Variability and Trend Analysis of Temperature, Rainfall and Characteristics of Crop Growth Season in Eastern Zone of Tigray Region, Northern Ethiopia

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Abstract

To favour farmers and adjusting their farming practices, long term weather analyses is essential to determine future directions and making adjustments required to existing systems. The main purpose of this study was thus to analyze the variability and trends of climatic variables (temperature and rainfall) and characteristics of crop growth season in Eastern zone of Tigray region for the period of 1980–2009. Detail investigations were carried out using parametric (Linear regression) and non-parametric tests (Mankendall and Sen's slope estimator). Moreover, homogeneity test was applied using a method developed by Van Belle and Hughes for the general trend analysis. Furthermore, the trend of rainfall end to characterize crop growth season using R-Instat and XLSTAT software. It was found that the general trend of monthly rainfall experienced an overall significant increasing trend. The seasonal rainfall experienced significantly increasing trend during the summer rainy season (June–September) whilst a significant decreasing trend occurred in the short rainy season (February–May). Likewise, the seasonal maximum temperature trends exhibited a significant increasing trend in all seasons whereas the minimum temperature showed inhomogeneous trend across seasons as well as stations. Despite significant increase of rainfall in summer season, the trend of growing season characteristics (onset, cessation, length of growing period and dry spell length) did not change significantly over the study period. However, the variability of rainfall and dry spell length was found to be very large. Hence, crop production in the study area demands appropriate adaptation strategies that considers the erratic nature of the rainfall, the long dry spell length in the season and increasing trends of temperature.

1. Introduction

Trends of temperature and precipitation, the most important parameters for crop production, have been changed over time in Ethiopia. For the past four decades, Ethiopia's annual average temperature has been increased by 0.37 ^{0}C per decade since 1951 (NMA 2007; Aragie 2013). Moreover, Ethiopia has experienced a high degree of interannual rainfall variability (Cheung et al 2008; Gebremicael et al. 2017; Mekasha et al. 2014; Meze-Hausken 2004; Seleshi and Zanke 2004). The changes in temperature and rainfall patterns as a result of climate variability and change are very critical to most of the population of the country who are dependent on rain-fed agriculture for their livelihoods. The impacts of increased temperature and changes in rainfall patterns are expected to reduce crop production and water availability for irrigation and other farming uses which is more pronounced in the north, northeast and eastern lowlands of the country (Aragie 2013).

Most of the droughts caused by climate variability and change have been occurred in the eastern and southern part of Tigray region (Gebrehiwot and van der Veen 2013). The climate of the study area is characterized by frequent droughts. Almost every year, localized droughts associated with variable and erratic rainfall has been the main reasons for crop productivity failures and hence jeopardizing livelihoods and development activities of the region (Awulachew et al. 2011; Gebrehiwot and Van der Veen 2013). Indeed, moisture stress stands to be the major limiting factor for crop and animal production in the eastern zone of the Tigray region (Meles et al. 1997). As a result, crop yield has been severely affected during part of its growing period (Araya and Stroosnijder 2010).

Although rainfall variability and associated localized droughts have been the greatest concern in the study area, few attempts have been made so far to quantify the spatio-temporal characteristics of precipitation and temperature. Yet, the emphasis of most of the studies related to the trend analysis so far carried out in Tigray region has been limited to rainfall analysis (Abraha 2015; Cheung et al 2008; Gebrehiwot et al 2011; Gebrehiwot and van der Veen 2013; Hayelom et al 2017; Gebremicael et al. 2017; Mekasha et al. 2014; Meze-Hausken 2004; Seleshi and Zanke 2004). Whereas temperature analysis has been ignored in many of these studies, although it is also vital for crop production and water-related issues.

In addition, the rainfall trend analyses made by many of the studies listed above are based on few station data and/or with few number of years especially regarding the study area (Eastern zone of Tigray) and many of the studies were restricted to even trends of annual or monthly or seasonal total values. Rainfall variability based on agricultural practices such as onset and cessation at an interval of days, length of growing period (LGP), and wet and dry spells weren't included in those studies with the only exception of Araya et al. (2010) who determined LGP of two crops, Teff (Eragrostis tef) and barley (Hordeum vulgare) in Giba catchment of the Tigray region. Yet, the rainfall and rainy season characteristics are important to make proper crop-based decisions in seeding, fertilizing, selecting crop variety, selecting suitable cropping pattern, and selecting the best agro-techniques. Assessing long-term trends of rainfall and rainy season characteristics (including onset, cessation and LGP) can help to formulate farming strategies to efficiently use the available water (Fiwa et al. 2014). Rainfall statistics for dry spells are also very important for the planning and management of water resources (Almazroui et al. 2017).

Overall, assessing spatio-temporal of changes in temperature & rainfall, and rainfall characteristics was the main purpose of this research. Findings of this study will help to better understand the uncertainties associated with rainfall and temperature patterns and will favour knowledge-based management of agriculture, irrigation and other water related sectors in the region.

2. Materials and methods

2.1 Description of the study area

This study was carried out in the Eastern zone of Tigray region of Ethiopia, bordered on the east by the Afar Region, on the south-by-South Eastern zone of Tigray, on the west by central zone of Tigray and on the north by Eritrea. Its geographical location is between $13^{0}33'2''$–$14^{0}40'54''$ latitude and $39^{0}11'39''$–$39^{0}59'11''$ longitude (Figure 1). The zone has an area of 561,000 ha and seven districts (Erob, Hawzen, Wukro, Atsbi-Womberta, Ganta-Afeshum, Gulo-Mekeda and Saesie-TsaedaEmba). The altitude ranges between 1500-3280 meter above sea level (masl). The area is characterized by three traditional agro-ecologies of highland (>2300 masl), midland (1500-2300 masl) and lowland (<1500 masl) (Meles et al. 1997).

