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Impacts of Climate Variability on Food Security in Eastern Part of Ethiopia

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Abstract: *The objective of this study is to access the variability of climate and its impacts on crops productivity in the eastern part of Ethiopia. We used climate data from the National Meteorology Agency of Ethiopia, crop data from the Central statistical agency of Ethiopia and monthly soil moisture and temperature data from the European Centre for Medium-Range Weather Forecasts (ECMWF) website for the period from 1996 to 2016. We analyzed the trends and variability in precipitation and temperature at the annual and seasonal times. The results showed that the patterns of climate variables with moderate to the high variability with an increase in Belg and Kiremt rainfall trends. This identified the high climate variability in two districts identified to have the potential to limit or adversely affect maize and sorghum production. We performed the correlation of summer rainfall and temperature with annual crop yield: The results show that Correlations between seasonal rainfall and annual yield are particularly weak for maize (R=0.156) and sorghum (R=0.2016) statically insignificant at a 10% confidence level. And the Correlations between seasonal temperature and annual yield are strong for maize (R=0.538) and sorghum (R=0.444) which are statistically significant at a 98% confidence level. These results suggest that maize and sorghum are sensitive to variations in rainfall and temperature. Farmers need to complement rain-fed agriculture with water-conserving techniques, coping strategies for the variable climate to improve food security.*

Key Words: *food security, climate variability, crop yield and crop production.*

1. INTRODUCTION:

Agriculture is the main source of food; is directly dependent on climatic conditions and highly exposed to the effects of Climate Change (Gutu, 2012). Climate is one of the most important factors that impacting on agricultural productivity, threatening food security and livelihoods in most parts of Ethiopia (Solomon, 2019).The rising temperature and variability in rainfall patterns have a direct impact on crop production and food security (Abegaz, 2020), and are expected to threaten food production in the future.

Studies confirmed that the country's annual temperature is increasing about 0.37˚C, whereas the rainfall has no clear trend and there is high variability (Bezu, 2020). This rainfall variability has a significant impact the outputs of crop agriculture in Ethiopia, where more than 95% of crop production is rainfall-dependent (Wubie, 2015). Currently, an increase in erratic rainfall with marked seasonal deficits, an increase in heavy rainfall and extreme events (floodand droughts) frequency, and a high rate of evapo-transpiration due to increasing temperature are conditions that adversely impacting and contributing to agricultural sector vulnerability (USAID, 2015). It affects all four dimensions of food security: food availability, food accessibility, food utilization and food systems stability (Mohammed, 2020). Therefore, the objectives of this study are to analysis the variability and trends of the climate variables, its relationships with crop yields and to examine the impact on productivity and food security over the eastern part of Ethiopia. Knowledge of climate and its impact enables agricultural systems to be more resilientto weather and climate-related shocks by adaptation and mitigation practices of communities. Therefore, the study aims to improve understanding of climate variability and its impacts on Crop production in eastern parts of Ethiopia; and it is important for adaptation and mitigation responses tailored to the specific local environmental and socio-economic conditions of a particular community.

2. METHOD AND DATA:

2.1 The study area

Hararand Jijiga are Zones found in the eastern part of Ethiopia. These zones are among the areas highly affected by variable weather and climate conditions like in-drought, flood and untimely rain; have different agro climatologically future with complex topography (Gummadi et al, 2017). Maize, sorghum, rice, and cowpea are widely planted across and maize and sorghum production are considered as the main economic driver (Thurlow and Wobst, 2003).

