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# Effects of climate variability on maize yield in the arid and semi arid lands of lower eastern Kenya

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## Abstract

**Background:** Climate is a key input of rain-fed agriculture. Climate variability and change has been the most important determinant of crop yields in Kenya and other parts of the world. However, there has been not much research on local understanding of the effect of climate variability on maize yields in Arid and Semi arid Lands (ASALs) of lower eastern Kenya counties. The effect of three climatic parameters on maize yields on different temporal and spatial scales was evaluated in order to provide basis for maize crop monitoring and modeling.

**Results:** This paper argues that maize yields were declining at high levels in Machakos County followed by Kitui, Mwingi, and Makueni Counties. The maize yields *Z*-values and thus the effect of climate was predominately negative in the period 1994–2008 in all the counties. Rainfall trend analysis revealed that four of the six weather stations were declining up to 3 mm pa. Evidently there was upward warming of annual and seasonal temperatures at rate of 0.03 °C pa.

**Conclusion:** The study has confirmed that the arid and semi arid counties suffer from significant climate variability which has huge implications on maize yields and food security of lower eastern Kenya. Thus, to counter the adverse effects of climate change, it is necessary to climate-proof agricultural crops through adaptation strategies such as developing maize varieties that tolerate water stress and mature early, practice early planting, increase the awareness of climate change and its impacts on agriculture, and develop appropriate mitigation measures. These findings are crucial in planning appropriate adaptation mechanisms in support of enhancing resilience of maize production and food security.

**Keywords:** Climate variability and change, Maize yields, Arid and Semi Arid Lands

## Introduction

Agriculture is one of the key socio-economic activities substantially affected by climate variability and change globally [1]. The impact of weather and climate variability and change is more remarkable in the Arid and Semi Arid Lands (ASALs). The ASALs cover about 40 % of the earth's surface, which are inhabited by approximately 20 % of world population and provide 10 % of the world's meat supply [2, 3]. Africa's ASALs comprise 66 % of total land area and harbor approximately 200 million people [4]. In Kenya, the ASALs occupy more than 80 % of the country, are home to about 10 million people and approximately 70 % of the national livestock herd, and more vulnerable to climate variability and change [5–8].

Climate change and climate variability are projected to contribute to increased drought episodes, food insecurity, irreversible decline in herd sizes, and deepening poverty [9, 10]. The ASALs are inflicted by a major drought once in every 5 years resulting in widespread food insecurity, poverty, and irreversible decline in herd sizes. The constraints posed by climate change on agriculture range from pronounced seasonality of rainfall to severe and recurrent droughts. Parry *et al.* [11]) demonstrated that most of Sub-Saharan Africa (SSA) countries will experience decreased precipitation of about 20 %. Overall crop yields in many parts of Africa will fall by 10–20 % up to 2050 because of warming and drying [10]. The burden of climate change will be enormous on those already poor and food insecure particularly in the ASALs [9, 10]. Generally, extreme climatic events and

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the mean value of climate variables such as rainfall, maximum temperature, minimum temperature, potential evapotranspiration, and solar radiation influence crop yields under rain-fed conditions in many parts of the world's ASALs [1]. Evaluating the response of maize to a changing climate can provide viable options for enhancing adaptive capacity of small holder farmers in the ASLs.

As demonstrated by [12–16], crop productivity is highly dependent on climate and weather under rain-fed agriculture. Additionally, works carried out on crop-climate relationship around the globe have revealed that there is a considerable relationship between weather and climate on crop yields [9, 10, 16, 17]. In Nigeria, inter-annual rainfall variability has shown to be a major cause of stress to farming and crop production [3]. In Argentina, Podesta, *et al.* [18] demonstrated that climate variability is strongly correlated with yields of maize, sorghum, and soy beans in the Pambas, Southern Argentina, as a result of El Nino Southern Oscillation (ENSO). The interaction between increase in temperature and precipitation as a result of climate change is likely result in the loss of arable land due to decreased soil moisture, increased aridity, increased salinity, and ground water depletion [19]. Overall, crop yields in Africa are projected to fall by 10–20 % to 2050 because of warming and drying, but there are places where yield losses may be much more severe, as well as areas where crop yields may increase [20]. There is a need to determine how changing climate parameters plays a critical role in yields of maize in lower eastern Kenya's ASALs to guide agricultural planning and enhance adaptive capacity of small holder farmers.

Bergamaschi [9] and IPCC [21] verified that climatic hazards are exacerbated by climate change which is a key determinant of crop yields. The principal climatic hazard in the ASALs being drought has caused considerable reduction in crop yields due to climate variability and change [21, 22]. Most of the droughts exhibit such characteristics as false and late onset of the rains, pronounced breaks during the rainy season, and early cessation of the rains, leading to drastic alterations in the pattern of seasonal rainfall distribution [23–25]. The irregular distribution of rainfall, during the crop cycle, may explain a lot of the crop yield variability attributed to the growing conditions.

Maize is the most important and widely consumed food crop in Kenya. It is the staple food crop for 96 % of the population with 125 kg per capita consumption and provides 40 % of the calorie requirements in Kenya [26]. Recent reports reveal that total crop failure has been realized owing to severe drought and associated risks [10, 22]. Within Kenya's ASAL, the potential mean maize yield is a meager 1.1 t ha$^{-1}$ [22]. Analysis of trends in maize production reveals that the country is not self-sufficient due to low adoption of technologies, high incidence of pests and diseases, and unfavorable climatic conditions [27]. The precarious situation has adversely affected poor rural households who divert their little household incomes to purchase maize.

