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Effect of climate on sorghum yield in the semi arid counties of lower eastern Kenya

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Abstract

Sorghum is a key crop in Kenya's attainment of food and nutrition security. Climate is a key determinant of sorghum production under rainfed conditions. The overall objective of this study was to examine variations of sorghum yields in response to climate. This is crucial in documenting future strategic options to enhance food security in a changing climate. A longitudinal research design was used in the study. Purposive and cluster sampling techniques were used to select sorghum and climate data from lower eastern Kenya's districts covering the period 1979-2009. Association between sorghum crop yields and climate data were sought through correlation analysis, while variability in yields was determined through the coefficient of variation (CVs) and standard deviations (STDEV). There wide sorghum yield and climate variability with high CV values of up 60 % of rainfall. Kitui had the lowest variation in sorghum yields with a Standard deviation of 344.1 Kg/Ha (CV = 38.7 %) while Machakos had the highest variation with STDEV of 591.6 Kg/Ha (CV = 60.5 %). This information is useful to monitor and forecast future sorghum production under rain-fed agriculture. There is a need to continue with focused applied research to unleash sorghum's capacity to be the cornerstone of food security in Kenya.

Keyword: Sorghum, Yields, Food Security, Drought, Climate Variability, And Change

1. Introduction

Sorghum (Sorghum bicolor L. Moench) is the fifth most important cereal crop in the world and the second most cultivated crop in Africa after maize. It is a native and well-adapted cereal crop to the tropical areas of Africa. The cereal crop is a self- pollinating plant and its drought tolerance is regarded to be higher than that of maize. It belongs to the grass family graminea. The main sorghum varieties cultivated in Kenya are Serena, Seredo, Gadam, Mtama 1 and 2 and local varieties (Akram *et al.,* 2007; Esipisu, 2011; Fetene *et al.,* 2011; Ogeto *et al.*, 2013). It is cultivated in most parts of the ASALs where it is preferred as it is tolerant to drought, water logging and heat stress (Taylor, 2003; Muui *et al.,* 2013; Mwadalu and Mwangi, 2014). It is cultivated by some of the poorest and food insecure households, predominately in low humidity areas of eastern, coastal and western Kenya where it does well on a wide range of soils (Ashiono *et al.,* 2006; KIRDI, 2011; GoK, 2012; Ogeto *et al.*, 2013).

Sorghum has many uses in enhancing food security of resource poor households. This include dehulled boiled sorghum, sorghum stew, sorghum pilau, sorghum green grams, sorghum *ugali*, sorghum ginger biscuits, sorghum bread, sorghum queen cakes, sorghum cake, sorghum chapatti, sorghum porridge and sorghum beverage. In the commercial front, sorghum is the second after barley in the commercial production of beer. The other uses of sorghum crop are: use of stalks as dry season fodder and as fencing materials (GoK, 2009, Ogeto *et al.,* 2013; Mwadalu and Mwangi, 2014). These diverse uses of sorghum indicates has it a huge potential for enhancing household food security particularly for poor households and catalyse socio economic development in Kenya and Africa.

However, the productivity of sorghum in the ASALs is low due to a number of factors including: low processing capacity, lack of ready market, low processing efficiency levels, and the food crop is less palatable while the market is less readily available compared to maize crop (Mwadalu and Mwangi, 2013). The crop is also vulnerable to attack by Quelea birds thus need daily scaring of birds, which increases the production costs. There is also notable inadequate government support in promoting the production of sorghum in spite of its potential to improve food security and enhance economic development in the ASALs.

Climate variability and change is another factor undermining the performance of the crop thus putting into risk the food and economic security of the small scale farmers (Ogeto *et al.,* 2013; Abegunde*, et al.,* 2019). Extreme weather and climate events such as drought in the Arid and Semi-Arid Lands (ASALs) has been increasing in frequency and intensity making sorghum cereal a preferred crop than maize for household food security (Omoyo *et al*., 2015). The declining rainfall and increased warming trends in the ASALs sub-Saharan Africa, which, are likely to linger up to the end of the 21st century, are likely to impact negatively on crop productivity (Omoyo *et al.,* 2005; IPCC, 2014; Abegunde*, et al.,* 2019). The impact of climate variability and change is particularly significant among subsistence farmers in the ASALs, which cover about 40 per cent of the earth's surface. These are inhabited by approximately 20 per cent of world population and provide 10 % of the world's meat supply (Abengunde *et al.,* 2019; Omoyo *et al.,* 2015, Sivakumar *et al.,* 2005; UNSO, 1997; WRI *et al*., 2007; GoK, 2012; Herrero, 2010).

In such circumstances, progress on achieving food security will require significant transformation and effective adaptations measures for agriculture (Barnabás *et al.,* 2008). This study performs an analysis of sorghum yield responses to climate variables at sub national level for Kenya's lower Eastern Semi-arid lands. It seeks to enhance understanding of the association between weather and climate variables on sorghum yields to enable make appropriate adaptation measures. The climate data was obtained from local weather stations within the study area. This works builds on our previous work on responses of maize to climate variability and change in the same study area.

2. MATERIALS AND METHODS

2.1 Study site

This study was carried out in the four ASAL Districts (Counties) of lower Eastern Kenya (Fig. 1). The Districts, currently referred to, as Counties were Makueni, Machakos, Kitui and Mwingi. Lower eastern Kenya comprise of three counties created in 2013 through Kenya Constitution 2010 namely: Machakos, Makueni and Mwingi. Before 2013, the three counties of lower Eastern Kenya had four districts namely: Kitui, Mwingi, Makueni and Machakos. Mwingi district, which is part of Kitui County, was a distinct district.

The altitude of the area varies from 600m to 1,100m above sea level (Jaetzold *et al.,* 2007). The mean annual rainfall, evaporation and temperatures are in the order of 600mm, 1,150mm and 28 ^{0}C, respectively. The main agro ecological zones (AEZs) in lower Eastern Kenya Counties are: Lower highland zone, upper highland zone, low midland zones and lowland zones. The AEZs were based on their probability of meeting the temperature and water requirements of the main leading crops, that is, climatic yield potential (Jaetzold, 2007).

A block diagram of a model workflow used in the study is shown in Fig. 2, made up of strands dealing with climate and weather data, crop data, and the crop models used. These elements are described below.

