The Nature of Drought and Influence on Cereal Yields in Makueni County, Kenya

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Abstract

Increasing frequency and severity of drought is a major challenge to rain-fed cereal production and productivity hence food insecurity in Arid and Semi-Arid Lands (ASALs). Further, the location of Kenya along the equator, Indian Ocean coastline and widespread ASALs that cover 80% of the country, significantly increase vulnerability of the smallholder cereal farmers to frequent and severe droughts. The increase in severity and frequency of droughts have resulted in food supply gap and famine-related deaths in the past three decades despite drought management efforts by the Government of Kenya (GoK). The objective of this study was to establish the nature and effects of drought on cereal yields in Makueni County between 1990 and 2020. The study adopted Explanatory Sequential Mixed Methods Research Design. Rainfall data was obtained from Kenya Meteorological Department (KMD) for Makindu and Dwa Sisal Estate meteorological stations. Gridded rainfall data was also obtained from KMD for Kathonzweni and Salama meteorological stations. Standardized Precipitation Index (SPI) was used to establish the nature of drought while Pearson's *r* correlation analysis was conducted on rainfall and cereal yields. A survey on cereal farmers was also conducted to find out the cereal yield levels. The study established erratic, unpredictable and fluctuating rainfall patterns accompanied by 2 severe droughts, 1 moderate, 2 mild and 18 near-normal drought episodes. Frequent droughts in Makueni County resulted in low cereal yields where 43%, 42% and 60% of the cereal farmers produced between 1 to 10 bags of sorghum, finger millet and maize respectively. Information and data generated by the study is expected to result in better understanding of nature and effects of drought in Makueni County. This will enable achievement of the objectives of GoK and County Government of Makueni (CGoM) on improving adaptive capacity of the smallholder cereal farmers.

Key Words: ASALs, Drought

1. INTRODUCTION

Drought is a prolonged period of limited precipitation that is statistically below the seasonal or annual means recorded in a given region (Chivangulula *et al.*, 2023; Tsige *et al.,* 2019). Drought indicators include variation in climatic conditions which results in a deficit in rainfall and high temperatures hence low moisture in soils and low water levels in hydrological systems. Drought contributes largely to soil degradation, loss of biodiversity and reduced productivity of ecosystems. Drought also leads to water stress in Arid and Semi-Arid Lands (ASALs) thereby influencing rain-fed cereal production, leading to poverty, and famine-related deaths.

An increase in frequency and severity of droughts was recorded in various parts of the world where 52 global mega-droughts were established between 1951 to 2016 (Spinoni *et al*., 2019); resulting in aridity and desertification. Africa experienced frequent and almost decadal droughts in 1910s, 1940s, 1960s, 1970s, 1980s, and 1990s (Masih *et al*., 2014). The frequent droughts have contributed to the increase in aridity where approximately 16% of the land globally is ASAL (African Enterprise Challenge Fund [AECF] & NIRAS, 2021) while 43% of land in Africa is ASAL (Mabhuye *et al*., 2015).

Several drought episodes were experienced in the Horn of Africa (HoA) in 1980s, 2000s, and 2010s while Central parts of East Africa experienced severe drought in 2003 (Haile *et al*., 2019; Masih *et al*., 2014). These droughts significantly affected cereal yields despite the rapid annual increase in demand thereby making the continent food insecure.

According to Haile *et al*. (2019), over ten severe droughts were recorded in East Africa since 1970s whereby Kenya recorded droughts in 2010, 2011, and 2012. Further, increased drought severity and frequency significantly affected cereal yields hence food insecurity in Kenya (Mutua *et al*., 2016; Nyangena, 2020). Furthermore, Kenya experienced a reduced drought return period from five to three years during which the 1999-2000 La Niña droughts were indicated as the most severe in the last 50 years (Karanja, 2013).

According to Ghebrezgabher *et al*. (2016), Nyaoro *et al*. (2016), Ondiko and Karanja (2021) and Venton (2018), droughts occurred in all the decades since 1900 while severe droughts were experienced in Kenya in 1930s, 1940s, 1950s 1980s, 1990s and 2000s. The studies also indicated that the periodic droughts ranged from mild to severe; mostly affecting North-eastern, Coast, Nyanza, parts of North Rift Valley and Western and Eastern parts of the country. Numerous drought events were also identified as more severe where ASALs such as Makueni County were most affected. The increase in frequency and severity of droughts have heightened the unpredictability of the events hence increasing the vulnerability of the smallholder cereal farmers in the face of food insecurity in ASALs in Kenya.

