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Analysis of Climate Variability and Its Impact on Crop Yield Over Waghemra Zone, Ethiopia

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ABSTRACT

Climate variability manifested by seasonal rainfall and temperature variability greatly affects agricultural crop production under rain-fed conditions (main source of income for rural communities). Therefore, this study has focused on analyzing the impacts of climate variability on rain-fed wheat and sorghum production in Waghemra Zone, Ethiopia. Daily rainfall and temperature data were collected from National Meteorological Agency of Ethiopia and crop yield data was collected from Central Statics Agency of Ethiopia. Temporal variability of rainfall, temperature and crop yield was analyzed using coefficient of variation (CV) and standardized anomaly method. The rainfall and temperature trends were assessed via Mann-Kendall test and Sen's slope estimator. The impacts of climate variability on crop yields were evaluated using correlation and regression analysis. The rainfall analysis exhibited large inter-annual and seasonal variation both in amount and distribution. The rainfall has showed decreasing trends in Belg and increasing in both annual and Kiremt season. Moreover, the detected trends are not significant. In contrast, minimum and maximum temperature showed significantly increasing trends at annual and seasonal time scales. The number of warm days and nights has increased and the number of cold days and nights has decreased. The regression analysis revealed that climate variability over the study area has differential effects on the yield of Wheat and Sorghum with coefficient of determination 86% and 84%, respectively. The observed rainfall and temperature variability has posed major risks to rain-fed agriculture and specific adaptation strategies are needed to cope with the risks, sustain farming and improve food security.

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Introduction

Precipitation and temperature are the two widely studied and very important climate parameters in climate research because of their huge impact in many socio-economic sectors including agriculture, hydrology, and environment [1]. The changes of rainfall and temperature patterns are broadly observed in various semi-arid parts of the developing world that are likely even to be hotter and dryer with time [2].

Climate change and variability impacts directly or indirectly on all economic sectors to some degree, but agriculture is among the sectors most sensitive and inherently vulnerable to climate variability [3-5]. Similarly, climate variability and change is expected to bring frequent occurrence of extreme events like flood, drought, high temperature, and windstorms, resulting in a deleterious global impact on human beings and ecosystems [6]. Hence, combination of rainfall variability (with erratic nature) and warming trends are making rain-fed agriculture at risk by aggravating food insecurity in Ethiopia. This is because agriculture in Ethiopia contributes about 47% of the country's Gross Domestic Product (GDP) and more than 70 million people'slife (85% of the Ethiopian population) depend on agriculture directly or indirectly for their livelihoods [7,8]. Therefore, any effect on agriculture will significantly affect the Ethiopian economy. Crop yield is inherently susceptible to climate variability [8,9]. Temperature and rainfall have therefore become important variables, which can have direct and indirect effects on agricultural crops in general.

According to the National Meteorological Agency (2001) report, climate variability in Ethiopia is primarily manifested by rainfall and temperature variability (i.e. decreasing trend in rainfall and increasing trend in temperature). Reports strongly agreed that observed variation in climate and weather conditions, such as recurrent droughts, heat waves, shift in onset and cessation, short duration of growing season, erratic and uneven rainfall distribution and long dry spell conditions during the growing seasons significantly affecting the efforts of sustaining food production in Ethiopia with more severity in rural communities subsists in dry areas [9,11,12]. For instance, understanding the seasonal pattern of climatic conditions is the most crucial point to manage and identify the possible climatic risks of a given location with respect to the production season. Having the information, helps to develop appropriate measures; like to select adapted crops/varieties, to choose best sowing time and land management practices; in respective of the location and the seasonal climate situation of the area [13]. Therefore; the main objective of this study was to assess the impact of climate variability on major crop production and local coping and adaptation mechanisms that are vital to the effect of climate variations particularly characteristics of rainfall and temperature that are crucial for planning and designing appropriate adaptation strategies.

Materials and methods

Description of the study area

The study was conducted in Waghemra Zone, which is one of the 11administrative zones in Amhara National Regional State (ANRS), Ethiopia. It is located in between 12.26º - 13.29º N latitude, and 38.33º -39.32 º E longitudes with an area of about 9,039.04 km^2 (Figure 1).

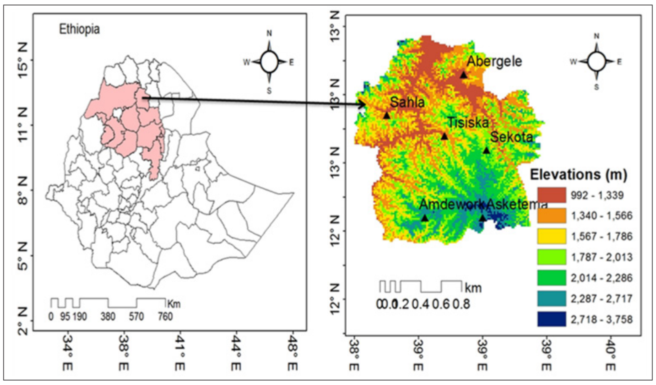

Figure 1: Map of Waghemra Zone (study area)

Waghemra Zone is characterized by three distinct seasons with four months each, classified based on the climatology of temperature and rainfall. These seasons are locally known as 'Bega' (ONDJ), 'Belg' (FMAM), and 'Kiremt' (JJAS) [14]. The main and small rainy seasons of the Zone are Kiremt and Belg, respectively whereas Bega is the dry season. The main reason for the inconsistency of rainfall in terms of its starting and ending date, amount and distribution includes the seasonal shifting of the Inter Tropical Convergence Zone (ITCZ) (Northwards in July and Southwards in January), and the complex topography with a noticeable disparity in altitude. Recently, the rainy seasons (Kiremt and Belg) are showing higher inconsistency due to climate change [14]. According to current studies, on average,Waghemra receives a mean annual rainfall ranging between 512.9 mm to 876.2mm. Likewise the mean annual temperature varies from 16.6 °C to 21.1 °C .

Data source

In this study, daily rainfall, minimum and maximum temperature data from six meteorological stations were obtained from the National Meteorology Agency of Ethiopia for the period 1986-2016 (Table 1).The wheat and sorghum yield data were acquired from the Waghemra Zone agriculture office for the period 1998-2016.