Two sets of data were used as inputs in the construction and analysis of regression models. These were sorghum yield time series acting as the dependent variable and climate dataset-independent variable. The climate parameters used were rainfall onset, seasonal rain, annual rainfall, potential evapotranspiration and temperature. The choice of sorghum crop was based on its importance both in the local diet in lower eastern Kenya and potential for adaptation to climate change in Kenya. The four Counties/districts selected for the study were Machakos, Makueni, Kitui and Mwingi. Their selection was based on the fact that they are found in a corridor that suffers from food insecurity and there high proportion of residents who frequently suffer from effects of drought (nomoyo *et al*., 2015). Coefficient of variation (CV) was used to measure the extent of maize yields in response to a changing climate in the region. By this unique study location, it should be possible to extend the findings of this study to other parts of northern Kenya and indeed the larger Sub Saharan Africa (SSA).

Figure 1: Study area consisting of four districts (now counties) of Machakos, Kitu, Mwingi and Makueni

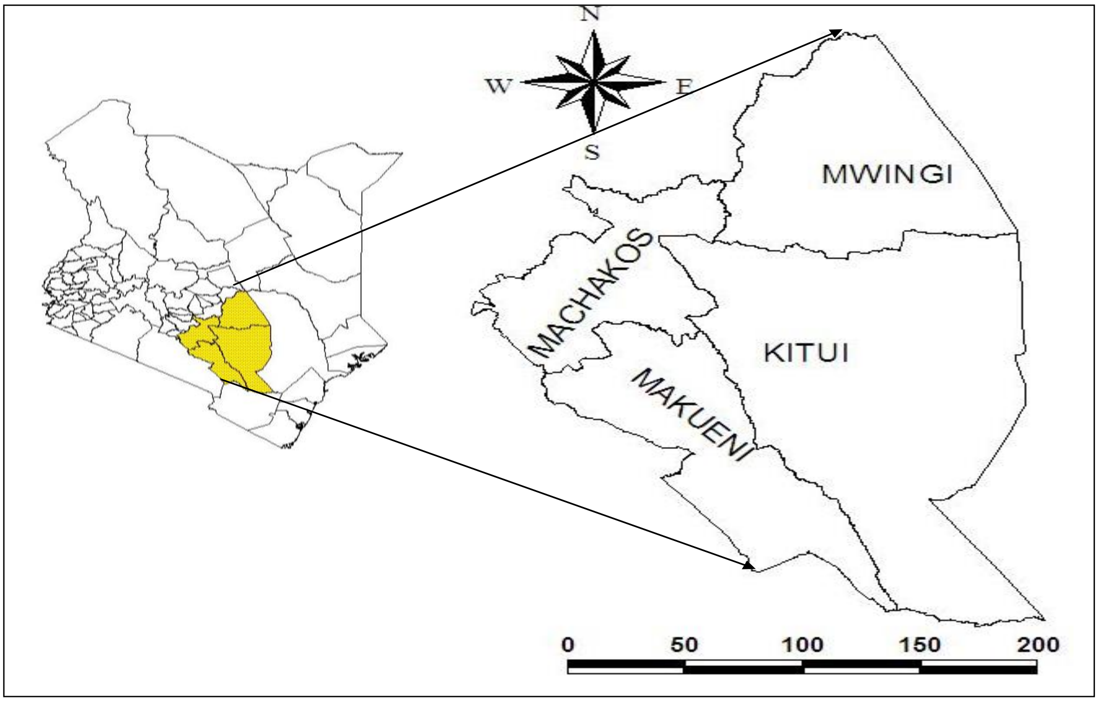
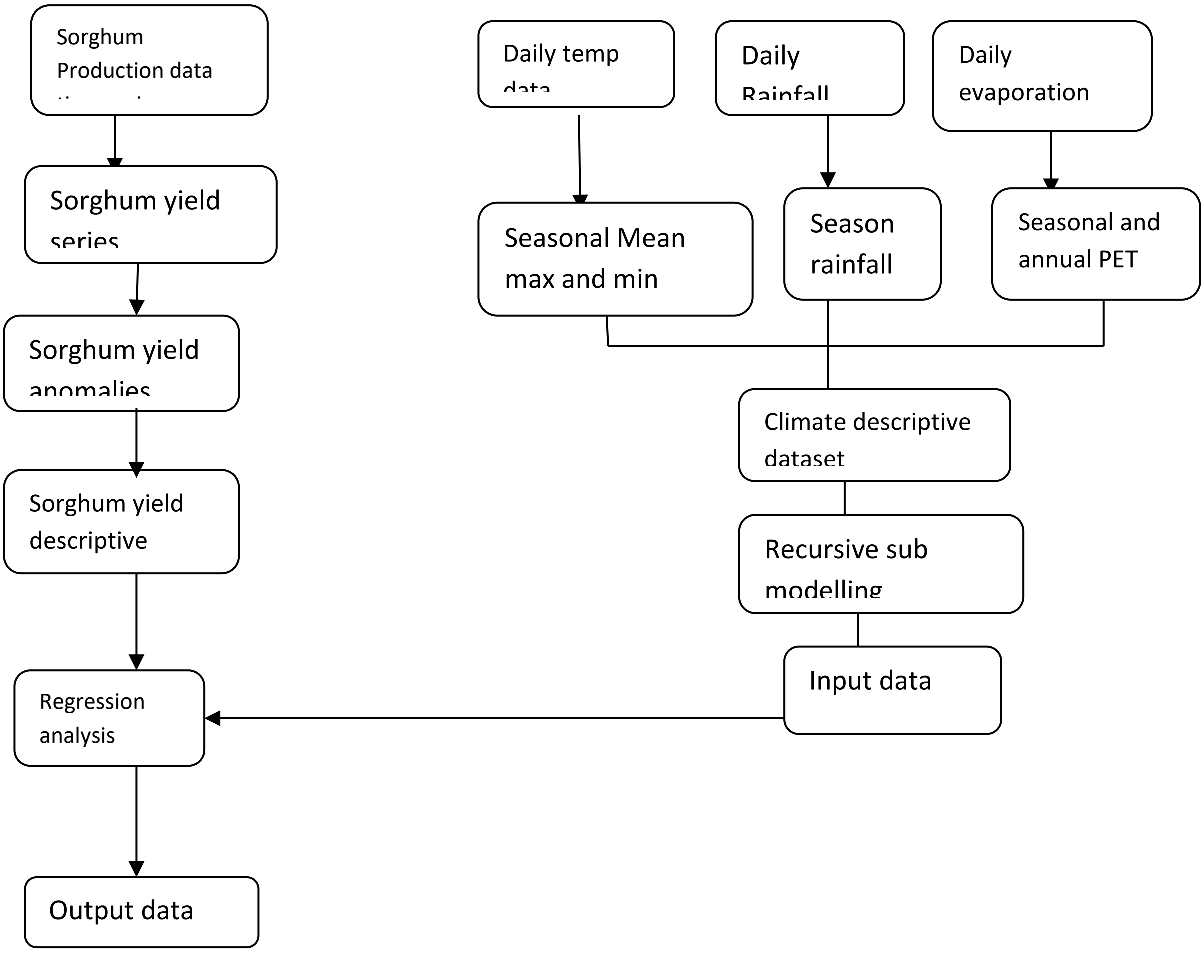


