



## **CHARACTERIZING HISTORICAL CLIMATE VARIABILITY AND ITS INTERCONNECTION WITH MAJOR CROPS PRODUCTION IN THE SOUTH GONDAR ZONE, AMHARA, ETHIOPIA**

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### **1. INTRODUCTION**

#### **1.1. Background of the Study**

Today, climate change has become one of the most important issues, and the biggest concern of humankind. As a consequence of increased concentration of atmospheric greenhouse gases (GHG), temperature is increasing and the amount and distribution of rainfall is becoming variable. According to the Intergovernmental Panel on Climate Change (IPCC) reports, global average temperature has increased over the last century and is expected to rise by 1.4 and 5.8°C by 2100 (IPCC, 2014a) with the doubling of the current CO<sub>2</sub> concentration in the atmosphere (Cubasch *et al.*, 2001).

Associated with this unprecedented global warming, climate variability and the associated changes in frequency and intensity of extreme weather events such as drought, cold and heat waves, floods, cyclones and hails are also increasing worldwide (Marvi and Tupper, 2004; Mannava and Raymond, 2007; Ninan and Satyasiba, 2012). As a result, many studies have shown that the frequency, duration, and severity of drought have significantly increased in Africa, Eastern Asia, Mediterranean region, and Southern Australia since 1951 (viste *et al.*, 2012, Spinoni *et al.*, 2013). In many cases globally days are becoming warmer and rainfall is more variable and irregular (IPCC, 2009).

In Ethiopia, where over 85% of the population is directly dependent on agriculture for employment and subsistence, and almost 50% of the GDP and export earnings of the country are reliant on climate sensitive sector, rainfall variability and drought are not a new phenomenon (Tuffa, 2012). However, its frequency of occurrence and intensity has repeatedly increased during the past few decades. Over the last 55 years alone the country experienced increase in minimum and maximum temperatures, and numerous episodes of extreme dry and wet years that caused significant damage to life, property, natural resources and the whole economy. The recent past flood of 2006 at Diredawa alone for example claimed 719 human lives, displaced over 241,699 people, severely damaged infrastructures and houses, and caused property loss worth million USD across the country (Tadesse and Dagnachew, 2006; DDAEPA, 2011). Moreover, the country's farming systems have been subjected to variability and fluctuations in production due to inter-annual and seasonal variability of rainfall (Bewket, 2009) which in many cases translated in to cycles of episodic food crises that labeled the country as one of the "most vulnerable in the world". Consequently, the impacts caused by extreme droughts to the economy are estimated to be equivalent to the annual overseas development assistance received (Oxfam International, 2009).

Nevertheless, the agricultural and livelihood impacts of climate variability and climate change varies from region to region and largely depend on other factors such as farm land size, the

soil types, type of crops grown, topography, and use of improved technologies (stern,2007).

The Amhara National Regional State in general and the South Gondar Zone in particular, where land holdings have been under continuous sharing and fragmentation. Many farmers have very small farm land size, and are unable to compensate for unit area yield loss by increasing area of production; where land is under continuous cultivation without resting , and where low or no external input use characterize the farming system, impacts of climate variability and change is expected to be more significant

A study conducted by Bewket (2009) showed that there is a strong correlation among monthly, annual and seasonal total rainfall, and cereal production. However, the study of Bewkwt (2009) failed to provide detailed account on the most important elements of climate variability indices of extreme rainfall and temperatures that have far reaching effect than the long term mean changes.

On the other hand, analysis of climate data of weather stations located in the region showed that there is marked spatial and temporal variability among weather stations in annual and seasonal rainfall totals (Bewket, 2009; Hadgu,2013; Getaneh,2015). This indicates possibility of existence of local level variation in all other elements of climate variability and change detection indices.

The recent work of Getaneh (2015) on rainfall variability and its implication on crop production in the North Eastern part of Amhara Region attests this. However, that did not give an account of temperature and the interconnection of historical climate and yield of major crops production in or around the study area.

## **1.2. Problem of the Study**

Agricultural region can be considered as a collection of individual fields that vary in environmental conditions and management practices. Day to day extreme events are increasing and the population demands requires rising in the agricultural production with available resources. Available resources with stable weather conditions is essential to increase productivity of agriculture. But in the study area climatic variables especially SOS,EOS which determines LGS, probability of dry spell occurrence NRD etc are more variable due to this reduction of productivity and crop faller faced. On the other hand an increase of warming decreases the yield of habituated crops variety.

## **1.3. Objectives**

### **General objective**

The general objective of this paper was to characterize climatic variability and trends in terms of agriculturally important rainfall and temperature parameters, and interconnection between the historical climate and major crops grown in the South Gondar Zone of the Amhara National Regional state of Ethiopia with the following specific objectives:

- ✓ to characterize climate variability of rainfall and temperature parameters and their trends.
- ✓ to investigate the interconnection of observed climate variables with major crop production in the study area.

## **2. MATERIAL AND METHODS**

### **3.1. Description of the Study Area**

The study was conducted in the South Gondar Zone of the Amhara National Regional State of Ethiopia. The study area covers 14,669.99 square Kilometers.

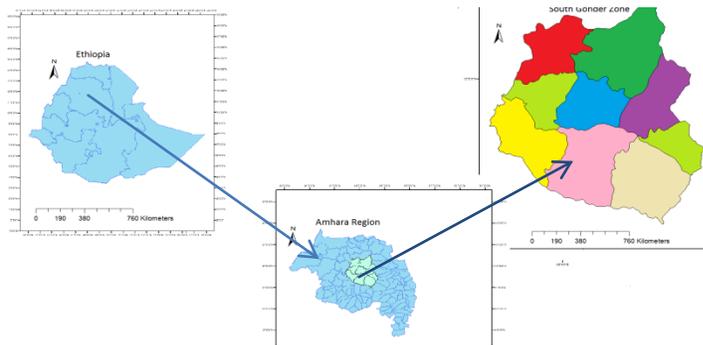


Figure 1. Location map of the study area

It is located in between  $11.325^{\circ}$  and  $12.421^{\circ}$  N latitude, and  $37.677^{\circ}$  and  $38.524^{\circ}$  E longitudes. The South Gondar Zone shares administrative boundaries with North Gondar Zone in North, West Gojjam Zone in West, East Gojjam Zone in South, South Wollo Zone in East and North Wollo Zone in the North East.

The climate of the study area is characterized by Kola (hot zone) below 1500 meters above sea level, Woyina Dega (warm zone) between 1500 - 2500 m above sea level and Dega (cold zone) above 2500 m above sea level. The annual mean temperature of the Zone is between  $15^{\circ}\text{C}$  and  $21^{\circ}\text{C}$ , but in valleys and marginal areas the temperature exceeds  $27^{\circ}\text{C}$  (Astatkie, 2012). The study area is highly variable in terms of rainfall.

The study region experiences a mono modal rainfall that begins from March-April and gradually reach peak in months from June-September and then recedes. As a result crop production in the study region is solely dependent on main rain season. The dominant soil type of the study area is verti sols (FAO 1984) while the crops grown in the study area are barley, wheat, *Teff*, sorghum, maize, field beans, peas, chickpeas, and oil crops like linseeds and *Nug* as well as root and tuber crops like potato. *Teff* is the dominant crop grown in low and mid altitude areas while wheat and barley are dominating the mid and highland areas, respectively. According to Astatkie (2012) annual crop production in the study area is less, and could not meet the food need of local farmers throughout a year.

## 3.2. Data Source and Station Selection

### 3.2.1. Observed climate data

Long term daily rain fall, maximum and minimum temperatures data of all weather stations located in the Zone were collected from the National Meteorology Agency of Ethiopia. Three weather stations (Debre Tabor, Nefas Mewcha and Werota) were then selected for the study on bases of spatial representation of the Zone, length of record period, was taken for (1985-2014).

### 3.2.2. Crop Data

Zonal level yearly data (1985-2014) on area of production, yield and productivity was obtained from the Central Statistics Agency (CSA) of Ethiopia for the major crops (*Teff*, wheat and barley) grown in the Zone.

Table1. Description of weather stations selected for the study in the South Gondar Zone, Amhara National Regional State, Ethiopia.

Station name	Latitude (°N )	Longitude (°E)	Altitude (M)	Data record years	Missing data (%)		
					RF	Tmax	Tmin
Debre Tabor	11.89	37.98	2612	1985-2014	9.8	5.3	5.3
Nefas Mewcha	11.81	38.36	3098	1985-2014	9.9	9.4	9.4
Werota	11.92	37.69	1819	1985-2014	8	8.9	9

Where: RF is Rainfall, Tmax is maximum temperature, Tmin is minimum temperature

### 3.3. Data Quality Control

#### 3.3.1. Filling Missing Data

Missing data and outlier rainfall and temperatures data in the data series was estimated using INSTAT+ v3.37 first order Markov-chain simulation model (Stern *et al.*, 2006). The main reason for choosing this model to fill the missing daily rainfall, minimum and maximum temperature data was that it does not overstate the results and gives a more accurate model to each of the study areas as explained by NMSA (1996b).

#### 3.3.2. Outlier detection

Since identification of outliers (suspicious data) is the primary emphasis of climate database development, the Turkey fence method was used for trimming outliers (Ngongondo *et al.*, 2011) in order to reduce the size of the distribution tails to a safer non-resistant homogenization as indicated in Gonzalez-Rouco *et al.* (2001) and Ngongondo *et al.*(2011). The data range was represented as:

$$Q_1 - 1.5 * IQR, Q_3 + 1.5 * IQR$$

Where: Q1 and Q3 were lower and upper quartile ranges respectively, IQR was an interquartile range, 1.5 were standard deviation from mean. Mean values, outside the turkey fence were considered as outliers.

### 3.4. Variables Studied

#### 3.4.1. Climate variables

##### 3.4.1.1. Rainfall variables

The rainfall variables studied include: onset date, end date, length of rainy season, dry spell length, maximum one day precipitation, very heavy precipitation days, simple daily intensity index, number of wet or rainy days, number of dry days, consecutive dry days, and consecutive wet days.

Each of which were determined as follows: the onset date of rainy season was determined as the date when 20 mm or more rainfall was accumulated over three consecutive rainy days for the growing season and no dry spell greater than 7 days in the next 30 days as in Tesfaye and Walker (2004). On the other hand, end date of rainy season was determined using soil water balance model of FAO (1978) where the date when soil water balance becomes zero (0) mm after September first as indicated in Tesfaye and Walker (2004), and, Getaneh (2015). Whereas, the length of the growing seasons was determined as the difference between the

onset date and end date of the season as indicated in Mamo (2005), Hadgu *et al.*,(2013) and Hadgu *et al.*, (2014). Also number of rainy and dry days were determined by counting all days with rainfall greater than or equal to 1mm as rainy day and those days with less than 1 mm rainfall as dry days, respectively as outlined in NMSA (2001), Segele and Lamb (2005) and Getaneh (2015). Similarly total rainfall was determined as sum of rainfall of each day during the crop growing period as indicated in NMSA(2001), Segele and Lamb(2005), Mesay(2006) and Hadgu *et al.*(2013). Dry spell length was also determined as consecutive days with rainfall less than 1 mm per day exceeding 7, 9, 10 and 15 days and analyzed by Markov Chain analysis as indicated in Stern *et al.*,(2006) and Stern and Cooper (2011) using INSTAT v3.36. Likewise, the maximum one day precipitation was determined as the highest precipitation amount received in one day in a month, and number of very heavy precipitation day was determined by counting the annual number of days in the season having precipitation greater or equal to twenty mm, and the simple daily intensity index was computed as total precipitation of rainy days in the season divided by the number of rainy days with precipitation  $\geq 1$ mm as out lined in Mekasha *et al.*, (2014) and Degefu *et al.*,(2014).

#### 3.4.1.2. Temperature variables

The temperature parameters studied include: mean seasonal maximum, mean seasonal minimum, mean seasonal, diurnal range, maximum of the maximum, maximum of the minimum, minimum of the maximum, minimum of the minimum, number of warm days, number of warm nights, number of cool days and number of cool nights.

Each of which were determined as follows: the mean seasonal maximum, and mean seasonal minimum temperatures were determined as mean of the sum of the daily maximum and daily minimum temperatures recorded, respectively during the crop growing season, while the mean seasonal temperatures are determined as average values of the daily maximum and minimum temperatures recorded for the crop growing season. Similarly the diurnal range of temperature was computed as average of the sum of the daily differences between the daily maximum and daily minimum temperatures recorded during the crop growing season.

