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Climate Change and Yield Fluctuation of Maize and Sorghum Crops in Arba Minch District, Ethiopia

Assefa Derbew Tegen[a]*, Tesema Adamu Deressa[b]

[a,b]*Department of Meteorology and Hydrology, Arba Minch University, Arba Minch, P.O. Box 21, Ethiopia*
[a]*Email: assefa1979@gmail.com, assefa.derbew@amu.edu.et*

Abstract

For a country like Ethiopia, where agricultural activity is very much linked to the socioeconomic activity of the people, studying the impact of climate variability and change on yield fluctuation is crucial. Therefore, this paper estimated the impact of climate variability and change on crop production in Arba Minch district, Ethiopia; as Agricultural sector in the country provides employment to more than 80% of the population and contributes around 43 % to the overall GDP. Time series data of Temperature and rainfall disintegrated in to 2 crop types were used for this study. Meteorological and yield data for Arba Minch district were gathered from National Meteorological Agency and Central statistical Agency respectively. Future projections of Temperature and precipitation were made up to 2060 using RCP4.5 & RCP8.5 emission scenarios. Finally, an analysis namely coefficient of variation, correlation coefficient and standardized anomalies have been computed after data quality control has been made. Results showed that negative climate impact (TMax) was recorded in 1993 for maize (the only slightly better correlation computed from the data). In the other years, nevertheless, crop yield anomalies did not attain the levels at which they could be considered as impacted. Extreme reduction and excess of crop production are not associated with rainfall and temperature high/low values. Moreover, the projected TMax, precipitation and TMin are likely to have no significant change for 2040s. Depending on the result obtained in the present study, it is highly recommended that an assessment of the underlying causes of rainfall variability should be made with respect to oceanic and atmospheric synoptic systems such as ENSO, different waves, jets and other disturbances.

Key words: Climate variability; crop production; RCPs.

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* Corresponding author.

1. Introduction

In countries like Ethiopia, Climate variability and other climate related extremes have a direct influence on the quantity and quality of agricultural production and in many cases, adversely affect the society at large.

Agricultural sector in the country provides employment to more than 80% of the population and contributes around 43 % to the overall GDP. Yet, Climate variability and change affect mainly the agricultural sectors through the emission of greenhouse gas (GHG) from different farming practice [4, 8]. Climate change in the form of higher temperature, reduced rainfall and increased rainfall variability reduces crop yield and threatens food security in low income and agriculture based economies. Adverse climate change impacts are considered to

be particularly strong in countries located in tropical Africa that depend on agriculture as their main source of livelihood [3, 6]. Agriculture is the main sector of the Ethiopian economy. It is the livelihood of about 85% of the population living in the rural areas and serves as the major sector for sustainable development and poverty reduction in Ethiopia. Nevertheless, the sector suffers from various factors such as soil degradation caused by overgrazing and deforestation, poor complementary services such as extension, credit, marketing, infrastructure and climatic factors such as drought and flood [1, 10].

As the Ethiopian agriculture is highly rainfall dependent, the amount and distribution of the rainfall during the crop growing seasons are critical [9], In Ethiopia, the onset and cessation of the rains and their pattern of distribution and the length, frequency and probability of dry spells in the growing season are the key elements that decide the planning, performance, and management of agricultural operations [7]. The unusual low amounts and distributions of rainfall usually lead to poor harvest and failure of crop production, which results in pasture and animal feeds. Such extreme conditions lead to drought with a resultant depletion of assets, societal vulnerability, mass migration, and loss of life. In line with this, this research is aimed to investigate the statistical relationships between climate parameters and crop productivity and determine how climate variability and change affects future crop production in Arba Minch district. Last but not least, this study is limited to

2. Materials and Methods

2.1. Data Source, Methods of collection and analysis techniques

The demographic and climate data used in this study were obtained from the Central Statistical Agency (CSA) and the National Meteorological Agency (NMA) respectively. The maize and sorghum yield data were collected from Gamo Gofa Zone rural and Agricultural extension bureau and it covered a period of 26 years from the 1987-2012 and 5 years from the 2003-2007 for maize and sorghum respectively. Downscaled regional Climate Change data such as precipitation, TMax, TMin and TAve for the period of 2031-2060 have been obtained from CORDEX Africa database. The GCM data is derived from HadGEM2-ES Global climate model outputs that are statistically downscaled by the CORDEX-Africa program (http://wcrp-cordex.ipsl.jussieufr) using RCA4 regional model for the RCP 8.5 and RCP 4.5 emission scenarios. According to [6], the first scenario considers what the future climate looks like under conditions with a representative concentration pathways (RCP) that assumes the radiative forcing will stabilize at 8.5 W/m^2 in 2100 (RCP8.5); the second less extreme scenario assumes that radiative forcing will stabilize at 4.5 W/m^2 in 2100 (RCP4.5). Last but not least, data quality control methods were employed to make sure that the data are ready for further analysis. Data analysis and visualization was computed using Microsoft Excel, Ferret and R programming language.