Figure 2: Schematic presentation of the data sets for the study



2.2 *Weather/Climate data*

Rainfall, temperature and evaporation records from six weather stations were analyzed to determine trends and patterns. The six weather stations that supplied climate data were Machakos (Katumani), Makindu, Kibwezi, Kitui, Mwingi and Mutomo for the period 1979-2009. We obtained the weather/climate data from Kenya Meteorological Department (KMD). Sorghum yield data set for the four ASAL Counties was extracted from Ministry of Agriculture data base for the period 1979-2009.

We ran the Principal component analysis (PCA) to transform the correlated data set to uncorrelated and establish the most important factors influencing sorghum yield. We computed the correlation matrix to obtain redundancy of the data. Sorghum yield was plotted against time to establish the trend. Detrended sorghum yields were plotted against each variable from the PCA process to determine the strength of the correlation.

2.3 Determination of variations in rainfall

We used two approaches to determine the association between climate variability and sorghum yields: Z-scores to evaluate the impact of climate parameters on sorghum yields and simple crop modelling techniques by use of regression. Statistical models are simple technique for analysing and forecasting crop yields, in which historical data on crop yields and weather are used to calibrate relatively simple regression equations (Lobell and Burke, 2010). Climate/weather data was obtained from Kenya Meteorological Department (KMD) of nearby weather stations in the four Counties. We employed Z-scores technique to reveal the distribution of sorghum and climate anomalies. Associations between sorghum yields and weather/climate were explored by use of regression and correlation techniques. Principal component analysis was used to reduce number of variables.

Seasonal and annual patterns were computed from daily rainfall data and the variations were illustrated by means of graphs and trend lines. We disaggregated the rainfall data into two growing seasons March-June (MAMJ) and October- January (ODNJ). The main growing season spreads over ODNJ while the second growing season is MAMJ, a fact corroborated with Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs). The trend line equation $y = aX + b + e$ was used to describe the changes in rainfall where 'y' represents the rainfall amount in millimetres, 'a' represents the slope hence the rate of change of rainfall over the period and 'b' represents the intercept on y-axis. To determine the seasonal variations we normalized the seasonal rainfall. We also established rainfall onset and cessation another important parameter that influences crop yields (Odekunle, 2006). In addition, we normalized the rainfall data to yield rainfall anomalies for the two seasons.

Rainfall onset and cessation was determined by use of number of rainy days and compared with percentage cumulative mean rainfall model (Odekunle, 2006; Omoyo *et al.,* 2015). The threshold value for a rainy day to be counted as rainy was set at a value of 4.95 mm. This implies that rainfall below this threshold value was not included in the data analysis. The start of the main rainy season was defined as the first day after October 1st when rainfall accumulated in at least three days was at least 20 mm and was not followed by a dry spell of 10 consecutive dry days in the following 30 days (Stern *et al.,* 2003). We used Machakos weather station to demonstrate daily rainfall variability as it had adequate daily data.

2.4 Determination of variations in temperature

Seasonal and annual trends of maximum and minimum temperatures were computed from daily data, and trend and patterns determined by means of graphs and trend lines. The trend line equation $y = aX + b$ was used to describe the changes in temperature where 'y' represents the temperature amount in ^{0}C, 'a' represents the slope hence the rate of change of temperature over the period and 'b' represents the intercept on y-axis. Machakos and Makindu weather stations were the only stations with daily temperature data and have been used to analyse its trend. Temperature was measured in degrees Celsius (^{0}C).

2.5 Determination of annual and seasonal trend and patterns of evaporation

Daily evaporation data set was obtained from KMD and converted to potential evapotranspiration and then organized to generate seasonal and annual means. The trend line equation y = aX + b was used to describe the changes in potential evaporation where 'y' represents the evaporation amount in millimetres, 'a' represents the slope hence the rate of change of evaporation over the period and 'b' represents the intercept on y-axis. Machakos and Makindu weather stations were the only stations with daily evaporation data and have been used to analyse its trend. Evaporation was measured in degrees Celsius (^{0}C). Pan evaporation method was used to compute potential evapotranspiration (Smith *et al.,* 1992).

2.6 Determination of sorghum yield anomalies, variations and associations with climate variables

We obtained sorghum yield data from Ministry Agriculture records for the period 1979-2009 for the four ASAL districts of lower Eastern. However, for Makueni and Mwingi Districts the sorghum records were for the period 1993-20009 when the two were created. Sorghum yield was measured in Kilograms per Hectare (Kg/Ha). Sorghum yield was converted into Z-scores-a normal distribution to help compare different scores from different distributions. Z-score is the number of standard deviations sorghum yield is above the mean. Positive score shows data is above the mean while negative score shows data is below the mean. Negative sorghum yield anomalies (Z-scores) signified negative impact of the climate or weather and vice versa. The Z-score distribution of the entire crop yield data set was of varying magnitude in the range of +3 to -3. Thus, the higher the values of sorghum yield anomaly the higher the impact of the climate.

We utilized Coefficient of Variation (CV) to further analyse the variations of sorghum yield in response to the climate variables. Coefficient of variation (CV) is a ratio of SD to the mean of the sorghum yield time series. The yield was established as the ratio of total production to the harvested area, expressed in Kg/Ha. The classic regression approach was used to establish the relationship between the sorghum yield and one or more independent parameters related to climate/ weather parameters. Regression equations of the form: Y = a + bX + e; where Y = the dependent variable; a = intercept on y-axis; b = partial regression coefficient of the independent variables; X = the independent variable; e = the random error term representing the proportion of unexplained variation were used. It is instructive to note that the dependent variables were regressed singly on the independent variables, thus avoiding the problem of co-linearity, especially among solar radiation, temperature and sunshine hours.