Maximum of the maximum temperature was also determined as the monthly maximum value of daily maximum temperature during the crop growing season while minimum of the maximum temperature was estimated as monthly minimum value of the daily maximum temperature. In the same way minimum of the minimum temperature was determined as monthly minimum value of the daily minimum temperature recorded during the study period, whereas maximum value of daily minimum temperature as determined as given by ETCCDI (<http://cccma.seos.uvic.ca/ETC> ETCCDI).

The number of warm days was determined as percentage of days when maximum temperature was greater than 90th percentile of base period, while number of warm nights was estimated as percentage of days when minimum temperature was greater than 90<sup>th</sup> percentile of the base period. In a similar way, number of cool days was determined by counting percentage of days when maximum temperature is less than 10<sup>th</sup> percentile of the base period, and number of cool nights was identified by counting percentage of days when minimum temperature was less than 10<sup>th</sup> percentile of the base period as given by ETCCDI). <http://cccma.seos.uvic.ca/ETCCDI>

#### 3.4.2. Crop variables

The crop variables studied include: annual area of production which was determined as the annual area (ha) devoted to each of the major crops (*Teff*, Barly and wheat) grown in the Zone during the study years (1985-2014); annual yield was determined as the amount of grain yield (quintal)/hectare obtained from each of the major crops grown in the Zone during the study years; Production: was estimated as the amount of grain obtained per year (qut) from the major crops grown in the Zone during the study years.

### 3.5. Variability Analysis

Variability in rainfall and temperature variables/parameters were analyzed using descriptive statistics (frequency, mean), coefficient of variability, standardized anomaly index and standard deviations. The SAI was calculated as the difference between the total of a particular year and the long term average records divided by the standard deviation of the long term data as following:  $SAI(Z) = \frac{x-\mu}{\delta}$

Where, Z was the standardized rainfall or temperature or crop anomaly; x was the crop growing seasonal rainfall total or mean crop growing season temperature of a particular year;  $\mu$  was the mean crop growing season rainfall over a period of observation and  $\delta$  was the standard deviation of crop growing season rainfall over the period of observation.

Coefficient of variation (CV) was also calculated to evaluate the variability of all parameters/variables in the study and its characteristics by dividing the standard deviation of the event to its mean. Coefficient of variation was computed as:

$$CV = \left(\frac{\delta}{x}\right)100$$

Where CV was the coefficient of variation; X was the average long-term rainfall or temperature over the given decade and  $\delta$  was the standard deviation.

Based on CV the degree of variability was classified as less variable, for  $CV < 20\%$ , as moderately variable for CV from 20% to 30%, and as high variable for  $CV > 30\%$  as indicated in Hare (1983). Moreover, based on values of standard deviation (SD) it was classified as less stable for  $SD > 40$ , as moderate for  $SD 20-40$ , as highly stable for  $SD 10-20$ , and very high stability for  $SD < 10$  after Reddy (1990).

### 3.6. Trend Analysis

Several tests are available for the detection and estimation of trends. In this study, Mann-Kendall's test was employed for rain fall, temperature and crops trend analysis. The choice of this test was due to the fact that Mann-Kendall's trend test as a non-parametric method, was less sensitive to outliers and test for a trend in a time series without specifying whether the trend is linear or non-linear (Partal and Kahya, 2006; Yenigun *et al.*, 2008). The Mann-Kendall's test statistic was given as:

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

Where S was the Mann-Kendal's test statistics;  $x_i$  and  $x_j$  were the sequential data values of the time series in the years  $i$  and  $j$  ( $j > i$ ) and  $N$  was the length of the time series. A positive  $S$  value was interpreted as indicative of an increasing trend and a negative value as indicative of a decreasing trend

in the data series. The sign function was given as: 
$$sgn(X_j - X_i) = \begin{cases} +1 & \text{if } (X_j - X_i) > 0 \\ 0 & \text{if } (X_j - X_i) = 0 \\ -1 & \text{if } (X_j - X_i) < 0 \end{cases}$$

The variance of S, for the situation where there could be ties (that was, equal values) in the x

Values was given by:

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

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

$$Z_{mk} = \begin{cases} \frac{s-1}{\text{var}\sqrt{(s)}} \text{ If } s > 0 \\ 0 \text{ if } s = 0 \\ \frac{s*1}{\text{Var}\sqrt{(s)}} \text{ if } s < 1 \end{cases}$$

The presence of a statistically significant trend was evaluated using the  $Z_{MK}$  value. In a two- sided test for trend, the null hypothesis  $H_0$  was accepted if  $|Z_{MK}| < Z_{1-\alpha/2}$  at a given level of significance.  $Z_{1-\alpha/2}$  was the critical value of ZMK from the standard normal table. In the present study significance level of a trend was examined under at 5% probability level. The slope (change per unit time) was estimated following the procedure of Sen (1968) which was

Computed as:

$$Ti = \frac{(Xj - Xk)}{j - k} \text{ for } i = 1, 2, 3 \dots N$$

Where:  $X_j$  and  $X_k$  will be considered as data values at time  $k$ , ( $j > k$ ), correspondingly. The median of these  $N$  values of  $T_i$  will be represented as Sen's estimator of slope given by

$$Qi = \begin{cases} T\left(\frac{T+1}{2}\right) \dots N = \text{odd} \\ \left\{ T\frac{N}{2} + T\left(\frac{N+2}{2}\right) \right\} \dots N = \text{even} \end{cases}$$

Sen's estimator was computed as  $Q_{med} = T(N+1)/2$  if  $N$  appeared odd and it was considered as  $Q_{med} = (TN/2 + T(N+2)/2)$  if  $N$  appeared even. At the end,  $Q_{med}$  was computed by a two sided test at 100 (1-  $\alpha$ ) % confidence interval and then a true slope was obtained by the non-parametric test. Positive values of  $Q$  was interpreted as indicative of an upward or increasing trend, and the negative values were interpreted as indicative of decreasing trends and in case if the values were zero, it was taken as indicative fluctuations in the data series around the mean as indicated in Sen (1968). MAKESENS\_1\_0 excel based template software was used to carry out the computation.

### 3.7. Correlation Analysis

Pearson correlation coefficient ( $r$ ) analyses was used to analyze the correlation between zonal level area (ha), yield (qt) and productivity (qt/ha) of major crop (*Teff*, Barley and Wheat) grown in the zone with characteristics different rainfall and temperature variables. Correlation coefficient ( $r$ ) value close to +1 were interpreted as indicators of a strong positive correlation, and a correlation coefficient close to -1 were interpreted as indicators of a strong negative correlation while a correlation coefficient of 0 were interpreted as indicators of no correlation or association .

## 3. RESULTS AND DISCUSSIONS

This section, presents results of the observed historical (1985-2014) climate variability and trend in terms of rainfall and temperature as well as its inter connection with the historical production of major crops grown in the South Gondar Zone of the Amhara National Regional State of Ethiopia.

## 4.1. Characteristics of the Observed Climate

Climate characterization is a key issue for rain fed crop production. Thus under this section, results of the observed / historical rainfall and temperature such as contribution of the seasonal rainfall to the total annual, number of rainy and dry days, lengths of growing period, maximum of the maximum temperature, maximum of the minimum temperature, minimum of the minimum temperature, minimum of the maximum temperature and others variability and trends for the study period are presented and discussed.

### 4.1.1. Observed rainfall variability

The observed/historical rainfall showed that *Kiremt* rainfall had much more contribution to the annual total rainfall of the South Gondar Zone (Table 2). The same finding was also reported by Ayalew *et al.* (2012(a)) for he studied the entire Amhara National Regional State. The observed contribution; however, was variable among locations within the Zone. As is evident from the table, the highest contribution was observed at Werota which is located in the western part of the Zone and the least at Nefas Mewcha (located in the eastern part of the Zone). Similar spatial variability was also reported by Getaneh (2015) and Ayalew *et al.* (2012(a)) in the western and north eastern part of the Amhara National Regional State of Ethiopia. In the study area the highest observed contribution at Werota and the lowest at Nefas Mewcha could indicate a general decline in contribution of the *Kiremt* rainfall to the annual total from west to east in the Zone. This might be owing to the general shortening of the duration of the *kiremt* rainfall as one goes from the western extreme part of the zone to the east guided by the position of *kiremt* rain bearing ITCZ (Segele and Lamb, 2005).

Over the study period, the South Gondar Zone on average, received an annual *kiremt* rainfall of 1049 mm. The maximum was recorded at Werota in the west and the minimum at Nifas Mewcha to the east. However, over the study period, the maximum and minimum rainfall and years of occurrence of such rainfall events varied among weather recording stations. To this end, at Werota and Nefas Mewcha, the maximum rainfall of the study period was recorded in the year 1992 while the minimum in varying years indicating wide spatial differences in occurrence of periods of extreme rainfall events in the Zone. Moreover, the CV of the present study was less than 20% at all the three weather stations and the areal average as well. As a result, based on the classification of Hare (1983) *kiremt* season rainfall in the South Gondar Zone could be classified as less to moderately variable. Similar results were also reported by Zanke and Seleshi (2004), Segele and Lamb (2005), Ayalew *et al.* (2012), Hadgu *et al.* (2013) and Getaneh (2015) in the north and north eastern parts of the country.

Nevertheless, the inter-annual distribution of rainfall was less stable as the observed values of the standard deviation (SD) at all the three weather stations and the Zonal average exceeded the 40 mm limit set by Reddy (1990), indicating wider inter-annual variability. In line with this for the 25% of the study years, total rainfall of the season was less than the Zonal average of the first and third quartile (Q1) at Nefas Mewcha, and conversely higher than the Zonal mean values of Q1 and Q3 at Debre Tabor and Werota. This mean that at the Zonal level, on average, three times in four years, the total seasonal rainfall was less than 1169mm and this was less than 899 mm, at Nefas Mewcha, and less than 1266mm and 1258mm at Debre Tabor and Werota, respectively. On the other hand, for every four years the probability of occurrence of seasonal total rainfall higher than 1169 mm in one year was 25%, and this was less than 712 mm, at Nefas Mewcha, less than 1001mm and 1055mm at Debre Tabor and Werota, respectively. On the other hand, for the 75% of the study years total rainfall of the season was more than the Zonal average of the first and third quartile (Q1) at Debre Tabor and Werota and conversely less than the Zonal mean at Nefas Mewcha in Q1 and Q3.

Table 2. Summary statistics of observed Kiremt seasonal rainfall totals at the three weather stations (Debre Tabor, Nefas Mewcha, and Werota) in the south Gondar Zone, Amhara National Regional States Ethiopia (1985-2014)

Station	CT (%)	Max(mm)	Media n(mm)	Mean (mm)	Min(mm)	CV (%)	SD(mm)	Q3	Q1		
		Value	Year		value	year					
Debre Tabor	79	1793	1986	1502	1156	719.8	2009	20	231	1266	1001
Nefas Mewcha	72	1313	1992	1113	812	445.3	1987	19	161	899	712
Werota	86	1938	1992	1303	1181	782.0	1997	19	227	1258	1055
Areal Average	79	1680	1992	1049	1049	649	2004	19	206	1141	939

SD is standard deviation, CV is coefficient of variation, Q3 is upper quartile, Q1 is lower quartile range and CT is contribution of Kiremt rainfall.

#### 4.1.1.1. Start of season (SOS)

As shown in Figure 2 and Appendix Table 1, the start of *kiremt* season in south Gondar Zone showed spatial and temporal variation during 1985-2014. For instance the start of the season was earlier than 23<sup>rd</sup> of May (DOY 145), 3<sup>rd</sup> of June (DOY 155) and 24<sup>th</sup> of May (DOY 146), once in four years' time ( for less than 25% of the study years) at Debre Tabor, Nefas Mewcha and Werota respectively. On the other hand, earlier start of the season before 8<sup>th</sup> of July (DOY 190), 18<sup>th</sup> of June (DOY 180) and 8<sup>th</sup> of June (DOY170), was possible three times in four years ( for 75% of the study years) at Debre Tabor, Nefas Mewcha and Werota, respectively(Figer2).