3. Result and Discussion

3.1. Coefficient of Variation

Rainfall and temperature (Max and Min) analysis of the observed meteorological data for Arba Minch station indicate a coefficient of variation of 17.84%, 7.25% and 8.25% respectively. Based on [5], CV is used to classify the degree of variability of rainfall events as; less (CV < 20%), moderate (20% < CV < 30%), and high (CV > 30%). Hence, rainfall and temperature (Max and Min) are less variable in the study area.

3.2. Correlation coefficient

Table 1 and 2 demonstrated the bivariate correlation coefficient between crop yields (dependent variable) and weather variables (independent variables) at a significant level (α≤0. 05). There exist low correlation coefficients as depicted in the table; this may be because secondary data sources that were subjected to different types of errors have been used. However, the results showed that the maize yield was negatively correlated with rainfall and TMax, while it was positively correlated with TMin (Table 1). The correlation coefficient value happened to be close to zero, revealing that the correlation is weak, though it exists. Generally, the correlation statistics (Table 2) demonstrate the sorghum yield data was positively correlated with TMin and TMax with a correlation value of 88 and 76% respectively. Nevertheless, Sorghum yield and RF have shown a negative correlation of 66%. If this result were supported by a long time sorghum yield data, they would have helped with agrometeorological advisory issues.

Table 1: Correlation coefficient of maize yield, rainfall and Temperature

Variables	Yield (Maize)	RF	Tmax	T Min
Yield (Maize)	1	-0.02399	**-0.42116**	0.197422
RF	-0.02399	1	0.006909	-0.0814
Tmax	**-0.42116**	0.006909	1	0.085214
T Min	0.197422	-0.0814	0.085214	1

Values in bold are different from 0 with a significance level alpha=0.05

Table 2: Correlation coefficient of sorghum yield, rainfall and Temperature

Variables	Sorghum yield (Quentals/ha)	RF	Tmax	Tmin
Sorghum yield (Quentals/ha)	1	-0.65561	0.761812	0.883037
RF	-0.65561	1	-0.92991	-0.64389
Tmax	**0.761812**	-0.92991	1	0.658266
Tmin	**0.883037**	-0.64389	0.658266	1

Values in bold are different from 0 with a significance level alpha=0.05

3.3. Trend Analysis

Mann-Kendall trend test result (Table 3) revealed that trends of annual TMin, rainfall, maize and sorghum do not show any significant change for this period of time. In contrary, demonstrated TMax among others has experienced a statistically significant positive trend.

Table 3: Mann-Kendall trend test results for mean TMin, TMax, rainfall, maize and sorghum Yield

Ho: 'There is no trend' at the 5 % level of significance							
Series	Data record length		Statistic			ACCEPT/	Type of
Name	From	To	value	Threshold	p-value	REJECT	test
Yield (Sorghum)	2003	2007	1.4011213	1.959964	1.838822	Accept	nonparametric
Yield (Maize)	1987	2012	0.81539	1.959964	1.585148	Accept	nonparametric
RF	1987	2012	1.379489	1.959964	0.167744	Accept	nonparametric
TMax	1987	2012	2.757314	1.959964	0.005828	Reject	nonparametric
TMin	1987	2012	0.42961	1.959964	0.66748	Accept	nonparametric
TAve	1987	2012	2.193165	1.959964	0.028296	Reject	nonparametric

3.4. Standardized Anomaly

3.4.1. Maize Production

A significant standardized positive anomaly of maize yield was observed in 1993 and 1995 (Figure 1). This event strongly coincides with a significant negative anomaly of TMax in 1993. Moreover, a significant negative anomaly of TMin was seen in 1992 with no effect on the maize yield.