The relationship between maize yield and climate variables has been demonstrated by Bergamaschi *et al.* [28]) and Berlato *et al.* [18]. The findings revealed that maize plants tend to experience extreme sensitivity to water deficit, during a very short critical period, from flowering to the beginning of the grain-filling phase [18, 28]. Maize crops tend to have the highest water requirement during the critical period, when the maximum leaf area index combines with the highest evaporative demand [29]. Thus, maize crop is very sensitive to water deficit during its critical period (flowering to beginning of grain filling) for two reasons: high water requirement, in terms of evapotranspiration; and high physiological sensitivity when determining its main yield components such as the number of ears per plant and number of kernels per ear.

Maize has shown to be most sensitive to environmental stresses in the period of bracketing to flowering [4, 30]. Runge and Hons [31] and Thompson [32] evaluated long-term experiments under constant or mean management using regression techniques and concluded that yield in the US Corn Belt was highly correlated with water at flowering. Of the likely environmental stresses, water deficit is also a prime candidate owing to the combination of shallow soils and erratic summer rainfall [33].

In lower eastern Kenya, there is generally high variability of rainfall amidst rising temperatures that tend to increase evapotranspiration. The rainfall has been characterized by pronounced variability from year to year and place to place. Onset, cessation, and length of growing season seem to be unpredictable in recent decades. Duration of the main and second growing seasons has been affected with serious repercussions of the residents as it seriously undermines efforts of households, organizations, and county governments in this ASAL region. The food security status of the residents has gradually worsened in recent past. Previous studies have focused on rainfall variability and determining rainfall onset and cessation but have not related the effect of climate variables on maize yields and thus food security in the four counties. It is against this background this study focuses on examining selected climate variables and their impacts on maize yields. Specifically, the study sought to determine the effect of weather and climate variability on maize yields in lower eastern Kenya's dry lands for the period 1979–2009.

The following were the specific objectives:

- To demonstrate evidence of climate variability and change in lower eastern Kenya

- To provide the trend of maize yield production in lower eastern Kenya under climate variability associated with climate change phenomena
- To recommend adaptation strategies as mitigation measures for improving food security

## Materials and methods

### Study site

This study was carried out in the four ASAL Counties of lower eastern Kenya (Fig. 1). The Counties were Makueni, Machakos, Kitui, and Mwingi. The altitude of the area varies from 600 to 1100 m above sea level [22]. The mean annual rainfall, evaporation, and temperatures are in the order of 600 and 1150 mm and 28 °C, respectively. The main agro ecological zones (AEZs) in lower eastern Kenya Counties are the following: 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 [22].

A block diagram of the approach 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 maize yield time series acting as the dependent variable and climate-independent variable. The climate parameters used were rainfall onset, seasonal rain, annual rainfall, potential evapotranspiration, and temperature. The choice of maize crop was based on its importance both in the local diet in lower eastern Kenya and their widespread cultivation throughout Kenya. The four Counties 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 frequently suffers from drought. 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).

### 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 climate data from Kenya Meteorological Department (KMD). Maize 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 maize yield. We computed the correlation matrix to obtain redundancy of the data. Maize yield was plotted against time to establish the trend. Detrended maize yields were plotted against each variable from the PCA process to determine the strength of the correlation.

### Determination of variations in rainfall

We used two approaches to determine the association between climate variability and maize yields: $Z$-scores to