During the study period, the observed median SOS was 23<sup>rd</sup> of June (DOY 169) at Debre Tabor 24<sup>th</sup> of Jun (DOY 170) at Nefas Mewcha and 29<sup>th</sup> of Apr (DOY 120) at Werota. On the other hand, as depicted in the Figure 2 and the Appendix Table 1, the latest start of the season was DOY195 (13-July) and the earliest start was DOY 81 (21-Mar) at Debre Tabor weather station. In line with the present study, Ayalew *et al.* (2012) also found, 9<sup>th</sup> of July (DOY 189), 13<sup>th</sup> of May (DOY 136) and 4<sup>th</sup> of July (DOY 186) as the median start date of the *Kiremt* growing season at Srinka, Debre Tabor and Kombolcha weather stations, respectively for the period 1978-2008.

However, at the three weather stations, the earliest start of the season was on DOY81 (21-Mar), DOY 85 (25-Mar) and DOY 120 (29-Apr) at Debre Tabor, Nefas Mewcha and Werota, respectively. The presence of more number of SOS days above the second quartile indicates late start of rain for most of the study years in the south Gondar Zone which might be contradictory to the reports of Ayalew *et al* (2012) who found less number of years with late SOS days above the median values for the western Amhara Region. The discrepancies could be an indication of less predictability of SOS for making decisions with regard to tillage, sowing and other agricultural Activities (Appendix Table 1).

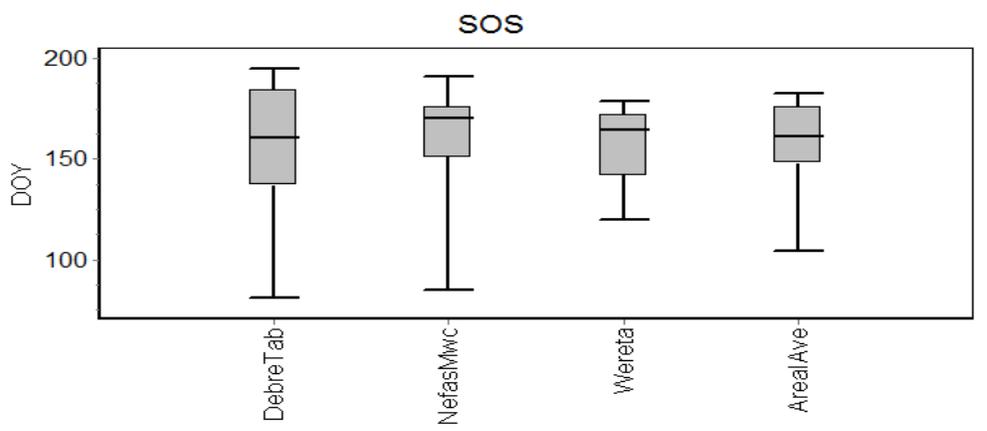


Figure 2. Box and Whisker plots of observed start date of *Kiremt* season (SOS) at the three weather stations (Debre Tabor, Nefas Mewcha, and Werota) in the south Gondar Zone, Amhara National Regional State Ethiopia (1985-2014).

#### 4.1.1.2. End of season (EOS)

The observed end of *kiremt* season was variable among weather recording stations in the south Gondar Zone. The median end date of the season during the study period was 23<sup>rd</sup> of Sep (DOY 267), 08<sup>th</sup> of October (DOY 282), and 8<sup>th</sup> of September (DOY 252) at Debre Tabor,

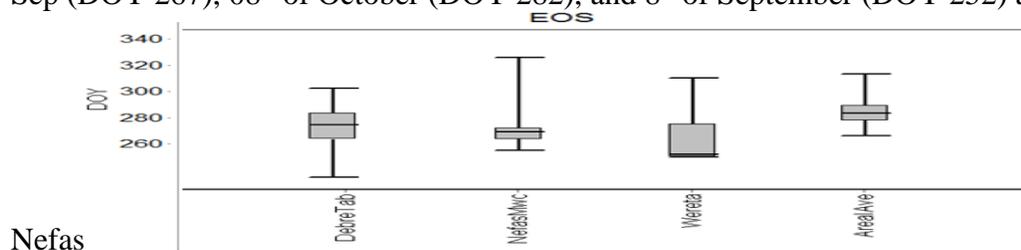


Figure 3. Box and Whisker plots of observed end date (EOS) of *Kiremt* growing season (EOS) at the three weather stations (Debre Tabor, Nefas Mewcha, and Werota) in the south Gondar Zone, Amhara National Regional State Ethiopia (1985-2014)

Mewcha and Werota, respectively (Figure 3 and Appendix Table 1), whereas, the mean end date of the season was on DOY 263 (18-September), DOY 284 (10-October) and DOY 307 (2-November) at Werota, Nefas Mewcha and Debre Tabor, respectively.

The rainy season terminated earlier than 22<sup>nd</sup> of October (DOY 295), 2<sup>nd</sup> of October (DOY 275), and 7<sup>th</sup> of September (DOY 250) once in four years (for 25% of the study years) at Debre Tabor, Nefas Mewcha and Werota stations, respectively. Whereas the inter-quartile range for the study period was 52 at Debre Tabor, 31 at Nefas Mewcha and 33 at Werota indicating relatively more variable EOS at Debre Tabor for 50% of the study years whose value was close to the long term average EOS. On the other hand, the observed CV values were low (5-18%) indicating less varying EOS over a short time span and the patterns could be more understood. Nevertheless, at weather station level the CV values were relatively less at Nefas Mewcha when compared to that of the Debre Tabor and Werota that could be because of presence of extended extreme EOS days at Werota indicated in Figure 3 where latest EOS was on DOY 310 (5 November), DOY 335 (30-November) and DOY 339 (4-December) at Werota, Debre Tabor and Nefas Mewcha, respectively. On the other hand, the earliest recorded EOS date was DOY 250 (6-September), DOY 252 (8-September) and DOY 262 (24-September) at Werota, Debre Tabor and Nefas Mewcha, respectively (Appendix Table 1) and Figure 3.

### 4.1.1.3. Length of season (LGS)

Over the study period, length of the growing period varied from the maximum of 237 days at Debre Tabor to the minimum of 72 days at Werota weather stations (Figure 4 & Appendix Table 2). Mean LGS of 151, 125 and 105 days were recorded at Debre Tabor, Nefas Mewcha and Werota respectively, and the median LGS was 141, 115, and 108 days at Debre Tabor, Nefas Mewcha and Werota stations, respectively. In line of this, Ayalew *et al.* (2012) also reported a comparable median length of 100, 108 and 85 days at Kombolcha, Debre Tabor and Srinka station, respectively for the period 1978-2008. The CV of present study also varied from 21 days at Debre Tabor to 36 days at Nefas Mewcha indicating moderate to highly variable LGS in the Zone. The observed high variability of LGS at Nefas Mewcha implies less predictability of the LGS as compared to that of Debre Tabor and Nefas Mewcha, though the standard deviation was relatively higher for Nefas Mewcha than Debre Tabor and Werota (Appendix Table 2). Similarly for 25% of the study years LGS was less than 85, 105 and 87 days at Debre Tabor, Nefas Mewcha and Werota, respectively indicating relatively more number of years with short LGS at Nefas Mewcha. On the other hand, for 75% of the study years LGS was less than 137, 133 and 120 days at Debre Tabor, Nefas Mewcha and Werota, respectively indicating relatively more number of years with longer LGS at Werota and less at Debre Tabor. The inter-quartile range of the present study was also higher at Debre Tabor (52 days) compared the 28 days at Nefas Mewcha and 33 days at Werota indicating relatively more variable LGS.

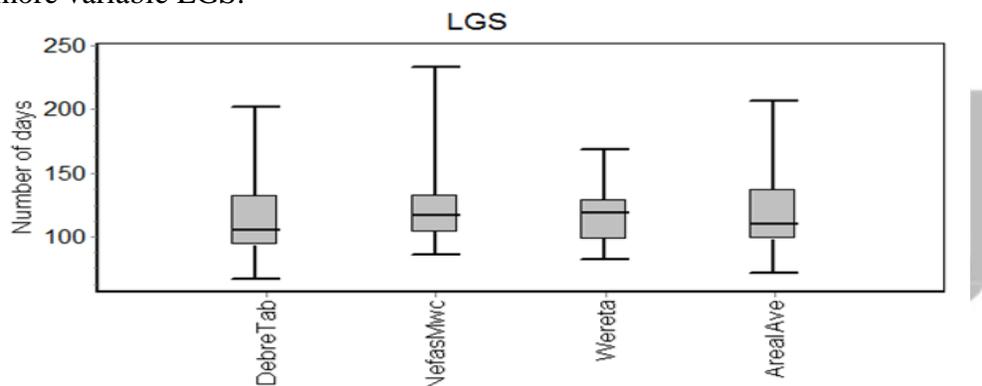


Figure 4. Box and Whisker plots of observed Length of growing Season (LGP) at three stations and areal average of the south Gondar Zone Amhara National Regional State, Ethiopia,(1985- 2014).

### 4.1.1.4. Probability of dry spell lengths

The probability of occurrence of dry spell lengths of 5, 7, 10 and 15 days length for the study period was given in Figures 5. As indicated in the figure the probability of occurrence of dry spells of 5 days length, was less than 10% at Werota, whereas at Debre Tabor and Nefas Mewcha, the probability of occurrence of dry spells of 5 days length was less than 20%. On the other hand, during the peak months, the probability of occurrence of dry spells of 7 days was less than 15% at Debre Tabor and Werota, and less than 20% at Nefas Mewcha. Moreover, probability of dry spell lengths of 10 and 15 days were nil at all the three weather stations as the curves converge to their minimum during the peak rainy season (DOY 150–244) and there after diverge after September (DOY 245–274) signaling the end of the season (Figure 5).

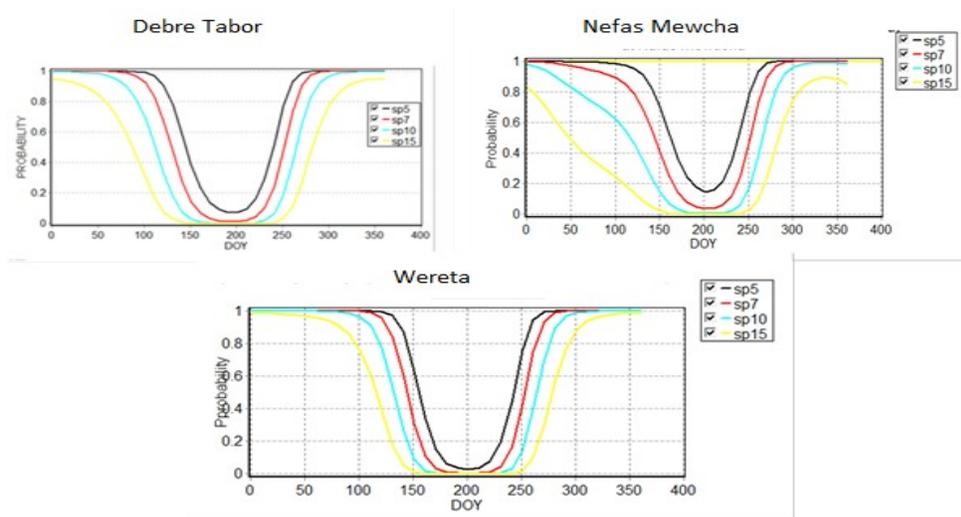


Figure 5. Probabilities of occurrence of dry spells exceeding 5, 7, 10 and 15 days length within 30 days after start date at three stations and areal average of the south Gondar Zone Amhara National Regional State, Ethiopia,(1985-2014).

#### 4.1.1.5. Number of rainy days (NRD)

As depicted in Figure 6 and Appendix Table 3, the number of rainy days (NRD) in the south Gondar Zone varied from maximum of 106 day at Debre Tabor to the minimum of 56 days at Nefas Mewcha. Over the study period, on average Debre Tabor had relatively more number of rainy days (88 days) compared to that of Werota (81 days) and Nefas Mewcha (76 days) respectively. However, the observed coefficients of variability and the standard deviations did not show differences among weather stations indicating comparable level of stability or variability at all locations over the study years.

For 25% of the study years, the number of rainy days was less than 83, 70 and 78 days at Debre Tabor, Nefas Mewcha and Werota, respectively indicating there was relatively more number of years with short number of rainy days at Nefas Mewcha. On the other hand, the study further revealed that in three of four years the number of rainy day expected at Debre Tabor, Nefas Mewcha and Werota were 95, 82 and 88 days respectively, and this shows there were relatively more number of years with longer number of rainy days at Werota and less at Debre Tabor over the study period.