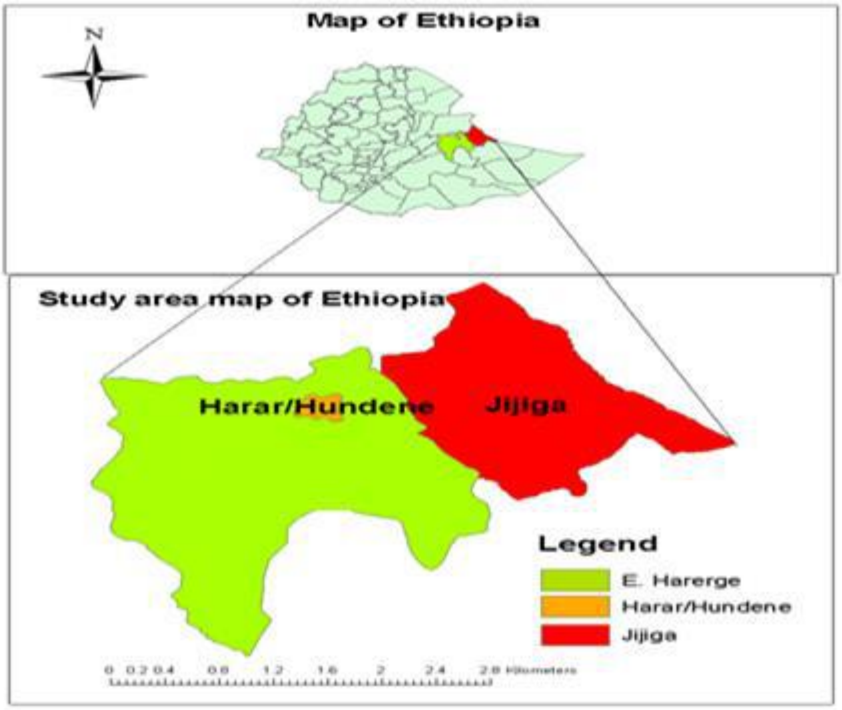

Figure 1. The study area descriptions map of Ethiopia

2.2. Data:

Different data sources were used for this study. Monthly precipitation girded data was collected from National Meteorology Agency of Ethiopia (NMA) archives; monthly temperature data was collected from European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis-Interim (ERA-Interim) Model from http://data-portal.ecmwf.int/data/d/interim_monthly/and seasonal crop yield data from Central Statistics Agency (CSA) archives for the period of 20 years (from 1996-2015). The resolution for precipitation data is 0.1^0 x 0.1^0 and for temperature is 0.5^0 x 0.5^0. Data were being collected, compiled and analyzed to determine impacts of climate variability on food security over the study area.

2.2.1 Data analysis:

Descriptive statistics such as frequency, mean, percentage, bar charts and line graphs were used to analyze both time series and primary data collected from secondary data sources. Descriptive statistics were used to detect relationships between variables, for temporal and spatial comparison and summarize crop yield patterns. Seasonal and annual patterns were computed from monthly rainfall and temperature data, and then normalized as per the season to show the variations and quartiles for long-term evaluation.

Trend Analysis
Trend line equation: Y = ax +b -- (1)
Y=Rainfall/temperature, a= slope or rate of change of the parameter and b= y intercept (1)
Coefficient Variations (CV)

This statistical method was used to test the level of mean variation in both FMAM and JJAS season and crop yield, and then t-test was performed to determine the significance of the variation.

$$CV = \frac{\sigma}{\mu} * 100 - - - - - - - - - - - - - - - - - -(2)$$

Where: CV is coefficient of variation, σ is the Standard deviation of meteorology parameters and μ is the mean of meteorology parameters

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Statistical Z-score

The statistical Z-score is simple index dimensionless Coefficient commonly used to characterize drought at different time scales, or to identify abnormal wetness or dryness (Alemayehu, 2020). crop yield responses to climate was evaluated using Z-score, whereby the negative score indicates the period which climate had the worst impact on crop yields, positive scores indicates affirmative impact of climate particularly rainfall on crop yields and big range indicates enormous impacts of climate on crops.

$$Z = \frac{\chi_i - \mu}{\sigma} ------------(3)$$

Whereby: Z is the number of standard deviation from the mean a data point, X_i is the individual value of meteorology parameters μ is the mean of meteorology parameters and σ is the Stand deviation of meteorology parameters. Its values indicate extreme drought (Z <− 1.65), severe drought (− 1.28 > Z >− 1.65), moderate drought (− 0.84 > Z >− 1.28), and no drought (Z >− 0.84) (Alemayehu, 2020)

Correlation Method:

This method was used to determine the degree of association between the climate variables and the annnual maize and sorghum production and yield.

If we have a series of n measurements of X and Y written as xi and yi

Where i = 1, 2..., n, then the sample correlation coefficient can be used to estimate the population Pearson correlation r between X and Y. The sample correlation coefficient is written

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{(n-1)s_x s_y} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}\sum_{i=1}^{n}(x_i-\bar{x})^2 \sum_{i=1}^{n}(y_i-\bar{y})^2}} ----------------------------(4)$$

Whereby x and y are the sample means of X and Y, and sx and sy are the sample standard deviations of X and Y, X_i =mean for the climate variables, Y_i =mean maize and sorghum yield, Y_i =yields of each year, n=number of weather parameters and r_{xy} =correlation coefficient between X and Y

Where: Z is the number of standard deviation from the mean a data point, X_i is the individual value of meteorology parameters μ is the mean of meteorology parameters and σ is the Stand deviation of meteorology parameters. Its values indicate extreme drought (Z <−1.65), severe drought (−1.28 > Z >−1.65), moderate drought (−0.84 > Z >−1.28), and no drought (Z >−0.84) (Alemayehu, 2020).

3. RESULT AND DISCUSSION:

We discussed Jijiga and Harardistricts the climate variations: seasonal, inter-annual variability, trend lines, coefficients of variation, seasonal trend analysis, standard anomaly index, length of growing season and climate yield correlation by linear regression analysis method.

a. The Pattern of monthly mean rainfall, potential evapotranspiration, maximum and minimum Temperature over the Jijiga and Harar districts.