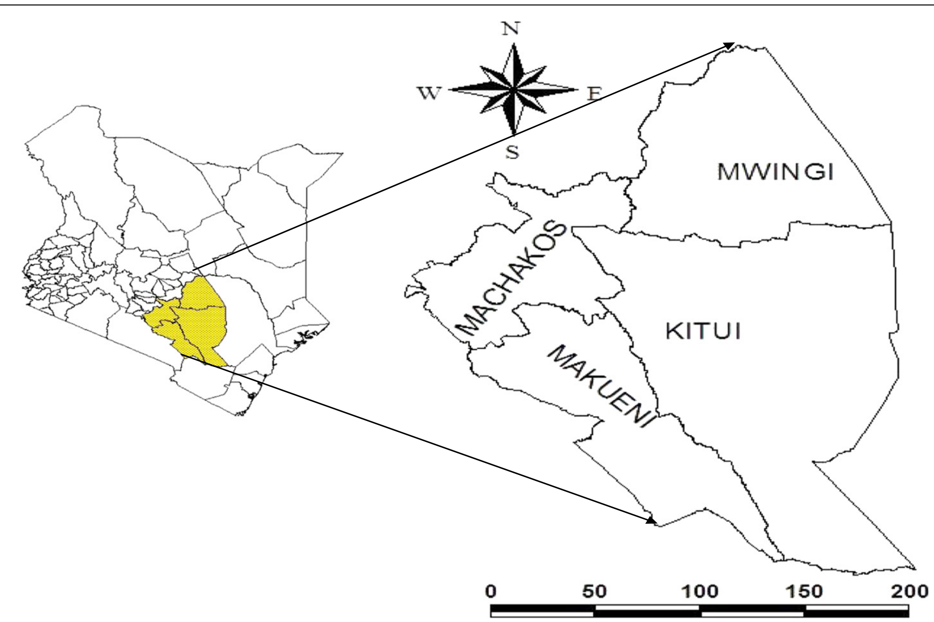


**Fig. 1** Map of study counties extracted from Kenya map

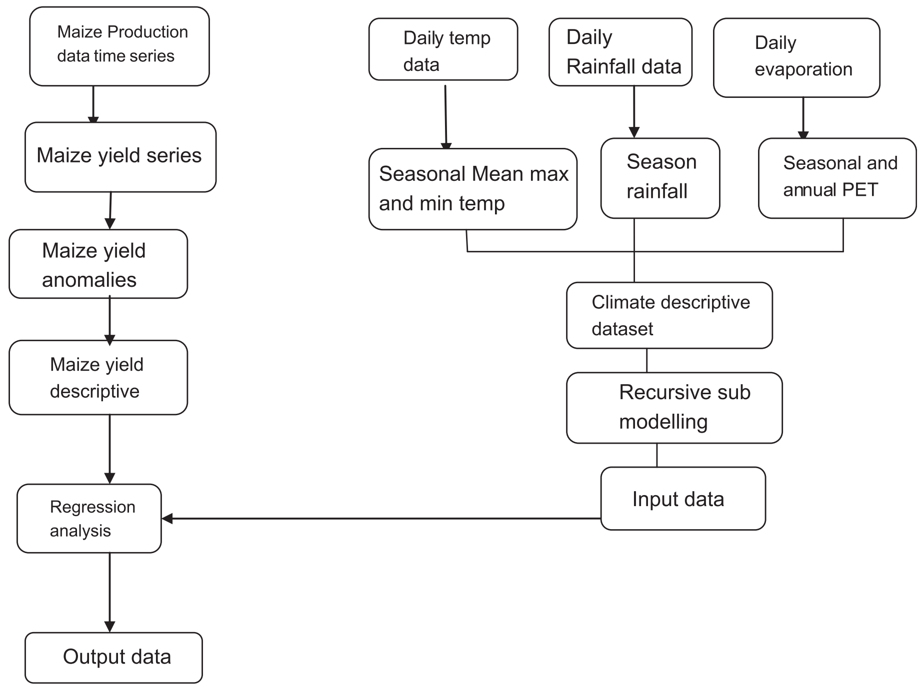


**Fig. 2** Block diagram of the methods used in relation to climate and weather data, crop data, and the crop model

evaluate the impact of climate parameters on maize yields and simple crop modeling techniques by use of regression. Statistical models are simple technique for analyzing and forecasting crop yields, in which historical data on crop yields and weather are used to calibrate relatively simple regression equations [34]. 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 maize and climate anomalies. Associations between maize yields and weather/climate were explored by use of regression 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 is ODNJ while the second growing season is MAMJ. The trend line equation $y$ = aX + $b$ + $e$ was used to describe the changes in rainfall where "y" represents the rainfall amount in millimeters, "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 that is another important parameter that influences crop yields [15]. In addition we normalized the rainfall data to yield rainfall anomalies for the two seasons.

Rainfall onset and cessation was determined by use of the number of rainy days [15] and compared with percentage cumulative mean rainfall model. 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 3 days was at least 20 mm and was not followed by a dry spell of 10 consecutive dry days in the following 30 days [35]. We used Machakos weather station to demonstrate rainfall variability as it had adequate daily data.

### 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 °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 analyze its trend. Temperature was measured in degree Celsius (°C).

### 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 millimeters, "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 analyze its trend. Evaporation was measured in degree Celsius (°C). Pan evaporation method was used to compute potential evapotranspiration [36].

### Determination of maize yield anomalies, CV (%) and associations with climate variables

We obtained maize yield data from the Ministry Agriculture records for the period 1979–2009 for the four ASAL Counties of lower eastern. However, for Makueni and Mwingi Counties, the maize records were for the period 1993–2009 when the two counties were created. Maize yield was measured in kilograms per hectare (kg/ha). Maize 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 maize yield is above the mean. Positive score shows data is above the mean, while negative score shows data is below the mean. Negative maize 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 from +3 to −3. Thus, the higher the values of maize yield anomaly, the higher the impact of the climate.

We utilized Coefficient of Variation (CV) to further analyze the variations of maize yield in response to the climate variables. Coefficient of variation (CV) is a ratio of SD to the mean of the maize yield time series. The yield was established as the ratio of total production to the harvested area. The classic regression approach was used to establish the relationship between the maize 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 colinearity, especially among solar radiation, temperature, and sunshine hours.

## Results

### Variations in rainfall onset and cessation

From the analysis, the earliest onset date of main growing season rainfall is 2 October 1983, while the latest is on 10 December 2002. The mean onset date for main growing season is 10 October, while the latest onset date is 10 December 2003 (Fig. 3). The earliest onset of

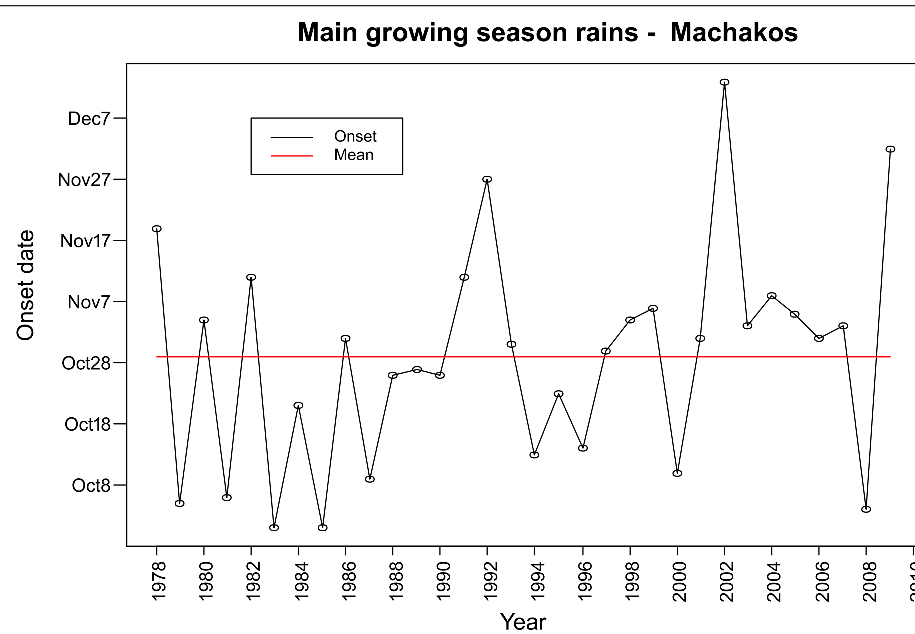


**Fig. 3** Machakos weather station variations in rainfall onset for main growing season (1979–2009), Kenya. The main season starts from October and ends around January. The mean rainfall onset for the main growing season is on 28 October while the earliest onset date is 5 October 1983

second growing season rainfall is 5 March 1989, while the latest is 30 May 2006. The mean onset date for the second growing season rainfall is on 7 April (Fig. 4). There was failure of the growing season rains in 12 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 10 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.