3 RESULTS

3.1 Variations in rainfall onset and cessation

From the analysis, the earliest onset date of main growing season rainfall is 2nd October 1983 while the latest is on 10th December 2002. The mean onset date for main growing season is 10th October while latest onset date is 10th December 2003 (Fig. 3). The earliest onset of second growing season rainfall is 5th March 1989 while the latest is 30th May 2006. The mean onset date for the second growing season rainfall is on 7th April (Fig. 4). There was failure of the growing season rains in twelve out of 31 years (about 39 %) during the main growing season of ONDJ. The longest growing season had 75 days in 1990 while the years with less than ten rainy days were 1983, 1984, 1991, 1992, 1994, 2004, 2007, 2008 and 2009. The coefficient of variability of rainfall onset revealed towering unpredictability (CV = 98.1%). This implies that the dates of planting are very unreliable. Machakos weather station rainfall was utilized in computing the onset and cessation dates as it had few missing daily rainfall data set.

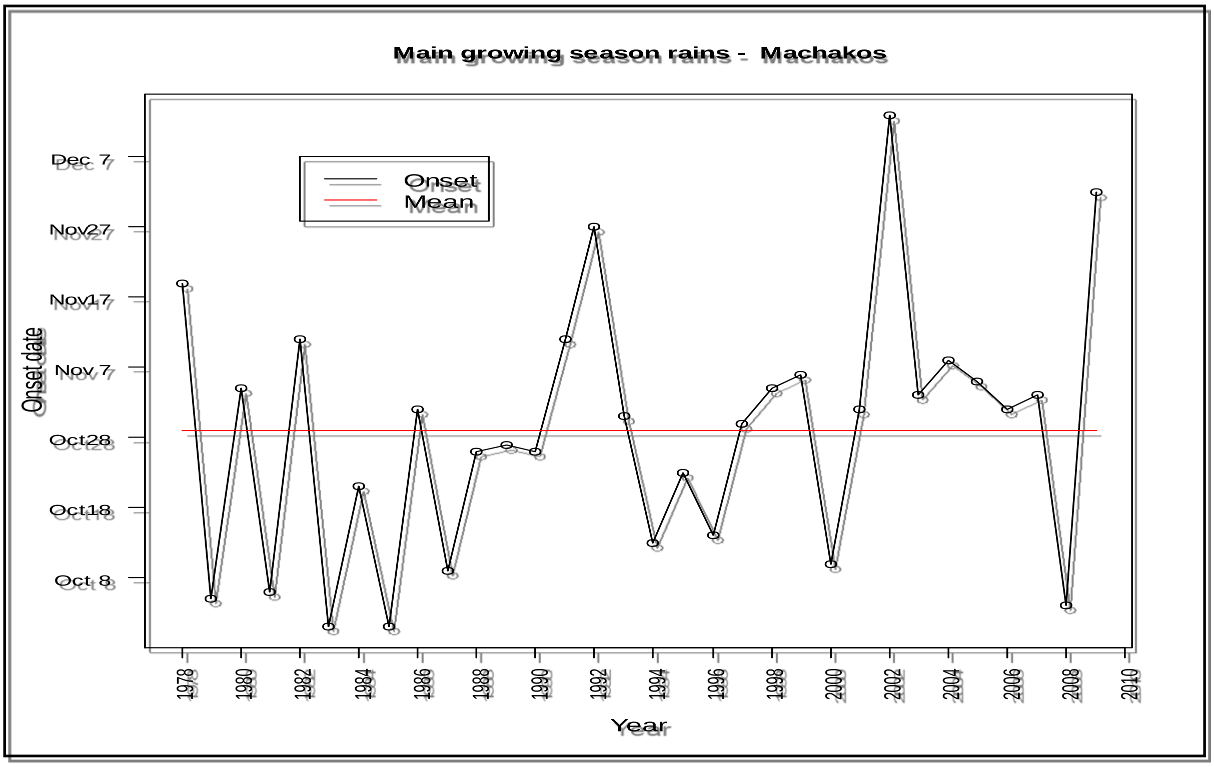


Figure 3: Mean onset of the main growing season rainfa

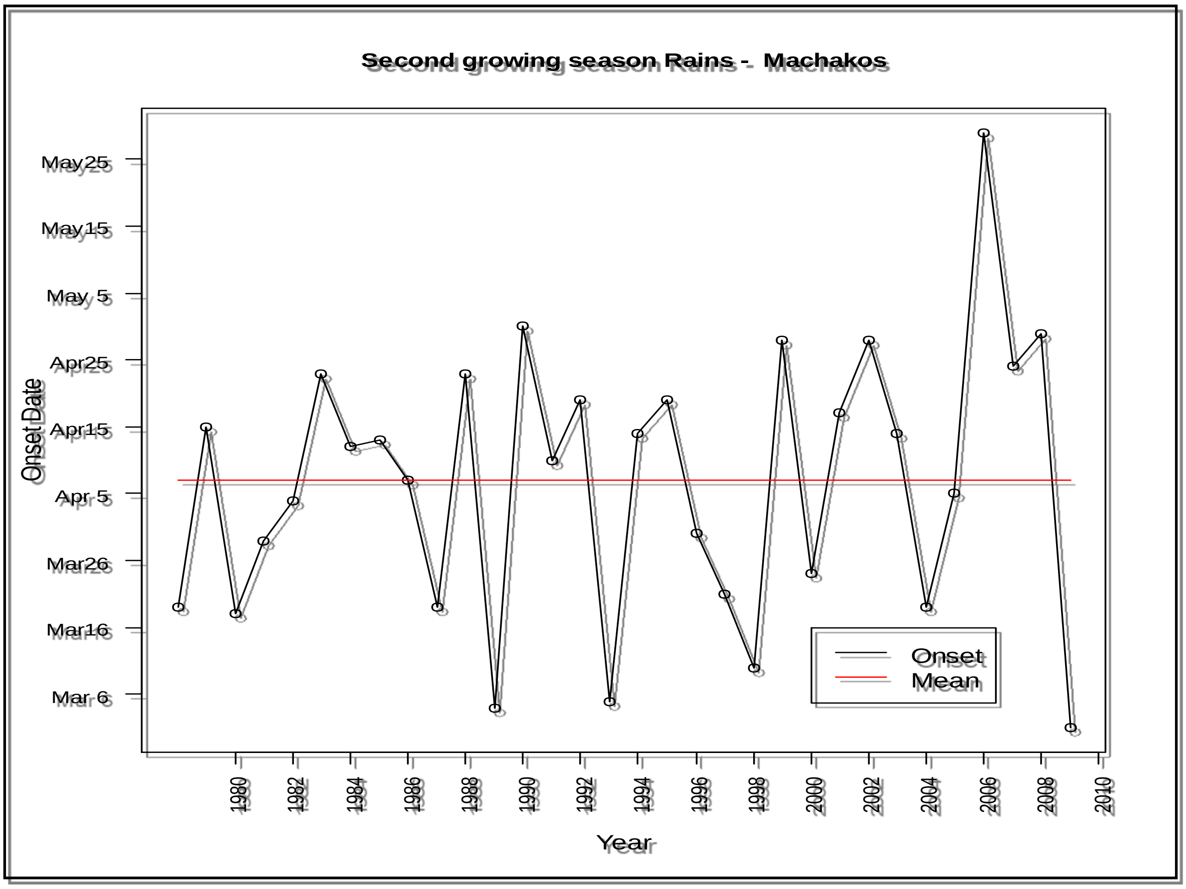


Figure 4: Mean onset of the second growing season rain

3.2 Variations in growing season rainfall

Descriptive statistics shown in Table 1 indicates the March-June mean rainfall is generally lower than October-November – December seasonal rainfall in all the weather stations. This finding concurs with the views of the farmers during FGDs that indicated that October-November-December as the main and reliable season than MAMJ. The wettest MAMJ station is Machakos with mean rainfall of 273.8 mm. Makindu weather station had the driest MAMJ with mean of 180.6 mm of rainfall. With regard to October-December, growing season the wettest station was Mutomo with 601.6 while Machakos is had the lowest with 371.0 mm. The results show that Makindu had the lowest mean seasonal rainfall totals (594.6 mm) while Mutomo had the highest (mean =808.0 mm).

Wide variations in seasonal rainfall are observed in all the weather stations with the main season ODNJ CVs higher than those of the second MAMJ season (Table 1). Kitui MAMJ and the ONDJ season had highest variability (CV = 60.4 and 61.4 % respectively) while Makindu MAMJ had the lowest variation (CV = 33.4 %). High variability existed in temporal and spatial season-to-season rainfall amounts and distribution in all the weather stations ranging 195.5-273.8mm for MAMJ and 371- 601 mm for ONDJ. Kitui ONDJ season had the highest CV (61.4 %) while Machakos had the lowest (CV = 51%). This finding indicates that the rainfall variability for the main season is generally higher, thus more risky to farmers than for the second season.