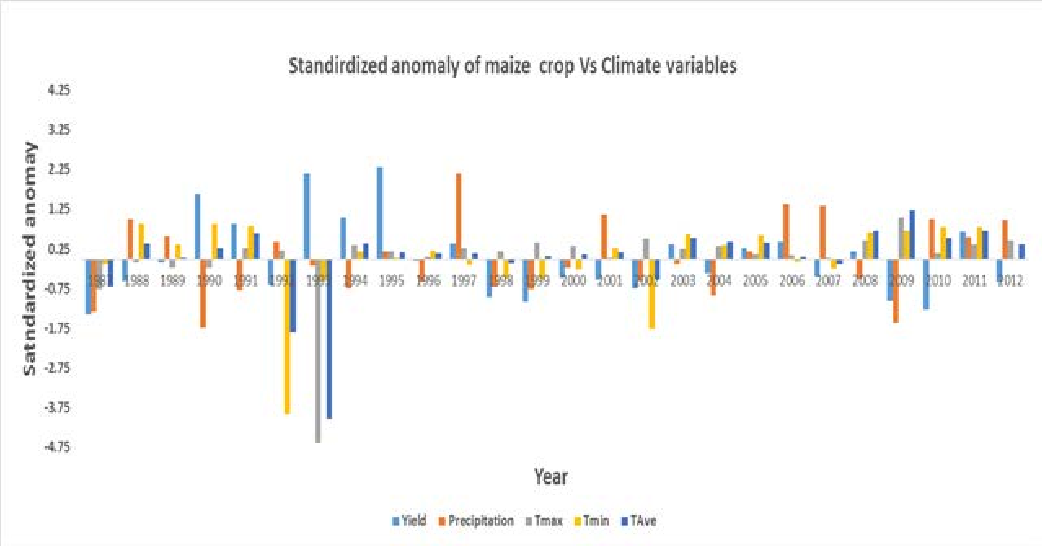

Figure 1: Maize crop yield anomalies as a response to climate variability

As for rainfall, the significant positive anomaly was observed in 1997 preceded by the significant negative in 1993 (Figure 1). However, the above anomaly of rainfall has no correlation with the crop yield. Generally, the data manifested the year from 1998-2003 was regarded as dry year (Figure 1). Positive standardized anomalies indicate greater than the long-term mean value, whereas negative anomalies indicate less than the mean value.

3.4.2. Sorghum production

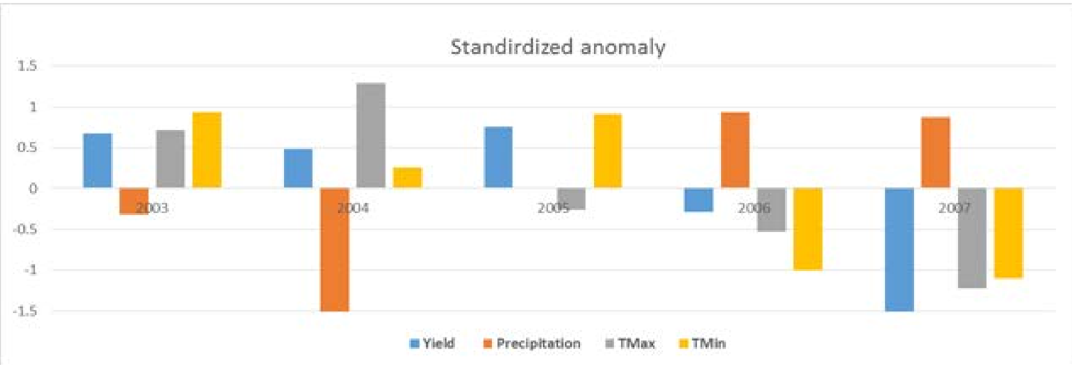

Figure 2: Standardized Anomalies as a response to climate variability

The standardized anomaly analysis of sorghum yield and the climate variables has shown no significant anomaly during the study period (Figure 2). This might have happened due to the data period considered for analysis. In general, a standardized anomaly is often considered significant if the value is well above ± 1.5.