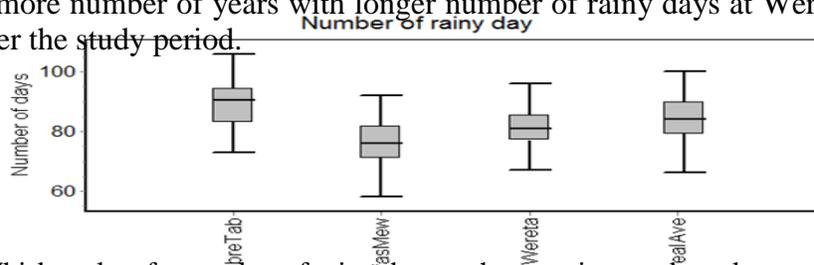


Figure 6. Box and Whisker plots for number of rainy days at three stations and areal average of the south Gondar Zone Amhara National Regional State, Ethiopia,(1985-2014).

The inter-quartile range of the present study was comparably the same at all the three stations (Figure 6), at Debre Tabor and Nefas Mewcha, and 10 days at Werota, and this could be an indication of less variable number of rainy days across locations over the study years.

#### 4.1.1.6. Rainfall anomaly

*Kiremt* rainfall showed marked irregularity among years over the study period (Figure 8(a), 8(b) and 8(c)). As is evident from the Figure 8(a), at Debre Tabor, the years 1985, 1987,1989-1993, 1996, 2002-2004, 2009, 2011 and 2014 were characterized by *Kiremt* rainfall of less than the long term mean of the study period, and that could be classified as

moderate to severe drought years. The years 1986 and 2009 were the wettest and the driest years respectively at Debre Tabor weather station, and years 1996 and 2009 were found to have rainfall less than 1.5 times the SD of the mean of the study period (1985-2014).

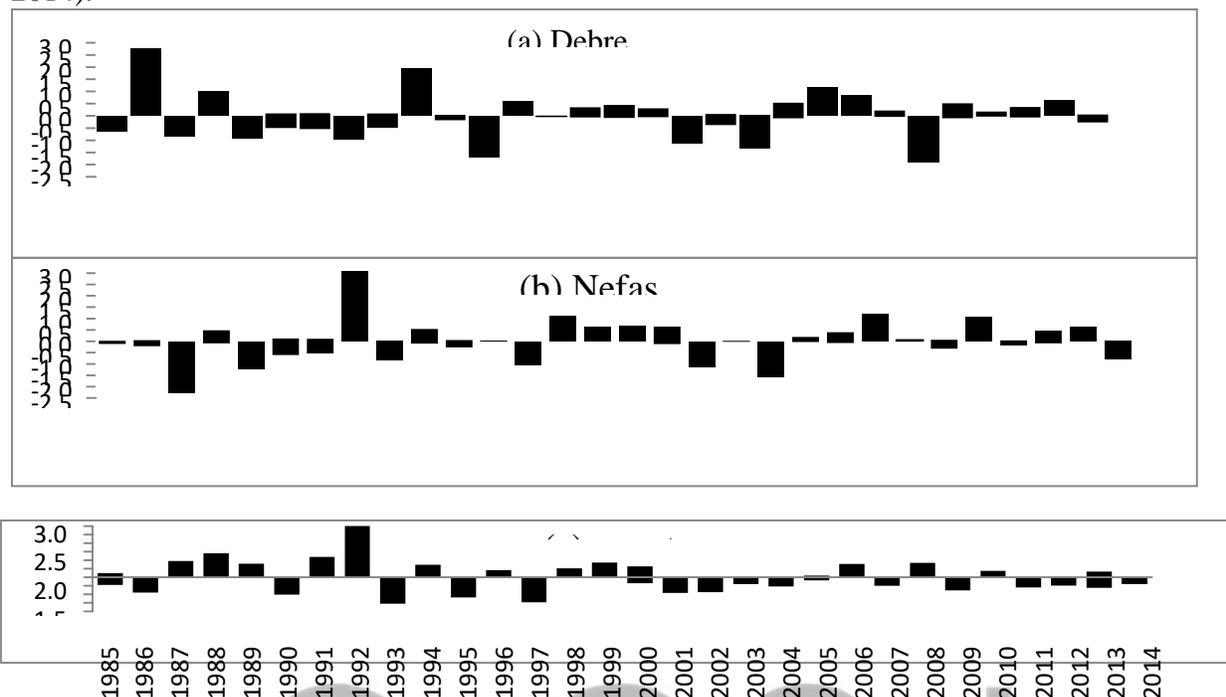
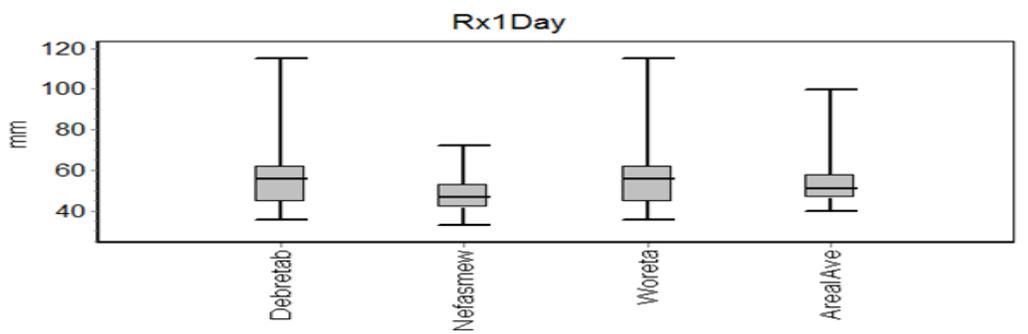


Figure 7 Observed *Kiremt* seasonal rainfall anomalies at (a) Debre Tabor (b), Nefas Mewcha and (c) Werota weather stations in the south Gondar Zone, Amhara National Regional state, Ethiopia (1985-2014)

According to the classification index used by Taye *et al.* (2013) these years could be classified as years of sever to extreme drought. In line with this, Viste *et al.* (2012) indicated that years 2002 and 2009 were years of severe drought in Ethiopia. At Nefas Mewcha ( Figures 8(b)), the years 1985, 1986, 1987, 1989, 1990, 1991, 1993, 1995, 1997, 2002, 2004, 2009, and 2014 were observed to have *Kiremt* rainfall total below the long term mean with year 1997 marked as the driest year, and conversely year 1992 was the wettest year. Similarly at Werota (Figure 8(c) years 1985, 1986, 1990, 1993, 1997, 2001, 2002, 2003, 2004, 2007, 2009, 2011, 2012, 2013 and 20014 were dry years with rainfall less than the mean of the study period while the year 1992 was the wettest and conversely the year 1993 was the driest year which was in agreement with previous reports of Bewket (2009), Ayalew *et al.* (2012) and Viste *et al.* (2012).

#### 4.1.1.7. Maximum one day precipitation amount Rx1Day)



Maximum one day precipitation amount (Rx1Day) varied spatially among weather stations in the South Gondar Zone (Figure 9). Rx1Day was less variable at Nefas Mewcha than either in Debre Tabor or Werota in the study area. On the other hand, the Rx1Day was relatively more variable at Werota weather station. In three of the four years Rx1Day expected to be 42, 41 and 41 at Debre Tabor, Nefas Mewcha and Werota weather stations, but for the 75% of the study years, it was less at Nefas Mewcha over both the Debre Tabor and Werota weather stations.

Figure 8. Box and Whisker plot of Rx1Day Box and Whisker plots for number of dry days at the three stations and areal average of the south Gondar Zone Amhara National Regional State, Ethiopia (1985-2014).

#### 4.1.1.8. Simple daily intensity Index (SDII)

The simple daily intensity index (SDII) was also variable in the study Zone (Figure 10). More variability was observed at Werota, and less at Nefas Mewcha. The median value of the SDII was higher at Werota when compared to that of the Debre Tabor and the Nefas Mewcha weather stations. The same variability of SDII was also reported by Mekasha *et al.* (2014). In the present study for 25% of the study years, the SDII was below 9, 11 and 13 mm/day at Nefas Mewcha, Debre Tabor, and Werota, respectively, whereas for the 75% of the study years the SDII was less than 10, 12.6 and 15 mm/day at Nefas Mewcha, Debre Tabor, and Werota weather stations respectively indicating more intense rain at Werota compared to the other two weather stations in study area.

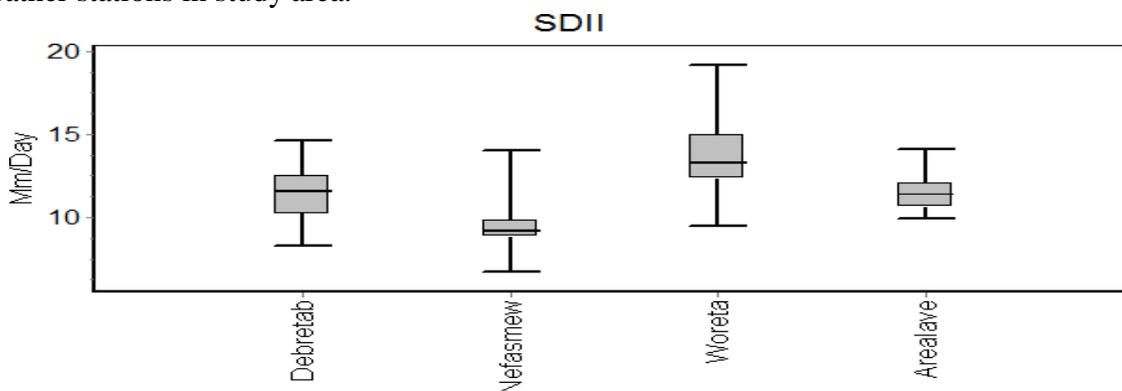


Figure 9. Box and Whisker plot of SDII Box and Whisker plots for number of dry days at the three stations and areal average of the south Gondar Zone Amhara National Regional State, Ethiopia (1985-2014)

#### 4.1.1.9. Number of very heavy precipitation days (R20)

The number of very heavy precipitation days (R20) in the south Gondar Zone varied spatially for the study period (Figure 11). The R20 was more variable at Werota weather stations when compared to that of Debre Tabor or Nefas Mewcha, and conversely fewer variables at Nefas Mewcha which is in agreement with previous reports in other parts of the country (Mekasha *et al.*, 2014). In the present study, for the 25% of the study years the R20 was less than 11, 18 and 19 days at Nefas Mewcha, Werota and Debre Tabor weather stations, respectively. Whereas for

the 75% of the study years the R20 was less than 18, 22 and 29 days at Nefas Mewcha, Werota and weather stations respectively indicating more number of very heavy rainy days Debre Tabor and less at Nefas Mewcha over the study period.

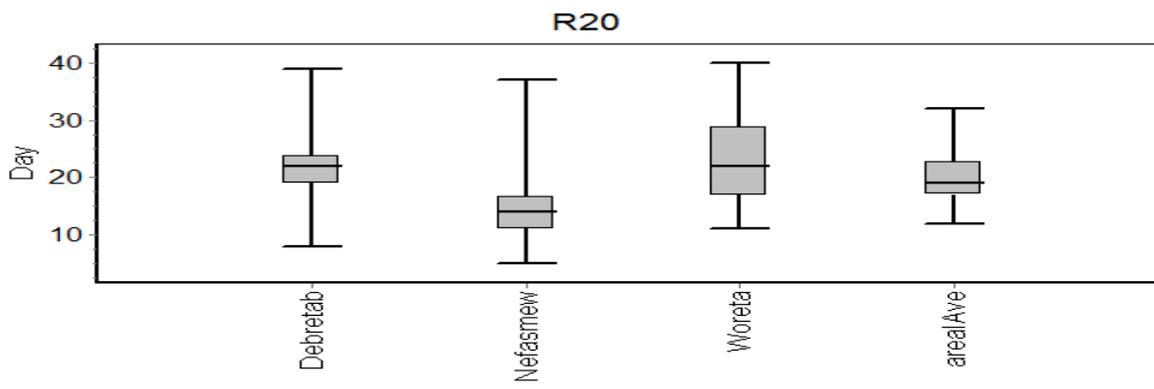


Figure 10. Box and Whisker plot of very heavy rainfall days (R20) at the three stations and areal average of the south Gondar Zone Amhara National Regional State, Ethiopia (1985-2014)

### 4.1.2. Trends in observed rainfall

There were no significant trends in all the studied rainfall parameters/variables (Table 3) indicating that there were similar SOS, EOS, LGS, NRD, NDD, SDII, Rx1day, and R20 across all stations over the 30 years study period (Table 3). However, there was a tendency of earliness in start of season (EOS) at Nefas Mewcha, and shortening of end of the season (EOS) and length of the growing season (LGS) at Debre Tabor and Werota. Similarly, the number of rainy days (NRD) showed a decreasing tendency only at Werota while numbers of dry days (NDD) were shortening at Debre Tabor and Nefas Mewcha. Likewise, at Debre Tabor the daily intensity of rainfall (SDII) and the number of heavy precipitation days (R20) have shown a decreasing tendency indicating existence of non-systemic and weak changes in rainfall characteristics with respect to those variables. In a similar studies Mekasha et al (2014) reported lack of systemic and meaningful changes in many of the rainfall variables in the central and south western Ethiopia.