Table 1: Growing season rainfall descriptive summary for five weather stations of lower Eastern Kenya. The data is for six weather stations. The rainy seasons have been disaggregated into two: March-June and October-January. The wettest and driest seasonal rain is shown. CV and Standard deviations have been used to demonstrate rainfall variation in the study area.

Station	Wettest season average (mm)		Driest season average (mm)		Average seasonal rainfall (mm)		SD (mm) and CV(%) in brackets	
	MAMJ	ONDJ	MAMJ	ONDJ	MAMJ	ONDJ	MAMJ	ONDJ
Machakos	538.8 (1990)	821.6 (1997)	55.4 (1984)	149.1 (1998)	273.8	371.0	112.9 (41.2)	190.6 (51.3)
Makindu	472.2 (1981)	1010.6 (1997)	198.0 (1993)	363.8 (2003)	180.6	594.6	91.4 (33.4)	218.1 (58.8)
Kibwezi	584.9 (1991)	1024.0 (1988)	47.2 (1984)	291.6 (1981)	245.7	461.0	121.4 (44.3)	184.3 (49.7)
Kitui	360.5 (1989)	1029.5 (1997)	59.0 (2000)	166.0 (1998)	194.5	452.8	165.3 (60.4)	227.9 (61.4)
Mwingi	405.0 (1990)	821.8 (2007)	65.0 (1983)	140.3 (1983)	245.7	402.0	97.1 (35.4)	181.0 (48.8)

Regression lines were fitted to determine evidence of trends in rainfall totals but not all were statistically significant. Trend analysis of seasonal and annual rainfall showed most of the stations had a negative slope except Mwingi and Mutomo stations (Table 2). The Machakos annual rainfall had a slope of up -1.4 mm, Makindu had -5.6 mm pa while Kitui had -15 mm and Kibwezi station had -2.3 mm. However, Mutomo and Mwingi stations reveal positive trends of up to 7.3 mm pa.

Table 2: Rainfall trend analysis and summary of other statistics by station of lower eastern Kenya. The trends were not significant at 0.05 level.

District	Season	Slope	a-value	R^2	Sig	Trend
Machakos	MAMJ	-0.070	1143	0.000	0.976	Negative
Machakos	ODNJ	-0.302	1143	0.000	0.943	Negative
Machakos	Annual	-1.4	1218	0.004	0.727	Negative
Makindu	MAMJ	-2.93	6028	0.085	0.11	Negative
Makindu	ONDJ	-1.70	3731	0.004	0.707	Negative
Makindu	Annual	-5.60	11869	0.056	0.198	Negative
Mutomo	MAMJ	2.9	7812	0.033	0.325	Positive
Mutomo	ONDJ	3.16	7990	0.012	0.554	Positive
Mutomo	Annual	7.3	19002	0.04	0.260	Positive
Kibwezi	MAMJ	-1.30	3696	0.012	0.587	Negative
Kibwezi	ONDJ	-2.30	6662	0.014	0.523	Negative
Kibwezi	Annual	-1.70	5201	0.004	0.715	Negative
Mwingi	MAMJ	0.731	-1744	0.005	0.700	Positive
Mwingi	ONDJ	4.10	-10693	0.047	0.24	Positive
Mwingi	Annual	4.67	-8639	0.003	0.672	Positive
Kitui	MAMJ	-5.06	10300	0.078	0.203	Negative
Kitui	ONDJ	-10.5	21335	0.112	0.127	Negative
Kitui	Annual	-14.37	29374	0.152	0.072	Negative

3.3 Temperature and evapotranspiration trends

Seasonal and annual maximum and minimum temperature revealed wide variability. Analysis of growing season (October-January) maximum temperature for Makindu reveal upward warming at the rate of up to 0.03 ^{0}C pa. Machakos station analysis indicate it is warming at a slightly lower rate of 0.017 ^{0}C (Fig. 5). Similarly, Potential Evapotranspiration is increasing at a rate of 0.02 mm pa (Fig. 6). A substantial part of sorghum yields can be explained by temperature increases at lower elevations as a result of heat stress and increased evaporaton such as lower estaern Kenya.