Table 1: Location of the meteorological stations and length of rainfall and temperature data series

Station name	Latitude (North)	Longitude (East)	Altitude (meter)	Years of observation
Amdework	12.4°	38.7°	2561	1986-2016
Asketema	12.4°	39°	2435	1986-2016
Sahla	12.9°	38.5°	1266	1986-2016
Sekota	12.6°	39.6°	2258	1986-2016
Tisiska	12.8°	38.8°	1469	1986-2016
Abergele	13.1°	38.9°	1571	1986-2016

Data quality control assessment

Validity checks (quality control) were undertaken for the historical time series climate data prior to undertaking the analysis. In this study, errors due to data digitization and reporting and data internal inconsistency, which minimum temperature higher than maximum temperature and rainfall values less than zero (0 mm) were evaluated and managed [15]. In addition, outliers in a time series data were detected carefully to check that whether the values are really outliers or naturally extreme values [16]. A standard outlier threshold, which is defined using inter-quartile range (IQR), was used to manage the outliers (Gonzalez-Rouco et al, 2001). The threshold values were estimated using the formula below, i.e,

$$\text{Threshold}=(Q1-3IQR, Q3+3IQR) \qquad (1)$$

Where, Q1 is first quartile, Q3 is third quartile and IQR is an inter-quartile range (which is the difference of Q3 and Q1). The inter-quartile range method is known as a technique which is resistance to outliers but still keep the information of extremes. The detected outlier values were then removed and substituted by outlier threshold [17].

Methodology

The data analysis were done using tools such as R studio, INSTAT, XLSTAT, GenStat, and MS-Excel spreadsheet [18,19].

Analysis of temperature and rainfall variability

The CV proposed by Hare, precipitation concentration index (PCI) proposed by Gocic et al. and standardized rainfall anomaly (SRA) proposed by Agnew and Chappel were used to compute rainfall variability over the study site [20,21]. Contribution of seasonal rainfall to the total annual rainfall in percent (CT) for each station is also computed. For analysis, the monthly rainfall of all the stations was used to calculate an areal average rainfall for Waghemra Zone using the equation of Nicholson, i.e., $RJ = \frac{\sum_{k=1}^{j} x_{ij}}{I_j}$ where R_j is a real integrated rainfall for year j; X_{ij} is rainfall at station i for year j and I_j is the number of stations available for year j [22].

Moreover, the temporal variability of temperature was determined by calculating the CV and standardized temperature anomaly. The temperature indices such as mean seasonal and annual maximum, mean seasonal and annual minimum, maximum of the maximum, maximum of the minimum, minimum of the maximum, minimum of the minimum temperature were analyzed. In addition, the relationship of climate variables such as rainfall with crop production can be developed via correlation and regression analysis and then the most predictor variable can be also identified [9,23-25].

Analysis of temperature and rainfall trend

For trend detection, the non-parametric Mann-kendall test and Sen's slope estimation method (Sen, 1968) were used [26,27]. The ZMKvalue were used to evaluate the statistical trends. In a two-sided trend test, the null hypothesis H_o should be accepted if $|Z_{MK}| < Z1\text{-}\alpha/2$ at a given significance level. Where, $Z1\text{-}\alpha/2$ is the critical value of ZMKfrom the standard normal table (Partal, 2006; Yenigun, 2008).For instance, the value of $Z1\text{-}\alpha/2$for 5%significant level is 1.96. In this study, a 5% significant level is used. It is also important to note that the modified Mann-Kendall test was not applied as the data has no serial dependence [28].

Results and Discussions

Temporal and spatial characteristics of temperature and rainfall in the study area

Temporal characteristics of annual and seasonal rainfall amount

The mean annual rainfall ranged from 513mm at Tisiska to876 mm at Amdework, while Belgand Kiremt rainfall amount varied from 26 mm at Sahla to 124 mm at Sekota and 421 mm at Sekotato 754 mm at Amdework, respectively. On the other hand, the mean areal annual rainfall was ranging from 392 mm to 892mm while Kiremt and Belg rainfall were ranging from 271mm to 846mm and 6mm to 85 mm, respectively (Table 2). The CV revealed that from moderate to high inter-annual variability while that of Kiremt and Belg rainfall showed high variability. This agrees with the study by Woldeamlakand Conway (2007). Kiremt rainfall had contributed 72 to 94% to the annual rainfall totals while that of Belg rainfall also has had contributed 5 to 21% in the study area. This result agrees with the study by Bewket and Conway and Ayalew et al. [10,29]. Therefore, the study area is characterized by monomodal rainfall pattern and about 86% of the rainfall is concentrated in the Kiremt season (June to September).The analysis of PCI showed that in all stations the rainfall pattern was not uniformly distributed. This is supported by Bewket and Conway and Ayalew et al. [10,29]. which is conducted in Amhara Region.In general, seasonal rainfall variability was higher than the annual rainfall variability,supported by the results of previous studies done in Ethiopia [7,31]. The corresponding spatial distribution of annual and seasonal rainfall in the Waghemra Zone is shown in Figure 2. From Figure2, it can be seen that the highest annual and Kiremt season rainfall amount were recorded in the Southern part and the lowest values were observed in the Northern parts of the Waghemra Zone. During Belg and Bega season, better rainfall were recorded in the South Western and South Eastern parts than the other parts of the Zone. Generally, the rainfall distribution showed a general decrease in annual mean rainfall from South to North.

Table 2: The mean annual and seasonal rainfall, coefficient of variation (CV %), the contribution of seasonal rainfall to the annual rainfall (CT %) and precipitation concentration index (PCI %) for six meteorological stations

Stations	Belg					Kiremt					Annual				
	Min	Max	Mean	CV	Ct	Min	Max	Mean	CV	Ct	Min	Max	Mean	CV	PCI
Amdework	0	251	92	66	11	269	1600	754	37	86	358	1734	876	32	26
Sekota	24	325	124	69	21	126	724	421	35	72	267	845	589	30	30
Tisiska	0	175	39	89	8	159	743	459	34	89	201	756	513	30	30
Sahla	0	126	26	90	5	314	807	538	35	94	328	828	574	20	30
Asketema	0	253	92	71	12	190	1654	640	47	85	356	1662	754	37	28
Abergele	0	142	35	96	7	268	900	471	30	91	323	928	517	24	29
Areal mean	6	85	68	59	11	271	846	547	34	86	392	892	637	29	27

