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Trends in Observed Temperature and Rainfall Variability in Major Potato Growing Districts of Eastern Ethiopia

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Abstract

Potato (Solanum tuberosum L.) is a major cash crop in the eastern highlands of Ethiopia owing to the cooler and moist climate in the region. Climate variability threatens potato production since variations in rainfall patterns and temperature lead to severe moisture as well as other abiotic and biotic stresses for the crop. Therefore, we conducted a study to analyze trends in the variability of rainfall and temperature in three major potato growing districts (Woredas) in eastern Ethiopia, namely, Haramaya, Chiro, and Kombolcha. We acquired 38-year (1980–2017) historical and observed meteorological data from the National Meteorology Agency of Ethiopia. Trends of rainfall and temperature were analyzed using the Man-Kendall test. Rainfall variability analysis was done using the Precipitation Concentration Index (PCI), Standard Anomaly Index (SAI), and coefficient of variation (CV %). The results showed that, over the 38-year period, the annual amount of rainfall in Haramaya district varied by 17.8% while those of Kombolcha and Chiro varied by 66.8% and 28.7%, respectively. Both annual and seasonal maximum temperatures in Haramaya district showed significantly ($P < 0.05$) increasing trends whereas the maximum temperature in Chiro district showed a non-significantly increasing trend. The PCI value of Kombolcha ranged from high to very high indicating high concentration of rainfall in few months. Comparatively, Haramaya and Chiro districts experienced higher frequencies of drought than Kombolcha district. It is concluded that there was a significant increasing trend of minimum temperature at Haramaya and Chiro districts, and a significant increasing trend of Kiremt rainfall at Haramaya district that could lead to reduced potato yields and increased incidences of diseases. Therefore, options should be sought to tackle the variability in trends of temperature and rainfall and sustain potato production and enhance farmers' resilience to climate change.

Keywords: Annual rainfall; Annual temperature; Man-Kendall test; Precipitation Concentration Index (PCI); *Solanum tuberosum* L.; Standard Anomaly Index (SAI),

Introduction

Climatic variability plays an important role in agricultural production with a significant impact on crop growth, development, and yield, thus making the agricultural activity one of the most sensitive and vulnerable sectors among the anthropological activities (Ventrella *et al.,* 2012). Climate change-induced risks due to temperature variability, changes in rainfall pattern, and pest and disease outbreaks negatively influence agricultural production, productivity, and quality (Tesfahun, 2018). Long-term variability in rainfall and temperature is likely to increase the frequency of droughts and floods in Ethiopia (Amogne *et al*., 2018). High rainfall variability in both temporal and spatial scale is a typical characteristic of climate in Ethiopia (Gissila *et al.*, 2004).

Precipitation is the key climatic variable that affects both the spatial and temporal patterns of water resources (Girma *et al*., 2016; Xu *et al*., 2018). Rainfall variability is directly related to the occurrence of flooding and drought (Li *et al.*, 2017). A study by FEWS NET (2012) indicated the declining rainfall and Belg crop production occurred along the eastern highlands of Ethiopia, stretching between the cities of Asebe Teferi (now Chiro) and Harar. In addition, recent observations (1990–2009) have indicated that this area no longer receives the average of 500 mm of rainfall during the March–June season. Over the past decade, the average minimum and maximum temperatures of Ethiopia have increased by around 0.25°C and 0.1 °C, respectively. Further, it is expected that in the year 2050, the mean temperature in the country ill increase by 1.7–2.1°C (Tadege, 2007).

Knowledge and technology are required for adaptation to climate change, seasonal climate prediction, and land productivity management (FAO, 2007). Previous studies revealed inconsistent results in annual and seasonal rainfall trends (Gebre, 2014) and rainfall and temperature patterns showed large regional differences (Zerga and Gebeyehu, 2016). Therefore, investigations into climate change trends at local levels is recommended because large-scale studies of climate change scenarios that focus on large areas would be of little use for local agriculture, particularly in places where rainfall is highly variable and geophysical characteristics vary within short distances. Besides, local level climate change trend analysis is vital for context-specific planning and implementation of adaptation interventions (Gebre *et al*., 2013; Aragaw and Woldeamlak, 2017).

Potato is highly vulnerable to climate variability (Aniek *et al*., 2013). The main climatic factors that can greatly influence the growth and development of potatoes are air temperature, rainfall, and light (Fleisher *et al*., 2017). The yield and total profit from potato are affected by unpredictable variability in rainfall patterns, changes in temperature, precipitation, and unusual storms (Fleisher *et al*., 2017). Fluctuations in quantity and quality of potato yields have been also caused by increasing temperatures, drought and floods, post-harvest losses, increasing costs of replanting and production, increasing pest and disease incidences, as well as increasing soil erosion (Jovovic *et al*., 2016).

The eastern highlands of Ethiopia are characterized by high population density, small land size, declining soil fertility, rugged topography, severe land degradation, fragile ecosystems (Tesfaye and Seifu, 2016) and recurrent weather-induced shocks such as drought. As a result, the region is among the most chronically food-insecure areas of the country (Mulugeta *et al*., 2018). In this connection, potato producing smallholder farmers in eastern Ethiopia face frequent risks of disease outbreaks, pest damage, post-harvest losses, and occurrence of extreme weather events (Sisay *et al*., 2019). Therefore, understanding the magnitude and trend of variability of climate variables and documenting the influence of climate variability on specific crops in major production areas could provide useful information for early warning and suitable adaptation options. However, to understand and document the change in climate, specific causes of potato crop failures that are related to rainfall and temperature variability have not been elucidated in the area. Therefore, this paper presents research results on trends in rainfall and temperature variability that affect potato production in major areas growing the crop in the eastern highlands of Ethiopia.