Drought leads to significant fluctuations in cereal production. Besides, worrying projections between 10% to 20% maize yield reductions by 2050 have also been linked to frequent droughts (Omoyo *et al*., 2015). These significant fluctuations in cereal yields due to droughts are a major concern to the Government of Kenya (GoK), the County Government of Makueni (CGoM), smallholder cereal farmers and stakeholders in the agricultural sector in Makueni County which is a drought risk ASAL in Kenya.

The GoK and CGoM implemented the Kenya Cereal Enhancement Programme – Climate Resilient Agricultural Livelihood (KCEP-CRAL) which was effective from 2014 to 2022, in Makueni County through the Ministry of Agriculture (MA) (Food and Agriculture Organization of the United Nations [FAO], 2015; GoK, 2016). The main objectives of KCEP-CRAL were to contribute towards increasing productivity and profitability of key cereals - maize, sorghum, and millet, and associated pulses hence potentially improving national food security and smallholder income generation by supporting farmers in both medium- and high-potential cereal production areas in Kenya.

This article focused on drought-tolerant cereals such as sorghum, finger millet and dryland maize varieties. These cereals were chosen for this study due to their adaptability to varied Agro-Ecological Zones (AEZs) including ASALs such as Makueni County and because they are staple foods in the region. They were also chosen due to their nutritious nature and multipurpose uses including livestock feed and source of energy among other uses (Handschuch, 2014).

Sorghum and finger millet were also chosen for the study due to their autonomous adaptability to drought conditions, C_4 photosynthetic nature and high genetic variability (Belete, 2020; Borell *et al*., 2014; Crutchfield, 2017; Omoyo *et al*., 2015; Ranum *et al*., 2014; Tigchelaar *et al*., 2017). The cereals were also popular among communities in ASALs such as Makueni County. Furthermore, finger millet was also chosen for this study due to its disease-preventive health benefits (Saleh *et al*., 2013). Therefore, these cereals were regarded as having the potential of improving food security and nutrition in Makueni County.

2. Materials and Methods

2.1 Study Area

This study was conducted in Makueni County which is located 200 kilometres (km) Southeast of Nairobi city, Kenya. The County is located between latitudes 1^0 35' and 3^0 00'S and between longitudes 37^0 10' and 38^0 30'E (Figure 1). The County is bordered by Machakos County to the North, Kitui County to the Northeast and East, Kajiado County to the West and Southwest and Taita Taveta County to the South. Makueni County has a surface area of 8,177 square kilometres (km^2) (Kenya National Bureau of Statistics [KNBS], 2019). The County has six Sub-Counties namely: Mbooni, Kilome, Kaiti, Makueni, Kibwezi West, and Kibwezi East (KNBS, 2019). The sample study sites were Kibwezi West, Kibwezi East, Makueni and Kilome sub-Counties. Makueni County was purposively sampled for the study due to climatic and socio-economic factors.