Bimodal temporal distributions of rainfall with a high contribution in Kiremt and Belg seasons were observed. High temperatures were observed in March and April. This high temperatures increase the rapid loss of the soil moisture (High PET) during the Belg season which has serious consequences for crop development and farmers livelihoods. Jijiga is hotter as compared to Harar from February–May, is cooler from December– February.

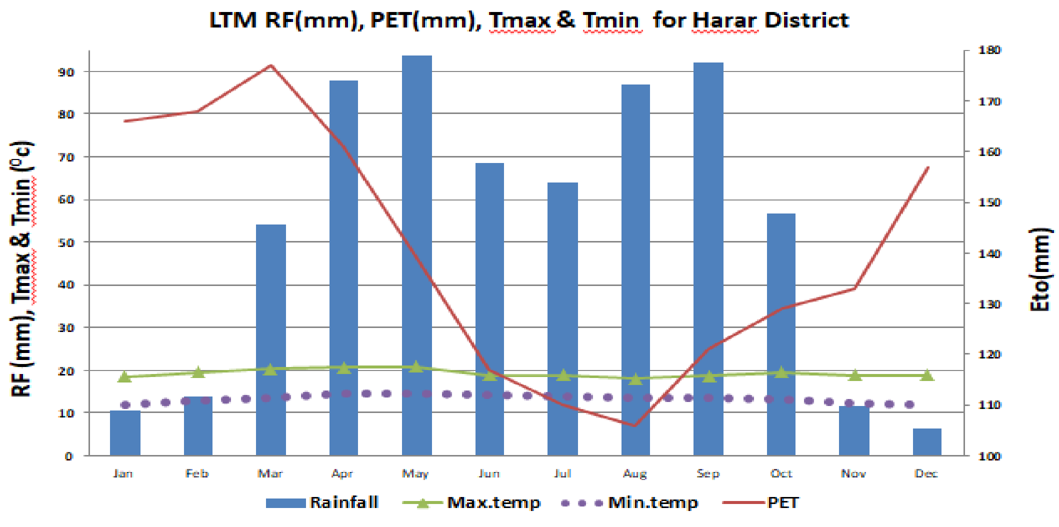

Figure 3a.The Pattern of rainfall, potential evapotranspiration, maximum and minimum Temperature at Jijiga (1996 to 2016)

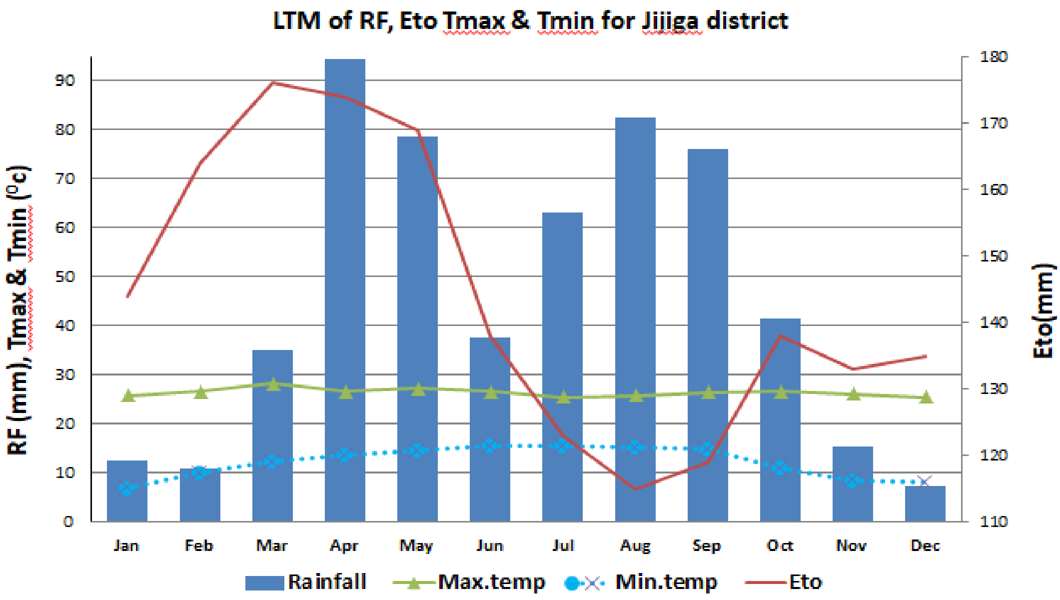

Figure 3b.The Pattern of rainfall, potential evapotranspiration, maximum and minimum Temperature at Harar (1996 to 2016)