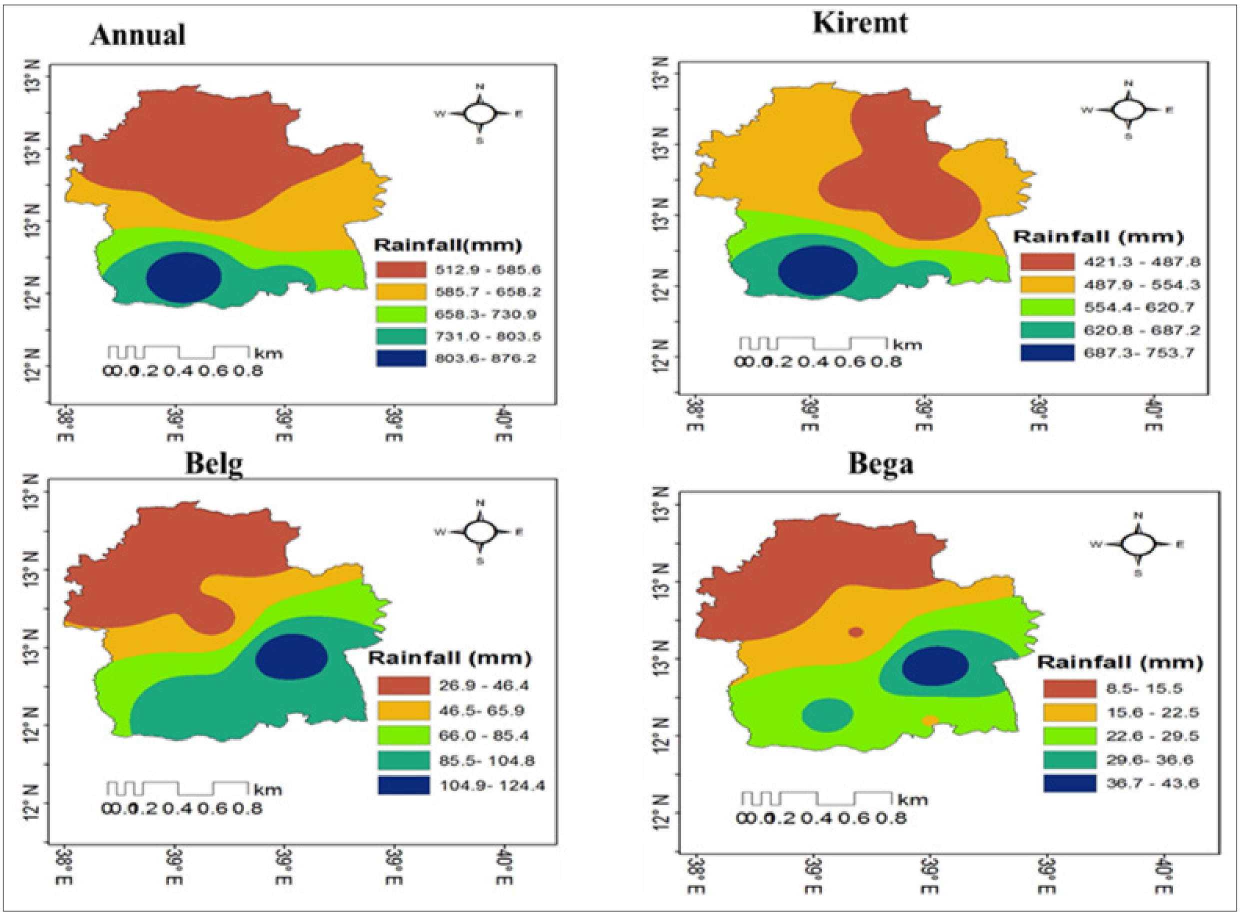

Figure 2: Spatial distribution of annual and seasonal rainfall climatology of Waghemra Zone

Annual and Kiremt Seasonal rainfall anomalies

The result of standardized rainfall anomaly showed a 39% dry tendency and 61% wet tendency over the study area on annual basis. For Kiremt season, 45% showed weak to strong negative departure from the long term mean rainfall and 55% recorded above the long-term average rainfall (Figure 3). The deviation of annual and Kiremt areal rainfall from the long term averages is shown in Figure 3.Based onAgnew and Chappel drought assessment method: six dry years with varying severity, two extremes (1987 and 1993), three severe (1989, 1997 and 2015), and one moderate (1990) dry years were identified [21]. In contrast, 1998, 2001 and 2003 had experienced the wettest years during Kiremt season.Low yield is resulted by higher negative rainfall anomalies whereas high yield is related with smaller rainfall anomalies. Damage of crops and yield reduction is also caused by extremely positive rainfall anomalies.

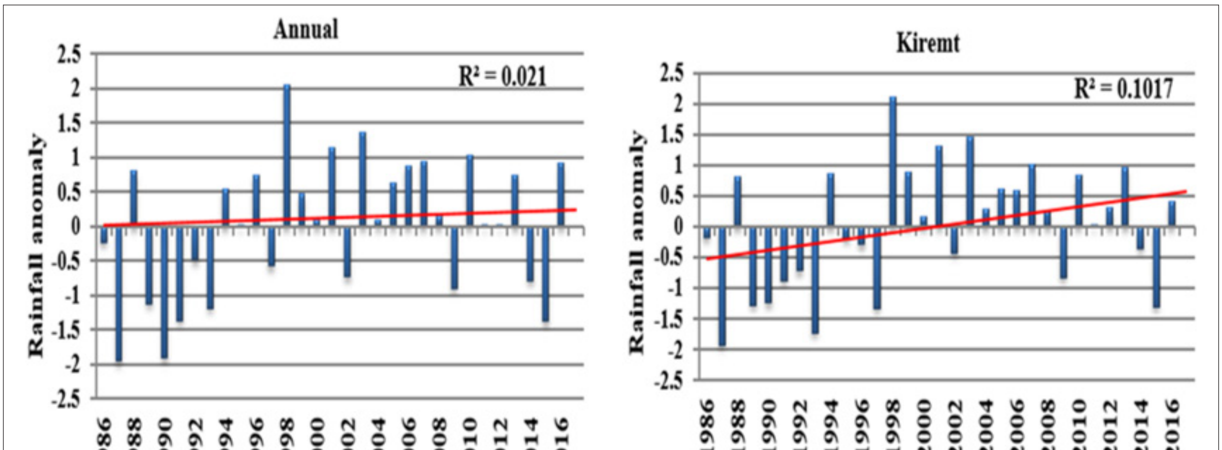

Figure 3: Annual andKiremt seasonal areal rainfall anomaly (in mm) in Waghemra Zone

Variations in rainfall onset, cessation and growing season

The Kiremt rainfall at Amdework and Tisiska stations starts around first week of July and second week of July, respectively (Table 3). On the other hand, the areal mean onset date was found to be in between the 2nd and 3rd week of July with a mean onset date of July-8. Similar study conducted by Hadgu et al. in the northern Ethiopia has found that the start (onset) date of Kiremt rainy season is between 1st and 3rd week of July [32]. The variability of Kiremt onset date was lower showing its dependable patterns across the study area.Similarly,Kiremtrainfall in the studied stations ceased starting from the 1st week of September at Abergele to 2nd week of September at Amdework with a mean cessation date in the1st week of September (Table 6), agreeing with the study by Hadgu et al. [32]. For all probability levels considered, the end of Kiremt season was more extended at Amdework as compared to other areas. Furthermore, the average length of the growing period (LGP) was ranging from 58 days at Abergele to 74 days at Amdework stations with anaverage LGPof 64 days in the study area. In line with this, a study conducted by Hadgu et al. reported that the average LGP varies from 66days at Edagahamus to 85 days at Mekele stations in the Tigray region, Ethiopia [32]. The coefficient of variation of LGP also ranged from 20.8 days at Abergele to 29.5 days at Tisiska areas. The result also revealed that LGP is more variable than onset and cessation dateover the study area. The study area is generally characterized by late onset and early cessation of Kiremt rainfall resulting in shortened growing period which influences the agricultural activities.