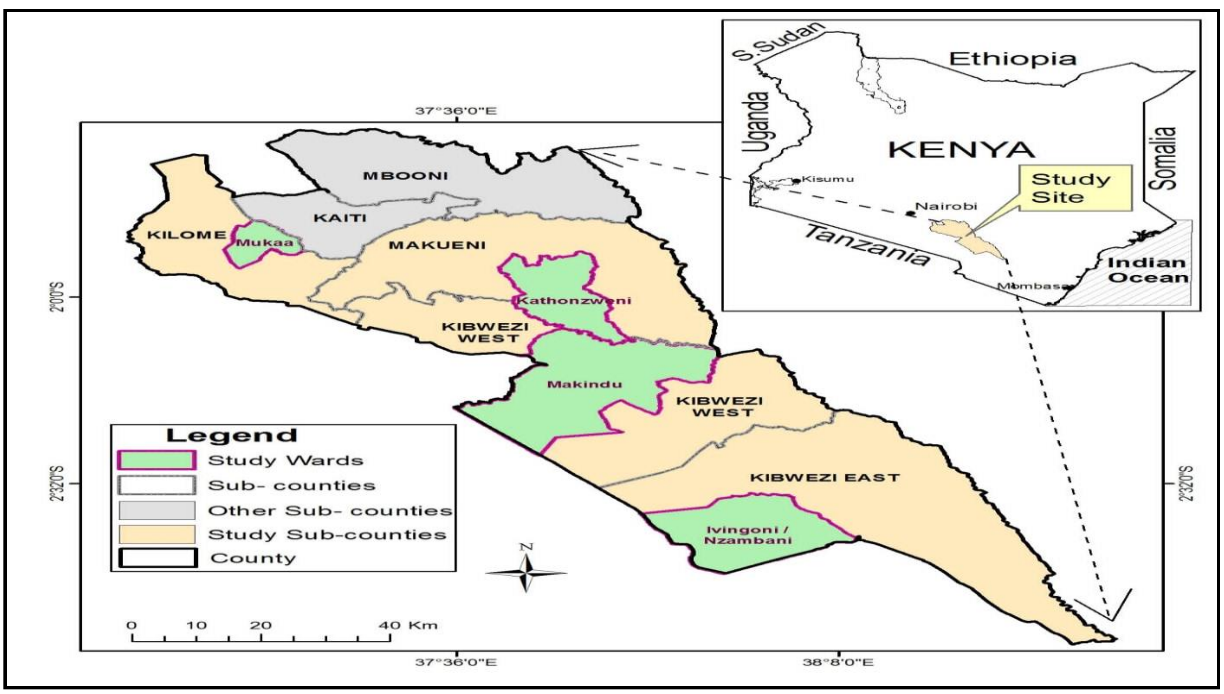

Figure 1: **Map of the Study Area Showing the Study Sites.**

Source: IEBC (2013).

2 Data Collection

This study collected daily rainfall data from meteorological stations and gridded rainfall data from Kenya Meteorological Department (KMD) to derive annual rainfall mean for 1990 to 2020. The data sets were collected from 4 meteorological stations distributed across Makueni County and recorded from 1990 to 2020. The study also used cereals (sorghum, finger millet and maize) data which were collected from MoA, Makueni County, for 1990 to 2020. In addition, a survey was used to collect data from cereal farming households on cereal yields and farm sizes in Makueni County.

2.3 Data Analysis

The datasets were processed and subjected to control checks for data quality and homogeneity tests. Missing values in both rainfall and cereals data were filled using Multiple Imputation (MI) method which is relevant for filling statistical gaps (Lloyd *et al*., 2013).

Annual rainfall means was analysed based on March 12-month SPI time series. SPI was used to establish meteorological droughts for the time scale identified for the study (Diani *et al*., 2019). The annual rainfall data sample Y: 1=1, 2, 3,… n was assumed to be independent and distributed identically. The independent observations were used as the source of data at specified data points. Further, SPI values were considered to be varying from -2.0 to 2.0. Drought episodes were recorded when SPI values turned negative while the episode ended when the SPI became positive (McKee *et al*., 1993). SPI has an index which is used for drought categorization (Table 1). The equation for SPI is indicated in Equation 1.

$$SPI = \frac{X - \bar{X}}{\sigma} \quad \textbf{(Equation 1)}$$

Where: X - Precipitation
$\bar{x}$ - Mean Precipitation
σ – Standard Deviation

Annual rainfall mean was correlated with annual cereal yields at 5% levels of significance, based on Statistical Package for Social Sciences (SPSS) version 22. Karl Pearson's Coefficient of Correlation (PCC), a bivariate correlation based on the coefficient of determination, Pearson's *r* was used for the analysis. The correlation analysis examined the effect of drought on cereal yields whereby the strength of the association and direction of the relationship was identified. PCC varies from -1 to 1. A PCC>0 is an indication of the existence of a positive correlation between the two variables. On the other hand, a PCC<0 is an indication of the existence of a negative correlation between the two variables, while PCC=0 indicates the non-existence of a correlation between the two variables.

Table 1**: Drought Characteristics Using Standardized Precipitation Index**

SPI Range Value	**Drought Category**
>2.00	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Near-normal
-1.00 to -1.49	Mild drought
-1.50 to -1.99	Severe drought
<-2.00	Extreme drought

Source*:* McKee *et al*. (1993)

3. Results and Discussion

3.1 Rainfall Trends in Makueni County

Results of the analysis of the rainfall trend revealed fluctuations in amount of rainfall from 1990 to 2000 (Figure 2). There was a significantly high amount of rainfall in 1998 due to El Niño event. In addition, there were fluctuations in amount of rainfall received between 2008 and 2017. Rainfall amounts also indicate an increasing trend from 2018 to 2019 then a declining trend in 2020.