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Methodology

Description of the study areas

The study was conducted in three major potato growing districts in eastern Ethiopia. They are Haramaya and Kombolcha districts in the East Hararghe Zone and Chiro district in the West Hararghe Zone. Haramaya is located at 42^{o}3'E longitude, 9^{o}26'N latitude, and at a mean altitude of 2006 meters above sea level, which puts the area into the category of a highland. Haramaya district (*Woreda*) has the altitude ranging from 1400 to 2340 meters above sea level. It is situated in the semi-arid tropical belt of eastern Ethiopia. The mean annual rainfall received in the district ranges from 600 to 1260 mm. The rainfall is bimodal. The district is representative of a sub-humid mid-altitude agro-climatic zone. The short rainy season usually starts in March and ends in May, and the long rainy season (*Ganna or Kiremt*) occurs between June and September. The relative humidity varies between 60 and 80%. The minimum and maximum annual temperatures range from 6^{o}C to 12^{o}C and 17^{o}C to 25^{o}C, respectively (Nigussie *et al*., 2014). Kombolcha district is situated between 09^{o}22' N–09^{o}35‘N and 42^{o}06' E–42^{o}13' E with the altitude that ranges from 1200 to

2460 meters above sea level (Nigussie *et al*., 2014; Nigussie *et al*., 2018). The short rainy season usually starts in March and ends in May, and the long rainy season rainfall occur between June and September. Chiro district has latitude and longitude of $09^o05'$ N $40^o52'$ E/ 09^o083‘N $40^o867'$ E. The altitude of the area ranges between 1826–1950 meters above sea level. The mean annual rainfall received in the district was 927 mm. The minimum and maximum annual temperatures were 27.87^oC and 12.72^oC, respectively.

Climate variability analysis

Climate data including daily rainfall (RF) and temperature (T-max and T-min) of 38 years for Haramaya, Kombolcha, and Chiro were obtained from the National Meteorological Agency (NMA) of Ethiopia. Before analysis, the data were scanned for missing values. The World Meteorological Organization recommends 30 years as the minimum duration for data required to search evidence of climatic change in hydro-climatic time series (IPCC-GCIA, 1999). Therefore, the maximum flexible threshold of 10% missing value adopted by Ngongondo *et al*. (2011) was considered in this study. To reconstruct the gap and fill the missing values, data were generated using the weatherman database in the DSSAT version 4.7. Then, the generated data were checked for physical representativeness of the respective sites. INSTAT + version 3.36) (Stern *et al.,* 2006) was used to summarize the daily data into annual, monthly, and seasonal totals and to analyze the onset and cessation of the rainy season and length of the growing period (LGP).

Data quality control

Outlier detection: identification of outliers (suspicious data) has been the primary emphasis on the climatic database development (Gonzalez – Rouco *et al.,* 2001). Outliers are values greater than a threshold value of a specific time-series data that can affect the detection of in homogeneity (Gonzalez-Hidalgo *et al*., 2009). For non- normally distributed data like rainfall, the Tukey fence is recommended for trimming the outlier (Ngongondo *et al*., 2011):

$$[Q_1 - 1.5 \times IQR, Q_3 + 1.5 \times IQR]$$

Where Q1 and Q3 are, respectively, the lower and upper quartile points, 1.5 is a standard deviation from the mean, and IQR is the inter quartile range. Values outside the Tukey fence are considered as outliers. In this study, such outliers were set to a limit value corresponding to ±1.5×IQR.

Homogeneity test: the second step of the quality control process was the analysis of homogeneity.

In this particular study, due to its lower demands in application and interpretation, a cumulative deviation test was used for absolute testing (using stations own data). This method is commonly used in climatology to detect in homogeneities in the meteorological time series

(Ngongondo *et al.*, 2011; Kang and Yusof, 2012). Buishand (1982) noted that tests for homogeneity can be based on the adjusted partial sums or cumulative deviations from the mean and it is given as follows:

$$S^*_0 = 0 \text{ and } S^*_K = \sum_{i=1}^{k} (y_i - \bar{y}), \quad K = 1 \ldots n$$

The term S^*_K is the partial sum of the given series. If there is no significant change in the mean, the difference between y_i and $\bar{y}$ will fluctuate around zero. The significance of the change in the mean was calculated with 'rescaled adjusted range' R, which is the difference between the maximum and the minimum of the S^*_K values scaled by the sample standard deviation is:

$$R = (\max_{0 \le k \le n} S^*_K - \min_{0 \le k \le n} S^*_K) / SD$$

Then the critical value for $R/\sqrt{n}$ was calculated by Buishand (1982) and for n=30 its value is 1.5 and 1.4, respectively, for 5% and 10% probability levels.