Table 3. Trends in seasonal Kiremt start of season (SOS), end (EOS), Length of Growing Season (LGS), Number of Rainy Days (NRD), Number of Dry Day (NDD), Simple daily intensity (SDII), maximum one day Precipitation (Rx1Day), and number of heavy precipitation days (R20) at (Debre Tabor, Nefas Mewcha, and Werota) station in the south Gondar Zone, Amhara National Regional State Ethiopia (1985-2014).

Variable	Debre Tabor		Nefas Mewcha		Werota		Areal average	
	Zmk	Slope	Z <sub>MK</sub>	slope	Z <sub>MK</sub>	slope	Z <sub>MK</sub>	slope
SOS	0.77	0.22	-0.95	-0.47	0.20	0.10	1.05	0.44
EOS	-0.63	-0.21	2.42	0.04	-0.30	0.20	0.51	0.18
LGS	-0.73	-0.44	0.91	0.50	-0.20	-0.07	-0.34	-0.11
NRD	0.14	0.01	0.39	0.07	-1.90	-0.8	0.05	0.06
NDD	-0.14	-0.10	-0.39	-0.07	1.60	0.30	-0.5	-0.07
Rx1Day	1.01	0.33	1.02	0.33	0.45	0.22	0.76	0.23
SDII	-0.36	-0.02	0.10	0.01	0.25	0.02	0.00	0.00
R20	-0.68	-0.08	0.11	0.00	0.00	0.00	-0.39	-0.04

Z<sub>Mk</sub> is Man Kendal's trend Test, slope is rate of changes/annum, NRD number of rainy days, NDD

is number of dry days, SOS is start of season, EOS end of season, and LGS is length of the season.

### 4.1.3. Observed temperature variability

#### 4.1.3.1. Seasonal mean (Mean Tmp), mean maximum (TMAXmean), mean minimum (TMINmean) and diurnal range of temperatures (DTR)

The seasonal mean temperature (Mean Tmp), mean maximum temperature (TMAXmean), mean minimum temperature (TMINmean) and diurnal range of temperatures (DTR) at the three weather stations and the areal average indicated by the Figure 12 and Appendix table 5. showed that the Mean Tmp, TMAXmean, TMINmean and diurnal range of temperatures (DTR) were more variable at Werota when compared to the other two weather stations and the areal average as well. On the other hand, the TMAXmean, the TMINmean and the DTR were less variable at Nefas Mewcha indicating less existence of variability on these parameters over the study area and across weather stations except at Werota.

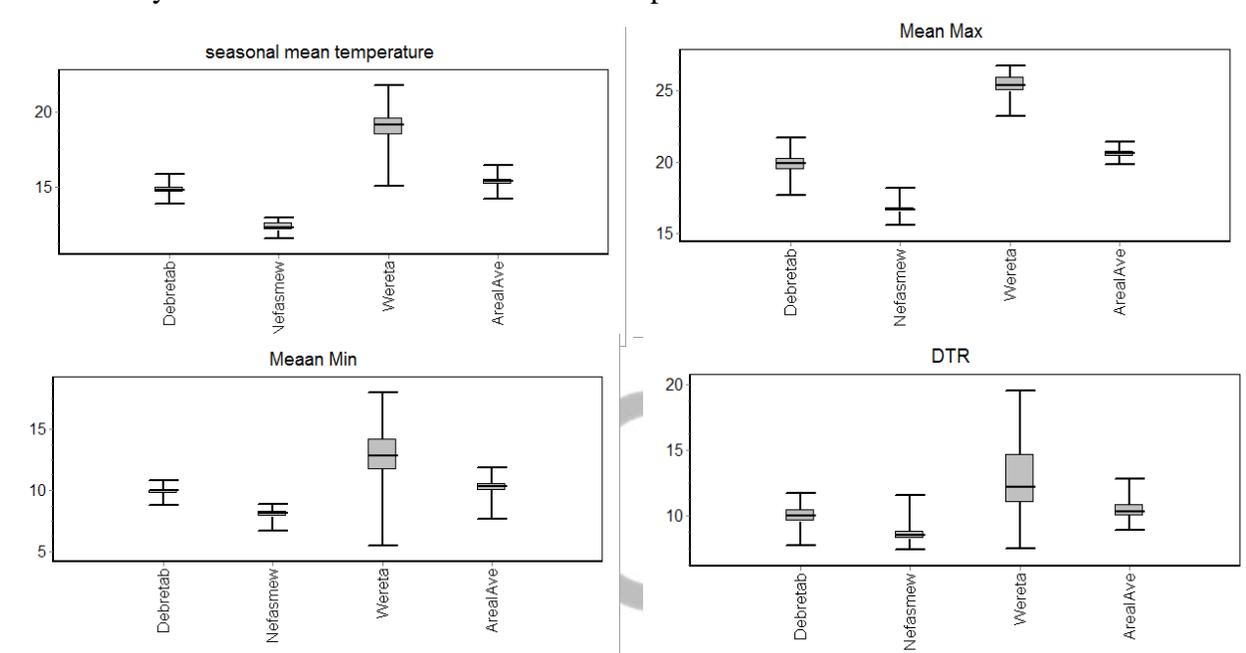


Figure 11 . Box and Whisker plot of seasonal mean, mean of maximum, mean of minimum and diurnal range of temperatures at the three stations and areal average of the south Gondar Zone Amhara National Regional State, Ethiopia (1985-2014)

#### 4.1.3.2. Maximum of the maximum (TXx), Maximum of the minimum (TNx),

Minimum of the minimum (TNn) and Minimum of the maximum (TXn) Maximum of the maximum (TXx), maximum of the minimum (TNx), minimum of the minimum (TNn) and minimum of the maximum (TXn) temperatures variability also showed differences among weather stations in the study area for the study period (Figure 13 and Appendix table 5). Among others, maximum of the maximum temperature (TXx) was more variable at Debre Tabor while maximum of the minimum (TNx), minimum of the minimum (TNn) and the minimum of the maximum (TXn) temperatures were more variable at Werota when compared with the rest of the stations and the areal average of the Zone

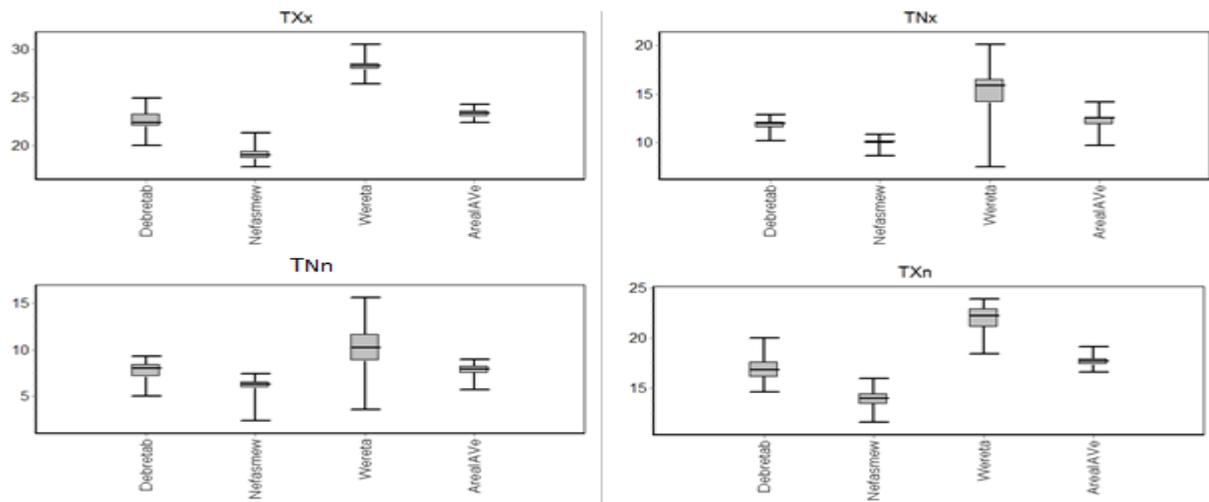


Figure 12. Box and Whisker plots of maximum of the maximum (TXx), maximum of the minimum (TNx), minimum of the minimum (TNn) and minimum of the maximum (TXn) temperatures at the three stations and areal average of the south Gondar Zone Amhara National Regional State, Ethiopia (1985-2014)

#### 4.1.3.3. Number of cool nights (TN10p), cool days (TX10p), warm nights (TN90p) and warm days (TX90p)

As Figure 14 and Appendix table 5 presents variability in the numbers of cool days (TX10p), cool nights (TN10p), warm nights (TN90p) and warm days (TX90p) in the study area.

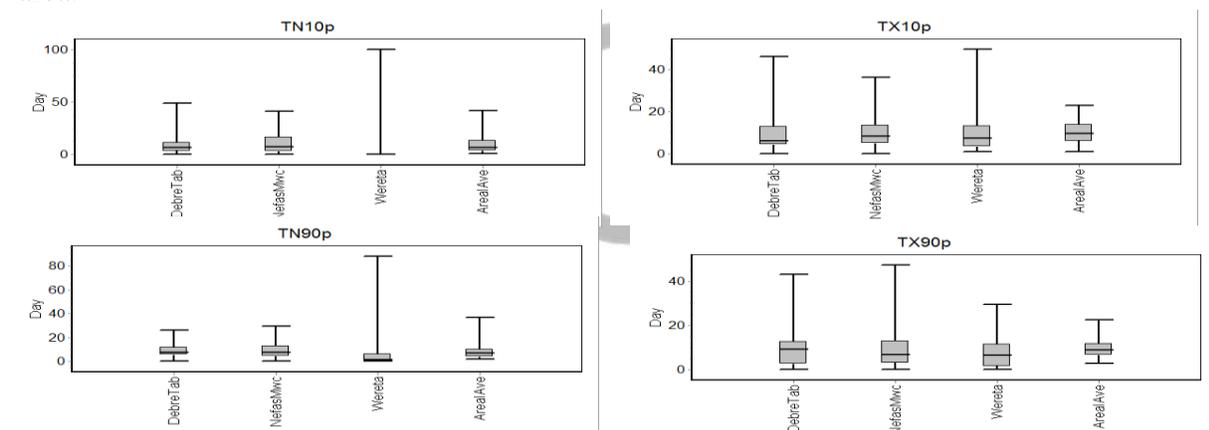


Figure 13. Box and Whisker plots of Number of cool nights (TN10p), cool days (TX10p), warm nights (TN90p) and warm days (TX90p) at the three stations and areal average of the south Gondar Zone Amhara National Regional State, Ethiopia (1985-2014).

As indicated by the figure, the number of cool nights (TN10p) and warm nights (TN90p)

were more variable at Werota, while the numbers of cool days (TX10p) were more variable at Debre Tabor and Werota, With regard to the number of warm days (TX90p) it was more variable at Debre Tabor and Nefas Mewcha.