b. *Descriptive statistics and variability of annual and seasonal rainfall.*

The long-term rainfall data for the two stations are presented in Table 1. The mean annual rainfall of the study areas ranged from 591.3 mm (Jijiga) to 803.0 mm (Harar) and varied slightly from district to district with a standard deviation ranging from 134 mm (Harar) to 155.6 mm (Jijiga) and CV ranging from 19.4 (Harar) to 22.7 % (Jijiga). This indicates that the rainfall at Jijiga is more variable than the Harar site. Kiremt season contribute 50.8%and 44.5% to annual rainfall budget for Harar and Jijiga, respectively. Whereas, the Belg (FMAM) season contribute 34.9 and 40.3%, for Harar and Jijiga, respectively. This finding agrees with (Bayable et al, 2021) and (Admasu, 2006). Jijiga district according to seasonal and annual rainfall more variable implications for crop production and yields like maize and sorghum also varies when compared with in Harar districts and more vulnerable for inter-annual variability problems in which affect negatively the ability of farmers to cope with climate change and variability.

Table1: Descriptive statistics of rainfall at Harar and Jijiga station (1996-2016).

Descriptive Statistics	Harar				Jijiga			
	FMAM (Belg)	JJAS (Kiremt)	ONDJ (Bega)	Annual	FMAM (Belg)	JJAS (Kiremt)	ONDJ (Bega)	Annual
25th Quartile	207.9	345.3	39.1	712.2	160.2	212.4	29.6	475.9
50th quartile	277.4	381.4	95.9	789.2	215.5	256.4	85.2	570.1
Mean	280.7	408.3	114.0	803.0	238.5	262.9	89.8	591.3
75th quartile	346.0	501.6	186.1	931.1	297.0	311.4	130.1	701.7
Standard Deviation	86.4	87.8	85.6	155.6	109.2	62.1	70.5	134.0
CV%	30.8	21.5	75.1	19.4	45.8	23.6	78.5	22.7
% of contributions	34.9%	50.8%	14.2%		40.3%	44.5%	15.2%	

c. *Rainfall Trends in annual and seasonal rainfall*

Results of annual rainfall and Belg seasons trend tests showed an increasing but insignificant trend while Seasonal rainfall trends of Kiremt showed increasing significant trend for Harar and deceasing trends for Jijiga during the period from 1996 to 2016 which is in agreement with other studies (Bayable, Et al. 2021; Bezu 2020 and EbaMuluneh 2017) for annual and Belg season. However, the finding showed decreasing non-significant trends for the Kiremtseason and increasing annual trends are not consistent with the work of Admasu 2006. This implies that the district was highly under the influence of spatial rainfall variability due to altitudinal variations (Bezu, 2020).

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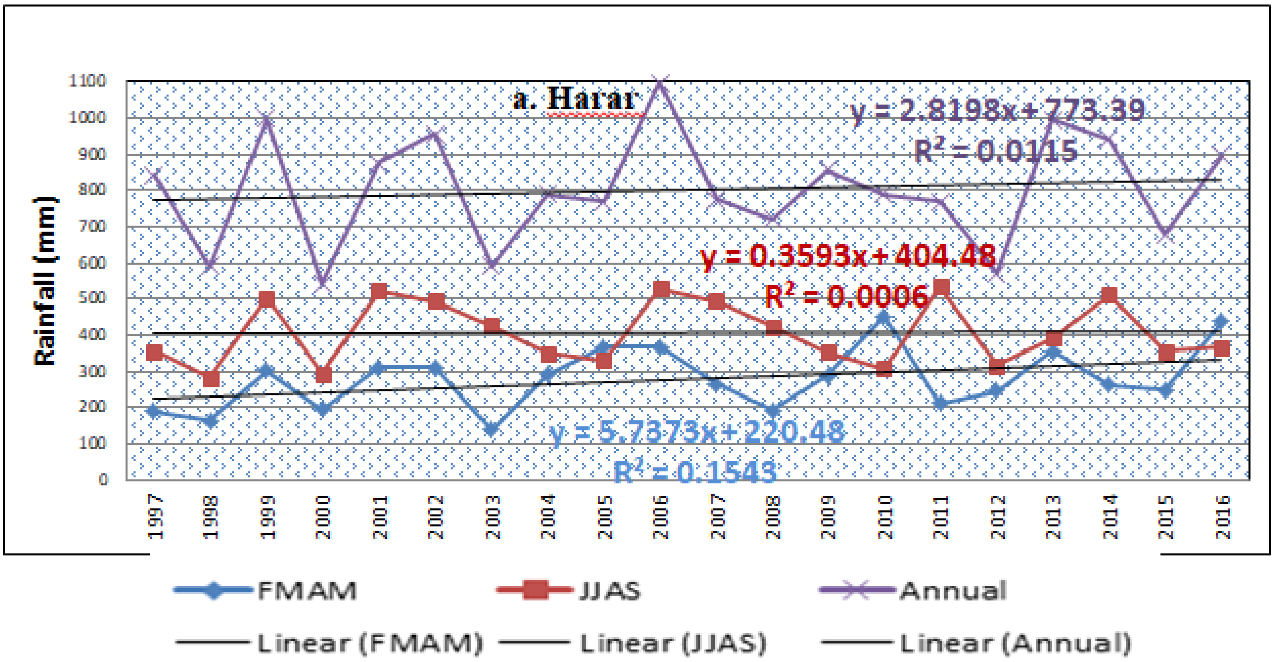