Three watersheds, namely Agulae, Suluh and Genfel were selected from the zone for this research purpose based on population growth, expansion of urbanization, and availability of small-scale irrigation schemes in each watershed (Figure 1). The livelihood of the community is mainly dependent on rainfed agriculture. Common rainfed crops in the watersheds include teff, wheat, barley, maize, sorghum and pulses. However, irrigation agriculture has increased significantly at household level in the recent years (Nyssen et al. 2010). According to Gebreyohannes et al. (2013), the dominant soil texture classes in the area is clay loam (40%) followed by sandy clay loam (30%), clay (19%), loam (10%), and sandy loam (1%).

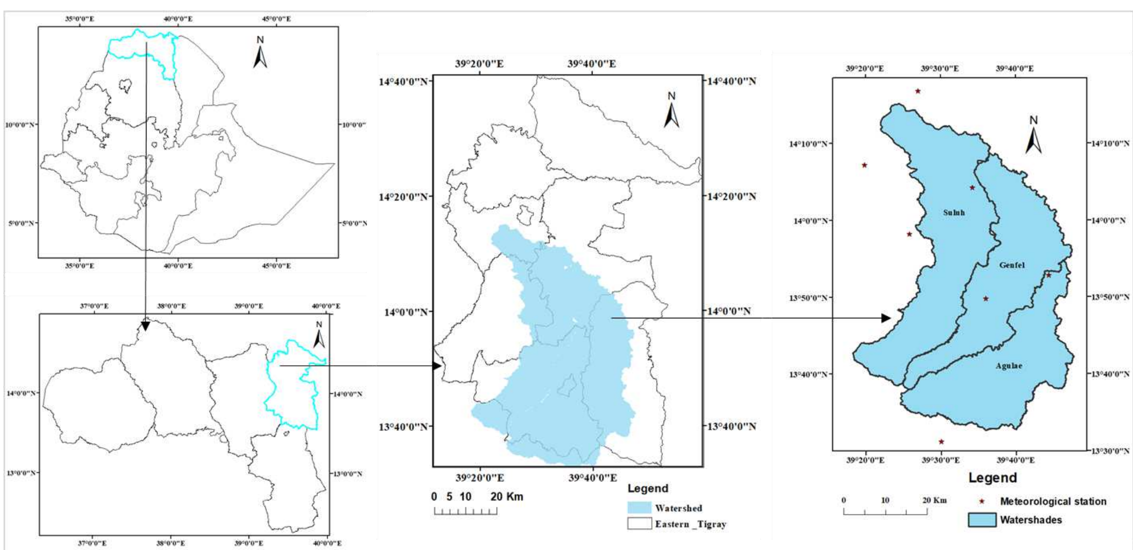

Figure 1: Location of the study area and selected watersheds

2.2 Data used

30 years of climate data (rainfall and temperatures) from seven stations within and nearby the Eastern zone of Tigray region from 1980-2009 were collected from Enhancing National Climate Services Initiative (ENACTS) recently implemented at Ethiopian National Meteorological Agency (NMA).The quality of provided climate data by ENACTS is improved by combining careful quality control of data from weather stations with that of satellite

estimates. The combined data set is generated at a 10-daily time scale and for every 4 km grid across Ethiopia. This is the best available dataset for the country which is homogeneous and recommended for climate analysis (Dinku et al. 2014). The detailed information about ENACTS is elucidated in Dinku et al. (2014) and Dinku et al. (2018). The stations together along with their geographical locations and elevations are shown in (Table 1).

Table 1:Geographical location of the meteorological stations

Station	Latitude (DD)	Longitude (DD)	Elevation (meter)
Illala	13.52	39.50	2012
Adigrat	14.28	39.45	2470
Edagahamus	14.12	39.33	2700
Atsbi	13.88	39.74	2600
Sinkata	14.07	39.57	2480
Wukro	13.83	39.60	1995
Hawzen	13.97	39.43	2255

2.3 Data analysis

To identify linear and non-linear trends in monthly, annual and seasonal time scales of rainfall and temperature series, both parametric (linear regression) and non-parametric (Mann-Kendall and Sen's estimator of slope) statistical tests were considered. For homogeneity test of data the Van Belle and Hughes was also utilized.

2.3.1 Linear regression

A straight line is fitted to the data to determine whether the slope is different from zero or not. A simple linear regression method was used to determine the tendency (Eq. 1). Student t-test was applied to determine the statistically significance of the trend at a 5% significant level.

$$Y = ax + b \qquad (1)$$

Where: Y is the dependent variable, a is the slope, x is the independent variable and b is the intercept.

The parametric test is commonly applied to normal data. Hence, before analysis, the rainfall and temperature data were tested for normality using the Shapiro-Wilk test (Shapiro and Wilk 1965). Shapiro-Wilk statistical test was widely used in several studies to test for normality of data (De Lima et al. 2010; Machiwal and Jha 2008; Muchuru et al. 2016; Suryadi and Sugianto 2018) and recommended for normality test as it provides better estimates, for example as compared to Kilmogorov-Smirnov method (Aura et al. 2019).

2.3.2 Mann-Kendall and Theil-Sen's Slope estimator

Monthly, seasonal and annual trends were assessed using the Mann-Kendall trend test (Kendall 1975) and Sen´s slope estimator (Sen 1968) (2–5). The Mann-Kendall test and Sen's slope estimator are two non-parametric tests and widely applied in various trend detection studies (Asfaw et al. 2017; Chattopadhyay and Edwards 2016; Hamza et al. 2017; Palaniswami and Muthiah 2018; Samo et al. 2017).