3.5. The effect of projected climate change on crop production

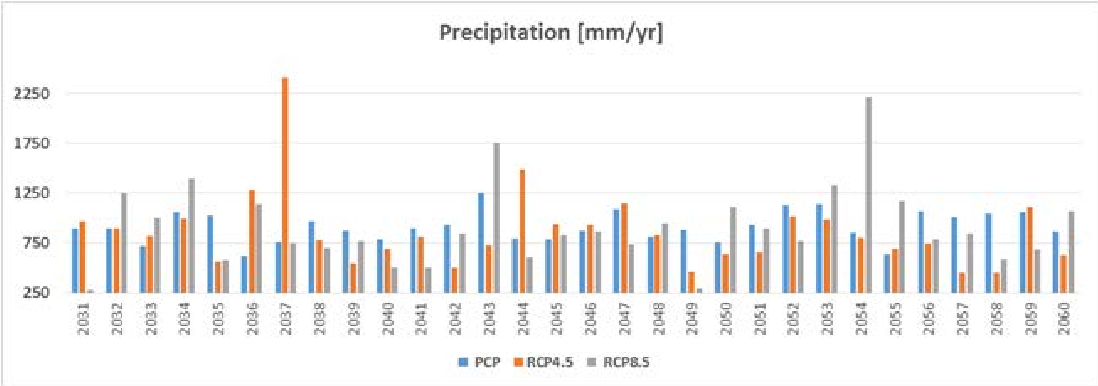

Figure 3: Annual Precipitation variability relative to the baseline run

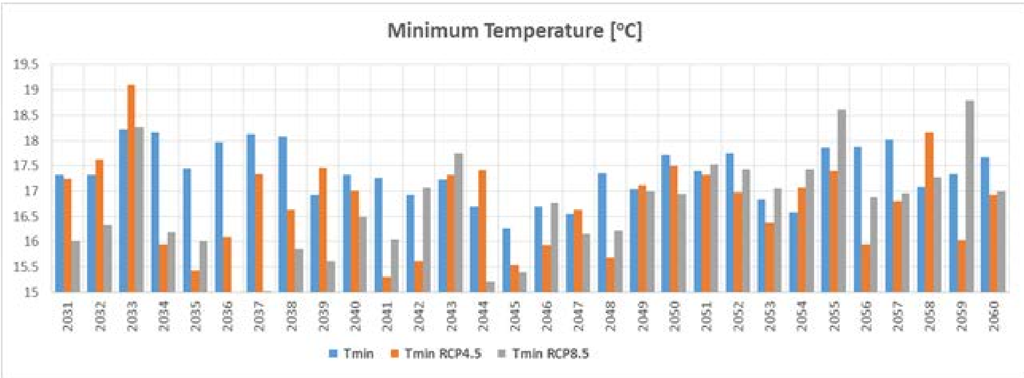

Figure 4: Annual TMin variability relative to the baseline run

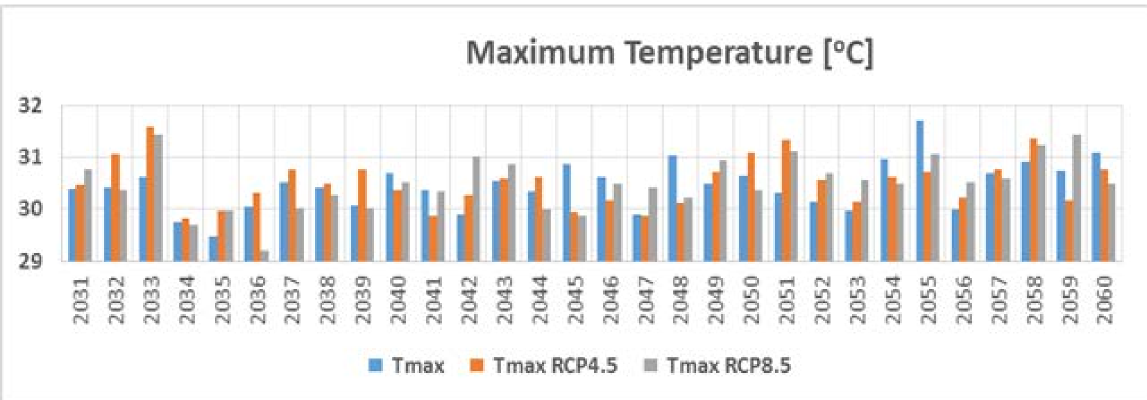

Figure 5: Annual TMax variability relative to the baseline run

Figure 3-5 and Table 4 depict that under RCP 4.5 the projected precipitation and TMin showed a decreasing trend. This might be due to the fact that local temperature change is highly defined by global variables used by general circulation models. Unlike that of precipitation and TMin, the projected TMax showed an increasing trend.

For RCP 8.5, both precipitation and TMax are likely to increase where TMin is anticipated to decrease. On the other hand, the future percentage increase and decrease of the climate variables is insignificant (Table 4).

Table 4: Total percentage change of the climate variables relative to the baseline period for both emission scenarios

Climate Variable	***Total Percentage change***	
	RCP 4.5	***RCP 8.5***
Precipitation	***-0.009***	***0.021***
TMax	***0.22***	***0.17***
TMin	***-0.03***	***-0.04***

4. Conclusion and Recommendations

4.1. Conclusions

The weak positive correlation coefficient showed from the most predictive variables and the crop yield implies that the combination of climatic parameters used has less influence on crop yield. Although not considered in this study, other environment factors such as, soil fertility, seed variety or type and others could also play a significant role.

The results of the study have clearly revealed that climatic parameters, except TMax, do not play a very significant role on the crop yield. Therefore, as per the analysis performed in this study,thebfollowing conclusion can be drawn.

1. Negative climate impact (TMax) was recorded in 1993 for maize (the only slightly better correlation computed from the data). In the other years, nevertheless, crop yield anomalies did not attain the levels at which they could be considered as impacted.
2. Maize crop yield in the study area is not significantly correlated with RF, TMin and TMax.
3. Extreme reduction and excess of crop production are not associated with rainfall and temperature high/low values.

4. The projected TMax, precipitation and TMin are likely to have no significant change for 2040s.

5.2. Recommendation

Depending on the result obtained in the present study, the following limited but very useful points are being forwarded as recommendations:

1. Assessments of the underlying causes of rainfall variability should be made with respect to oceanic and atmospheric synoptic systems such as ENSO, different waves, jets and other disturbances.
2. The crop water requirement under rain fed agriculture and dry spell length should be future works.

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