Figure 5: Machakos growing season temperature trend

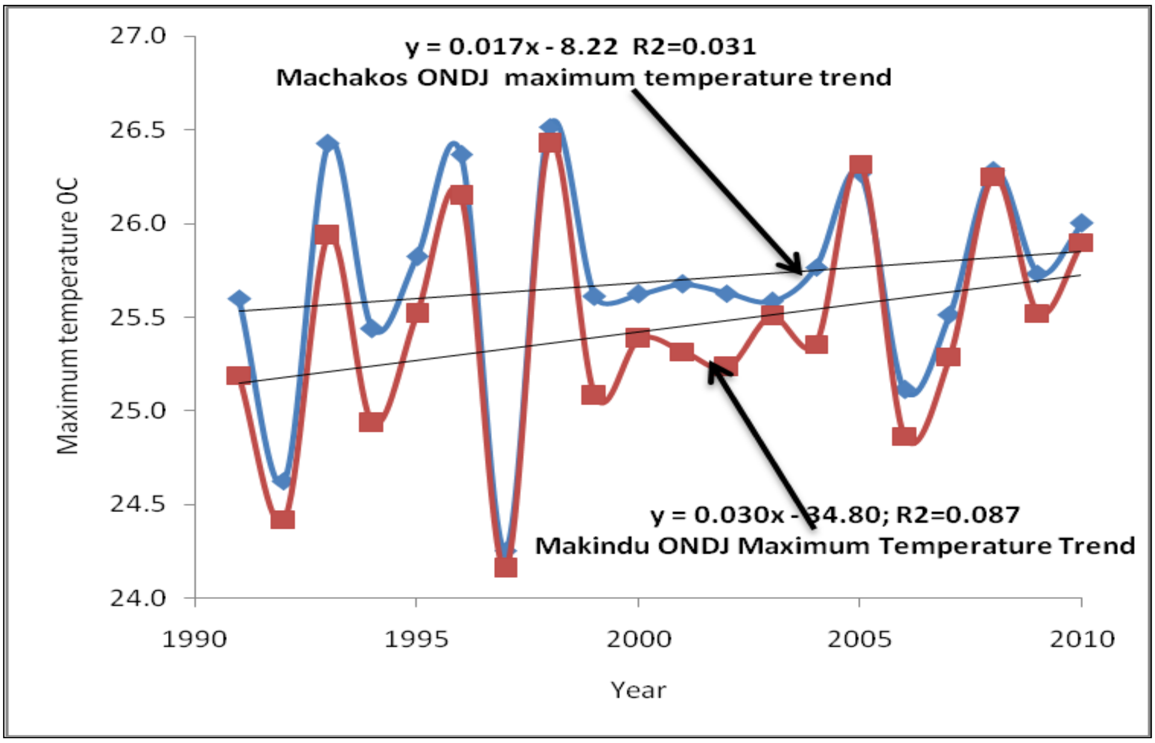
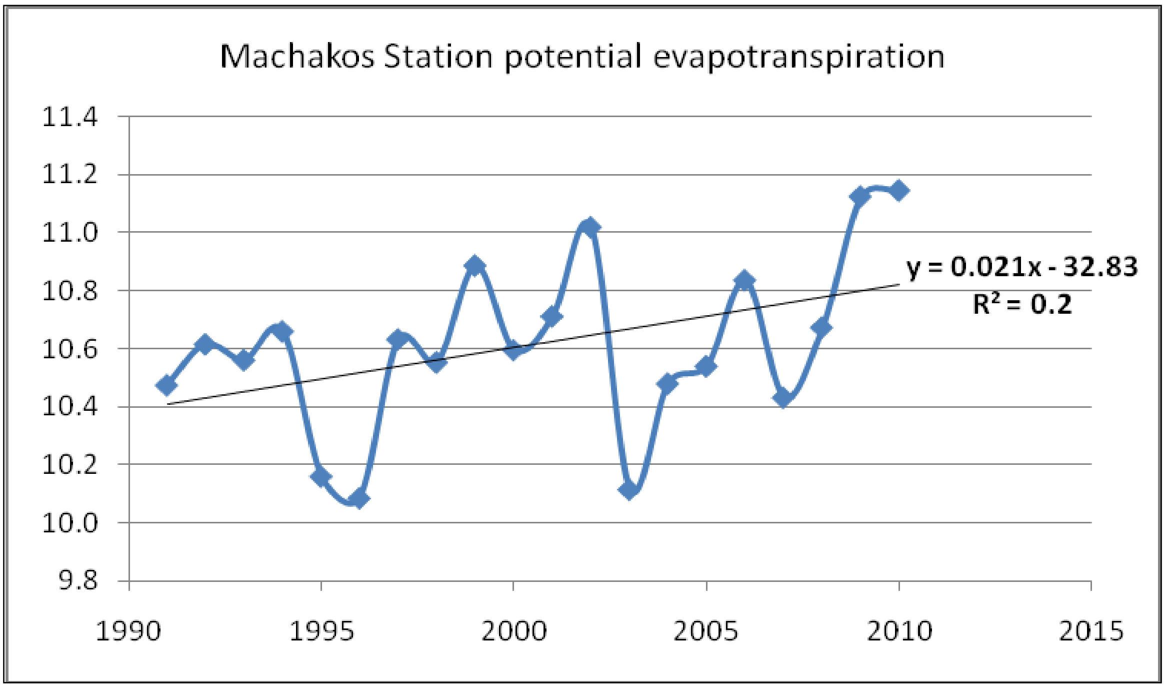


Figure 6: Machakos potential evapotranspiration trend



3.4 *Sorghum yield descriptives, Z-scores and coefficient of variations (CV)*

Table three shows sorghum yield descriptive summary where the mean sorghum yield for the four ASAL Counties over the period was 1078 Kg/Ha. Machakos had the highest mean yield (mean =1721.8 Kg/Ha), followed by Kitui County (mean = 1370 Kg/Ha) and Makueni is 1270.1 Kg/Ha, while Mwingi had the lowest (mean = 1030 Kg/Ha). Kitui had lowest mean sorghum yield over the period at 370.2 Kg/Ha.

Kitui had the lowest variation in sorghum yields with Standard deviation of 344.1 Kg/Ha (CV = 38.7 %) while Machakos had the highest variation with standard deviation of 591.6 Kg/Ha (CV = 60.5 %) over the period (Table 3). Student's one-sample t-test of mean sorghum yields time series revealed that they were not statistically significant at 0.05 per cent level.