Test of randomness and persistence: It is well known that the time series data required for trend analysis should be random and/or non-persistent (Ngongondo *et al.*, 2011). Before proceeding to trend analysis, the time series data was tested for randomness and independence using the autocorrelation function (r_1) as described in Box and Jenkins (1976) in the following manner.

$$r_1 = \frac{\sum_{i=1}^{n-1} (x_i - \bar{x})(x_{i+1} - \bar{x})}{\sum_{i=1}^{n} (x_i - \bar{x})}$$

Where x_i is an observation, x_{i+1} is the following observation, $\bar{x}$ is the mean of the time series, and n is the number of data. Also, Dahmen and Hall (1989) defined the critical region at 5% probability as follows;

$$\left[(-1 - 1.96\sqrt{(n-2)})/(n-1), \quad (-1 + 1.96\sqrt{(n-2)})/(n-1)\right]$$

For the study serial correlation of lag-1 (the correlation of two consecutive observations in the time series data) was employed. Whenever a significant correlation appeared in the data series, the data series was 'pre-whitened' following the procedure described by Partal and Kahya (2006). The pre-whitened data series was obtained as:

$$(X_2 - r_1 x_1, x_3 - r_1 x_2, \ldots, x_n - r_1 x_{n-1})$$

Variability Analysis

Analysis of standardized anomaly index, rainfall/precipitation concentration index (PCI), and coefficient of variation were used as descriptors of rainfall variability (Bewket and Conway, 2007; Ayalew *et al.*, 2012).

Standardized Anomaly Index (SAI) was calculated as the difference between the annual total of a particular year and the long-term average rainfall records divided by the standard deviation of the long term data. This index was used to examine the nature of the trends and enable to determine the dry and wet years in the record. The choice of the index is justified by its capacity to rapidly detect situations of drought and assess its acuteness. It is also highly recommended by climatologists because it is less complex than many other drought indexes (Tossou *et al.*, 2017). It is calculated as:

$$RA_{ij} = \frac{P_t - P_m}{\delta}$$

Where, RA_{ij} is normalized rainfall total for station i during a year (or season) j; P_t is the annual rainfall in year t; P_m is long term mean annual rainfall throughout observation; and δ is the standard deviation of annual rainfall throughout the observation. Positive normalized rainfall anomalies indicate greater than long-term mean rainfall, while negative anomalies indicate less than the mean rainfall. When averaged over several stations, the normalized rainfall anomaly yields a normalized rainfall anomaly index. Drought severity classes include extreme drought (SAI< -1.65), severe drought (-1.28 > SAI, moderate drought (-0.84 >SAI> -1.28), and no drought (SAI> -0.84) (Dereje *et al.*, 2012).

Precipitation concentration index (PCI) was used for characterizing the monthly rainfall distribution and was analyzed using the formula described by De Luıs *et al*. (1999) as:

$$PCI = 100 \times \left[\sum_{i=1}^{12} P^2{}_i / \left(\sum_{i=1}^{12} P_i\right)^2 \right]$$

Where, P_i is the rainfall amount of the i^{th} month. According to Oliver (1980), PCI values can be categorized ranging from a uniform distribution (low) to a strong irregular distribution (very high) (Table 2). An inter-annual fluctuation was evaluated by calculating standardized rainfall anomalies and graphically presenting the results. Precipitation Concentration Index (PCI) values categorized as PCI<10 (uniform rainfall distribution (low rainfall concentration), 10<PCI≤15 (moderate rainfall distribution), 16<PCI<20 (irregular distribution (high concentration), and PCI >20 (strong irregularity (very high concentration) **(**Oliver, 1980). For climate variability, the precipitation concentration index (PCI) is a powerful indicator of the temporal distribution of precipitation on the annual scale and seasonal scale in different parts of the world. This method is recommended as it can provide information on long-term total variability in the amount of rainfall received for a given area (Oliver, 1980).

For this study, precipitation concentration index (PCI) is analyzed. The PCI allows quantifying the relative distribution of precipitation patterns. Many scholars divided seasons into four but in this study, the season was divided into three. And also, unlike most of the tropics where two seasons are common (one wet season and one dry season), three seasons are known in Ethiopia, namely '*Bega*' (dry season) which extends from October- January, '*Belg*' (Short rain season) which extends from (February- May), and 'Kiremt' (long rainy season) which extends from June- September (NMSA, 2007). The PCI was calculated on a seasonal scale for *Belg*, *Kiremt*, and *Bega*.

$$PCI = 33.333 \times \left[\sum_{i=1}^{4} P^2_i / \left(\sum_{i=1}^{4} P_i \right)^2 \right]$$

The coefficient of variation (CV): it was calculated to evaluate the variability of the rainfall and its characteristics by dividing the standard deviation of the event to its mean. In this study, the coefficient of variation (CV) was calculated to evaluate the variability for each year of the rainfall and its characteristics. A higher value of CV is the indicator of larger variability, and vice versa which is computed as:

$$CV = \frac{\sigma}{\mu} \times 100$$

Where CV is the coefficient of variation; σ is the standard deviation and μ is the mean precipitation. According to Hare (2003), the degree of variability of rainfall events was classified as less (CV< 20%), moderate (20 %< CV <30%), and high (CV >30%). However; according to (Hadgu *et al.*, 2013) the CV has been classified as low variability (CV<20%), moderate rainfall variability (between 20% and 30%), high variability (CV>30%), very high (CV>40%) and extremely high inter-annual (CV>70%) variability; hence this study used the scales used in this category.

Determination of trends in annual and seasonal rainfall and temperature

In this study, the Mann–Kendall trend test was employed. Mann–Kendall trend test is a non-parametric method which is less sensitive to outliers and test for a trend in time series without specifying whether the trend is linear or non-linear (Partal and Kahya, 2006; Yenigun *et al.*, 2008). World Meteorological Organization (WMO) recommends the non-parametric Mann– Kendall (MK) test statistic for the assessment of trends in meteorological data (Ngongodo, 2011).