### Variations in growing season rainfall

Descriptive statistics shown in Table 1 indicate that the March-June mean rainfall is higher than October-November in all the weather stations. 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-January growing season, the wettest station was Mutomo with 601.6 while Machakos is the driest 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). Mutomo MAMJ had the highest variability (CV = 68.1 %), 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 195.5–273.8 mm for MAMJ and 371–601 mm for ONDJ. Kitui ONDJ season had the highest CV (61.4 %) while Machakos had the lowest (CV = 51 %).

Regression lines were fitted to determine evidence of trends in rainfall totals but all were not 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). However, the trend was not significant. 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.

### Annual and seasonal temperature patterns and trends

Seasonal and annual maximum and minimum temperature revealed wide variability. Analysis of growing season (October-January) maximum temperature for Makindu reveals upward warming at the rate of up to 0.03 °C pa. Machakos station analysis indicates that it is warming at a slightly lower rate of 0.017 °C (Fig. 5). Similarly, potential evapotranspiration is increasing at a rate of 0.02 mm pa (Fig. 6). A substantial part of maize yields

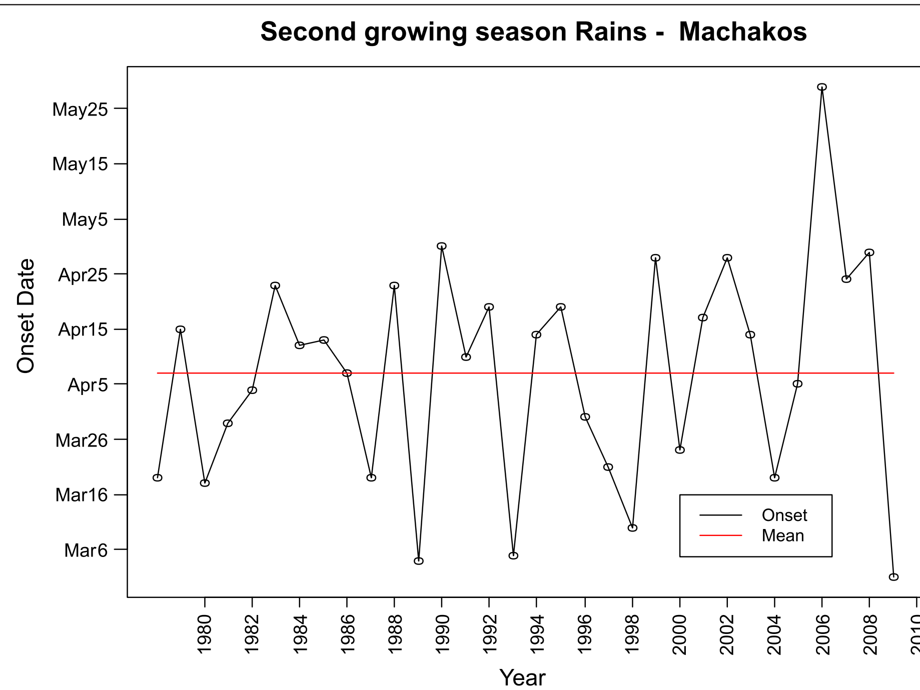


**Fig. 4** Rainfall onset and cessation for the first rainy season in Machakos (1979–2009), lower Eastern Kenya. The rainfall onset was computed from daily rainfall data by use of Instat statistical software. Mean onset for second growing season is on 7 April

**Table 1** Growing season rainfall descriptive for lower eastern Kenya. The data is for six weather stations. The rain 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) |
| Mutomo | 563.0 (1990) | 1182 (1992) | 16.0 (1993) | 226 (1983) | 229.3 | 601.6 | 155.8 (56.9) | 335.3 (90.4) |
| 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) |

can be explained by temperature increases at lower elevations as a result of heat stress and increased evaporation such as lower eastern Kenya.

### Maize yield descriptives, Z-scores and coefficient of variation (CV)

Table 3 shows maize yield descriptive summary with the highest mean yield in Machakos (mean = 1721.8 kg/ha), followed by Kitui County (mean = 1370 kg/ha), and Makueni is 1270.1 kg/ha, while Mwingi was the lowest (mean = 1030 kg/ha). Kitui County had both the highest and lowest mean maize yield over the period at 4830 and 44.5 kg/ha, respectively (Table 3). The mean maize yield for the four ASAL counties over the period was 1078 kg/ha. Kitui County had the highest variation in maize yields with a standard deviation of 1072 kg/ha (CV = 78.3 %), while Machakos had the lowest variation with a standard deviation of 616 kg/ha (CV = 42 %) over the period (Table 3). Student's one-sample $t$ test of mean maize yields time series revealed that they were not statistically significant at 0.05 % level.