The results of this study are in concurrence with those of a study done in China by Liu *et al.* (2020) which established fluctuations in rainfall trends whereby a decreasing trend was identified in Northern China from mid-1970s. The declining trend in rainfall was associated with increasing temperatures in the region and the weakening trend of East African Summer Monsoon (EASM).

The results of this study are also in agreement with those of a study done in Southern Ethiopia by Shibru *et al.* (2023) which established a high variability in rainfall (20%-35%) in Southern Ethiopia as compared to the variability in East Africa which was indicated as ranging between 15% to 25%. The high rainfall variability in both regions is an indication of increased drought risks. The study also revealed that high variability in rainfalls in Southern Ethiopia were exacerbated by rising temperatures experienced in the HoA. Further, the results of this study are in concurrence with those of a study done in Sudan by Yagoub *et al*. (2017) which established an association between increasing drought frequency with declining rainfall from 1961 to 2013.

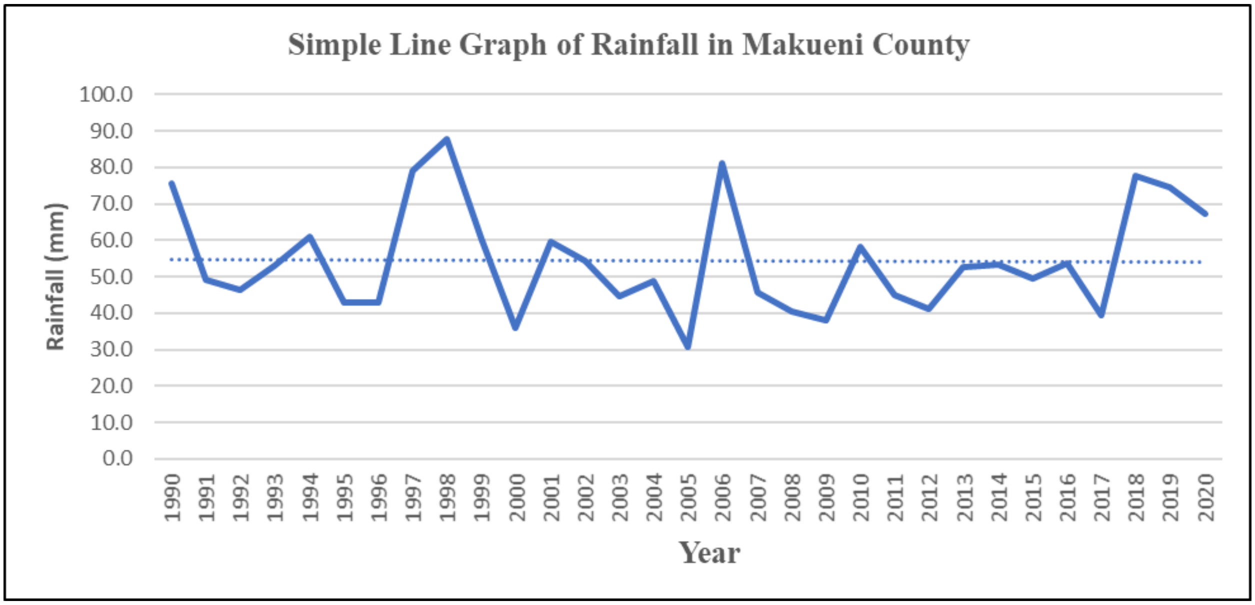

Figure 2: **Rainfall Trend in Makueni County**

Source**: Field Data (2023)**

3.2 Drought Characteristics in Makueni County

This study established 18 episodes of near-normal droughts while 2 mild droughts and 1 episode of moderate drought were experienced in Makueni County between 1990 and 2020 (Figure 3). Severe droughts occurred between 2004 and 2005. Further, near-normal droughts occurred annually from 1992 to 1996, 1999 to 2002, 2007 to 2008, and 2011 to 2016. The near annual drought conditions were also exacerbated in the study area by recurrence of mild droughts in 2000, 2009 and 2017. Further, mild droughts occurred in 2000, 2009 and 2017. Furthermore, a severe multi-year drought occurred in 2004/2005. These drought conditions are an indication of erratic, unpredictable and fluctuating rainfall which significantly impacted cereal production and yields in Makueni County.