The data values are evaluated as an ordered time series. Each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic, S, is assumed to be 0 (*e.g.*, no trend). If a data value from a

later period is higher than a data value from an earlier
period, S is incremented by 1. On the other hand, if the data value from a later period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S.

Let $x_1, x_2, \ldots x_n$ represents n data points where j x represents the data point at time j. Then the Mann-Kendall's test statistic is given as:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn(x_j - x_i)$$

Where S is the Mann-Kendal's test statistics; x_i and x_j are the sequential data values of the time series in the years *I* and *j* (*j* >*i*) and *N* is the length of the time series. A positive *S* value indicates an increasing trend and a negative value indicates a decreasing trend in the data series.

The sign function is given as

$$sgn(x_j\text{-}x_i) = \begin{cases} +1 \; if \; (x_j - x_i) > 0 \\ 0 \; if \; (x_j - x_i) = 0 \\ -1 \; if \; (x_j - x_i) < 0 \end{cases}$$

A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with S and the sample size, n, to statistically quantify the significance of the trend.

The variance of *S*, for the situation where there may be ties (i.e., equal values) in the *x* values, is given by

$$Var(S) = \frac{1}{18}\left[N(N-1)(2N+5) - \sum_{i=1}^{m} t_i \, (t_i -\right.$$

Where: *m* is the number of tied groups in the data set and $t_i$is the number of data points in the i^{th}tied group. For n larger than 10, Z_{MK} approximates the standard normal distribution (Partal and Kahya, 2006; Yenigun *et al.*, 2008) and computed as:

$$\begin{cases} \frac{S-1}{\sqrt{Var\,(S)}} & if \; S > 0 \\ 0 & if \; S = 0 \\ \frac{S+1}{\sqrt{Var\,(S)}} & if \; S < 0 \end{cases}$$

The presence of a statistically significant trend was evaluated using the Z_{MK} value. In a two-sided test for trend, the null hypothesis *Ho* should be accepted if $|Z_{MK}| < Z_{1-\frac{\alpha}{2}}$at a given level of significance. $Z_{1-\frac{\alpha}{2}}$is the critical value of Z_{MK} from the standard normal table. E.g. for a 5% significance level, the value of $Z_{1-\frac{\alpha}{2}}$is 1.96.Z implies the significance of the trend analyzed in the study if Z calculated is greater than Z tabulated (1.96) and (2.57) considered as significant at 5% and 1%; respectively. However, if Z calculated is greater than Z tabulated (1.64) considered as significant at 10%.

The Sen's estimator of slope: This test is applied in cases where the trend is assumed to be linear, depicting the quantification of changes per unit time. The slope (change per unit time) was estimated following the procedure of Sen (1968). A detailed outline of the procedure is given in Partal and Kahya (2006); and Karpouzos *et al*. (2010).

Table 1. Baseline period, weather variables and geographical locations of the study areas

Location	Altitude (m.a.s.l.)	Latitude (^oN)	Longitude (^oE)	Baseline period	Years with Missing values/No. of years with missing values	Weather variable
Haramaya	2020	9.40	42.0333	1980-2017	1993-1996	RF, T-max, T-min
Kombolcha	2122	9.4333	42.1167	1980-2017	1992,1993,2016,2017	RF
Chiro	1792	9.0725	40.8715	1980-2017	1991,1992	RF, T-max, T-min

Key: *m.a.s.l. = meters above sea level; RF = rainfall; Tmax = maximum Temperature; Tmin = minimum temperature.

Results and Discussion

Analysis of Climate Variables

Coefficient of the variability of temperature and rainfall

The total amount of annual rainfall for Haramaya district was low in coefficient of variability (CV). However, Chiro and Kombolcha districts had moderate and high CV values, respectively (Table 2). This result implies that variability was higher in the latter two stations than the former one. Unlike the coefficient of variability in the total annual rainfall, the coefficient of variability in the amount of *Kiremt or Ganna* rainfall for Haramaya district was moderate. However, Kombolcha district showed high variability for both seasonal and annual rainfall amounts (Table 2). This indicates the existence of high intra-annual variability. The annual rainfall variability of Haramaya was low (Table 4).

Seasonal variability was found for all of the study areas with varying magnitude. The seasonal rainfall variability for all of the study districts indicated that the *Belg* season rainfall was more variable than the *Kiremt* season rainfall. This inter- and intra-annual variability could have an impact on productivity of the potato crop. Consistent with this result, Amogne *et al*. (2018) reported a higher CV value for *Belg* rainfall than for *Kiremt* rainfall. This result also agrees with the findings of Seleshi and Zanke (2004), Bewket and Conway (2007), Hadgu *et al*. (2013), who reported that the variability in *Belg* season rainfall was higher than that in *Kiremt* season rainfall.

In this study, the mean contribution of *Belg* rainfall to the total amounts of rainfall in Haramaya and Chiro districts was found to be about 35%. Likewise, the mean contribution of *Kiremt* rainfall to the total rain that fell in the two districts was on average about 53%. On the other hand, the contribution of *Belg* rainfall to the total amount of rain that fell in Kombolcha district was relatively high, which was above 40% (Table 2). This indicates that the areas have close similarity in spatial rainfall patterns which makes them potential areas for potato production. Furthermore, the data revealed that Kombolcha district had a more favorable rainfall pattern for double cropping the potato crop than the other two districts given the relatively higher amount of rainfall it receives compared to the other two districts.