**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 | 11,869 | 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 | 19,002 | 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 | −10,693 | 0.047 | 0.24 | Positive |
| Mwingi | Annual | 4.67 | −8639 | 0.003 | 0.672 | Positive |
| Kitui | MAMJ | −5.06 | 10,300 | 0.078 | 0.203 | Negative |
| Kitui | ONDJ | −10.5 | 21,335 | 0.112 | 0.127 | Negative |
| Kitui | Annual | −14.37 | 29,374 | 0.152 | 0.072 | Negative |

Maize yields Z-distribution is varying in magnitude between −1.5 and + 2.2 in all the four ASAL counties (Table 3). The observed Machakos County maize yield for 2007 represented the lowest yield anomaly ($Z$ = −1.5). Mwingi County maize yield had the highest anomaly in 1993 ($Z$ = +1.7) (Table 3). Evidently, Machakos County has 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 Counties maize yield was realized in 1993. In 2009, Makueni County had the highest negative impact ($Z$ = −1.5). Mwingi maize yields $Z$-scores shows positive scores for the period 2000–2004, and then the period 2005–2009, all $Z$-values are negative. Positive Z-values imply that there has been affirmative impact of climate particularly rainfall on maize yields. On the other hand, negative $Z$-score indicates negative impacts of climate on the yields. Evidently, there is higher

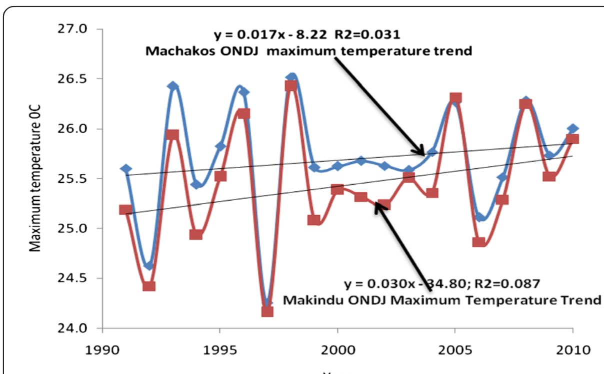


**Fig. 5** Seasonal maximum temperature trend line for lower eastern Kenya. The data used was for Machakos and Makindu weather stations found in lower eastern Kenya. Both trend lines indicate that there is warming up to 0.03$^0$ C of the area

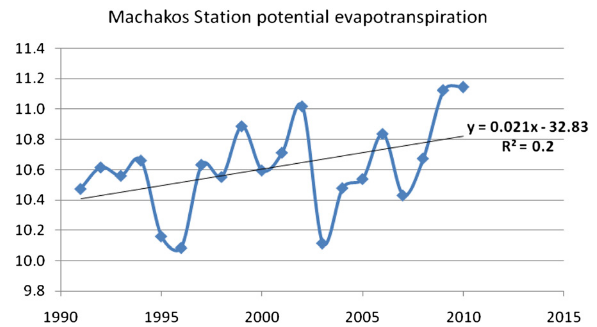


**Fig. 6** Potential evaporation trend for Machakos weather station (1991–2009)

frequency of negative *Z*-score in Kitui County followed by Machakos. In the same period, Mwingi and Makueni Counties created in 1992 have the lowest.

Mwingi County emerged with the highest magnitude of maize yield *Z*-score of +2.2 in 2002 while Machakos County had the lowest *Z*-value of −1.5 in 2007 (Table 4). Noticeably all the four ASAL Counties have distinctively negative *Z*-scores in 1996, 1998, 1999, 2004, 2005, 2006, and 2007 (Table 4). The year 2005 had the lowest (negative) *Z*-values in all the counties. This is also the year when the rainfall for the main growing season of October-November-December-January (ODNJ) had a high magnitude of negative anomaly (Fig. 2). This implies that the climate had the worst impact on maize yields in year 2005. Analysis of maize yield trends revealed that all were negative in the four counties with Machakos having the highest trend (58.5 kg/ha) while Mwingi had the lowest (18.2 kg/ha) (Table 5).

### Impact of climate and weather variables on maize yields

The correlations between rainfall characteristics and maize yield show that ONDJ rainfall and Machakos County maize yield had the strongest (significant) positive correlation value with maize yield (0.75). Generally, all ONDJ rain had the strongest positive (significant) correlation values than MAMJ from all the weather stations. Annual rainfall had the lowest correlation values with maize yields from all the four counties with the highest correlation value of 0.6 observed with Kitui annual rainfall and Machakos maize (Table 6). The lowest correlation value between maize and ONDJ rainfall is with Kitui weather station ($r$ = 0.12). The highest correlation value between MAMJ and maize is 0.66 observed at Mwingi weather station.

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

| District | Lowest yields (kg/ha) | Highest yield (kg/ha) | Mean (kg/ha) | S.D (kg/ha) | CV (%) |
|---|---|---|---|---|---|
| Machakos | 441.3 (1998) | 4657.0 (1988) | 1721.8 | 616.2 | 41.9 |
| Makueni | 323.2 (2005) | 2750.0 (1993) | 1270.1 | 660.0 | 52.0 |
| Kitui | 44.5 (1987) | 4830.0 (1990) | 1370.0 | 1072.0 | 78.3 |
| Mwingi | 240.8 (2005) | 2475.0 (1993) | 1030.0 | 612.0 | 59.4 |
| Average | 262.5 | 3677.5 | 1078.2 | 740.2 | 68.6 |

**Table 4** Maize yield *Z*-score values for the four ASAL districts in lower eastern Kenya. Mwingi County was split from Kitui County in 1993 while Makueni County was split from Machakos County in 1992