2.3.2.1 Mann-Kendall test

The Mann-Kendall test S of the series X was calculated by applying equation 2 and 3 (Mann 1945; Kendall 1975):

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn(X_j - X_i) \quad (2)$$

$$sgn(X_j - X_i) = \begin{cases} +1 \; if \; (X_j - X_i) > 0 \\ 0 \;\; if \;\; (X_j - X_i) = 0 \\ -1 \; if \; (X_j - X_i) < 0 \end{cases} \quad (3)$$

Where, sgn (X_j-X_i) is the signum function, X_i ranked from i = 1, 2…N–1 and X_j ranked from j = i+1, 2…N. Each data point X_i is used as a reference point and is compared with all other data points X_j values.

The Mann-Kendal test statistics (S) represents asymptotically normal distribution and give the mean of zero and the variance of one (Mann 1945; Kendall 1975).

The variance associated with S is calculated by applying equation 4:

$$Var\ (S) = \frac{1}{18}\left[N(N-1)(2N+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)\right] \quad (4)$$

Where: m is the number of tied groups and t_i is the number of data points in group i

The standardized test statistic Z(S) is calculated by applying equation 5 (Mann 1945; Kendall 1975).

$$Z(S) = \begin{cases} \dfrac{S-1}{\sqrt{Var\ (S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{S+1}{\sqrt{Var\ (S)}} & if\ S < 0 \end{cases} \quad (5)$$

The H_o (null hypothesis) is rejected, if absolute value of Z(S) is greater than $Z_{critical}$ ($Z_{\alpha/2}$), in which α represents the level of significant. Positive values of normalized test statistics Z(S) indicate an increasing trend and negative Z values indicate decreasing trends. In this study, statistically significant level at 95% confidence level (at α = 0.05) was used.

2.3.2.2 Theil-Sen's Slope estimator

This method is used to quantify the linear trend in time series analysis. The slope ϴi between two values in a time series X is estimated by equation 6:

$$\Theta i = \frac{X_k - X_j}{k - j}\ , k \neq j \quad , \qquad where\ i = 1, 2, \ldots . N \quad (6)$$

Where X_k and X_j are data values at times k and j (K>J)

The median of these N values of ϴi is known as Sen’s estimator of slope and calculated by equation 7. The positive sign of Θ_{median} represents an increasing trend while negative sign shows a decreasing trend.

$$\Theta_{\text{median}} = \begin{cases} \Theta_{\frac{(N+1)}{2}}, & N\ odd \\ \dfrac{\Theta_{\frac{N}{2}} + \Theta_{\frac{(N+1)}{2}}}{2}, & N\ even \end{cases} \tag{7}$$

2.3.3 Van Belle and Huges' homogeneity of trend tests

To test homogeneity of trends, the most widely used Van Belle and Hughes (Belle and Hughes 1984) test was applied. This provides a single statistic which indicates whether the months/seasons are behaving in similar (homogeneous) fashion or different (heterogeneous) from each other. This test uses Z-values (standardized test statistics (Z(S)) from MK-test statistics for each station.

To get the trend homogeneity of temperature and rainfall at multiple stations, Van Belle and Hughes proposed a procedure based on the partitioning of the sum of squares. The analysis procedure uses chi-square (X^2) test statistics of various chi-squares (X^2 homogeneous, X^2 month/season, X^2 station, X^2 month/season-station interaction) for testing the trend homogeneity.

The formulas from 10–15 were used to test the homogeneity of the trends by partitioning the X^2_{total} into respective source of variations

1. X^2_{total}

$$X^2_{total} = \sum_{i=1}^{K}\sum_{m=1}^{M} Z^2_{im} \tag{10}$$

Where: K is the number of month or seasons, M is the number of stations and Z is the standardized test statistics with KM d.f.

2. Test for significant of common trend (X^2_{trend})

$$X^2_{trend} = KM\ \bar{Z}^2 \tag{11}$$

Where: K is the number of month or seasons and M is the number of stations and, $\bar{Z}^2$ is the average square of standardized test statistics with 1 d.f.

3. Homogeneity trend test at different stations in different months/seasons ($X^2_{homogeneous}$)

$$X^2_{homogeneous} = X^2_{total} - X^2_{trend} = \sum_{i=1}^{k}(Z_i)^2 - k\ (\bar{Z})^2 \tag{12}$$

The values of Z_i and $\bar{Z}$ are calculated as:

$$Z_i = \frac{S_i}{\sqrt{Var\ (S_i)}}\ \ and\ \bar{Z} = \frac{1}{k}\sum_{i=1}^{k} Z_i$$

Where: S_i is the Mann-Kendall statistic for month i, and k= 12 for monthly data values, with (KM-1) d.f.

4. Test for monthly or seasonal heterogeneity ($X^2_{month/season}$)

$$X^2_{month/season} = M.\sum_{i=1}^{k}(\bar{Z}_{iM})^2 - X^2_{trend} \tag{13}$$

Where: M is the number of stations with (K-1) d.f.

5. Test for station heterogeneity ($X^2_{station}$)

$$X^2_{station} = K.\sum_{i=1}^{M}(\bar{Z}_{kM})^2 - X^2_{trend} \tag{14}$$

Where: K is the number of month/season and with (M-1) d.f.

6. Test for the interaction ($X^2_{month/season-station}$)

$$X^2_{month/season-station} = X^2_{homogeneous} - X^2_{month\ or\ season} - X^2_{station} \tag{15}$$

During homogeneity test, four possible scenarios were examined based on Van Belle and Hughes (1984):

(i) When all values of X^2 for stations, X^2 months/X^2 seasons, and the interactions are non-significant

(ii) When values of X^2 months/X^2 seasons is significant and X^2 values of stations is non-significant, different trend direction of each months/seasons was tested using $M\bar{Z}_k^2$, (i = 1,2, …, K)

(iii) When X^2 values of stations is significant and X^2 months/X^2 seasons is non-significant , different trend directions at each station was tested using $K\bar{Z}_m^2$, (m = 1,2, … , M), and

(iv) When both months/seasons and stations or the interactions are significant, the only meaningful trend test was possible for individual month/season-station using Z_{im}, (i = 1, 2, …, K; m = 1, 2, …, M).