Table 2. Mean standard deviation (SD), coefficient of variation (CV) and percentage proportion of seasonal and annual rainfall amount for three locations in eastern Ethiopia for the baseline years 1980–2017

Season	Haramaya				Chiro				Kombolcha			
	Mean rainfall (mm)	Seasonal contribution (%)	SD	CV (%)	Mean rainfall (mm)	Seasonal contribution (%)	SD	CV (%)	Mean rainfall (mm)	Seasonal contribution (%)	SD	CV (%)
Belg (FMAM)	274.70	34.60	104.14	37.92	328.77	36.26	161.71	49.18	430.52	43.24	472.36	109.72
Bega (ONDJ)	82.80	10.43	68.48	34.60	108.98	12.02	108.29	99.36	86.14	8.65	90.08	104.57
Kiremt (JJAS)	436.30	54.97	87.39	20.03	468.93	51.72	154.46	32.94	478.98	48.11	215.89	45.07
Annual	793.70	100.00	141.23	17.8	906.68	100	260.33	28.71	995.65	100	665.55	66.84

Key: 'Kiremt' means main rainy season; 'Bega' means dry season; 'Belg' means short rainy season; FMAM = February, March, April, and May; ONDJ = October, November, December, January; JJAS= June, July, August, September

The mean main (*Kiremt)* season rainfall for Haramaya was 436.3 mm, that for Chiro was 468.93 mm, and that for Kombolcha was 478.98 mm (Table 2). The potato plant is not resistant to drought but requires only moderate rainfall or equivalent irrigation, which is uniformly distributed throughout the growing season. The crop is most sensitive to water stress during tuber initiation and bulking (Devaux and Haverkort, 1987). Accordingly, the study areas receive optimum mean annual rainfall for potato production. This indicates that the total amount of rainfall received in the districts is moderate and sufficient for potato production.

In contrast to the *Belg* rainfall, the Man-Kendall test result of this study revealed a significantly increasing trend in *Kiremt* rainfall for Haramaya. However, the variability in the amount and any erratic distribution of the rainfall would have significant negative impacts on potato production. This suggestion is consistent with that of Girma *et al*. (2016) and Xu *et al*. (2018) who indicated that precipitation is the key climatic variable that affects both the spatial and temporal patterns of water resources. On the other hand, the increment in *Kiremt* rainfall could create unfavorable condition for potato production by enhancing incidences of diseases particularly potato Late Blight disease caused by *Phytophthora infestans* (Mont) de Bary. Consistent with this suggestion, Olanya *et al*. (2006) reported that Late Blight disease of potato became a serious problem in potato production especially under high rainfall condition. In particular, the potato plant is most sensitive to water stress during tuber initiation and bulking. This suggestion is consistent with that of Devaux and Haverkort (1987), Loon van (1981), and Haverkort (1990) that too much rainfall and high humidity predisposes the potato plant to various fungal and bacterial diseases. Therefore, farmers should practice control measures against the disease to produce the crop under intense amounts of rainfall occurring as a result of climate variability. On the other hand, the increasing trend in *Kiremt* (main season rainfall) rainfall in the districts studied could be seized as an opportunity to use water harvesting technologies for enhancing production of the crop.

Table 3. Mean standard deviation and coefficient of variation of seasonal and annual temperature variability in Haramaya and Chiro districts for the baseline years of 1980–2017

Variable	Season	Location					
		Haramaya			Chiro		
		Mean	SD	CV (%)	Mean	SD	CV (%)
Maximum temperature (^{o}C)	*Belg*	25.10	0.67	2.60	28.23	1.05	3.74
	Bega	23.21	0.45	1.90	27.12	1.11	4.09
	Kiremt	23.84	0.57	2.40	28.11	1.04	3.70
	Annual	24.05	0.45	1.88	27.82	0.92	3.30
Minimum temperature (^{o}C)	*Belg*	10.74	1.13	10.53	13.70	2.19	16.02
	Bega	5.10	1.50	29.47	12.17	1.79	14.73
	Kiremt	13.39	0.96	7.19	14.30	0.51	14.36
	Annual	9.74	0.90	9.25	13.39	1.88	14.03
Mean temperature (^{o}C)	*Belg*	17.92	0.66	3.67	20.97	1.30	6.19
	Bega	14.15	0.75	5.31	19.65	0.96	4.90
	Kiremt	18.61	0.68	3.67	21.21	0.96	4.54
	Annual	16.90	0.57	3.36	20.61	0.94	4.57

The optimum temperature for potato production ranges between 18 to 30 ^{o}C (Hijman, 2003; Muthoni and Kabira, 2015). However, the CV of the minimum temperature for Haramaya showed high variability for *Bega* (dry) season. However, the other seasons (*Kiremt* and *Belg*), showed low variability (Table 3). On the other hand, the CV for *Chiro* revealed that both annual and seasonal minimum temperatures had moderate variability. Temperature variability could influence tuber initiation and bulking of potato. Higher temperatures have adverse effects on metabolic activities and increase evapo-transpiration from the plant. Rising temperatures also accelerate plant development and leaf senescence. Higher temperatures during tuber bulking reduce translocation of carbohydrates from other plant part to the tubers (CIPC, 2007). If the temperature is higher than 30^{o}C, the crop will not tuberize and grows mainly vegetatively. Potato yields decrease in many regions especially in the tropics because of increasing temperatures. All potato varieties do well in cool climate between 15^{o}C to 18^{o}C, and temperatures beyond 20^{o}C shorten the growing period, thereby reducing assimilate accumulation and ultimate yields obtained from the crop (Hijman, 2003).