| Year | Machakos | Kitui | Mwingi | Makueni |
|---|---|---|---|---|
| 1979 | 0.786356 | 0.575322 | | |
| 1980 | 1.235854 | 0.817523 | | |
| 1981 | 0.521948 | 0.380608 | | |
| 1982 | 1.235849 | 0.817513 | | |
| 1983 | 0.521948 | 0.380608 | | |
| 1984 | −0.18929 | 0.054856 | | |
| 1985 | −0.90051 | 0.054856 | | |
| 1986 | 0.142575 | −0.61594 | | |
| 1987 | 0.845923 | −1.32809 | | |
| 1988 | 1.182972 | 1.104854 | | |
| 1989 | 1.625137 | 1.694813 | | |
| 1990 | 0.756231 | 0.229131 | | |
| 1991 | 1.711783 | −1.23646 | | |
| 1992 | 0.331038 | 0.161554 | | 0.77773 |
| 1993 | 0.521946 | 0.547139 | 0.419806 | 2.241552 |
| 1994 | −1.19673 | −0.38961 | 0.597489 | 0.122868 |
| 1995 | −0.42994 | −0.4417 | 0.162405 | −0.67619 |
| 1996 | −1.29864 | −0.70081 | −0.57526 | −1.27456 |
| 1997 | −0.54823 | −0.49542 | −0.01675 | 1.441978 |
| 1998 | −1.39109 | −0.98219 | −0.63601 | −0.93779 |
| 1999 | −0.77473 | −0.4652 | −0.49038 | −0.56105 |
| 2000 | −0.6603 | −0.5802 | −0.37847 | 0.472081 |
| 2001 | −0.5986 | −1.25224 | −0.20612 | 0.111183 |
| 2002 | 0.184625 | 0.345585 | 0.515331 | 0.010476 |
| 2003 | −0.76637 | −0.73358 | 0.190283 | −0.92497 |
| 2004 | −1.16023 | −0.4652 | −0.47653 | −0.47019 |
| 2005 | −1.19849 | −1.04162 | −0.77353 | −1.4976 |
| 2006 | −0.17986 | −0.86408 | −0.44848 | −0.79932 |
| 2007 | −1.49532 | −0.39319 | 0.195344 | 0.138148 |
| 2008 | −0.41089 | 0.441494 | 0.388534 | 0.652542 |
| 2009 | 0.67342 | 1.276293 | 0.581184 | 1.166954 |

## Discussions

### Climate variability and change

The results have revealed that seasonal rainfall, daily maximum and minimum temperature, and potential evapotranspiration used as climate variables have wide

**Table 5** Summary of maize yield trend statistics by district in lower eastern Kenya (1979–2009)

| District | Gradient (kg/ha/year) | a-value (intercept) | $R^2$ | Sig | Remarks |
|---|---|---|---|---|---|
| Machakos | −58.5 | 47,336 | 0.12 | 0.065 | Negative trend |
| Kitui | −30.1 | 24,588 | 0.14 | 0.36 | Negative trend |
| Mwingi | −18.2 | 14,964 | 0.023 | 0.84 | Negative trend |
| Makueni | −21.8 | 17,855 | 0.031 | 0.286 | Negative trend |

variations in the entire study area. Evidently, there was higher rainfall variability during the main growing season of ODNJ than the second growing season of MAMJ. From the study, temperatures are also warming at the rate of up to 0.03 °C. Rising temperature and high evapotranspiration together with variability in season-to-season rainfall distribution have a robust impact on length of growing season, seed germination, grain filling, and food security in the entire lower eastern Kenya. Kitui County appears to be suffering the highest climatic variations while Machakos has the lowest.

Generally, rainfall onset, cessation, distribution, and amount have considerable effect on maize yields and food security particularly under rain-fed conditions common in lower eastern Kenya. Rainfall distribution and amount is of paramount importance to rain-fed agriculture prevalent in Kenya's ASALs. The impact of this variability can be very momentous on crop yields especially under rainfall agriculture in the ASALs [7, 16]. The results have shown that the less the rainfall variability, the less maize yield anomalies thus the more reliable the rain is for maize production. The results appear to support the view of [16] that higher variations in rainfall above the mean eventually leads to fluctuations in maize yields and thus food insecurity. Within the ASALs which are more dependent on rain-fed agriculture variable rains, increasing temperatures and high evapotranspiration will adversely affect maize yields. As recently demonstrated [10] maize yields in Africa at lower altitudes is likely to fall by 20–50 % because of drying and warming as a result of climate change. In many places in lower eastern Kenya recent studies have indicated that there is an increased warming and potential evapotranspiration thereby worsening stress [37]. In terms of adaptation options at household level, it means that the farmers have to turn planting drought and heat tolerant crops.

Earlier work by Hulme *et al.* [38]) on Africa Climate change 1900–2100 and recently by [7] appear to corroborate with our findings. This study used characteristics of the seven global models available at the IPCC Data Distribution center by utilizing greenhouse gas-forced integrations. Most climate predictions of future green house gas-induced climate change clearly suggest that this warming will continue and most scenarios accelerate so that on most cases Africa on mean could be between 2 and 6 °C warmer in 100-year time. From our study, it is accelerating up to 0.03 °C implying in 100 years it would be 3.0 °C within the range suggested by Hulme *et al.* [38]). The high temperatures in lower highlands in Kenya will most likely increase evaporation, soil moisture, and heat stress, worsen household food insecurity, and hamper poverty reduction efforts. With regard to crop production in the ASAL where poverty is generally widespread and small holder farmers depend on rain-fed agriculture with low adaptation strategies, the likelihood of significant loss of yields are likely to be high.

### Maize yield variability

Generally, the study has revealed high variability in maize yields in the entire region both spatially and in temporal terms. The year 2005 had the lowest (negative) *Z*-values in all the counties. This is also the year when the rainfall for the main growing season of October-November-December-January (ODNJ) had a high magnitude of negative anomaly (Fig. 2). This implies that the climate had the worst impact on maize yields in year 2005. ODNJ is the main crop growing season when most farmers plant their food crops such as maize, beans, sorghum, and pigeon peas in lower eastern [22]. High yield variability of maize which is currently the most important food crop in Kenya would imply high vulnerability of poor households to food insecurity.

These findings appear to corroborate the views of Adejuwon [13] that variability in climate has wide impacts on maize yields in southern part of Nigeria. The work revealed that the more the climate variability, the greater the *Z*-scores and the less reliable the maize yields in Southern Nigeria. These findings are also explained by Thornton *et al.* [10] on a study on spatial variation of crop yield responses to climate in East Africa region. This may call for major reversals in the way adaptation strategies are being pursued in Kenyan dry land farming.