The number of rainy days and probability of dry spell lengths

The average number of rainy days per year ranges from about 42 at Sekota to 62 at Amdework station with an areal mean of 53 days (Table 3). This result is supported by Hadgu et al [32]. In the study area, the mean number of rainy days was characterized by low standard deviation at all stations which indicated that the rainy season in these stations were stable. The inter-seasonal variability in the number of rainy days ranged from 15.8% at Sahla to 24.2% at Asketema stations.

The probability of dry spell occurrence for Belg (DOY = 32-152) and Kiremt (DOY = 153-274) seasons for six selected stations is shown in Figure 4 and dry spell lengths of 5,7,10, and 15 days were considered. Observations of the rainfall data illustrated that the probability of dry spells occurring within the growing seasons varied from month to month. The probability of occurrence of dry spells for 5, 7, 10, and 15 dry spell days during Belg season was above 65% in all stations which imply that planting of crops before June is highly at risk in the study area. In the main rainy season (Kiremt), the probability of 7, 10, and 15 days dry spell occurrence in July and August was zero; whereas for 5 days dry spell, it was more than 30% at all stations.

The probability of occurrence of shorter dry spell events is higher than the longer dry spell events. Additionally, higher probability of dry spells has occurred in Belg season as compared to Kiremt season which is liable to meteorological drought. The dry spell challenges and risks were higher at Sahla, Tisiska and Abergele areas. Seleshi and Camberlin also reported similar results that longer dry spell was observed in the Northern Ethiopia (Mekelle, 20.3 days) and Eastern Ethiopia (Jijiga, 16.2 days) [30]. The longer dry spells pose greater adverse impacts for crops whereas the intensity of the impact depends on the sensitivity of crop types and varieties to water deficit, at any of their critical growing stages, whereas, the shorter dry spells may not exert significant adverse impact for most seasons.

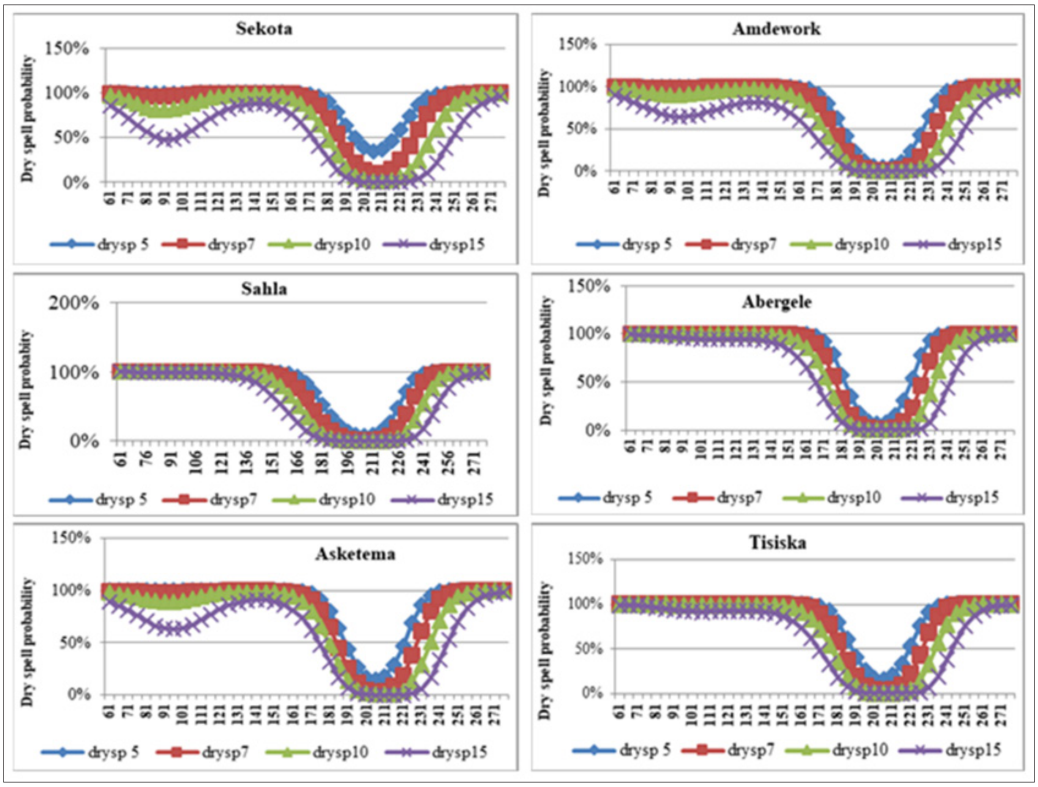

Figure 4: The probability of dry spell occurrence for 5, 7, 10, 15 days in Belg and Kiremt seasons.
3.1.5 The number of heavy rainfall and intensity of rainfall

The average number of days with heavy rainfall per year varies from 3.6days at Abergele to 13.5days at Amdework station with a mean of 7.5days. Similarly, the intensity of average rainfall per rainy day ranged from 9.1mm per day at Abergele to 14.3 mm per day Asketema with an areal mean of 19.3 mm per day over the study area (Table 3). The CV value revealed that extreme inter-annual variations were observed in the number of heavy rainfall at all stations. On the other hand, the CV for rainfall intensity varied from 14.1% at Sahla to 30.5% at Asketema stations. Flooding due to heavy rainfall events can wipe out the entire crop over larger areas and also excess water may cause other impacts such as water logging, and reduction of crop growth.