2.3.4 Crop risk assessments

In this study, crop risks associated with extreme events including dry spells and other growing season characteristics (e.g., Onset, Cessation and Length of Growing Period, LGP) was considered for the analysis in R-Instat (V.0.6.2) software (http://r-instat.org/Download) developed under the African Data Initiative (ADI) (https://africandata.org/). Growth season characteristics such as onset and cessation date, Length of Growing Period (LGP), and dry spell length were determined using 30 years of data from seven stations. Specific rainfall characteristics information is vital for crop planning and for carrying out agricultural operations. These are important to make crop-based decisions during seeding, fertilizing, selecting crop variety, selecting suitable cropping pattern, and selecting best agro techniques, etc.

Onset and cessation date: The onset of the rainy season in the Eastern zone of Tigray region was assumed to start as of June 19 after the wet spells occurred for at least three consecutive days and when the total rainfall is 20 mm or more if there was no dry spell longer than 7 or more days within 30 days. Moreover, the cessation date was assumed as the date when the stored soil moisture reaches 100 mm after rainfall falls below ET_o values as per Higgins and Kassam (1981), which considers annual crops utilize 75–100 mm sored soil moisture during their harvest stage. The possible onset day was selected based on the information collected from farmers during the field survey. A minimum threshold value of rainfall (<1mm) was considered as part of a dry spell, which is an insignificant amount for crop use (Siva Kumar 1992).

Length of Growing Period (LGP): The duration between the onset of the rain season (OS) and cessation of total seasonal rainfall (CS) represents the number of rainy days or the length of growing season (16).

$$LGP = CS - OS \tag{16}$$

Where: LGP is Length of Growing Season, CS is Cessation season rainfall and OS is onset season rainfall

Dry spell length is a time period with no rain or less than 0.1mm rain for more than 7 days within 30 days. The average value of the dry spells was computed at a seasonal time scale during the main rainy season.

3. Results and Discussion

3.1 Annual and seasonal rainfall variability

The mean rainfall amount throughout the study area was found to be 572 mm per annum. A minimum total rainfall amount of 554 mm was recorded in Edagahamus station while a maximum total amount of 617 mm was obtained in Hawzen station (Table 2). The contribution of "*Kiremt"(local language)* season to that of the annual total rainfall amount is very large in all stations which varies between 54% and 84%. In addition, the contribution of the "*Belg"* season was not to be underestimated. In the majority of the stations, it contributed to more than 25% of the total rainfall. The "*Belg"* season is very useful for long-cycle crops. The long cycle crops are planted during this season before "*Kirem*t". Moreover, farmers also used this season for land management practices, such as repeated ploughing and in-situ soil moisture conservation activities.

However, the coefficient of variability (CV) of the total rainfall amount was much higher for "*Belg* "season that ranged from 37–45% than Kiremt season rainfall (21–31%) and indicating a very higher temporal variability of the seasons (Table 2). Several studies also showed that the CV of "*Belg"* season is higher than "*Kiremt"* season in the northern Ethiopia (Hadgu et al. 2013; Kiros et al. 2017; Weldesenbet 2019). Of all stations, Hawzen showed the highest both '*Kiremt'* and '*Belg'* inter-annual variability with CV of 31% and 45%, respectively). In general, the variability of the seasonal total rainfall in the study area can be categorized from moderate to high variability. Our finding agrees with previous studies that have reported the annual and seasonal rainfall variability showed moderate and high inter-annual variability (Ademe et al. 2020; Ayalew et al. 2012; Bewket and Conway 2007; Hadgu et al. 2013).

Table 2: Descriptive statistics of annual and seasonal (Kiremt and Belg) rainfall variables

Stations	**Variables**	**Annual**	**Kiremt**	**Belg**
Ilalla	Rainfall, mm	569	392 (69%)	139 (24%)
	Std. deviation	93	83	56
	CV (%)	16	21	41
Edagahamus	Rainfall, mm	554	298 (54%)	195 (35%)
	Std. deviation	89	67	75
	CV (%)	16	22	38
Adigrat	Rainfall, mm	575	348 (61%)	179 (31%)
	Std. deviation	105	96	73
	CV (%)	18	28	41
Sinkata	Rainfall, mm	573	353 (62%)	167 (29%)
	Std. deviation	80	75	62
	CV (%)	14	21	37
Wukro	Rainfall, mm	556	387 (70%)	136 (25%)
	Std. deviation	104	100	58
	CV (%)	19	26	42
Atsbi	Rainfall, mm	560	375 (67%)	148 (26%)
	Std. deviation	105	99	65
	CV (%)	19	26	44
Hawzen	Rainfall, mm	617	519 (84%)	91(15%)
	Std. deviation	152	162	41
	CV (%)	25	31	45

3.2 Trend analysis of Rainfall and Temperature

3.2.1 Monthly rainfall trend

The two-tailed MK and LR monthly rainfall statistical tests showed an increasing positive trend in all stations (Table 3). The magnitude of change is indicated by Sen's slope estimator that ranges from 0.29–0.99 mm/month for June, 0.27–2.51 mm/month for July, 0.82–2.96 mm/month for August and 0.22–0.55 mm/month for September. Nevertheless, June and July months showed statistically significant increasing trends in 3 of 7 stations and 4 of 7 stations at $p = 0.1$, respectively. Each month showed statistically significant trend only in Hawzen station at $p = 0.05$ level. Similarly, September showed a significant increasing trend only in Edagahamus station at $p = 0.1$ level and other 2 of 7 stations (Sinkata and Wukro) at $p = 0.05$ level. August month showed statistically non-significant increasing trends in all stations.