The declining trend of maize yield in the four counties is mainly due to variable onset and seasonal rainfall, increased warming, and high potential evaporation ("Effects of climate on maize yields"). Generally increased warming has a tendency to accelerate the loss of water from soil thereby affecting maize growth from germination to vegetative growth and later grain filling. This effect can also interact with the heat stress if maize crop varieties grown are approaching their thermal maxima. It is therefore reasonable to consider the results collected in the present work that indicate that climate variability is significant in maize production in lower eastern Kenya. Declining yields and drought episodes would be one of the primary reasons why smallholder farmers in ASALs do not appear to be adopting improved farming practices as observed by Nyandiko *et al.*, (unpublished). A more reliable new

**Table 6** Correlation matrix of climate parameters and the maize yields in Machakos, Mwingi, Makueni, and Kitui districts of lower eastern Kenya

| | MCK_MAMJ | MCK_ONDJ | MCK_ANN | MAK_MAMJ | MAK_ONDJ | MAK_ANN | MTO_MAMJ | MTO_ONDJ | MTO_ANNL | KBZ_MAMJ | KBZ_ONDJ | KBZ_ANN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MACK_MY | −0.15 | 0.75[a] | 0.22 | 0.04 | 0.013 | 0.33 | 0.03 | 0.50[a] | 0.30 | −0.25 | 0.20 | 0.24 |
| MAK_MY | 0.45[a] | 0.70[a] | 0.11 | 0.10 | 0.65[a] | 0.30 | 0.03 | 0.41 | 0.12 | 0.50[a] | 0.20 | 0.32 |
| MW_MY | 0.15 | 0.02 | 0.09 | 0.31 | 0.18 | 0.14 | 0.58 | 0.22 | 0.38 | 0.18 | −0.10 | 0.24 |
| KIT_MY | 0.12 | 0.19 | 0.04 | 0.27 | 0.16 | 0.27 | 0.08 | 0.13 | 0.25 | 0.14 | 0.18 | 0.07 |

| | MWG_MAMJ | MWG_ONDJ | MWG_ANN | KITUI_MAMJ | KITUI_ONDJ | KITUI_ANN | MCK_MT | MCK_XT | MAK PET | MAK_MT | MAK-XT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MACK_MY | −0.12 | −0.05 | 0.22 | 0.11 | 0.12 | 0.60[a] | 0.16 | 0.22 | −0.30 | 0.12 | −0.74[a] |
| MAK_MY | −0.050 | 0.20 | 0.31 | −0.10 | 0.53[a] | 0.18 | 0.30 | 0.04 | −0.20 | 0.21 | −0.78[a] |
| MW_MY | 0.66[a] | 0.15 | 0.09 | 0.56[a] | 0.26 | 0.44 | −0.12 | −0.03 | −0.10 | −0.32 | −0.53[a] |
| KIT_MY | 0.21 | 0.06 | 0.07 | 0.36 | 0.35 | 0.30 | −0.04 | −0.28 | −0.44 | −0.10 | −0.60[a] |

*MACK _MY* Machakos Maize yields, *MAK_MY* Makueni Maize Yield, *MW_MY* Mwingi County maize yield, *KIT_MY* Kitui County maize yield, *MCK_MAMJ* Machakos March-July rainfall, *MCK_ODNJ* Machakos October-January rainfall, *MCK_ANN* Machakos annual, *MCK_MT* Machakos is minimum temperature, *MCK_XT* Machakos maximum temperature. The other subsequent acronyms follow same interpretation

[a]Indicates significant at 0.05 level

harvest would give farmers the confidence to adopt new technologies.

### Effect of climate on maize yields

Analysis of $Z$-score distribution for maize was used to demonstrate the impact of rainfall on maize yields in the study area. Generally, the impacts are enormous with highest in Kitui county recording 20 negative impacts out of the 31 years followed by Machakos County with 19 negative impacts out of 31 years suffering negative. Mwingi and Makueni Counties which were created in 1992 have 9 and 10 negative $Z$-scores. The frequency of negative impacts over the three decades appears to be increasing from 1990s up to 2008 reflecting the intensity of climate change in lower eastern Kenya. A number of scientists have hypothesized that climate variability and change will adversely affect the yield of crops such as maize in the ASALs. These findings appear to confirm the view of [10, 37] that there will be substantial reduction in cereal production of up 30 % in developing countries as a result of climate change under all special report on emission scenarios (SRES). The changes in crop yields in Africa will be as a result of interactions among temperature, rainfall, and adaptation strategies with benefits from $CO_2$ fertilization canceling out as suggested by [37].

Correlation analysis of maize yield from the four counties was computed against the climate variables. Markedly, there was a very strong negative correlation between mean maximum temperature and maize yields in lower Kenya (Table 6). The correlation between Makindu mean maximum temperature and Machakos County maize yields showed a strong negative relationship ($r$ = −0.74) significant at 0.05 %. The correlation values between Makindu mean maximum temperature and Makueni maize yield is strong but negative ($r$ = −0.78) significant at 0.05 %. This implies that maximum temperature accounts for nearly 60 % of variations in maize yields. Given that there is upward warming of the region by up to 0.03 °C annually and declining rainfall amount, this could suggest increased risk of crop failure in Kenya's ASALs.

The findings have shown that the highest proportion of yield variability is determined by Makueni maximum temperature ($R^2$ = 62 %) followed by Machakos seasonal ONDJ rainfall ($R^2$ = 56 %) (Table 6). Evidently, the maximum temperature has higher effect on maize yields than rainfall, implying the varieties cultivated would be approaching their thermal maxima. The findings appear to corroborate work by Adamgbe and Ujoh [39]) who demonstrated that high rainfall variability had an effect on maize yield variability in Benue State, Nigeria. The higher correlation values of ONDJ seasonal rain with maize indicates that the October-January seasonal had the greatest influence on yields compared to annual and the seasonal March-July to rain in this study. Trend analysis showed that maize yields were declining in all the counties over the period 1979–2009 but were not statistically significant when fitted with regression models.