Precipitation concentration index (PCI)

Chiro and Kombolcha districts had high concentrations of inter-annual variability (PCI >16%) (Table 4). This implies an irregular distribution of rainfall (poor monthly distribution). It means the degree of seasonality in the specified area is high. Correspondingly, the mean annual PCI value in case of Haramaya district was in the moderate and high categories (15.81%). Compared to that of Haramaya and Chiro districts, the inter-annual variability of Kombolcha was very high. This irregular distribution of annual rainfall could affect production of potato across years. *Kiremt* season rainfall distribution for Haramaya and Chiro was uniform whereas it was moderate for Kombolcha, indicating seasonality. Conversely, *Belg* season rainfall for Haramaya showed irregularity which could have impact on the growth and development of potato, which may create difficulty in implementing and maintaining the previously used optimal planned farming operations. These results are consistent with seasonal rainfall trends observed by Gebre (2014) and rainfall and temperature patterns that showed large regional differences in Ethiopia as reported by Zerga and Gebeyehu (2016).

Table 4 Annual and seasonal Precipitation Concentration Index (PCI) and percent proportion of Standard Anomaly Index (SAI) values of the three areas in Eastern Ethiopia for the Baseline Years 1980-2017

Location	PCI (%)				SAI			
					Positive Anomalies		Negative Anomalies	
	Annual	*Bega*	*Belg*	*Kiremt*	No. of years	% proportion	No. of years	% proportion
Haramaya	15.81	19.28	16.15	10.22	17	44.74	21	55.26
Chiro	16.17	18.84	9.23	10.62	23	60.53	15	39.47
Kombolcha	18.77	20.09	15.80	12.08	12	31.58	26	68.42

A higher precipitation concentration index value indicates that precipitation is more concentrated to a few rainy months during the year and vice versa (Zhao *et al*., 2011). Irregular rainfall patterns result in high risk of drought and intra-seasonal dry spell, leading to low crop yields and sometimes total crop failures (Kinoti *et al*., 2010). Therefore, potato production could be adversely affected particularly if the scarcity of water coincides with the critical growth stage of the crop, especially during tuber initiation and tuber bulking period. This suggestion is consistent with the fact that the potato plant is most sensitive to water stress during tuber initiation and bulking (Blom-Zandstra *et al*., 2015). However, the distribution of rainfall matters during growth of the crop. Except PCI values of Kombolcha for *Belg* season which were significant, the Man-Kendall trend test of both seasonal and annual precipitation concentration indices of all study districts showed non-significant trends (Table 5).

Table 5. Man-Kendall trend test of Precipitation Concentration Index (PCI) for three locations in eastern Ethiopia for the baseline years of 1980-2017

Location	Rainfall(mm)	Annual	*Bega*	*Belg*	*Kiremt*
Haramaya	Sen's slope	0.05	-0.05	-0.07	0.02
	MK	1.26	-0.59	-0.68	1.51
Chiro	Sen's slope	0.001	0.02	-0.06	0.01
	MK	0.03	0.19	-0.53	0.67
Kombolcha	Sen's slope	-0.05	0.112	0.11	-0.05
	MK	-0.60	1.23	2.16**	-1.36

Standard Anomaly Index (SAI)

From the 38-year average total rainfall data of each site, the greater portion of the years showed negative Standard Anomaly Index (SAI) values for Haramaya and Kombolcha (Table 4). This indicates that the mean annual precipitation amounts were below the mean annual precipitation values of long term rainfall data for the districts. The result also indicates that many of the years varied in mean annual precipitation compared to the long term mean values. This signifies the availability of year to year variability in rainfall which may put crop production at the risk of moisture stress. However, *Chiro* had the highest (60.53%) proportion of positive SAI values. The study also revealed that the intensity and magnitude of drought occurrence varied across the districts. This might show non-uniform distribution or random variability in rainfall.

In the duration from 1980 to 2017, drought occurred seven times in *Haramaya* and *Chiro* districts, resulting in significant reductions in agricultural production. Moreover, the frequency of drought had been very high from 2008 to 2013 for *Chiro*. Comparatively, *Kombolcha* showed the lowest frequency of drought followed by *Haramaya* and *Chiro*. This could be attributed to the higher elevation of Kombolcha district than the other two districts, which may attract clouds for enhanced precipitation. In agreement with this suggestion, Seleshi and Zanke (2004) also revealed that altitude greatly influences climate of Ethiopia and creates microclimate ranging from cool highlands to hot desert climate.

At the Haramaya station, a moderate drought occurred in 1995 and severe droughts occurred in 1980, 1985, 1992, 2002 and 2012. However, other study years showed no drought occurrence. On the other hand, Kombolcha district showed moderate drought occurrence in 1984 and 2002. Nevertheless, Chiro district had moderate drought conditions in 1980, 2008, 2012, and 1984; severe drought in 1995 and 2011 and extreme drought in 1996 and 2013. This result implies that recently dry years have occurred repeatedly in Haramaya district; hence, the rainfall trend signifies the need for suitable adaptation options and identifying causes of frequent drought occurrences in the areas to cope with climate change. In comparison to Chiro, Kombolcha station showed a high negative anomaly. Events of drought occurring early in the growing season reduce the number of tubers per plant while a single and intermittent drought events during tuber bulking can interrupt and inhibit future tuber bulking which not only decrease potato grade in terms of tuber size and quality but also lower the overall yields (Blom-Zandstra *et al*., 2015).

