temperatures by AEZs (1979 - 2013)

Figure 6

Trends in Mean Annual Minimum Temperatures by AEZs (1979 - 2013)

Figure 7

Mean Annual Rainfall Anomalies by AEZs (1979-2013)