Table 3: Descriptive statistics of the onset, cessation and length of the growing season in the study area

Stations	Onset		Cessation		LGP		NRD		NHF		RI	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
Amdework	186	7	261	4.2	74	23.6	61.9	16.8	13.5	96	13.5	20.4
Sekota	190	9.6	248	2.4	62	27.4	42.2	23.5	11.2	109.8	14.3	30.5
Tisiska	193	7.3	248	2.6	60	29.5	49.4	22.7	4.4	73.5	9.8	14.1
Sahla	190	4.6	250	2.7	66	21.6	58.8	15.8	7.3	65.1	14.2	23.9
Asketema	187	6	255	3.3	70	22.1	53.3	24.2	4.9	65.5	10.3	17.2
Abergele	190	6.1	246	1.8	58	20.8	51	18.6	3.6	72	9.1	20.3
Areal mean	190	6.8	252	2.8	64	24.2	52.9	14.2	7.5	80.3	19.3	21.3

LGP=length of growing period, NRD=number of rainy days, NHF=number of heavy rainfall, RI=rainfall intensity

Annual and seasonal rainfall trends

The Mann–Kendall trend test showed anon-significant decreasing trend of annual rainfall at Sekota, Tisiska and Abergele areas (see Table 4). This agrees with the results of Seleshi, Cheung, Viste, and NMA [33-36]. On the contrary, the annual rainfall had showed increasing trend at Amdework,Asketema and Sahla stations. However; the detected trends are non-significant at Sahla station only. This is supported by Abiy Gebremichael et al. [37]. Likewise, Kiremt seasonal rainfall showed increasing trend at all stations except Asketema and the observed trends are significant at Amdework and Asketema stations only. This agrees with the result of the study by Bewket and Conway [29]. Similarly, during Belg season, the rainfall had statistically non-significant decreasing trend at Asketema,Sekota and Abergele stations. While at Amdework and Tisiska stations anon-significant increasing trends were observed (Table 4).

Table 4: Trends of annual and seasonal (Belg and Kiremt) rainfall amount at the six stations

Stations	Annual (January-December)			Kiremt (June-September)			Belg (February-May)		
	ZMK	Q	p-value	ZMK	Q	p-value	ZMK	Q	p-value
Amdework	0.32	13.0	0.01	0.28	11.2	0.03	0.21	1.8	0.11
Asketema	0.42	15.2	0.001	0.41	16.2	0.001	-0.08	-0.6	0.52
Sahla	0.08	1.3	0.55	0.06	0.9	0.67	-0.02	0	0.91
Sekota	-0.05	-1.6	0.74	0.19	4.6	0.14	-0.18	-3.2	0.15
Tisiska	-0.12	-3.6	0.35	-0.16	-3.8	0.20	0.09	0.5	0.49
Abergele	-0.06	-0.5	0.66	0.06	1.4	0.67	-0.12	-0.6	0.34
Areal mean	0.19	3.7	0.15	0.20	5.4	0.11	-0.04	-0.3	0.76

ZMK indicates Mann-Kendal trend test (upward or down ward, its trend Q indicates Sen's slope the change per year/decade), statistically significant trend when p-value<5% (0.05), trend is non-significant when p-value ≥ 5%orat 0.05 probability level.

Trends of onset, cessation and growing season

The Mann-Kendall trend test on onset of Kiremt rainfall showed anon-significant decreasing trend at Amdework and Asketema stations. On the contrary, the trends were increasing at Sahla,Sekota,Tisiska and Abergele stations. However, the trend was statistically significant at Tisika station only (see Table 5).This agrees with the study by Hadgu et al. [38]. The cessation date of Kiremt rainfall exhibited an increasing trend at all stations except at the Tisiska station. However, the detected trends are significant at Amdework and Asketema stations only at 5% significant level. Similarly, the length of the growing period (LGP) showed anon-significant increasing trend at Amdework, Asketema and Sahla stations while at Sekota,Tisiska and Abergele stations the detected trends were decreasing non-significantly (Table 5) agreeing with the study by Kelemu [39].

Table 5: Trends of onset, cessation days and length of growing period at the six stations

stations	Onset date			Cessation date			Length of growing period		
	ZMK	Q	p-value	ZMK	Q	p-value	ZMK	Q	p-value
Amdework	-0.21	-0.5	0.11	0.35	0.6	0.01	0.33	0.9	0.01
Asketema	-0.18	-0.3	0.16	0.23	0.3	0.01	0.25	0.7	0.06
Sahla	0.13	0.2	0.29	0.24	0.1	0.076	0.27	0.6	0.03
Sekota	0.23	0.6	0.07	0.02	0.01	0.90	-0.25	-0.8	0.05
Tisiska	0.25	0.5	0.04	-0.16	-0.1	0.23	-0.29	-0.8	0.03
Abergele	0.18	0.3	0.16	0.18	0.1	0.196	-0.089	-0.1	0.496
Areal mean	0.16	0.15	0.21	0.21	0.16	0.095	0.12	0.14	0.332

ZMK indicates Mann-Kendal trend test (upward or down ward its trend Q indicates Sen's slope the change per year/decade), statistically significant trend when p-value< 5% (0.05), trend is non-significant when p-value≥ 5%or at 0.05 probability level.

Temporal variability of temperature

The annual mean maximum temperature varied between 23 ^{O}C at Amdework to 28.6 ^{O}C at Sahla station and the annual mean minimum temperature ranges from 10.1 ^{O}C at Amdework to 13.7 ^{O}C at Sahla stations (see Figure 5). The mean maximum temperature varied from 23.1 ^{O}C to 30.2 ^{O}C with a mean of 25 ^{O}C while that of mean minimum temperature ranged from 11.1 ^{O}C to 15.9 ^{O}C with a mean of 13.1 ^{O}C during the Kiremt season (Figure 5). The study area is characterized with mean annual temperature varying from 17.9 °C to 22.8 °C and a mean Kiremt temperature ranging from 17.8 ^{O}C to 22.5 ^{O}C.