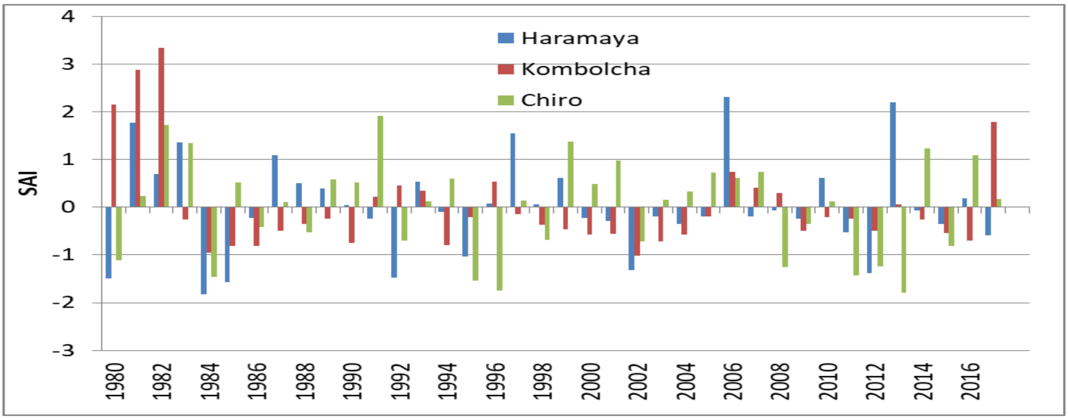

Figure 1. Standardized Anomaly Index (SAI) of three stations in Eastern Ethiopia over the period 1980-20017

The results of this study concur with the findings that severe and extreme drought occurred two times both in Haramaya and Chiro districts; thus, from the 1950s to1980s, droughts occurred on average once per decade, and recently, it has occurred once every three years in Ethiopia (Block, 2008). Concurrent with these findings, the World Bank (2006) reported that 16 drought events were experienced from 1980 to 2004 which makes Ethiopia the most drought-affected country. According to Haile (1986), drought occurs every three to four years in the northern and every six to eight years in other parts of Ethiopia. Conversely, in the current study, the SAI result revealed that drought occurrence is not consistent with forecasts in all the study areas. The current results show a ten-year interval for severe drought occurrence at Haramaya district.

Trend analysis of observed temperature and rainfall

Trend test for Annual and seasonal rainfall variability analysis

For the study period (1980–2017), the annual rainfall in Haramaya, Chiro and Kombolcha districts decreased by 44.84 mm, 73.91 mm, and 29.03 mm, respectively (Table 6). Non-significant decreasing trends were observed in the annual rainfall in all study districts. In contrast to this study, Amogne *et al.* (2018) indicated a significantly decreasing trend both for the main rainy season (*Kirem*t) and for yearly annual rainfall. As per the Mann-Kendall trend test, the amount of *Belg* rainfall of Haramaya decreased by 10.38 mm per decade, though not statistically significant. *Kiremt* season rainfall showed a significant increasing trend (84.78 mm) whereas the *Belg* season rainfall showed a decreasing trend (39.44 mm) for Haramaya district, which could be a sign for rainfall distribution change/variability rather than the total amount. Thus, potato productivity in the study area may be impacted either directly or indirectly as a result of both seasonal and annual rainfall variability.

Table 6. Annual and seasonal Man-Kendall trend test for rainfall parameters for three locations in eastern Ethiopia for the period of 1980–2017.

Location	Variable	Season	ZMK	Sen's slope (Slope)
Haramaya	RF (mm)	Annual	-0.60	-1.180
		Bega	0.04	0.041
		Belg	-0.78	-1.038
		Kiremt	2.21**	2.231
Chiro	RF (mm)	Annual	-0.45	-1.945
		Bega	0.1	0.1
		Belg	-0.7	-1.75
		Kiremt	-0.1	-0.259
Kombolcha	RF (mm)	Annual	-0.14	-0.764
		Bega	0.69	0.69
		Belg	-0.30	-4.636
		Kiremt	0.85	1.547

Where, ZMK is Mann–Kendall trend test, Slope (Sen's slope) is the change (days)/annual; ** is statistically significant at 0.05 probability level.

A non-significant decreasing trend in *Belg* season rainfall was Similarly, Amogne *et al.* (2018) reported a non-significant decreasing trend in *Belg* season rainfall. Negash *et al.* (2013) investigated the spatio-temporal variability of annual and seasonal rainfall in Ethiopia and reported a decreasing trend in *Kiremt* and annual rainfall in northern, northwestern and western parts of the country while observing an increasing trend in annual rainfall in a few grid points in eastern parts of the country. However, the results of this study showed a decreasing trend in annual rainfall. The findings of this study provide the basis for farmers to adjust their land preparation and planting dates to coincide with periods/months of reliable and uniformly distributed rainfall. Furthermore, the occurrence of late blight disease of potato is highly interrelated with both the amount and distribution of rainfall during the crop growing period. Hence, *Kiremt* season rainfall increment could make a suitable condition for late blight disease whilst the reduction in *Belg* season rainfall could have effect on the yield of potato.