Table 3: Monthly rainfall (June–September) MK and LR statistical test values

Rainfall			**Stations**					
Months	**Statistics**	**Illala**	**Edagahamus**	**Adigrat**	**Sinkata**	**Wukro**	**Atsbi**	**Hawzen**
June	LR (t-test)	NN	NN	NN	NN	NN	NN	NN
	MK (z-test)	1.75***	1.71***	1.25	1.32	1.61	1.78***	2.00**
	Sen's slope estimate	0.52	0.38	0.30	0.29	0.34	0.31	0.99
	Sen's slope (95% CI)	0.4-0.7	0.3-0.5	0.2-0.4	0.2-0.4	0.2-0.4	0.3-0.4	0.8-1.1
July	LR (t-test)	NN	NN	NN	NN	NN	NN	NN
	MK (z-test)	1.82***	0.39	1.82***	1.68***	1.64***	1.03	2.07**
	Sen's slope estimate	1.16	0.27	1.30	1.29	1.55	1.07	2.51
	Sen's slope (95% CI)	1.0-1.6	0.03-0.6	1.1-1.5	1.0-1.7	1.3-1.8	0.8-1.6	2.1-2.8
August	LR (t-test)	0.76	1.21	1.72	1.01	1.62	1.87	1.29
	MK (z-test)	0.54	1.03	1.36	0.89	1.43	1.57	1.53
	Sen's slope estimate	0.82	1.17	2.04	1.00	2.26	2.27	2.96
	Sen's slope (95% CI)	0.5-1.3	0.8-1.7	1.4-2.5	0.5-1.7	1.7-2.8	1.8-2.8	2.2-3.5
September	LR (t-test)	0.89	1.95***	1.40	2.10**	2.20**	1.52	0.44
	MK (z-test)	0.89	1.82***	1.14	1.96**	2.07**	1.53	0.71
	Sen's slope estimate	0.22	0.22	0.26	0.31	0.55	0.52	0.27
	Sen's slope (95% CI)	0.1-0.3	0.2-0.3	0.2-0.4	0.3-0.34	0.4-0.6	0.4-0.6	0.2-0.5

NN-Non-normal data ** Statistically significant at 5% significance level, *** Statistically significant at 10% significance level

3.2.2 Seasonal rainfall, maximum and minimum temperature trends

Table 4 and 5 showed seasonal trends of rainfall, maximum and minimum temperatures. The values obtained from the LR-test statistics are higher than those values obtained from the MK-test in most of the stations for all variables. Nevertheless, the significance trend direction results obtained from the LR test are in line with those obtained from the MK test in all incidences.

Annual rainfall showed a positive increasing trend in most of the stations and varied from 0.8–5.51 mm/year (Table 4). In addition, "*Kiremt"* season rainfall values also showed an increasing positive trend varied from 2.34–6.78 mm/season whilst "*Belg"* season showed a decreasing trend varied from 0.74–2.29 mm/season (Table 4). However, annual and seasonal trends are found to be non-significant at 5% significant level. Our results corroborate the findings of previous studies that indicated non-significant rainfall trend in northern Ethiopia (Cheung et al 2008; Gebremicael 2017; Gebremicael 2020; Seleshi and Camberlin 2006; Seleshi and Zanke 2004; Viste et al 2012).

Compared to all stations, Hawzen station showed the highest increasing trend magnitude of annual (5.51 mm/year) and *Kiremt* (6.78 mm/season) rainfall. In contrast, Edagahamus station showed the highest decreasing trend magnitude during the *Belg* rainfall season (2.29 mm/season). Few stations (Adigrat, Sinkata and Wukro) showed a significant increasing *Kiremt* rainfall and significant decreasing *Belg* rainfall (Edagahamus) at $p = 0.1$ level.

Table 4: Seasonal rainfall statistical trend values

			Stations					
Rainfall (mm)	**Statistics**	**Illala**	**Edagahamus**	**Adigrat**	**Sinkata**	**Wukro**	**Atsbi**	**Hawzen**
Annual	LR (t-test)	0.47	-0.11	0.93	0.73	1.40	1.42	1.25
	MK (z-test)	0.32	-0.25	0.86	0.64	1.43	1.50	1.43
	Sen slope estimate	0.8	-0.82	2.12	1.3	3.12	3.24	5.51
	Sen's slope (95% CI)	-0.1-1.7	-1.4-0.4	1.3-3.2	0.6-1.8	2.2-3.9	2.4-3.6	3.9-6.7
Kiremt	LR (t-test)	1.28	1.36	1.75	1.69***	1.85***	1.86***	1.46
	MK (z-test)	1.14	1.61	1.53	1.78***	1.64***	1.78***	1.61
	Sen slope estimate	2.34	2.38	3.19	2.93	3.97	3.61	6.78
	Sen's slope (95% CI)	1.6-2.9	1.8-2.7	2.8-4.2	2.5-3.2	2.9-5.1	3.2-4.3	6.0-7.6
Belg	LR (t-test)	-1.13	NN	NN	NN	NN	NN	NN
	MK (z-test)	-1.07	-1.89***	-1.57	-1.32	-1.03	-1.18	-1.07
	Sen slope estimate	-1.27	-2.29	-1.94	-1.67	-0.84	-1.05	-0.74
	Sen's slope (95% CI)	-1.7-(-1)	-2.8-(-2.1)	-2.4-(-1.5)	-1.9-(-1.2)	-1.2-(-0.4)	-1.4-(-0.7)	-1.1-(-0.4)

NN-Non-normal data, ** Statistically significant at 5% significance level, *** Statistically significant at 10% significance level