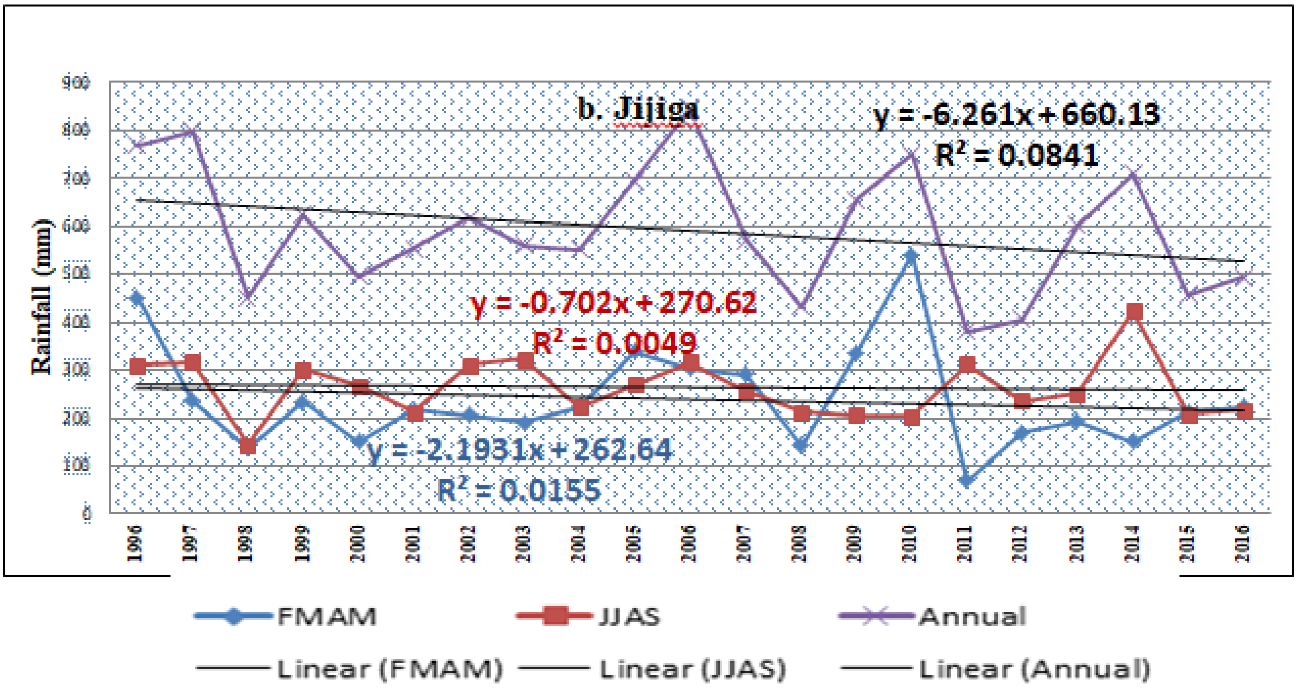

Figure 4. Trends of seasonal and annual rainfall for Harar (a) and Jijiga (b) (1996-2016)

d. Trends of maximum and minimum Temperature in the Harar and Jijiga district(1996-2016)

Analysis of temperature (maximum, and minimum) data 0.5 x 0.5 resolution inter-annual Averages were undertaken from European Centre for Medium-Range Weather Forecasts (ECMRWF) to detect trend for Harar and Jijiga (1996-2016). Using linear regression the slope of line defines the rate change in temperatures. The seasonal rainfall show positive slopes of the linear regression in Belg season for both Harar and Jijiga district. The highest maximum temperature is 29.51 °C (2002) in Harar. Conversely, the lowest minimum temperature over the period of observation is 13.92 °C (2008)in J ijiga. The regression equations of maximum and minimum temperature exhibits increasing linear trends in Harar and Jijiga, but it was not statistically significant (R^2<50). This shows year-to-year fluctuation of temperature.