Man-Kendall test for temperature variability

The mean annual maximum temperature increased by 0.29^{0}C, and 0.11 ^{0}C per decade, and minimum temperature increased by 0.18 ^{0}C and 1.19 ^{0}C per decade for Haramaya and Chiro districts, respectively (Table 7). Both annual and seasonal maximum temperature in Haramaya station showed an increasing trend which was significant at the level of 95% whereas minimum temperature revealed a positive trend even if non-significant in annual and *Kiremt* season. The variability (CV value) of minimum temperature was higher than that of maximum temperature for Chiro (Table 7). Mann-Kendall trend test output for Chiro indicated an increasing trend for both maximum and minimum temperatures. However, the change was statistically significant for *Bega* and *Kiremt* seasons minimum temperature. This non-significant trend during *Kiremt* season could be ascribed to rainfall that can diminish the effect of maximum temperature change, which occurs if rainfall variability is not found at a significant level unless other factors aggravate and facilitate the impact.

Man-Kendall test for minimum temperature for Haramaya resulted in a non-significant increment, both for annual and *Belg* season. However, *Bega* and *Kirem*t season showed significantly increasing trends at 90%. In the case of Chiro district, the minimum temperature for *Bega* and *Kiremt* seasons showed significant increasing trends at 95% and 90%, respectively (Table 7). On the other hand, the rate of change of mean temperature for Haramaya and Chiro districts were 0.023°C and 0.051°C, respectively. The overall increase in annual temperature observed in the study areas is, therefore, largely attributed to the increase in the minimum temperature. This could have its own impact on the *Belg* season potato production. These results signify that analyzing and finding suitable adaptation mechanisms for potato crop is important. In line with this result, Amogne *et al.* (2018) also indicated a significantly increasing trend in the mean and minimum temperatures through time while the trend for maximum temperature exhibited a non-significantly increasing trend.

Table 7. Annual and seasonal Man-Kendall trend test for temperature parameters for two locations in eastern Ethiopia for the Period of 1980-2017

Location	Variables	Season	ZMK	Sen's slope (Slope)
Haramaya	Tmax (^{o}C)	Annual	2.81**	0 .029
		Bega	2.29**	0.022
		Belg	3.42**	0.038
		Kiremt	3.39**	0.028
	Tmin (^{o}C)	Annual	0.77	0.018
		Bega	1.84*	0.030
		Belg	0.18	0.003
		Kiremt	1.82*	0.034
Chiro	Tmax (^{o}C)	Annual	0.27	0.011
		Bega	-0.67	-0.010
		Belg	1.06	0.024
		Kiremt	0.78	0.009
	Tmin (^{o}C)	Annual	1.45	0.119
		Bega	2.31**	0.092
		Belg	1.27	0.140
		Kiremt	1.66*	0.114

Where, ZMK is Mann–Kendall trend test, Slope (Sen's slope) is the change (days)/annual; **,* is statistically significant at 0.05 and 0.1 probability level.

The observed increasing trend of both maximum and minimum temperature could have effect on potato tuber initiation and bulking. Consistent with this suggestion, temperature patterns influenced potato in tuberization stage which in turn reduced the yield and quality of the crop (Borah et *al*., 1962). Wolf *et al*. (1990) reported that high temperatures during the long day favors assimilate partitioning to the above ground vegetative parts and results in increments in aboveground biomass and plant height while resulting in reduced partitioning of assimilates for tuber bulking at night, which requires lower soil temperatures. During the study period (1980–2017), in the months of June and July, rainfall decreased by 4.64 mm and 46.85 mm and also increased by 66.46 mm and 80.33 mm for Haramaya and Kombolcha districts, respectively. Similarly, the rainfall for the month of August increased by 14.71 mm and 73.53 mm for Haramaya and Kombolcha stations, respectively, whereas decreased by 25.95 mm for Chiro district. This is also an indication that the monthly distribution of rainfall was impacted during the last three decades. For potato, the critical growing months are July and August for Haramaya during which flower initiation and high vegetative growth proliferate. Concurrently, the increase in rainfall during this period creates a suitable condition for the most important fungal and bacterial disease of the crop. Therefore, potato production during the rainy season should be accompanied by the use of fungicides and bactericides or improved varieties that are resistant or tolerant to the disease.

Conclusion

The results of this study have revealed considerable variability and trends of temperature and rainfall over the 38-year period at three districts in eastern Ethiopia. Analysis of the data indicated that temperatures have increased over time and precipitation has exhibited high variability across seasons and the districts. The results have also indicated that overall rainfall amounts have reduced. This variation has led to more frequent occurrences of drought. The study further revealed that the *Belg* season was more variable than the main rainy (*Kiremt*) season in terms of rainfall amount and distribution. With the exception of PCI values of Kombolcha for *Belg* season which was significant, the Man-Kendall trend test of both seasonal and annual precipitation concentration index of all study districts showed non-significant trend. This problem would lead to increased vulnerability of farmers to shocks and induce them to replace potato with other crops that are less sensitive to climate variability such as drought, diseases, etc. The observed variability in temperature in particular signifies negative impact on the growth and development cycle of potato. This implies loss of cash income for farmers as well as exacerbated household food and nutrition insecurity. This means production of potato in the study area should suit the changing climate and management of the crop should be designed to suit weather variables. Therefore, it is important to create regional and national awareness on the existing as well as impeding climate variability in potato producing areas, identify adaptation options for improving of the crop and increase farmers' resilience to climate change. Future research should be geared towards developing drought tolerant as well as disease-resistant potato varieties for cultivation during both off-season using small-scale irrigation and during the main rainy season in a double cropping system to enhance farmers' income, food security, and resilience to climate shocks.

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