#### 4.1.4. Trends in observed temperature

The trends in the mean (Mean Tmp), mean maximum (TMAXmean), mean minimum (TMINmean), the diurnal temperature ranges (DTR), maximum of the maximum (TXx), maximum of the minimum (TNx), minimum of the minimum (TNn), minimum of the maximum (TXn), numbers of cool days (TX10p), cool nights (TN10p), warm nights (TN90p) and warm days (TX90p) for the study period are presented in Table 4 and Appendix table 5. As indicated in the table, there were both positive and negative trends of temperature

variables. Of the 12 variables studied, four variables (Mean Tmp, TMINmean, TNx and the TN90p) showed increasing trends at all the three weather stations, while only one ( TNn) at Debre Tabor, four (TXx , TNn , TX10p and TX90p) at Nefas Mewcha, and five (TMAXmean, DTR, TXn, TN10p and TX90p) at Werota showed decreasing trends. The observed trends however, were significant only for the increasing TXx, TX10p and TN90p and the decreasing TNn at Debre Tabor, and for the decreasing TNn at Nefas Mewcha, and for the increasing Mean Tmp, TMINmean, TNx, TNn and TN90p and for the decreasing DTR and TN10p at Werota. At areal average only three variables (Mean Tmp, TMINmean, TN90p) was significantly increasing (Table 4).

Table 4. Trends in seasonal mean (Mean Tmp), mean maximum (TMAXmean), mean minimum (TMINmean), the diurnal range of temperatures (DTR), maximum of the maximum (TXx), maximum of the minimum (TNx), minimum of the minimum (TNn), minimum of the maximum (TXn), numbers of cool days (TX10p), cool nights (TN10p), warm nights (TN90p) and warm days (TX90p) at the three weather stations (Debre Tabor, Nefas Mewcha, and Werota) in the south Gondar Zone, Amhara National Regional States Ethiopia (1985-2014).

Variables	Debre Tabor		Nefas Mewcha		Werota		Areal average	
	Zmk	Slope	Zmk	slope	Zmk	slope	Zmk	slope
Mean Tmp	0.87	0.01	0.25	0.00	3.25*	0.08	3.67*	0.03
TMAXmean	1.30	0.02	0.39	0.00	-0.21	-0.01	1.53	0.01
TMINmean	0.29	0.00	0.14	0.00	3.60*	0.17	4.05*	0.05
DTR	0.93	0.03	0.00	0.00	-3.39*	-0.21	-2.71	-0.05
TXx	1.79*	0.07	-0.34	0.00	1.23	0.03	1.78	0.03
TNx	0.00	0.00	0.77	0.02	2.28*	0.14	2.19	0.04
TXn	0.02	0.00	1.09	0.03	-0.68	-0.03	1.30	0.02
TNn	-3.26*	-0.09	-2.21*	-0.05	3.85*	0.21	0.87	0.01
TN10p	1.64	0.21	0.29	0.03	-2.70*	0.00	-0.49	-0.06
TX10p	1.95*	0.02	-0.91	-0.15	0.25	0.06	-0.46	-0.03
TN90p	2.50*	0.24	0.59	0.10	2.48*	0.17	2.56*	0.26
TX90p	1.45	0.26	-0.61	-0.11	-0.59	-0.08	0.67	0.10

\* Trends were significant at 5% probability level.

This result indicates that the majority of the studied variables were significantly changing at Werota and less at Nefas Mewcha indicating more variable spatial and temporal changes in temperature variables. This is in agreement with the previous reports of Mekasha *et al.* (2014) and Hadigu *et al.* (2014) in the central and the northern parts of the country, respectively. The observed variability could be attributable to the diverse physiographic condition which controls the regional synoptic and landscape level climate Dobrowski *et al.*, 2009).

#### 4.2. Characteristics of the observed crop production

##### 4.2.1. Crop production variability

###### 4.2.1.1. Zonal level area of production

Over the study period, on average more land area of production was devoted to teff followed by barley and the least for wheat (Table 23). The area devoted/ allocated to the production of all the

three crops however, showed extreme high variability over the study period as described by Hare (1983). Area under teff production was more variable while the area under wheat showed relatively less variability as compared to the other two crops, indicating more variable area of teff over barley and wheat which is in line with the previous reports of Bewket (2009). The noticed variability for teff, barley and wheat was in range of 2842900, 1012084 and 325660 ha, respectively (Table 23). The computed values of the standard deviation also indicated relatively more variable area of teff over barley and wheat, and hence relatively less stable in area allocation to cultivation of the *Teff* crop relative to that of barley and more for wheat over the study period.

Table 5. Summary statistics of zonal level area of production of teff, barley and wheat in the south Gondar Zone, Amhara National Regional State, Ethiopia during 1995-2014

Statistics	Teff	barley	wheat
Max (ha)	2943600	1047085	330279
Mean(ha)	1744952	107226	62867
Min (ha)	107000	35001	4619
Median(ha)	126556	55500	48685
SD (ha)	6547477	221640	66102
CV%	375	206	105

SD is standard deviation, CV is coefficient of variation

#### 4.2.1.2. Productivity

In the study period, wheat followed by barley showed higher grain productivity while teff yielded the least. The mean per unit area grain productivity of teff, barley and wheat varied in a range of 9.6, 10.3 and 10.7 qt/ha as a difference between the observed maximum and minimum yields (Table 24). The computed values of the coefficient of variability also revealed high level of inter annual variability in grain productivity of all the three crops as described by Hare (1983). The noticed variability however, was relatively less for teff by 6% and 4% when compared to that of barley and wheat, respectively, indicating relatively less variable per hectare grain yield of teff over barley and wheat which is in line with the previous reports of Bewket (2009). Similarly the computed values of the standard deviation also indicated relatively less variable grain yield of teff over barley and wheat, and hence relatively stable grain productivity of the crop relative to that of the more variable barley and wheat over the study period.

Table 6. Summary statistics of yield of teff, barley and wheat in the south Gondar Zone, Amhara National Regional State, Ethiopia during 1995-2014.

Climate variable	Teff	Barley	Wheat
Max (qt/ha)	15.3	19.2	19.3
Mean(qt/ha)	9.6	10.3	10.7
Min (qt/ha)	4.8	6	5.9
SD (qt/ha)	3.3	4.1	4.1
CV%	34	40	38

SD is standard deviation, CV is coefficient of variation

#### 4.2.1.3. Zonal level production

During the study period, teff showed the highest zonal level total grain production followed by barley while wheat the least. Zonal level total grain production of teff, barley and wheat showed

extreme variability in range of 247,375,000, 12,261,283 and 4,259,716 qt respectively as a difference between the observed annual maximum and minimum production of the study period (Table 25). The computed values of the coefficient of variability also revealed high level of inter annual variability in zonal level total grain production of all the three crops as described by Hare (1983). The noticed variability however, was relatively less for wheat by 34% and 53% when compared to that of barley and teff, respectively, indicating more variable grain yield of teff over barley and wheat which is in line with the previous reports of Bewket (2009). Similarly the computed values of the standard deviation also indicated relatively more variable grain production of teff over barley and wheat, and hence better relative stability in grain production of wheat over barley which in turn was stable when compared with the most unstable teff for the study period. With the observed less productivity (Table 25), the higher zonal level total teff grain production could thus be due to the observed more land area allocation for cultivation of the crop.

Table 7. Summary statistics of teff, barley and wheat production in the south Gondar Zone, Amhara National Regional State, Ethiopia during 1995-2014.

Climate variable	Teff	barely	wheat
Max (qt)	24788800	12685684	4299377
Mean(qt)	15760419	1201133	758341
Min (qt)	513000	24401	39661
Median(qt)	1208547	478686	478903
SD (qt)	55449937	2720881	930062
CV%	351	226	122

SD is standard deviation, CV is coefficient of variation

#### 4.2.2. Trends in crop production

##### 4.2.2.1. Zonal level area of production /Cultivated land

Results of the Mann Kendal trend analysis showed that over the study period (1995-2014) the total annual area of land allocated for all the three crops increased (Table 26). Each year the area allocated to teff, barley and wheat was increasing by over 981, 121 and 2548 hectare, respectively. The observed trend however, was significant only for wheat indicating farmers in the zone are increasingly allocating more land for wheat production. This might be owing to the better adaption of the crop to the climate of the zone coupled with the observed high grain productivity over the other major crops grown in the zone. On the other hand, the least rate of area expansion by barley could be because of the observed more unstable and variable productivity.

Table 26. Trends of teff, barley and wheat production in the south Gondar Zone, Amhara National Regional State, Ethiopia during 1995-2014

Crop	Zmk	Slope (ha)
Teff	1.20	982.82
Barely	0.92	121.42
Wheat	2.82*	2547.84

Z<sub>mk</sub> is Man-kendal test, slope is Sen's estimator of rate of change/annum, \* is significant change at 5% probability level.

##### 4.2.2.2. Productivity

The Mann Kendal trend test showed that, over the study period, the grain productivity of all the three major crops grown in the zone showed increasing trends over the study period (Table 27), and the trends were significant for all the three crops. Similar increasing trends in productivity of

major crops of the country were also reported by Taffesse et al. (2011). In the present study the productivity of teff, barley and wheat increased significantly by 0.5, 0.6 and 0.6 qt/ha indicating, more annual increase in per unit area yield of barley and wheat compared to that of teff. Such increase in productivity of the crops could be because of use of better crop management practices, including fertilizer and improved crop varieties that are more adaptive to the climate of the zone. Moreover, the annual increase in grain productivity was above the observed long-term mean of the study period since 2007 for all crops except in 2008 for teff and wheat (Appendix Figure 1).

Table 9. Trends of teff, barley and wheat yield in the south Gondar Zone, Amhara National Regional State, Ethiopia during 1985-2014

Crop	Zmk	Slope (qt /ha)
Teff	4.2*	0.5
Barely	5.2*	0.6
Wheat	4.5*	0.6

Z<sub>mk</sub> is Man-kendal test, slope is Sen's estimator of rate of change/annum, \* is significant change and at 5% probability level.

#### 4.2.2.3. Zonal level production

Over the study period, for the zonal level production, the Mann Kendal trend test showed that the total grain production of all the three major crops grown in the zone was increasing (Table 28). The observed increasing trends were significant for all the three crops. Over the period, annual grain produce of teff, barley and wheat increased by 64451, 32000 and 48900 quintals/year, respectively indicating even more increase for teff followed by wheat and least for barley. The increasing trends in production of all crops might be a result of the observed increasing trends in area of production and productivity in response to increase in human population, and hence to meet the ever growing food demand.

Table 10. Trends of teff, barley and wheat production in South Gondar Zone, Amhara National Regional State, Ethiopia during 1995-2014

Crop	Zmk	Slope (qt)
Teff	2.88*	64451.47
Barely	3.66*	32000.04
Wheat	3.47*	48900.56

Z<sub>mk</sub> is Man-kendal test, slope is Sen's estimator of rate of change/annum, \* is significant change at 5% probability level.

### 4.3. Interconnection of the observed climate and crop production

#### Correlation analysis

Correlation analysis of the observed climate variables and crop yield/ area of production (Table

29) revealed that among others, the DTR, TN<sub>n</sub>, NDD and TMAX<sub>mean</sub>, were negatively correlated with both yield and area of production of teff, barley and wheat, and conversely the seasonal rain fall total, EOS, LGS, NRD, R20, Mean Tmp, TN<sub>x</sub>, TX<sub>10p</sub> and TN<sub>90p</sub> were positively correlated with yield of teff, barley and wheat. The increase in yield with increase in night time temperatures (TN<sub>x</sub> and TN<sub>90p</sub>) contradicts the notion of increased respiration induced yield reduction which might indicate the observed increase could be to the level that the observed warming is within the cardinal need of the crops for optimum physiological function. On the other hand; the correlations of SOS, Rx1Day, SDII, TX<sub>x</sub>, TX<sub>n</sub>, TN<sub>10p</sub> and TX<sub>90p</sub> were variable with the different crops. The SOS was positively correlated with yield of *teff* and barley. Similarly the Rx1Day and TX<sub>90p</sub> were negatively correlated with area of production of barley and yield of teff in case of Rx1Day.

The degree of association also varied from very weak to strong. Among others teff yield and area of production were strongly correlated with EOS, LGS, TMINmean, DTR, TNx, TX10p, and TN90p indicating that the observed increase in teff yield over the study period could partly be due to late end of season, raise in mean of the minimum and maximum of the daily minimum temperatures and increase in number of warm nights. Whereas, barley yield was strongly correlated with EOS, TMINmean, TNx and TN90p, and its area of production was strongly correlated with EOS among others. This could indicate that the observed increase in barley yield over the study area could be because of positive effects of late end of season, raising maximum of the daily minimum temperatures and increase in number of warm nights, and the increase/ expansion in area of production with late end of season could suggest more engagement of farmers on barley cultivation as the season allows them.