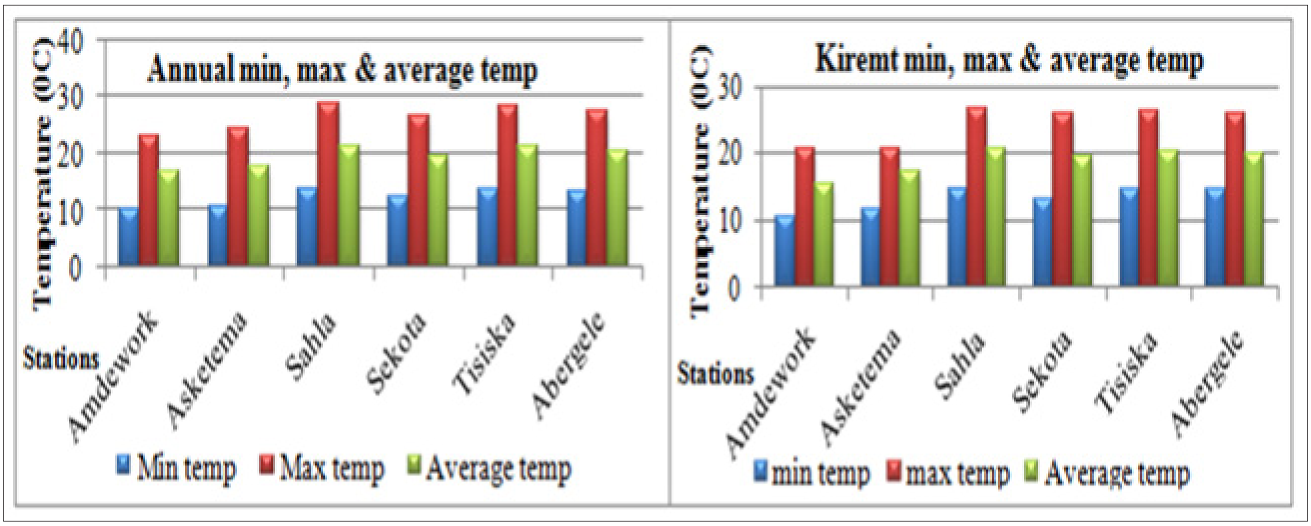

Figure 5: Mean annual & Kiremt minimum, maximum and average temperature patters at the study area.
3.2.1 Trends of minimum, maximum, and mean temperature

A trend of minimum, maximum, and mean temperature during annual and seasonal time scale is presented in (Tables 6, 7, 8). Maximum temperature has shown an increasing trend at all stations during annual and seasonal time scale. However, anon-significant trends were detected during Kiremt season at Asketema and Sekota areas whereas at Asketema and Sahla stations during Belg season (Table 6).This agrees with the result of the study by Nigusie over Tigray region, Ethiopia.

Table 6: Trends of annual and seasonal (Belg and Kiremt) maximum temperature at six stations

stations	Annual (January-December)			Kiremt (June-September)			Belg (February-May)		
	ZMK	Q	p-value	ZMK	Q	p-value	ZMK	Q	p-value
Amdework	0.49	0.06	<0.0001	0.47	0.06	<0.0001	0.39	0.07	0.002
Asketema	0.27	0.03	0.032	0.18	0.03	0.1651	0.18	0.02	0.155
Sahla	0.47	0.06	<0.0001	0.56	0.08	<0.0001	0.21	0.04	0.103
Sekota	0.49	0.06	<0.0001	0.19	0.05	0.1452	0.68	0.13	<0.0001
Tisiska	0.52	0.11	<0.0001	0.47	0.12	<0.0001	0.42	0.11	0.001
Abergele	0.44	0.06	0.0004	0.41	0.06	0.001	0.23	0.04	0.07
Areal mean	0.63	0.07	<0.0001	0.51	0.07	<0.0001	0.24	0.04	0.05

The highest increase of maximum temperature to the order of 1.3 ºC/decade is noticed at Sekota station in Belg Season. Increasing trend in minimum temperature has been noticed at all stations during annual and seasonal time scale. However, the detected trend was non-significant at Amdework and Asketema stations during annual and Belg time scales, respectively (Table7) and this agrees with the study reported by Solomon et al. [40].

Table 7: Trends of annual and seasonal (Belg and Kiremt) minimum temperature at six stations

stations	Annual (January-December)			Kiremt (June-September)			Belg (February-May)		
	ZMK	Q	p-value	ZMK	Q	p-value	ZMK	Q	p-value
Amdework	0.55	0.1	0.1001	0.38	0.06	0.0021	0.5355	0.08	<0.0001
Asketema	0.38	0.03	0.0021	0.29	0.03	0.02	0.1957	0.03	0.13
Sahla	0.51	0.07	<0.0001	0.41	0.07	<0.0001	0.5011	0.07	0.0001
Sekota	0.27	0.03	0.0316	0.38	0.05	0.002	0.2731	0.04	0.03
Tisiska	0.51	0.07	<0.0001	0.42	0.07	0.001	0.2774	0.06	0.02
Abergele	0.53	0.06	<0.0001	0.37	0.06	0.003	0.41	0.05	0.001
Areal mean	0.58	0.06	<0.0001	0.39	0.04	0.002	0.539	0.07	<0.0001

Similarly, annual and seasonal mean temperature have shown a significant increasing trend at all stations. This agrees with the results of World Bank, Ekpohand Nsa [41,42]. The highest mean temperature trend of 1 ºC/decade is observed at Tisiska station during Kiremt season while the lowest significant trend of mean temperature (0.3ºC/decade) is noticed during annual and seasonal timescales at Asketema station (Table 8). The magnitude of the increasing trend of the annual and Kiremt maximum temperature compared to the minimum temperature at Waghemra Zone particularly in Tisiska areas indicates higher daytime evaporative demand and therefore, a relatively higher water requirement is expected for growing crops in this particular area.

Table 8: Trends of annual and seasonal (Belg and Kiremt) mean temperature at six stations

stations	Annual (January-December)			Kiremt (June-September)			Belg (February-May)		
	ZMK	Q	p-value	ZMK	Q	p-value	ZMK	Q	p-value
Amdework	0.63	0.07	<0.0001	0.56	0.06	<0.0001	0.56	0.07	<0.0001
Asketema	0.37	0.03	0.003	0.29	0.03	0.024	0.187	0.03	0.15
Sahla	0.59	0.06	<0.0001	0.58	0.07	<0.0001	0.363	0.05	0.0037
Sekota	0.42	0.04	0.001	0.34	0.06	0.01	0.544	0.09	<0.0001
Tisiska	0.52	0.09	<0.0001	0.43	0.1	0.001	0.411	0.09	0.001
Abergele	0.514	0.05	<0.0001	0.406	0.05	0.001	0.34	0.05	0.01
Areal mean	0.66	0.07	<0.0001	0.381	0.04	0.002	0.548	0.08	<0.0001

ZMK indicates Mann-Kendal trend test (upward or down ward its trend Q indicates Sen's slope the change per year/decade), statistically significant trend when p-value < 5% (0.05), trend is non-significant when p-value ≥ 5% or at 0.05 probability level.

Variation and trends of crop yields

The maximum wheat yield was 17.77 quintal per hectare in 2006 and minimum yield of 6.25 quintal per hectare was recorded in 1998. Similarly, the highest sorghum yield was 18.03 quintal per hectare in 2011 and the minimum was 2.28 quintal per hectare during 2005 at Waghemra Zone (Table 9 & Figure 6).