The seasonal temperature exhibited non-uniform trend directions across the stations (Table 5). A significant increasing trend of maximum and minimum temperature, with a magnitude of (0.04–0.07^{0}C/year, 0.024–0.06^{0}C/year) and (0.07–0.1^{0}C/season, 0.06–0.12^{0}C/season, respectively) were observed during annual and *Belg* season in all stations at $p = 0.01$ significance level. Unlike the annual and *"Belg"* season, the maximum and minimum *Kiremt* season temperature showed an increasing and decreasing trend patterns. In most of the stations (5 out of 7), such as Illala, Edagahamus, Adigrat, Sinkata and Hawzen, the maximum temperature showed an increasing trend whereas in Wukro and Atsbi stations it showed a decreasing trend. In the case of minimum *Kiremt* temperature, a decreasing trend was observed in most of the stations (6 out of 7) except in Edagahamus. Yet, the Kiremt season maximum and minimum temperatures trends were not statistically significant at a 5% significant level in most of the stations. Few stations such as Edagahamus and Hawzen showed a significant increasing maximum temperature with a magnitude of 0.08^{0}C/season, at $p = 0.01$ level and 0.02^{0}C/season, at $p = 0.1$ level, respectively. Moreover, Adigrat and Hawzen stations showed a significant decreasing trend in minimum temperature by 0.04^{0}C/season at $p= 0.01$ level and 0.03^{0}C/season at $p = 0.1$ level, respectively.

Table 5:Seasonal maximum and minimum temperature statistical trend values

		Stations						
T_{max} (^{O}C)	**Statistics**	**Illala**	**Edagahamus**	**Adigrat**	**Sinkata**	**Wukro**	**Atsbi**	**Hawzen**
Annual	LR (t-test)	6.91*	6.47*	5.75*	5.99*	5.91*	5.58*	7.55*
	MK (z-test)	4.85*	4.53*	4.32*	4.85*	4.32*	4.57*	5.07*
	Sen slope estimate	0.05	0.07	0.05	0.05	0.044	0.048	0.052
	Sen's slope (95% CI)	0.05-0.06	0.07-0.08	0.047-0.05	0.051-0.06	0.04-0.05	0.046-0.049	0.05-0.056
Kiremt	LR (t-test)	1.13	4.56*	0.84	0.92	-0.13	-0.17	1.85***
	MK (z-test)	1.25	3.32*	0.43	1.25	0.00	-0.32	1.86***
	Sen slope estimate	0.02	0.08	0.004	0.015	-0.0007	-0.002	0.022
	Sen's slope (95% CI)	0.01-0.023	0.07-0.09	0.0-0.012	0.01-0.02	-0.01-0.01	-0.01-0.00	0.02-0.03
Belg	LR (t-test)	6.12*	3.46*	4.53*	5.07*	5.18*	6.14*	4.38*
	MK (z-test)	4.42*	2.89*	3.57*	4.42*	3.60*	4.39*	3.35*
	Sen slope estimate	0.09	0.08	0.07	0.09	0.083	0.108	0.068
	Sen's slope (95% CI)	0.09-0.1	0.07-0.09	0.065-0.08	0.09-0.097	0.08-0.09	0.1-0.11	0.06-0.08
T_{min} (^{O}C)	**Statistics**	**Illala**	**Edagahamus**	**Adigrat**	**Sinkata**	**Wukro**	**Atsbi**	**Hawzen**
Annual	LR (t-test)	7.86*	3.27*	2.16*	7.88*	6.83*	5.43*	5.62*
	MK (z-test)	4.75*	2.82*	1.89***	5.35*	4.60*	4.10*	3.93*
	Sen slope estimate	0.063	0.05	0.024	0.053	0.055	0.046	0.047
	Sen's slope (95% CI)	0.06-0.07	0.04-0.06	0.02-0.03	0.05-0.06	0.05-0.06	0.042-0.05	0.04-0.05
Kiremt	LR (t-test)	-0.09	1.17	-3.35*	-0.26	-1.52	-1.63	-2.42***
	MK (z-test)	0.00	0.79	-2.89*	-0.46	-1.39	-1.18	-1.93***
	Sen slope estimate	-0.0005	0.01	-0.04	-0.01	-0.02	-0.02	-0.033
	Sen's slope (95% CI)	-0.004-0.01	0.01-0.02	-0.05-(-0.04)	-0.01-(-0.001)	-0.03-(-0.02)	-0.03-(-0.013)	-0.04-(-0.03)
Belg	LR (t-test)	8.56*	2.78*	5.89*	9.82*	12.28*	8.86*	8.68*
	MK (z-test)	5.00*	1.93*	4.42*	5.67*	6.17*	5.17*	5.14*
	Sen slope estimate	0.1	0.057	0.088	0.1	0.117	0.089	0.098
	Sen's slope (95% CI)	0.09-0.11	0.05-0.07	0.08-0.09	0.098-0.1	0.1-0.12	0.084-0.094	0.09-0.1

NN-Non-Normal data, *Statistically significant at 1% significance level, ** Statistically significant at 5% significance level, *** Statistically significant at 10% significance level

3.3 Test of homogeneity of trends

3.3.1 Monthly and seasonal rainfall homogeneity

In the monthly rainfall series (June–September), none of the station, season and station-season interaction components exhibited significant trend heterogeneity since X^2 station, X^2 month, and the interaction are less than the X^2 critical values (Table 6). But, the overall trend heterogeneity was found to be significant since X^2 trend > X^2 critical. The average of Mann-Kendall test statistics over months (k=1, 2, 3, 4) and stations (m= 1, 2,….7) was found to be positive ($\bar{Z}_{.}$= 1.44) indicating an increasing trend.