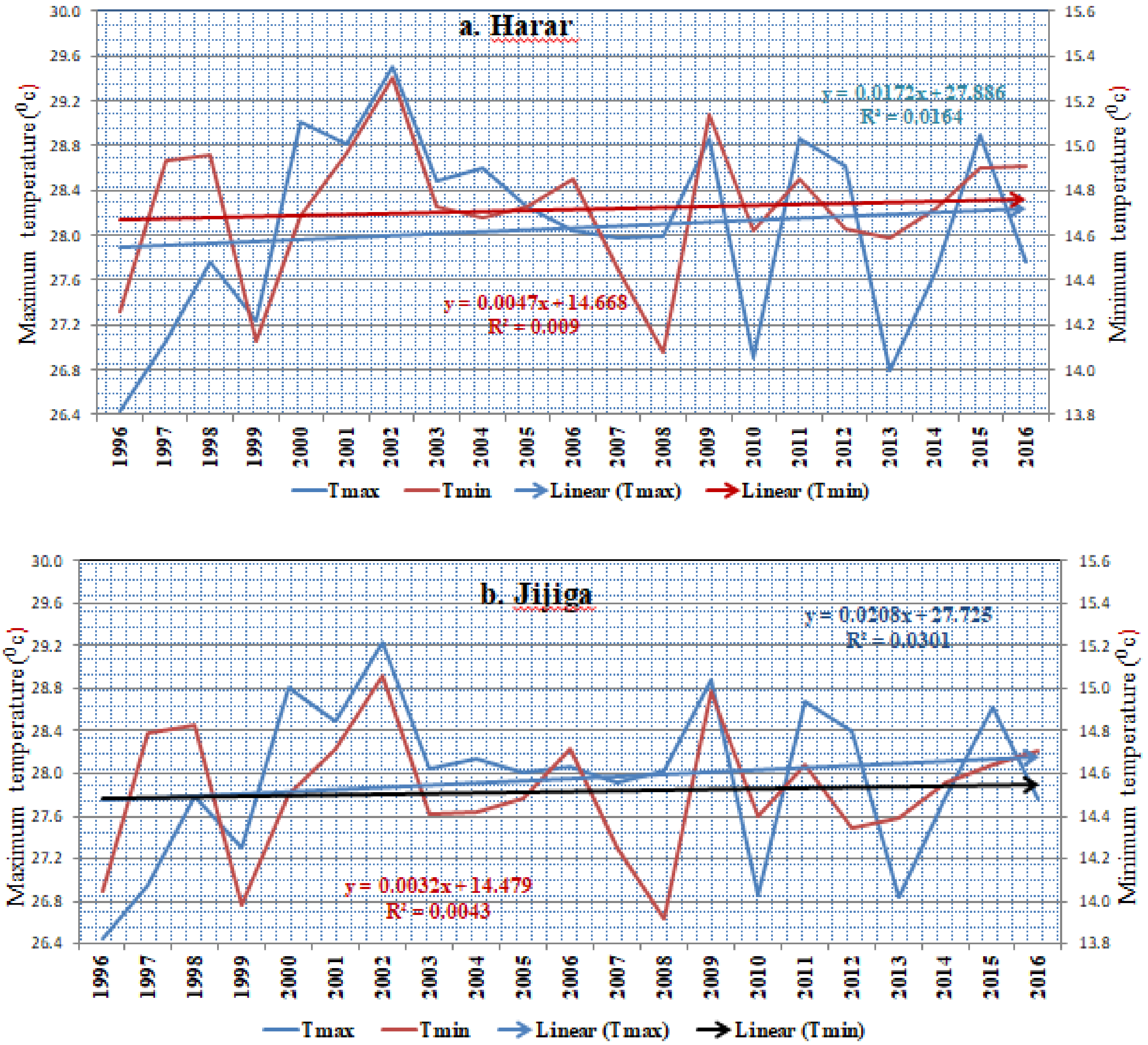

Figure 4: Trend analysis of Maximum and minimum temperature for Harar (a) and Jijiga (b) (1996–20 16)

e. Rainfall anomalies (Z-score) of Jijiga and Harar district (1996-2016.

Rainfall anomaly index (AI) is used to demonstrate the intensity and frequency of drought and inter-annual variation at various time scales and areas. The figureshowed annual and seasonal rainfall anomalies. The negative anomalies of annual rainfall Harar station were 57% and 52% for Jijiga throughout 1996 to 2016.The annual negative anomaly index (severely dry) was observed in 2003, 2011, 2015 and 2016 in both stations (Figures 3). This line with NMA (2015) reported that Ethiopia experienced drought years in 1999, 2003, 2011, 2012 and 2014 to 2016. The study shows drier seasonal and annual anomalies for Jijiga, whereas wetter for Harar in the study period. Extremely wet Kiremt experienced in the years of 1998, 2000, 2001, 2005, 2006, 2010 and 2016 for Harar. However, there were observed extreme and severe drought characteristics in Harar over the period of 1997,1999,2002,2011 and 2016 (figure 5).