Table 3: Sorghum yield descriptive summary for lower Eastern Kenya. The four districts in lower eastern are Machakos, Makueni, Kitui and Mingi. The number in brackets shows the year when the yield was observed.

District	Mean (Kgs)	S.D (Kgs)	CV (%)	Lowest yield (Kg/Acre)	Highest yield (Kg/Acre)
Machakos	407.67	246.5	60.5	45.4 (2000)	739.7
Makueni	380.1	136.4	35.9	208.0 (2006)	637.9 (2001)
Kitui	370.2	143.4	38.7	50.8 (1987)	720 (1993)
Mwingi	397.2	198.7	50.0	105.7 (1991)	900 (1993)
Average	388.8	181.2	46.3		

Table 4: Sorghum trend analysis of yield by district, Kenya

District	Gradient	a value(intercept)	R^2	Sign	Remarks
Machakos	-1.2	2819.0	0.002	0.38	Negative
Kitui	1.8	3268	0.01	0.04	Positive
Mwingi	6.4	12,681	0.054	0.252	Positive
Makueni	-0.93	2241	0.00	0.702	Negative

The Z-distribution values for sorghum yield were varying in magnitude between -1.5 and + 2.2 in all the four ASAL districts/Counties (Table 5). Machakos District had the lowest negative yield anomaly in 2007 represented (Z = -1.5). Mwingi County had the highest positive yield anomaly in 1993 (Z = +1.7). For instance, Machakos District, now a County, had predominately-positive Z-values in the period 1979-1993 followed by predominately-negative Z-scores in 1994-2009. The highest positive Z-score of +2.2 for Makueni District was realized in 1993. In 2009 Makueni County had the highest negative impact (Z = -1.5). Mwingi sorghum yields Z-scores shows positive scores for the period 2000-2004 and then the period 2005-2009 all Z-values are negative. Noticeably all the four ASAL districts/counties have distinctively negative Z-scores in 1996, 1998, 1999, 2004, 2005, 2006 and 2007 (Table 5). The year 2005 had the lowest (negative) Z-values in all the Counties. This implies that the weather had the worst impact on sorghum yield in year 2005.

Table 5: Sorghum yield Z-score values for the four ASAL districts/counties of lower Eastern Kenya. Mwingi District was split from Kitui District in 1993 while Makueni District was split from Machakos Distrct in 1992.

Year	MWINGI	MAKUENI	KITUI	MACHAKOS
1982			0.76	1.016324
1983			-0.31	0.197696
1984			-0.31	-1.28995
1985			-1.33	-0.40525
1986			0.47	1.123186
1987			-2.00	-0.32082
1988			-0.07	1.290986
1989			1.12	1.262907
1990			-0.82	1.361874
1991			0.19	-0.06644
1992			1.19	0.055049
1993	0.20	0.12	2.19	0.176946
1994	0.30	0.43	0.65	-1.11603
1995	1.14	-0.89	0.60	0.207589
1996	0.09	-1.07	-1.67	-1.74531
1997	-1.09	1.05	1.06	-1.11933
1998	-1.74	-0.64	-1.31	-0.23368
1999	-1.62	-1.83	-2.05	-1.89575
2000	-0.61	0.65	0.00	-1.77567
2001	-0.04	1.59	0.79	-0.19528
2002	1.10	1.62	0.33	0.129069
2003	0.09	1.04	-0.13	0.466121
2004	-1.18	-0.01	-0.38	-0.52999
2005	0.36	0.43	-0.06	-0.2335
2006	1.86	-1.06	0.19	1.265587
2007	0.99	-0.92	0.47	1.627597
2008	0.35	-0.51	0.45	0.746716
2009	-0.28	-0.10	0.45	-0.12971

Positive Z-values imply there was positive impact of climate particularly rainfall on sorghum yields while negative values indicate there was adverse impact of the climate on sorghum production. Generally, there is higher frequency of negative Z-scores in Kitui County followed by Machakos. In the same period Mwingi and Makueni Counties created in 1992 have the lowest.

The trend analysis of sorghum from the four districts revealed a mixed pattern. Machakos and Makueni sorghum yield trends are declining at 6.5 and 0.93 Kg/acre per year respectively (Table 4). Kitui and Mwingi sorghum yield trends are increasing at 1.8 and 6.4 Kgs/acre per year respectively. Mwingi shows the highest rate of yield increase while Machakos reveals highest decline over the period. However, the spatial sorghum trends were not statisitcally significant at 5 per cent level except for Kitui District.

3.4 Association between sorghum yields and climate parameters

The correlations between rainfall characteristics and sorghum yield was used to estimate the effect of the weather/climate on sorghum yields. The findings shows that ONDJ rainfall and Kitui sorghum yield had the strongest (significant) positive correlation value with sorghum yield (0. 762). Generally, all ONDJ season had higher positive correlation values than MAMJ season all the weather station, except for Makueni. This indicates that the ONDJ season is the main season favourable for sorghum production in lower eastern Kenya than the MAMJ season. The lowest correlation values between sorghum and rainfall are observed in Mwingi. Maximum and minimum seasonal temperatures appears to have an adverse effect on sorghum yields in all the four counties over the period. Generally, the correlation values between seasonal maximum and minimum temperatures and sorghum yield have negative values (Table 6). All the correlation values between sorghum yield and minimum temperature are higher than with maximum temperature, suggesting that minimum temperature has more adverse impacts than maximum temperature on sorghum yields in lower eastern Kenya.

Table 6: Correlation values of sorghum with MAMJ and ONDJ growing seasons by county, Kenya

County/District	MAMJ	ONDJ	Max-temp	Min-temp
Machakos	0.015	0.33	0.08	-0.53*
Makueni	0.48*	0.26	0.07	-0.55**
Mwingi	0.16	0.16	-0.22	-0.35
Kitui	0.19	0.76**	-0.04	-0.63*

(Source: Researcher, 2019)

4 Discussions

The sought to examine the variability of sorghum yields in response to climate and weather in the lower eastern Kenya districts/counties. The findings have shown that the seasonal rainfall, daily maximum and minimum temperatures and evapotranspiration, used as climate variables, have wide-ranging temporal and spatial variations. The average seasonal rainfall is ranging from 180 – 270 mm for MAMJ while its 400 – 600 mm for ONDJ. This indicates that the October-December season is more reliable that the March-May season as it experiences higher precipitation. Evidently, there is considerable seasonal rainfall variability with higher CV values for ONDJ than MAMJ season. This implies that rainfall variability during the main growing season i.e. ODNJ is higher than the second growing season of MAMJ. Further analysis of temperatures indicated the region is warming at the rate of up to 0.03 ^{0}C. The warming and high evapotranspiration together with variability in season-to-season rainfall distribution has a strong impact on length of growing season, seed germination, grain filling and food security in the entire lower eastern Kenya (Omoyo, *et al.*, 2015 and Thornton *et al.,* 2007). Kitui County appears to be suffering the highest climatic variations while Machakos had the lowest. Generally, the rainfall CV values for ONDJ are higher than the MAMJ suggesting the season is quite unpredictable and require more planning by smallholder farmers. In lower eastern Kenya, ONDJ is the main growing season (Jaetzold, 2007). The observed high variability of the main season rainfall has serious implications on farming of the food crops such sorghum.