However, in annual and seasonal (*Belg* and *Kiremt*) rainfall series, X^2 season only exhibited seasonal heterogeneity of rainfall trend since X^2 season is greater than X^2 critical values. However, the stations were found to have homogeneous trends (Table 7). Hence, according to scenario (ii) trend direction analysis at each season using K seasonal statistics becomes necessary while each season refers to the value of X^2 critical (with d.f.=1, i.e., 6.64) at 1% significant level. In evaluating the various homogeneity test it is best to use high significance level to obtain the same Z statistical sign by neglect small differences in the trend magnitude not seem too important (Belle and Huges, 1984).

Significance of trend homogeneity for each season was tested using the average Mann-Kendal test statistics (Z_k). The $M\bar{Z}_k^2$ was obtained to test the overall seasonal trend homogeneity. Accordingly, the K seasonal statistics of $M\bar{Z}_k^2$ becomes less than the X^2 critical values for annual and greater for *Kiremt* and *Belg* seasons (Table 8). As a result, despite previous studies do not show any clear signs of changing rainfall pattern in north Ethiopia (Viste et al 2012; Seleshi and Zanke 2004; Seleshi and Camberlin 2006; Cheung et al 2008), the Van Belle and Huges for general trend test indicated that the annual rainfall did not increase significantly while *Kiremt* increased significantly and *Belg* rainfall decreased significantly in Easter zone of Tigray region in Northern Ethiopia.

Table 6: Significance test of trend homogeneity for monthly rainfall (June-September)

Source	X^2 value	d.f.	X^2 critical, at 5%	X^2 critical, at 1%	Sign.
Total	63.67	K.M=4*7=28	41.34	48.28	-
Homogeneous	5.71	K.M-1=28-1=27	40.11	46.96	-
Month	0.70	K-1=4-1=3	7.82	11.35	
Station	0.64	M-1=7-1=6	12.59	16.8	
Month-Station	4.36	(K-1)*(M-1)=18	28.87	34.81	
Monthly homogeneity		X^2 months< X^2 critical			NS
Station homogeneity		X^2 station< X^2 critical			NS
Interaction		X^2 months-station< X^2 critical			NS
Trend	57.96	1=1	3.8	6.64	S
Global trend		X^2 trend> X^2 critical			Trend

Sign.: Significance; NS: not significant; S: significant; d.f.: degrees of freedom

Table 7: Significance test of trend homogeneity for seasonal rainfall (Annual, Kiremt, Belg)

Source	X^2 value	d.f.	X^2 critical, at 5%	X^2 critical, at 1%	Sig.
Total	38.04	21	32.67	38.93	-
Homogeneous	35.08	20	31.41	37.57	-
Season	31.56	2	5.99	9.21	
Station	1.96	6	12.59	16.81	
Season-Station	1.56	12	21.03	26.22	
Seasonal homogeneity		X^2 seasons> X^2 critical			S
Station homogeneity		X^2 station<X^2 critical			NS
Interaction		X^2 seasons-station< X^2 critical			NS
X^2 trend	2.96	1	3.8	6.64	Not used

Sign.: Significance; NS: not significant; S: significant; d.f.: degrees of freedom

Table 8: Seasonal rainfall trend test result for the stations

Season	$\bar{Z}_K$	$\bar{Z}_k^2$	M$\bar{Z}_k^2$	Significance
Annual	0.85	0.72	5.01	NS
Kiremt	1.59	2.51	17.59	S
Belg	-1.30	1.70	11.92	S

3.3.2 Maximum and Minimum temperature homogeneity

The value of X^2 season for maximum and minimum temperature was significant which suggests heterogeneous (Table 9), In contrast, the value of X^2 station for maximum and minimum temperature was non-significant indicating homogeneous time series data. According to scenario (ii), testing trend direction at each season using K seasonal statistics becomes necessary.

Table 10 and 11 indicated that the computed M$\bar{Z}_k^2$ values for seasons were found to be greater than the critical X^2 (equal to 6.64) with d.f. = 1 at 1% significance level. Hence, the annual, *Belg* and *Kiremt* maximum temperature increased significantly (Table 10). Similarly, annual and *Belg* minimum temperature increased significantly while *Kiremt* decreased significantly (Table 11).

The trends in minimum temperature of the different seasons were not homogeneous in the study area as the trends in *Kiremt* were different from that of annual and *Belg seasons*. It is also noticeable 6 out of the 7 stations had negative trends in the season of *Kiremt*, while all stations experienced positive trends in annual and *Belg* season.

Table 9: Maximum and Minimum temperature homogeneity test statistics

Sources	Maximum Temperature					Minimum Temperature				
	X^2 - value	d.f.	X^2 critical, at 5%	X^2 critical, at 1%	Sign.	X^2 - value	d.f.	X^2 critical, at 5%	X^2 critical, at 1%	Sign.
Total	273.05	21	32.67	38.93	-	304.05	21	32.67	38.93	-
Homogeneous	59.67	20	35.17	37.57	-	165.81	20	35.17	37.57	-
Seasons	47.71	2	5.99	9.21	S	136.83	2	5.99	9.21	S
Station	2.96	6	12.59	16.81	NS	12.88	6	12.59	16.81	NS@1%
Season-Station	9.00	12	21.03	26.22	NS	16.10	12	21.03	26.22	NS
Trend	213.38	1	3.84	6.64	Not used	138.24	1	3.84	6.64	Not used

Sign.: Significance; NS: not significant; S: significant; d.f.: degrees of freedom

Table 10: Seasonal maximum temperature homogeneity test statistics

	$\bar{Z}_K$	$\bar{Z}_k^2$	$M\bar{Z}_k^2$	Sign.
Annual	4.64	21.56	150.95	S
Kiremt	1.11	1.23	8.64	S
Belg	3.81	14.50	101.49	S

Table 11: Seasonal minimum temperature homogeneity test statistics

	$\bar{Z}_K$	$\bar{Z}_k^2$	$M\bar{Z}_k^2$	Sign.
Annual	3.92	15.37	107.56	S
Kiremt	-1.01	1.02	7.13	S
Belg	4.79	22.91	160.37	S

3.4 Trend characteristics of crop growing season

Table 12 presents the computed statistics on the crop growth season characteristics (Mann Kendall's-tau, and Sen's slope estimator) at a 5% significant level values. The 30-years median early onset date of the Kiremt season was found to be within the range of 30-June/ 182.5 DOY (Day of Year) at Hawzen to 8-July/190 DOY at Wukro. The onset dates of Ilalla, Adigrat, Edagahamus, Wukro and Atsbi are very close to Hawzen station. The onset date variability was lower (CV<10%) at all stations.