Similarly results of the present study showed that like teff, barley and wheat yield in the South Gondar Zone was also strongly correlated with EOS, LGS, TNx and TN90p, whereas the correlation of area of wheat production with the studied climate (rainfall and temperature) variables/ parameters studied was weak or moderate. This might indicate that like teff and barley, the increase in yield of wheat could partly be due to increased late end of season, raising maximum of the daily minimum temperatures and increase in number of warm nights while the lack of strong correlation with observed increase in area of production could be an indication of importance of other factors such as population pressure and economic growth that might have far reaching effect. The increase in yield of all crops with increase in late end of the rainy season might thus be due to increased availability of moisture at time when the crop is at reproductive stage, and hence for translocation of assimilate for increased grain size and thereby yield.

Table 11. Pearson's correlation of observed *teff*, barley and wheat yields and area of production, and the areal/zonal level area of production with recorded average values of different climate (rainfall and temperature variables/ parameters) in the south Gondar Zone, Amhara National Regional State, Ethiopia for the period during 1995-2014.

Climate variable	Teff Yield	Barely Yield	wheat Yield
Rain fall total	0.223	0.058	0.139
SOS	0.047	0.126	-0.011
EOS	0.631	0.501	0.599
LGS	0.485	0.313	0.505
NRD	0.344	0.249	0.248
NDD	-0.344	-0.251	-0.247
Rx1Day	-0.117	0.076	0.190
SDII	0.173	0.072	0.122
R20	0.166	0.112	0.103
Mean Tmp	0.413	0.401	0.401
TMAXmean	-0.108	-0.030	-0.038
TMINmean	0.572	0.514	0.518
DTR	-0.599	-0.497	-0.513
TXx	0.185	0.103	0.129
TNx	0.605	0.518	0.571
TXn	0.064	0.135	0.048
TNn	-0.084	-0.279	-0.262
TN10p	0.214	0.316	0.299
TX10p	0.515	0.411	0.041
TN90p	0.664	0.571	0.593
TX90p	0.195	0.251	0.179

## 4. SUMMARY, CONCLUSION AND RECOMMENDATION

### 5.1. Summary and Conclusion

Information on the seasonal climate (rainfall and temperature) variability and trends is very important for planning and water management practices in rain fed agriculture of Ethiopia where more than 85% of the population is dependent on agriculture. In response to this, in the present study climate variability and its interconnection to crop production in the South Gondar Zone, Amhara National Regional State, Ethiopia was conducted to investigate the variability and trends of historical climate in terms of various rainfall and temperature variables of agricultural significance; to investigate the interconnection of climate and production of major crops (teff, barley and wheat) grown in the Zone.

Accordingly observed rainfall and temperature data of three weather stations (Debre Tabor, Nefas Mewcha and Werota), and average of the three weather stations as areal average level for the period (1985-2014) rainfall and temperature data were analyzed. Temporal variability and trends using seasonal *kiremt* rainfall total, start for season (SOS), end of season (EOS), length of growing period (LGS), number of rainy days (NRD), number of dry days (NDD), maximum one day rainfall amount (Rx1Day), simple daily intensify index (SDII), number of very heavy precipitation days (R20), seasonal mean temperatures (Mean Tmp), mean maximum (TMAXmean), mean minimum (TMINmean) and diurnal range of temperatures (DTR), maximum of the maximum (TXx), maximum of the minimum (TNx), minimum of the minimum (TNn) and minimum of the maximum temperatures (TXn), number of cool nights (TN10p), number of cool days (TX10p), number of warm nights (TN90p) and number of warm days (TX90p) were analyzed using various statistical packages.

The results showed that the observed *kiremt* season rainfall was spatially decreasing from western to the eastern part of the Zone. The start of the rainy season was moderately variable and showed tendency of becoming late while end of season was less variable and more stable. On the other hand the length of the *kiremt* growing season was moderate to highly variable with varying probability of occurrence of dry spells and number of dry days. The number of rainy days also showed comparable variability among weather stations with more variability in the maximum one day precipitation/ rainfall amount, simple daily intensity index, and very heavy rainfall amounts at Werota. The observed trends were also non-significant for all studied rainfall variables at all weather stations and the Zonal average as well.

Similarly, among temperature variables, the seasonal mean temperature (Mean Tmp), mean maximum (TMAXmean), mean minimum (TMINmean), diurnal range of temperatures (DTR), maximum of the minimum (TNx), minimum of the minimum (TNn) and minimum of the maximum temperatures (TXn), number of cool nights (TN10p), number of cool days (TX10p) and number of warm nights (TN90p) showed more variability at Werota when compared with the others in the study area. Moreover, the observed trends of the temperature variables revealed variability with the majority showing an increasing trends. The trends however, were significant only for few with majority being at Werota and are spatially non-systematic.

Among temperature variables, the seasonal mean temperatures mean seasonal maximum, maximum of the minimum, and minimum of the maximum temperatures showed less variable condition for the study period while the number of cool nights, number of cool days, number of warm nights and number of warm days were highly variable. Moreover, though models generally agree, most temperature variables are non-significant, and the significant trends are not spatially coherent. Nevertheless, most of the studied temperature variables increased warming over the base period.

Over the study period (base period), zonal level areas devoted to production of major crops, productivity and yields were highly variable and showed significant increasing trends which also showed varied correlation with the studied temperature and rainfall variables. Among others

the degree of associations was high for increased late end of season, raising maximum of the daily minimum temperatures and increase in number of warm nights. Nevertheless, the temperature trend increase in the study, may result in crop area relocation.

## 5. REFERENCES

- Allen, R.G; Pereira Raes, D. and M, Smith. 1998. Crop evapo-transpiration. Guide lines for computing crop water requirements. FAO Irrigation Drain Paper No, 56.FAO, Rome, Italy.
- Astatkie,M; Legesse, B. and Elias Zerfu 2012 Analysis of economic impacts of triticale (*XTriticosecale Wittmack*) adoption: The case of FARTA WEREDA, Ethiopia Journal of Scientific Research and Reviews Vol. 1(2), pp. 020 - 025
- Ayalew, D; Tesfaye, K; Mamo, G; Yitafaru, B. and Bayu, W. 2012. Variability of rainfall and its current trend in Amhara region, Ethiopia. *Journal of African Agricultural Research*. 7(10):1475.
- Bewket, W. 2009 .Rainfall variability and crop production in Ethiopia Case study in the Amhara Region: *Proceedings of the 16th International Conference of Ethiopian Studies*.
- Conway, D.2000. Some Aspects of Climate Variability in the Northeast Ethiopian Highlands – Wollo and Tigray. *SINET – Ethiopian Journal of Science* 23: 139–161.
- Conway, D. and Schipper, E.L.F. 2011. Adaptation to climate change in Africa: challenges and opportunities identified from Ethiopia. *Global Environment Change* 21:227–237.
- Cooper, P., Rao, K.P.C., Singh, P., Dimes, J., Traore, P.S., Rao, K., Dixit, P. and Twomlow, S.J. 2009. Farming with current and future climate risk: advancing a ‘Hypothesis of Hope’ for rain-fed agriculture in the semi-arid tropics. *Journal of SAT Agricultural Research* 7: 1-9. (<http://ejournal.icrisat.org>). Accessed on September 10, 2014.
- Cubash, U., Meehl, G.A., Boer, G.J., Stouffer, R.J., Dix, M., Noda, A., Senior, C.A., Raper, S. and Yap, K.S. 2001. Projections of Future Climate Change. In: *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J; van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881p.
- DDAEP (Dire Dawa Administration program of adaptation to climate change) 2011. <http://www.epa.gov.et/pdf>. Accessed on September 10, 2015.
- Degefu, M.A, and Bewket, W.2014. Variability and trends in rainfall amount and extreme event indices in the Omo-Ghibe River Basin, Ethiopia *Regional Environmental Change* 14(2): 799-810.
- Diga, G.M.2005. Using seasonal climate outlook to advice on sorghum production in the central rift valley of Ethiopia. PhD Thesis submitted to the University of the Free State, Bloemfontein, South Africa. 171.
- EMA (Ethiopian Mapping Authority).1988. The National Atlas of Ethiopia. EMA, Addis Ababa. <http://www.ema.gov.et/web/guest/national-atlas>. Accessed on October 11, 2015.
- Evangelista, P., Young, N. and Burnett, J. 2013. How will climate change spatially affect agriculture production in Ethiopia? Case studies of important cereal crops. *Climatic Change* 119:855–873.
- FAO (Food and Agricultural Organization).2011:FAO in the 21st Century, Ensuring food security in a changing world. Food and agriculture organization of the united nations. Rome. 271p.
- FAO (Food and Agriculture Organization of the United Nations).2004. Drought Impact Mitigation and Prevention in the Limpopo River Basin. Land and Water Discussion Paper 4 [.http://www.fao.org/docrep/008/y5744e/y5744e00](http://www.fao.org/docrep/008/y5744e/y5744e00). Accessed on November 10, 2015.
- FAO (Food and Agriculture Organization of the United Nations) 1989. Assistance to Land Use Planning of Ethiopia: Physiography and soils of the Hykoch, Butajira and Yerer and Kereyu Awurajas (Shewa). FAO/AG: DP/ET/87/006. Field Document No. 37.
- FAO (Food and Agriculture Organization).1978. Report on the agro-ecological zones project Vol.1 Methodology and Result of Africa. Rome
- Fazzini, M., Bisci, C. and Billi, P. 2015. The Climate of Ethiopia School of Science and Technology, University of Camerino, Camerino, Italy. DOI 10.1007/978-94-017-8026-1.
- Feyera, M; Charles, S. and Kindie, T. 2015. Risks associated with dry soil planting time in Ethiopia. *International Journal of Agronomy and Agricultural Research (IJAAR)* Vol. 6, No. 4.
- GebreMichael, Y. and Kifle, M. 2009. Local innovation in climate change adaptation by Ethiopian pastoralists. Final report PROLINNOVA–Ethiopia and Pastoralist Forum Ethiopia (PFE), Addis Ababa, Ethiopia.
- Getaneh, M. 2015 Analysis of Past and Future Intra-Seasonal Rainfall Variability and Its Implications for crop Production in the North Eastern Amhara Region. MSc thesis submitted to Post Graduate Program Directorate, Haramaya University, Ethiopia.
- Gonfa, L. 1996. Climate Classification of Ethiopia, Meteorological Research Report Series No.3. *National Meteorological Services Agency of Ethiopia, Addis Ababa*.