Rainfall onset, cessation, distribution and amount have considerable effect on crop yields and food security particularly under rain fed conditions common in lower eastern Kenya. The impact of this variability can be very momentous on crop yields especially under rainfall agriculture in the ASALs (Ayanlade**,** *et al.,* 2009; Herrero *et al.,* 2010; Omoyo *et al,* 2015). The findings suggest that the less the rainfall variability, the less sorghum yield anomalies thus the more reliable the rain is for sorghum production.

Correlation of sorghum yields with the rainfall had positive values in all the counties implying that rainfall has positive effect on sorghum production. For instance, the correlation ONDJ rainfall with the Kitui sorghum yield was 0.762 suggesting that nearly 76 % of the yield variations are accounted by rainfall. Markedly there was stronger negative correlation between mean minimum temperature than with maximum temperature and the sorghum yields. This implies that lower temperatures are unfavourable for sorghum production, thus sorghum varieties cultivated are more tolerant to heat than cooler temperatures.

Machakos had the highest mean yield (mean =1721.8 Kg/Ha), while Mwingi had the lowest (mean = 1030 Kg/Ha). Kitui County had lowest mean sorghum yield 44.5 Kg/Ha respectively (Table 3). This may imply that the higher precipitation in Machakos than the other counties is favourable to production of beans. The mean sorghum yield for the four ASAL Counties over the period was 1078 Kg/Ha. The wide sorghum yield variability in Machakos among the four ASAL districts calls for measures to examine the type of varieties being cultivated with a view of breeding better varieties that would withstand climatic shocks.

However, recent works on impact of climate variability and change on maize yields reveals that it has higher effect than on sorghum, suggesting that sorghum is more resilient and adaptable to the harsh climatic conditions of lower eastern Kenya (Table 7 and Omoyo *et al.,* 2015. The average maize yield for the four ASAL districts over the period was 1,293.8 Kgs/Ha while for sorghum it was 933.1 Kg/Ha. With regard to yield variability of sorghum compared to maize, Kitui District had the highest variation in maize yields with SD of 1029.6 Kgs/Ha and CV of 78.3% while the highest variation of sorghum yields is observed in Kitui with SD of 246.5 Kg/Ha and CV (%) value of 60.5. Generally maize exhibits highest variability in yield (ranging up to 40 CVs) compared to sorghum (ranging 15% CV) in the four districts/counties (Table 7). Generally, the findings show there has been higher variability of maize compared to sorghum yields in the four districts over the period. This clearly demonstrates high possibility of higher maize failure than sorghum in the lower eastern semi-arid region of Kenya.

Table 7: Sorghum versus maize yield variability (Kgs/Acre) in lower Eastern Kenya

	Sorghum descriptive summary			Maize descriptive summary		
County	Mean	S.D	CV (%)	Mean	S.D	CV (%)
Machakos	407.7	246.5	60.5	688.7	246.5	41.9
Makueni	380.1	136.4	35.9	508.0	264.0	52.0
Kitui	370.2	143.4	38.7	547.8	429.0	78.3
Mwingi	397.2	198.7	50.0	411.8	244.8	59.4
Average	388.8	181.2	46.3	539.1	296.1	58.0

Years are in brackets. (Source, Omoyo, *et al.,* 2015)

The results appear to support the earlier views held by Thornton *et al.,* 2008 and Ayanlade, *et al.,* 2009 that a changing climate will lead to fluctuations in crop yields and thus food insecurity. Within the ASALs, which are more dependent on rain-fed agriculture variable rains, increasing temperatures and high evapotranspiration will continue to adversely affect sorghum yields hence food insecurity. For instance, Thornton *et al.,* 2009 and Omoyo *et al.,* 2015 had demonstrated that crop yields in Africa at lower altitudes is likely to fall by 20-50 % because of drying and warming as a result of climate change. Furthermore, most recent climate predictions of future green house gas-induced climate change clearly suggest that this warming will continue rising under most scenarios such that in Africa up to the end of the century (Abegunde *et al.*,2019) From our study its accelerating up to 0.03 ^{o}C implying in 100 years it would be 3.0 ^{o}C within the range suggested by Hulme *et al.,* (2001). The high temperatures in lower highlands in Kenya will most likely increase evaporation, soil moisture and heat stress and worsen household food insecurity, hamper poverty reduction efforts. However, our study indicates that lower temperatures are more deleterious to sorghumproduction that high temperatures. With regard to crop production in the ASAL where population is rising and poverty is generally widespread small holder farmers depending on rainfed agriculture sorghum production may offer an opportunity for ehancing food security.

5. CONCLUSIONS AND RECOMMENDATIONS

These results have shown that the region is warming while failure of seasons is increasingly widespread. The findings have shown that October-December rainfall is more reliable than Marc-May seasonal rainfall. However, the October-December rainfall has higher variability than the Marc-May rainfall. Precipitation for the two seasons has shown a declining trend in the region while there is upward warning of up 0.03 ^{0}C annually. Machakos weather and climate appear to be more favourable the other districts/counties with average yield of beans highest (1721.8 Kgs/Ha) in the region. Kitui had the lowest yield variability and production per unit area. These findings have clearly indicated that seasonal rainfall, maximum temperature and maximum temperature have profound effect on sorghum yields in lower eastern Kenya. The correlation absolute values between minimum temperature and crop yields are generally higher than with crop yields and rainfall. This implies that temperature (lower) has negative impact on sorghum yields than precipitation in the study area. Thus, there is need for agriculture sector, the counties and research institutions to work collaboratively to invest in research that will produce varieties that can endure cold stress to ensure the households in lower eastern Kenya are food secure.

Declaration of competing interest

The author declares there is no known competing interest or relationships that would have appeared to influence production of this work.

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