Table 9: Summary of the statistical yields (Qt/ha) of wheat and sorghum in the study area (1997-2016)

Crops	Min	Max	Mean	CV (%)
Wheat	6.25	17.77	10.37	31
Sorghum	2.28	18.03	10.79	44.2

Out of the two cereal crops on average, sorghum has the highest mean yield (10.8 quintal per hectare) while wheat has the lowest mean yield (10.4 quintal per hectare) in the study area. Sorghum and wheat productions show high year-to-year variations based on the value of coefficient of variation (CV>30%) in the study area. The highest coefficient of variability of wheat and sorghum could be resulted from the joint effect of rainfall and temperature variability in the study area.

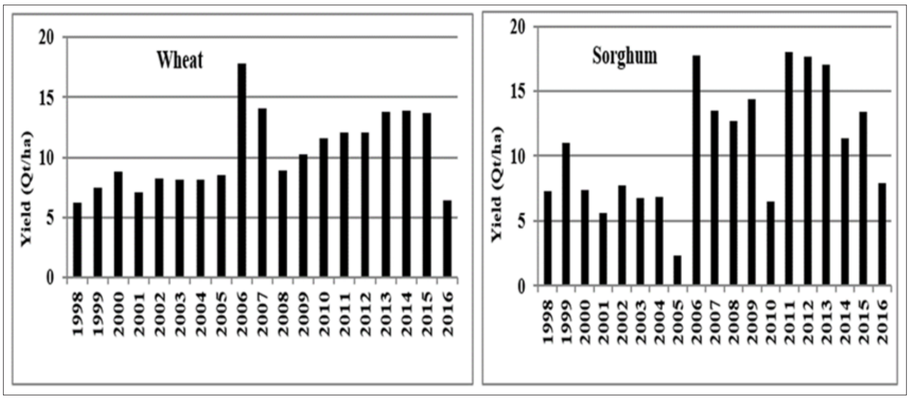

Figure 6: Mean annual wheat and sorghum production in Waghemra Zone

Trends of wheat and sorghum production in the study area

The Man-Kendall's trend test of wheat and sorghum yields result in Waghemra Zone is shown in Table 10. Therefore, the Man Kendall's trend test had showed anon-significant decreasing trend of wheat and sorghum yields by 3.2 and 1.5 quintal per hectare, respectively in the study area.

Table 10: Trends of wheat and sorghum yields in the study area for the period 2010-2018

Crop yield	ZMK	Q	P-value
Wheat	-0.24	-0.32	0.38
Sorghum	-0.16	-0.15	0.601

ZMK indicates Mann-Kendal trend test (upward or down ward its trend Q indicates Sen's slope the change per year/decade), statistically significant trend when p-value < 5% (0.05), trend is non-significant when p-value ≥ 5% or at 0.05 probability level.

Relationship between rainfall characteristics and crop yields

The correlation between rainfall characteristics, wheat and sorghum yields were computed and the result is presented in Table 11. The correlation between rainfall characteristics, wheat and sorghum yield shows that rainfall amount; number of rainy days, cessation date, and length of growing period shows positive correlations with wheat and sorghum yields in the study area. This implies that the higher the amount of rainfall spread over the number of rain days with extended duration in a year, the higher the yield of wheat and sorghum per hectare in the study area. On the contrary, onset date, number of very heavy rainfall and rainfall intensity was negatively correlated with wheat and sorghum yields over the study area (Table 11). This implies that as the onset increases (late onset) over higher intensity of rainfall with heavy rainfall occurrence, the yields of wheat and sorghum declines.

Table 11: The Correlation between rainfall characteristics and wheat and sorghum production

Rainfall characteristics	Wheat	Sorghum
Onset	-0.2	-0.1
Cessation	0.3	0.6
Length of growing period	0.03	0.1
Number of rainy days	0.1	0.3
Amount of rainfall	0.2	0.1
Number of very heavy rainfall	-0.004	-0.2
Simple daily intensity index	-0.20	-0.1

Relationship between temperature characteristics and crop yields

The correlation between minimum, maximum and mean temperature with yields of wheat and sorghum are shown in Table12. The results revealed that both sorghum and wheat production showed positive correlation with minimum, maximum and mean temperature. This suggests that as night time, daytime and average temperature increases, the production of wheat and sorghum is also increased. The Pearson correlation analysis between mean, maximum and minimum temperatures and crop production showed significant and positive relationships (Table 12).

Table 12: Correlation between production of crops and temperature at Waghemra Zone

	Wheat	Sorghum
Minimum temperature	0.19	0.09
Maximum temperature	0.16	0.08
Average temperature	0.26	0.14

Kiremt rainfall variability and crop yield anomalies

Figure 7 shows anomalies of wheat and sorghum yield and Kiremt rainfall variability at the zonal level. Both wheat and sorghum yield were below mean in the year 2000, 2002,2004,2008,2009 and 2015 in which the Kiremt rainfall was also below the mean for the same period. On the contrary, above average wheat yield was observed in 1998, 2006, 2007, 2010, 2013 and 2014and the Kiremt rainfall was also above average during those years. Similarly, both sorghum production and Kiremt rainfall showed above the mean in1999, 2006, 2007, 2013 and 2014 over the study area (Figure7).

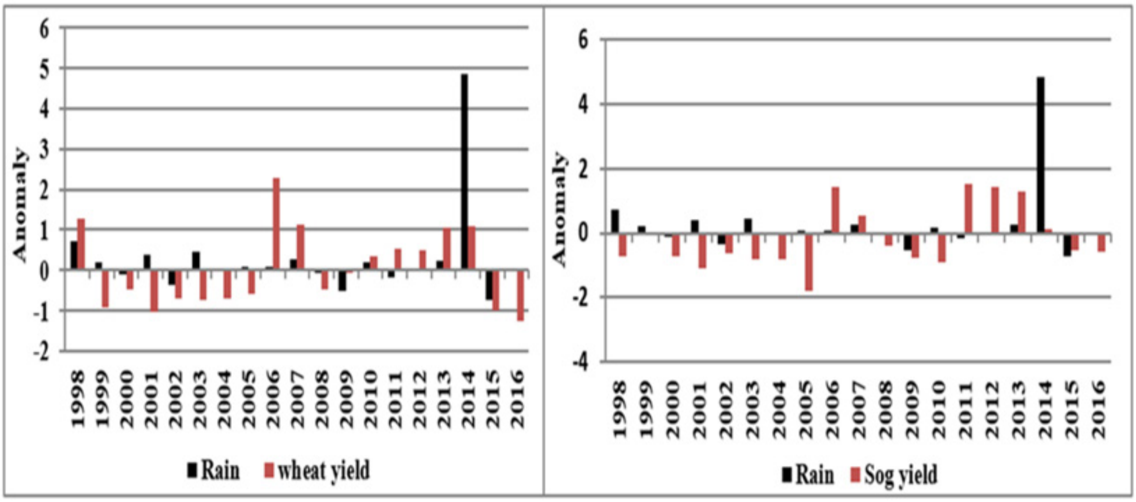

Figure 7: Wheat & sorghum yield and Kiremt rainfall departure from long term mean in the study area