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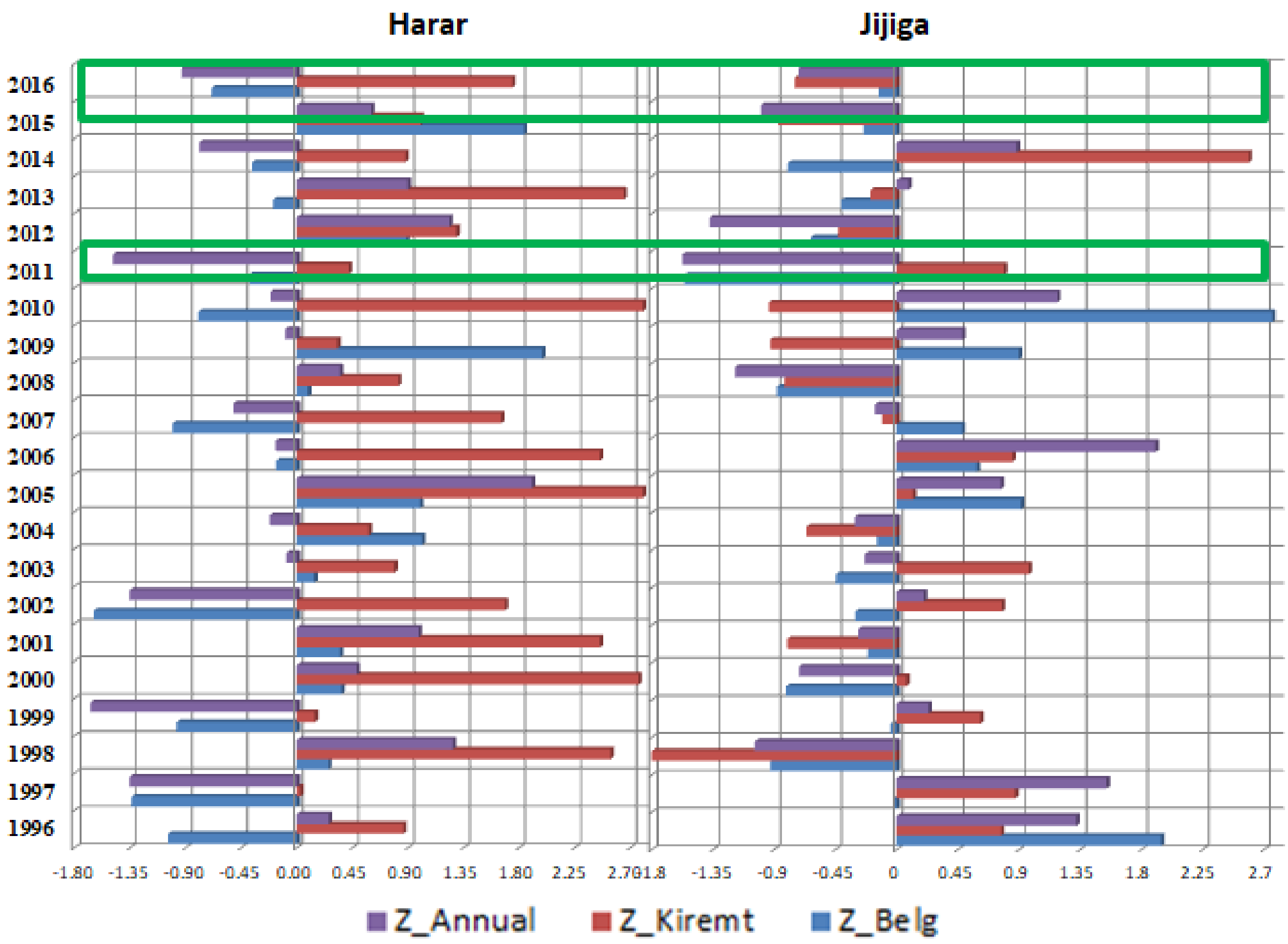

Figure 5: Seasonal and annual rainfall anomalies (Z-score) for Jijiga and Harar districts (1996-2016)

f. Climate-Yield Correlation

To determine the relationship between climatic variability and major crop yields (tons/ha), a correlation analysis was performed. The results reveal that there was a strong and positive relationship between the climatic variability and the yield of sorghum, whereas there were weak relationships between climatic variability and the yield of maize. While testing the effects of seasonal temperatures, a significant relationship was observed in the yield of sorghum. There was a weak significant effect of precipitation on the yield of maize (r = +0.169). Differences in precipitation have higher explanatory power than the temperature in describing changes in crop yields: The correlation between precipitation and yields is R=0.126 whereas the correlation between temperature and yields is R=0.226. Relationships between seasonal rainfall and annual yield are particularly weak for maize (R=0.156) and sorghum (R=0.2016). The results were statically insignificant at a 10% confidence level. The correlations between seasonal temperature and annual yield are particularly strong for maize (R=0.538) and sorghum (R=0.444). The results were statistically significant at a 98% confidence level. This result suggests that maizeand sorghum are particularly sensitive to variations in rainfall. The weak uphill positive linear correlations between rainfall and maize and sorghum could be explained by the fact that these crops are more drought-tolerant.