- Green, G.C. 1966. The Evaluation of Methods of Rainfall Analyses and the Application to the Rainfall Series of Nelspruit. MSc thesis (Agrometeorology) University of the Orange FreeState, Bloemfontein. 147.
- Hadgu, G; Tesfaye, K. and Mamo G. 2014. Analysis of climate change in Northern Ethiopia: Hadgu, G; Tesfaye, K., Mamo,G. and Kassa, B. 2013. Trend and variability of rainfall in Tigray, Northern Ethiopia: Analysis of meteorological data and farmers' perception. *Academic. Journal. Agricultural. Research.* 1(6): 088-100.
- Hare, F.K. 1983. Climate and Desertification. Revised analysis (WMO-UNDP) WCP-44 :5-20. Geneva, Switzerland
- Hellin, J; Shiferaw,B; Cairns, J.E; Reynolds, M; Ortiz-Monasterio,I ; Banziger,M ; Sonder, K. and La Rovere, R. 2012. Climate change and food security in the developing world: Potential of maize and wheat research to expand options for adaptation and mitigation. *Journal of Development and Agricultural Economics* 4(12): 311-321.
- ILRI (The International Livestock Research Institute), 2006. Mapping climate vulnerability and poverty in Africa. Report to the Department for International Development. Kenya. 173 p.
- IPCC (Intergovernmental Panel on Climate Change), 2014a. The IPCC's Fifth Assessment Report. What's in it for Africa.79 p.
- IPCC(Intergovernmental panel of climate change), 2009. Intergovernmental panel of climate change Working Group I : The physical science basis of climate change: Latest Findings to be Assessed by WGI in AR5.
- IPCC (Intergovernmental panel of climate change), 2007a. Climate Change 2007a: Impacts, Adaptation and Vulnerability. Summary for Policy Makers. [Http://www.ipcc.ch/publications\\_anddata/ar4/wg2/en/spm.html](http://www.ipcc.ch/publications_anddata/ar4/wg2/en/spm.html). Accessed on December 15, 2015.
- Jones, .G, and Thornton,P. K .2003. The potential impacts of climate change in tropical agriculture: the case of maize in Africa and Latin America in 2055. *Glob Environ Chang* 13:51–59.
- Jones, P. G. and Thornton, P. K. 2003.The potential impacts of climate change on maize production in Africa and Latin America in 2055. *Global Environmental Change* 13: 51–59.
- Jones, P.G, and Thornton, P.K .2013. Generating downscaled weather data from a suite of climate models for agricultural modelling applications. *Agricultural Synthesis* 114:1–5
- Jones, P.G. and Thornton, P.K. 2009. Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change. *International Journal of Environmental Science and Policy* 12:427–437.
- Kassie, B.A. 2014. Assessing the main causes of flood hazard through examining GIS and RS based land use land cover (Lulc) change, topography (slope) and drainage density analysis in Alamata Woreda, Southern Tigray Zone, and Ethiopia. *Asian Journal of Research in Social Sciences and Humanities* 4(7): 270-290.
- Kebede, A. 2007. Soil degradation assessment along the slope gradient of the cultivated fields in Adullala Mariam-Wakemia catchment, Adama Woreda, East Shewa Zone. MSc. Thesis submitted to the school of graduate studies, Addis Ababa, Ethiopia.
- Korecha, D. and A. Barnston .2007. Predictability of June–September rainfall in Ethiopia, Mon. *Weather Rev.*, 135, 628–650.
- Lemi, A .2005. Rainfall probability and agricultural yield in Ethiopia, Eastern Africa social science review, 1 :57-96
- Lobell, D.B, Burke, M.B .2010. On the use of statistical models to predict crop yield responses to climate change. *Agric For Meteorol.* doi:10.1016/j.agrformet.2010.07.008
- Lobell, D.B. and Field, C.B., 2007. Global scale climate–crop yield relationships and the impacts of recent warming. *Environmental Research Letters.* 140 .
- Mamo, G. 2005. Using seasonal climate outlook to advice on sorghum production in the central rift valley of Ethiopia. PhD Thesis. Faculty of Natural and Agricultural Sciences, Department of Soil, Crop and Climate Sciences, University of the Free State, Bloemfontein, South Africa.171 p.
- Mannava,S. and Raymond.M. 2007. managing weather and climate risks in agriculture. Marcella, V. and Salvatore, D.F., 2012. How African Agriculture Can Adapt to Climate Change? :A *Counterfactual Analysis from Ethiopia*: WP Number: 14.
- Marvi, H. and Tupper, G. 2004. Agrometeorology principles and applications of climate. studies in agriculture, food products press, New york.
- McSweeney, C; New, M; Lizcano, G. 2010. United Nation Development Program climate change profile for Ethiopia. Retrieved on June 03, 2011. <http://countryprofiles.geog.ox.ac.uk>.
- McSweeney, C; New, M; Lizcano, G and UNDP. 2008. Climate change country profiles: Ethiopia. <http://country-profiles.geography.ox.ac.uk>.Accessed Mar 2010.
- Mekasha, A., Tesfaye, K. and Duncana, A.J. 2014. Trends in daily observed temperature and precipitation extremes over three Ethiopian eco-environments. *International Journal of Climatology* 34: 1990–1999.
- Mekonnen, A.1998. Intra-annual Rainfall Variability over the Horn of Africa. MSc. Dissertation, University of Reading, UK.
- Mesay, A. 2006. The Onset, Cessation and Dry Spells of the Small Rainy Season (*Belg*) of Ethiopia. National Meteorological Agency of Ethiopia, Addis Ababa.
- MoA (Ministry of Agriculture), 2011.Crop variety register. Issue No 14. Animal and Plant health regulatory directorate. Addis Ababa, Ethiopia. 234.
- MoA (Ministry of Agriculture). 2000. Agro-ecological zonation of Ethiopia. Addis Ababa, Ethiopia. *Open Journal of Soil Science* DOI: [10.4236/ojss.2014.41001](https://doi.org/10.4236/ojss.2014.41001) Sep 06, 2014
- Ngongondo, C., Yu-Xu, C., Gottschalk, L. and Alemaw, B. 2011. Evaluation of spatial and temporal characteristics of rainfall in

- Malawi: a case of data scarce region. *Theoretical Applied of Climatology*. Doi: 10.1007/s00704-011-0413-0.
- Ninan, K.N. and Satyasiba, B. 2012. Climate Change, Agriculture, Poverty and Livelihoods: Working paper 277, The Institute for Social and Economic Change, Bangalore,
- NMA (National Meteorology Agency). 2011. Rainfall and temperature data of Debre Zeit. National Meteorological Service Agency, Addis Ababa, Ethiopia. 61 p.
- NMA (National Meteorology Agency). 2007. Final Report on Evaluation Criteria for Identifying High Priority Adaptation Activities prepared by B and M Development Consultants for NMA. Addis Ababa, Ethiopia.
- NMA (National Meteorological Agency). 2001. Report submitted to initial national communication of Ethiopia to the United Nations Framework Convention on Climate Change, Addis Ababa, Ethiopia.
- NMSA (National Meteorological Services Agency). 1996. Climate and Agro-climatic Resources of Ethiopia. *Meteorological Research Report Series. Vol.1, No. 1, Addis Ababa*.
- NMSA (National Meteorological Services Agency). 1996b. Assessment of drought in Ethiopia: *Meteorological Research Report Series. Vol.1, No.2, Addis Ababa. Pp259*.
- O'Brien, R.M. 2007. 'A caution regarding rules of thumb for variance inflation factors', *Quality & Quantity* 41: 673-690.
- Osman, M. and Sauerborn, P. 2002. A Preliminary Assessment of Characteristics and Long Term Variability of Rainfall in Ethiopia – Basis for Sustainable Land Use and Resource Management. In Challenges to Organic Farming and Sustainable Land Use in the Tropics and Subtropics, Deutscher Tropentag 2002: Witzchenhausen.
- Oxfam (Oxford Committee for Famine Relief). 2009. Band Aids and Beyond: Tackling disasters in Ethiopia 25 years after the famine. Oxfam Briefing Paper 133, October 2009.
- Partal, T. and Kahya, E. 2006. Trend analysis in Turkish precipitation data. *Hydrological Processes*, 20: 2011–2026.
- Philip, W. and Ralph, L. 2009. Downscaled climate change data from the HADCM3 and ECHAM5 models on precipitation and temperature for Ethiopia and Kenya. Report W-09/05. Institute for Environmental Studies. Vrije Universiteit De Boelelaan 1087, 1081 HV Amsterdam, The Netherlands. 106 p.
- Reddy, S. J. 1990. Methodology: Agro-climatic Analogue Technique and Applications as relevant to Dry land Agriculture. *Agroclimatological Series Eth 86/021- WMO/UNDP/NMSA, Addis Ababa, Ethiopia. P60*.
- Rockstrom, J; Jennie, B and Fox, P. 2002. Rainwater management for increased productivity among small-holder farmers in drought prone environments. *Physics and Chemistry of Earth* : 27 (11-22) 949-959.
- Sarr, B. 2012. Present and future climate change in the semi-arid region of West Africa: a crucial input for practical adaptation in agricultural production. *Atmospheric Science of Lett*. doi:10.1002/asl.368.
- Seleshi, Y. and Zanke, U. 2004. Recent changes in rainfall and rainy days in Ethiopia. *International Journal of Climatology* 24: 973–983.
- Sen, P. K. 1968. Estimates of the regression coefficient based on Kendall's tau. *Journal of American Statistical Association* 39:1379–1389.
- Sen, P.K. 1968. Estimates of the regression coefficient based on Kendall's tau. *Journal of American Statistical Association* 39:1379–1389.
- Sigel, Z. T. and Lamb, P. J. 2005. Characterization and variability of Kiremt rainy season over Ethiopia. *Meteorology and Atmospheric Physics* 89(1): 153–180.
- Spinoni, J; Naumann, G; Carrao, H; Barbosa, P and Vogt, J. 2013. World drought frequency, duration, and severity for 1951–2010. *International Journal of Climatology* DOI: 10.1002/joc.3875.
- Stern, R.D. and R.Coe 1984. A model fitting analyses of daily rainfall data. *Journal Royal State. Society (A)*. 147: 1-34.
- Stern, R. D; Dennett M.D. and Dale, I. C. 1982. Analyzing daily rainfall measurements to give agronomic ally useful results. I. Direct methods. *Experimental Agriculture* 18, 223–236.
- Stern, R., Rijks, D; Dale I. and Knock, J. 2006. INSTAT climatic guide. *Statistical Services Centre, The University of Reading, UK*.
- Tache, B. and Oba, G. 2010. Is poverty driving Borana herders in Southern Ethiopia to crop cultivation? *Human Ecology* 38 (5), 639–649.
- Tadesse, Y. and Dagnachew, S. 2006. Flooding in Dire-Dawa: A case study of the 2006 flash flood. In: Ethiopia between the sharp scissors of climate change and environmental degradation. Report on the 2006. Flood disaster in Ethiopia.
- Taffesse, A. S; Dorosh, P. and Asrat, S. 2011. Crop production in Ethiopia: Regional patterns and trends. Ethiopia Strategy Support Program II (ESSP II), ESSP II working paper No. 0016.
- Taye, M. and Zewdu, F. 2012. Spatio-temporal Variability and Trend of Rainfall and Temperature in Western Amhara: Ethiopia: A Gis Approach. *Journal of Geography and Regional Planning: Vol. 1(4) pp. 065-082*.
- Taye, M; Zewdu; F. and Ayalew, D. 2013. Characterizing the climate system of Western Amhara, Ethiopia: a GIS approach. *American Journal of Research Communication* 1(10): 319-355.
- Teklewold, A. Mamo, G. and Admassu, H. 2013. Impacts of climate change on crop production in Ethiopia. In: Mahoo, H., Radeny, M., Kinyangi, J. and Cramer, L. (eds). Climate change vulnerability and risk assessment of agriculture and food security in Ethiopia which way forward? Working paper No. 59, CGIAR research program on climate change, agriculture and food security (CCAFS).
- Tesfaye, K. and Walker, S. 2004. Matching of crop and environment for optimal water use: the case of Ethiopia. *Physics and Chemistry of Earth*. 29 : ( 15-18):1061-1067.
- Thornton, P.K; Jones, P.G; Alagarswamy, A. and Andresen, J. 2009. Spatial variation of crop yield responses to climate change in East Africa. *Global Environmental Change* 19:54–65.
- Travis, L. and Daniel, S. 2010. Agricultural Technologies for Climate Change Mitigation and Adaptation in Developing

- Countries: *Policy Options for Innovation and Technology Diffusion*. ICTSD (International Centre for Trade and Sustainable Development)-IPC Platform on Climate Change, Agriculture and Trade. Issue Brief No. 6. 33 p.
- Tuffa, A; Mekonen, A; Gebreegziabher, Z. and Seyoum, A. 2012. Climate Convention and Africa/Ethiopia.
- Van de Steeg, J; Herrero, M; Kinyangi, J; Thornton, P; Rao, K; Stern, R. and Cooper, P. 2009. The influence of climate variability and climate change on the agricultural sector in East and Central Africa-Sensitizing the ASARECA strategic plan to climate change. Research Report 22, ILRI. Nairobi, Kenya. 85 p.
- Verdin, J; Funk, C; Senay, G; Choularton, R. 2005. Climate science and famine early warning. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences* 360: 2155–2168.
- Viste E; Korecha, D. and Sorteberg, A. 2012. Recent drought and precipitation tendencies in Ethiopia. *Theoretical Application of Climatology*, DOI 10.10 07/s00704-012-0746-3.
- Waithak, M ;Nelson, G. C; Thomas, T. S. and Kyotalimye, M. 2013. East African agriculture and climate change: A comprehensive analysis. *International Food Policy Research Institute (IFPRI), Washington, DC 20006-1002, USA*.
- Yang, W; Seager, R. and A, Cane, M .2014. The East African Long Rains in Observations and Models. *Journal of Climate*, Volume 27. New York.
- Yenigun, K; Gumus, V. and Bulut, H. 2008. Trends in stream flow of the Euphrates basin, Turkey. *Proclamation Institute of Civil Engineering Water Management*. 161:189–198.