Regression analysis of rainfall characteristics, temperature and crop yield

Multiple regression analysis was carried out in order to determine the relationship between the climatic variables and crop yields, and the results of multiple regression analysis of precipitation and temperature on crop yields are presented in Table 13. The analysis described the effects of the two independent variables (temperature and rainfall) jointly on the yields of wheat and sorghum. The multiple regression equation (Table 13) revealed that a unit change in any of the rainfall and temperature while holding others constant, the highest variation in yield of wheat in the area will be accounted by rainfall amount (0.014 Qt/ha) and the least change in yield will be from temperature (-0.024 Qt/ha). Conversely, the highest variation for sorghum yields will be accounted by temperature (0.196 Qt/ha) and the least variation in yield will be experienced by rainfall amount (0.014 Qt/ha) over the last periods. This shows that among the climate variables, rainfall amount is the most important variable for the variation in wheat yieldin the study area, indicating that the yield of wheat is higher when a Kiremt rainfall is higher. On the other hand, temperature is the most important variable for the variation of sorghum yield in the study area implying that the yield of sorghum is more when temperature is higher. In general, the precipitation and temperature variability have a significant effect on wheat and sorghum yields with higher coefficient of determination ranging from 0.84-0.86, respectively. Therefore, it is concluded that climate variability had significantly affected wheat and sorghum yield. The remaining 16% and 14% of the variations in the yield of wheat and sorghum respectively can be attributed to the other unexplained non-climatic factors.

Table 13: Analysis of variance (ANOVA) of wheat and sorghum yields with climate variables

Wheat	Source	Df	SS	MS	F*	Sig	R^2	F**	Sorghum	Source	Df	SS	MS	F*	Sig	F**	R^2
	Model	2	21.5	10.7	10.6	0.008	0.84	4.74		Model	2	18.4	9.2	21.9	0.001	4.74	0.86
	Error	7	7.1	1.01						Error	7	2.9	0.42				
	Total	9	28.6							Total	9	21.3					

Variables in the multiple regression equations

Wheat	Parameter	Estimate	SE	T	Sig	Sorghum	Parameter	Estimate	SE	T	Sig
	Const	0.787	6.49	0.12	0.91		Const	-3.88	4.17	-0.92	0.38
	Temp	-0.024	0.269	-0.09	0.93		Temp	0.196	0.17	1.13	0.29
	Rain	0.014	0.003	4.05	0.005		Rain	0.014	0.002	6.32	0.004

Df=degree of freedom, SS=sum squares, MS=mean squares, SE=standard error, sig=significance at 95% confidence level, Const=constant, Temp=temperature, F*=calculated value, F**=tabulated value

Conclusions

Agriculture in Ethiopia is one of the key socio-economic activities substantially affected by climate variability. The trend of climatic variables with their fluctuation and variability of rainfall and temperature in Waghemra Zone was analyzed in this study. The trend of climate variability in Waghemra Zone revealed that there might be an increasing number and severity of natural disasters. Rainfall and temperature are the most determinant parameters determining the climate variability in the study area because more than 80%

of the study area's agriculture is dependent on rainfall. Increased rainfall variability, prolonged dry spells and droughts have great effects on crop yield. Likewise, increased temperature leads to an increase in evapotranspiration and affects soil moisture availability which limits crop growth, development and yield.

Therefore, the main aim of this study was to examine the effect of climate variability on wheat and sorghum production in Waghemra Zone. The relationship between climate variation and crop yields in the study area has been examined using multiple regressions analysis. Waghemra Zone is characterized by monomodal rainfall pattern where much of the rainfall concentrated in the main rainy season called Kiremt (June-September) and mostly the crops are planted during this season. The mean annual rainfall amount was 637mm while Kiremt, Belg, and Bega received 547, 68, and 22 millimeters, respectively. The mean onset date was between 1st and 2nd week of July whereas the mean cessation dates wasfirst week of September and the mean duration of the Kiremt season was 64days. The results showed that there was considerable temporal and spatial variation of rainfall over Waghemra Zone which leads to crop production at risk. The coefficient of variation revealed moderate to high inter-annual variability and Kiremt and Belg rainfall were highly variable. Spatially, a general decrease of mean annual rainfall from south to north was observed over Waghemra Zone. Moreover, the rainfall was characterized by a sporadic fluctuation of wet and dry years in a periodic pattern.

The study area is characterized with mean annual temperature varies from 17.9 ^{O}C to 22.8 ^{O}C and mean Kiremt temperature also ranges from 17.8 ^{O}C to 22.5 ^{O}C. The Mann–Kendall trend test showed anon-significant increasing trend of annual and Kiremt rainfall by a rate of 3.7 and 5.4 mm per year, respectively. During Belg season the rainfall was decreasing non-significantly by a rate of 3mm per decade. Also, the onset and cessation dates showed anon-significant decreasing trend by 1.5 and 1.6 days per decade, respectively. Likewise duration of the season showed anon-significant increasing trend by 1.4 days per decade.

On the other hand, a trend of maximum, minimum and mean temperature in annual and seasonal time scale have shown a significant increasing trend over Waghemra Zone. The variability of seasonal rainfall and temperature causes fluctuations in production of major crops. Due to high correlations between crop production and seasonal rainfall and temperature, small changes in amount and distribution of seasonal rainfall, increasing temperature causes significant negative impacts on crop production that varies from reduced yield to the total loss of the crop. As result wheat and sorghum production exhibits the largest year to year variations in the study area. This high inter-annual and seasonal variability is caused by rainfall and temperature variability where increase in temperature and decrease in rainfall amount may have a negative impact on crop production and soil water balance. The results of the regression analysis showed rainfall and temperature jointly contribute 86% and 84% in explaining the variation in the yield of wheat and sorghum per hectare, respectively in the study area. Evidently, the findingsof this study showed that climate variability has an adverse effect on crop production in Waghemra Zone. As a result both wheat and sorghum production exhibits the largest year to year variations in the study area. This high inter-annual variability is caused by climate variability in which the main climate parameters; temperature and precipitations often play the biggest role. Hence, this study provides further knowledge to improve our understanding on climate variability and change and its possible impact on crop production and would be also useful for future sustainable agricultural water resources planning and management in the study area [43-49].

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Conflict of Interest
The authors declare that there is no conflict of interest.

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