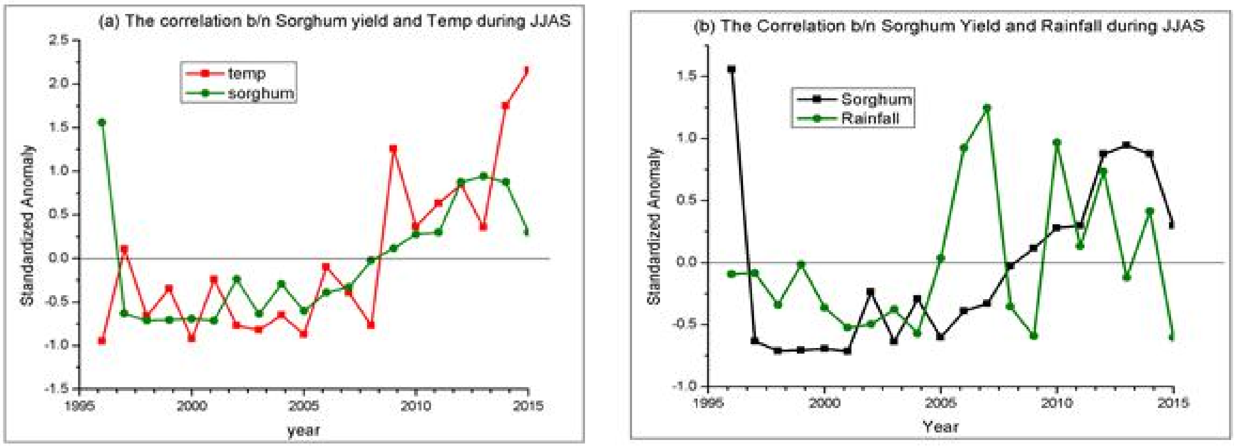

Figure 6: Correlations between annual sorghum yield and Kiremt seasonal temperature (a) and rainfall (b) for Harar and Jijiga districts (1996 - 2016)

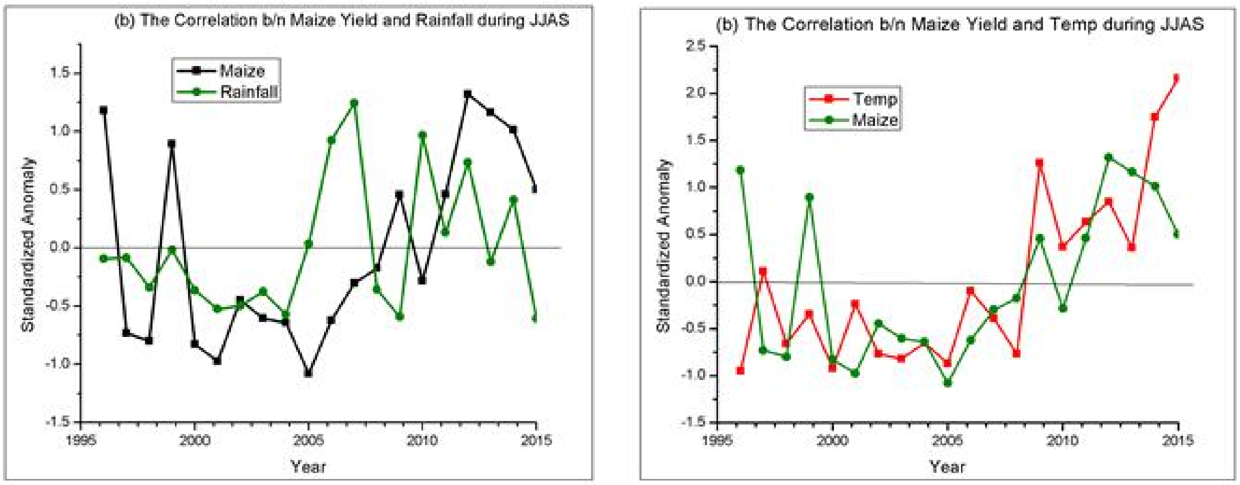

Figure 7: Correlations between annual maize yield and kiremt seasonal rainfall (a) and temperature(b) for Harar and Jijiga districts (1996 - 2016).

4. CONCLUSIONS:

From this study we conclude that increasing trends and climate variability factors have potential stresses on food security. The yield of maize and sorghum is one of the staple foods in the arid and semiarid regions of Ethiopia, is decreasing due to increased temperatures and decreased precipitation. On the other hand, though the increase in temperature, the increases in precipitation have contributed positively to the yield growth of crops. From this study, we observed that the production of maize and sorghum in both Harar and Jijiga districts could be highly linked to the decreased rainfall or its fluctuation. Yields of maize and sorghum are always distorted by a change in precipitation, temperature and moisture. Variation in rainfall patterns influences and high temperature (high Eto) reduce soil moisture was influencing on agricultural productivity and food insecurity over the study area.

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