Usually, there are two major ways by which rainfall variability influences maize yields. First is that the effect of a given rainfall variable is modified by the other. That is daily, seasonal, and annual variations in rainfall are greatly important in determining the efficiency of maize development. Secondly, in considering the rainfall requirement for any crop to grow, the microclimate immediately around the crop is vital. Water condition within the soil where germination takes place and very close to the ground where the crop growth is of higher significance determines crop performance [16]. It is very clear that rainfall of growing months also determines whether maize seed will germinate or not. This is because there is a reversible moisture sensitive block to germination that prevents germination in drying soils [16, 40], and therefore, seeds tend to germinate following rainfall patterns. In the absence of subsequent rain, only a brief opportunity for the completion of germination and seedling growth may be presented before the surface soil layers dry again, but the seeds/seedlings usually adapt to this.

It is imperative to note that the instability in the yield of maize has major consequences on population in the study area. Many poor and vulnerable people and most undernourished households in ASALs of lower eastern Kenya depend on cereal (most especially, maize) as a principal source of food and nutrition [27]. In fact, these farm households value maize because it produces large quantities of dietary energy and has stable yields under conditions in which other crops may fail [1]. Maize is high-yielding, easy to process and cook, readily digestible, and costs less than other cereals. Every part of maize has an important use and the people of lower eastern Kenya consume starchy maize in a wide variety of porridges, sacootashes, *Ugali*, grits, and green maize. Green maize is eaten roasted, baked, or boiled and plays an important role in filling the hunger gaps during drought [16].

It is quite remarkable that maize yields in the past few decades have been varying and is closely associated with climate variability. Thus, from all the analysis, tables, and figures, it is clear that the variations in rainfall, temperature, and evaporation tend to have remarkable effect on maize yields in the entire study area over the period 1979–2009 and subsequently astounding impacts on the population. This finding is in line with results of other authors like Jones and Thornton [20], Nyoro *et al.* [27]), Ayanlade *et al.* [10, 16]), and [39]. There is a great variety of possible adaptive responses available to deal with climate variability. These include technological options (such as more drought-tolerant crops), behavioral responses (such as changes in dietary choice), managerial changes (such as different livestock feeding practices), and policy options (such as planning regulations and infrastructural development) [10].

## Conclusions and recommendations

The study has shown that there is wide variability in onset and cessation of growing seasonal rainfall with a negative trend for Machakos, Makindu, Kibwezi, and Kitui stations, while it is positive in Mutomo and Mwingi stations. There is upward rising of temperature in Machakos and Makindu stations which has huge implications in soil moisture, potential evapotranspiration, and heat stress on crops. Consequently, the variations in climate have had enormous impacts on maize yields. Machakos, Kitui, and Makueni reveal drastic decline of maize yields of up to 15 kg/acre per year with $Z$-values predominately negative.

Wide variability in $Z$-values reflects enormous impacts of climate variables on maize with variability in maize yields closely related to Machakos weather station's October-January rainfall. Relationship between maize and rainfall was positive and negative, respectively, and was statistically significant. Maize yield has a pronounced declining negative trend in all the four counties of lower eastern Kenya. Makueni County had the highest magnitude of negative $Z$-scores implying that the climate had the highest impact on maize yield in the county followed by Kitui County. Mwingi County had the lowest $Z$-scores implying that the climate impacts were least on maize yields in the county. To ensure the effect of climate variability and change is reduced and maize yield is enhanced, the following has been recommended:

- The KMD should provide forecasts of onset and cessation of growing season in lower eastern Kenya. At present, the weather forecast in Kenya is usually for a period of 3 months. The forecast has not been able to give precise rainfall onset, cessation, and its impact on crop yields. This information could guide farmers, agriculture extension officers, and maize breeders on the type of adaption strategies to initiate and to enhance maize yields and enhance food security in Kenya;
- The national and county governments should sensitize farmers on climate/weather variability and monitoring of crop-climate relationship in the area in other to achieve improved crop yield;
- Irrigation to supplement crop water requirements should be promoted in ASALs;
- In view of high correlation and maximum temperature, maize that is tolerant to heat stress should be bred for farmers in the ASALs.

### Abbreviations

AEZ: Agro ecological zone; ASAL: Arid and Semi Arid Lands; CV: Coefficient of variation; ENSO: El Nino Southern Oscillation; FAO: Food and Agriculture Organization of the United Nations; IITA: International Institute of Tropical Agriculture; IPCC: Intergovernmental Panel on Climate Change; KIT_MY: Kitui County maize yield; KMD: Kenya Meteorological Organization; MACK_MY: Machakos maize yields; MAK_MY: Makueni maize yield; MAMJ: March-April-May-June; MCK_ANN: Machakos annual rainfall; MCK_ODNJ: Machakos October-January rainfall; MCK_MAMJ: Mchakos March-July rainfall; MCK_MT: Machakos is minimum temperature; MCK_XT: Machakos maximum temperature; MW_MY: Mwingi County maize yield; ODNJ: October-November-December-January; PCA: Principal component analysis; SRES: Special report on emissions scenarios; SSA: Sub-Saharan Africa; UNSO: Office to combat drought and desertification of United Nations.

### Competing interests

The authors declare that they have no competing interests.

### Authors' contributions

NNO conceived this study, conducted the bibliographic analysis, supported data collection, and developed the initial content of this manuscript. JW and SO performed the statistical analysis and contributed to the enhancement of the framework and writing of the article. All authors reviewed and approved the manuscript.

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