The median cessation date indicated a wide range of dates among the stations. The earliest cessation was on 11-Sep./255 DOY at Edagahamus and late cessation was on 25-Sep/269 DOY at Hawzen. As compared to the onset date, cessation variability was very low (<5%) at all stations. The CV of onset and cessation periods is small (<10%) which may relatively a stable onset and cessation. Stable onset and cessation is advantageous for the farmers in searching other off farm activities once they have stabilized onset and cessation dates.

Table 12 also showed the time series of LGP for the different stations. There is a general increasing trend of LGP which could be attributed to the observed early in onset and delay in the cessation date. Median LGP values in the study area varied from 68 days at Edagahamus to 85 days at Hawzen. Previous studies applied different criterions for onset and cessation analysis and reported LGP in the north eastern stations ranged from 60-100 days (Berhe 2011; Gebre et al. 2013). The CV in LGP was larger than 15% in all stations, suggesting crop growing season are relatively unstable and relaying on one type of crop is risky in the study area. However, providing such kind of information is essential in selecting crop cultivars that can grow based on their maturity.

Similarly, the mean seasonal dry spell length was analysed and found to be in the range of 24 days at Adigrat to 30 days at Edagahamus. The dry spell length was highly variable with CV of 25 to 43%. This indicates availability of high risk on intra-seasonal water deficit in the study area. These findings agree with those of Gebreselassie and Moges (2016) who reported greater than 30% of variability in the dry spell length of daily rainfall. The highest variability of dry spell length was observed at Illala while the lowest was occurred at Edagahamus station.

Table 12: Statistical values and trends of onset, cessation, LGP and dry spell length

Characteristics of crop growth	Statistics	Stations						
		Illala	Adigrat	Edagahamus	Wukro	Hawzen	Sinkata	Atsbi
Onset	Median	7-Jul	7-Jul	6-Jul	8-Jul	30-Jun	4-Jul	7-Jul
	Kendall's tau	-0.07	-0.10	-0.16	-0.06	-0.01	-0.18	0.07
	Slope	-0.10	-0.13	-0.29	-0.07	-0.05	-0.27	0.06
	P_{Value}	0.60	0.45	0.23	0.68	0.94	0.17	0.60
	SD (Days)	9	9	11	8	13	12	7
	CV%	5	5	6	4	7	6	4
Cessation	Median	22-Sep	20-Sep	11-Sep	21-Sep	25-Sep	20-Sep	23-Sep
	Kendall's tau	0.16	0.24	0.03	0.18	0.15	0.19	0.20
	Slope	0.14	0.13	0.00	0.20	0.15	0.13	0.30
	P_{Value}	0.23	0.09	0.85	0.17	0.25	0.15	0.13
	SD (Days)	6	7	3	7	7	6	9
	CV%	2	3	1	3	3	2	3
LGP	Median	74	72	68	74	85	77	78
	Kendall's tau	0.10	0.16	0.14	0.16	0.06	0.19	0.11
	Slope	0.25	0.35	0.29	0.33	0.20	0.50	0.25
	P_{Value}	0.44	0.24	0.30	0.22	0.68	0.15	0.40
	SD (Days)	11	11	12	11	14	13	11
	CV%	15	16	17	15	16	17	15
Dry Spell	Mean	26	24	30	23	26	27	29
	Kendall's tau	-0.10	-0.12	-0.25	-0.12	-0.06	-0.07	0.06
	Slope	-0.18	-0.11	-0.23	-0.16	-0.10	-0.08	0.08
	P_{Value}	0.47	0.35	0.06	0.38	0.65	0.59	0.67
	SD (Days)	11	8	7	9	10	10	10
	CV (%)	43	34	25	39	37	36	34

4. Conclusions

This study analyzed the variability and trends of rainfall, temperature and characteristics of crop growth seasons in Eastern zone of Tigray region. Despite the observed significant trends in the rainfall and temperature in the study area, the trend of growing season characteristics did not change significantly in all stations over the study period. In addition, the coefficient of variability of the onset (CV, <10%) and Cessation (CV, <5%) indicated very small, possibly relatively stable onset and cessation. However, the coefficient of variability of LGP was (CV, >15%) indicates unstable and how risky was crop production under rain-fed condition relying in one type of crop in the study area. Moreover, the CV of the dry spell length was (CV, >25%) this also showed the high risk of intra-seasonal water deficit situation in the study area. Overall, the higher variability of rainfall amount of *Kiremt* and *Belg* seasons and the higher variability of dry spell length of (CV, >25%) in association with short nature of LGP (68–85 days) had a negative impact on the agricultural activities of the study area during the study period (1980–2009). Hence, crop production in the study area demands appropriate adaptation strategies that considers the erratic nature of the rainfall, the long dry spell length in the season and increasing trend of temperature.

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Code availability Not applicable

Authors' contributions All the authors made a valuable contribution to this study. AGB has designed the study, collected and analyzed data, interpreted the results, and wrote the draft manuscript. SHM, GGA and AZA have participated in designing the study, analysis and interpretation, structuring the manuscript; and provided critical comments and suggestions on the draft manuscript. All authors read and approved the final manuscript.

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Declarations

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No potential conflict of interest was reported by the authors.

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