The results of this study mirror those of a study conducted by Chivangulula *et al*. (2023) which established that droughts accounted for 6% of total disasters globally where 7% of all economic loses were linked to the phenomenon. The study also established a high frequency of droughts in South Africa that were indicated by a three to five-year return period between 1980 to 2007. Wang *et al*. (2023) also established that drought events were fewer in Southwest China before 1930s. However, the frequency of drought events increased in the region after 1930 whereby severe droughts were experienced between 1936 to 1937 in the region. In addition, South Western China experienced more severe droughts in 1962, 1963, 1967, 1987, 2009 and 2010. The severity of the 2009 and 2010 droughts had not been felt in the 120 years under study. Ayugi *et al*. (2022) also revealed that frequent and prolonged severe droughts were common in North Africa which cause significant socioeconomic impacts and change in land use in the region where 70% of the land surface area is a desert.

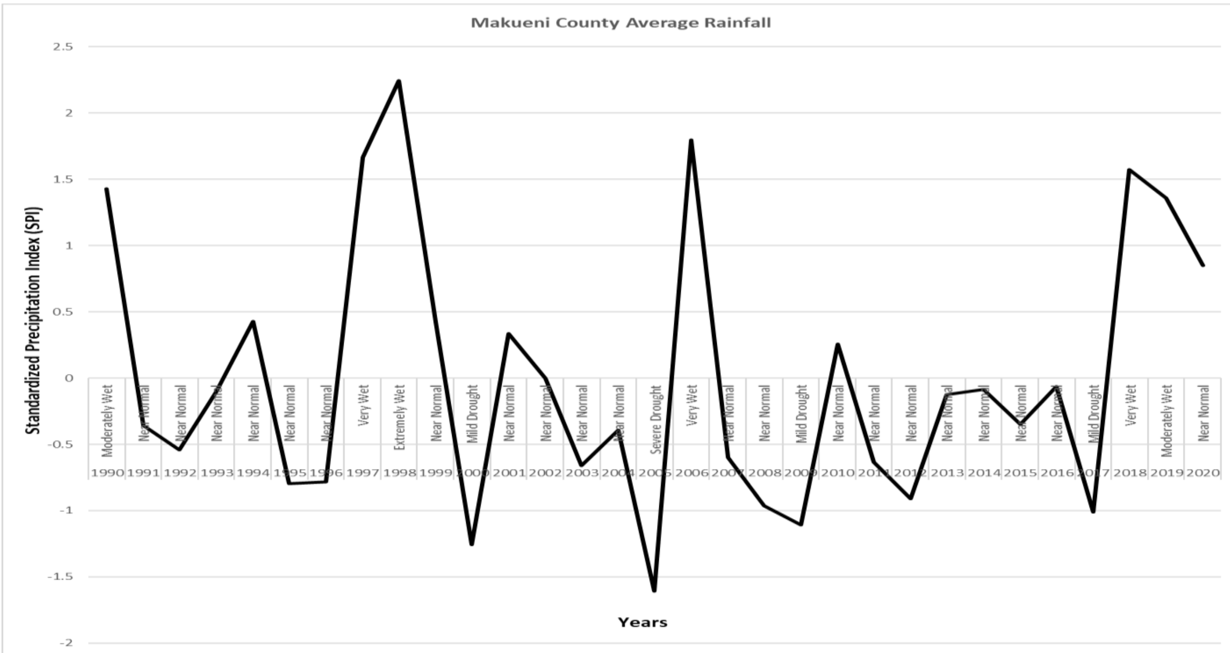

Figure 3: **Drought Trends in Makueni County**

Source: Field Data (2023)

3.3 Cereal Production Trends

There were significant fluctuations in sorghum, finger millet and maize yields in Makueni County between 1990 and 2020 (Figure 4). However, there was a significant increase in millet yields between 2008 and 2011 followed by a decline in yields between 2011 and 2012. On the other hand, sorghum and maize yields fluctuated over a similar period. Sorghum, finger millet and maize yields were consistently low between 2012 and 2014. Thereafter, a significant increase in maize yields was recorded from 2014 to 2016 which was followed by yield fluctuations up-to 2019. An increase in maize yield was also recorded from 2018 to 2019 followed by a sharp decline in 2020. On the other hand, a consistently gradual increase in sorghum and finger millet yields was recorded between 2016 and 2020.

The results of this study corroborate those of as study conducted by Odeph *et al. (2020*) which revealed that approximately 30.73 MMT of finger millet is produced annually globally where fluctuation in acreage was recorded. The results of this study are also in agreement with those of as study conducted in Ethiopia by Belete (2020) which established low maize yields at 3.06 tonnes per hectare (tha^{-1}) despite a high potential between 7.0 to 12.0 tha^{-1} annually.

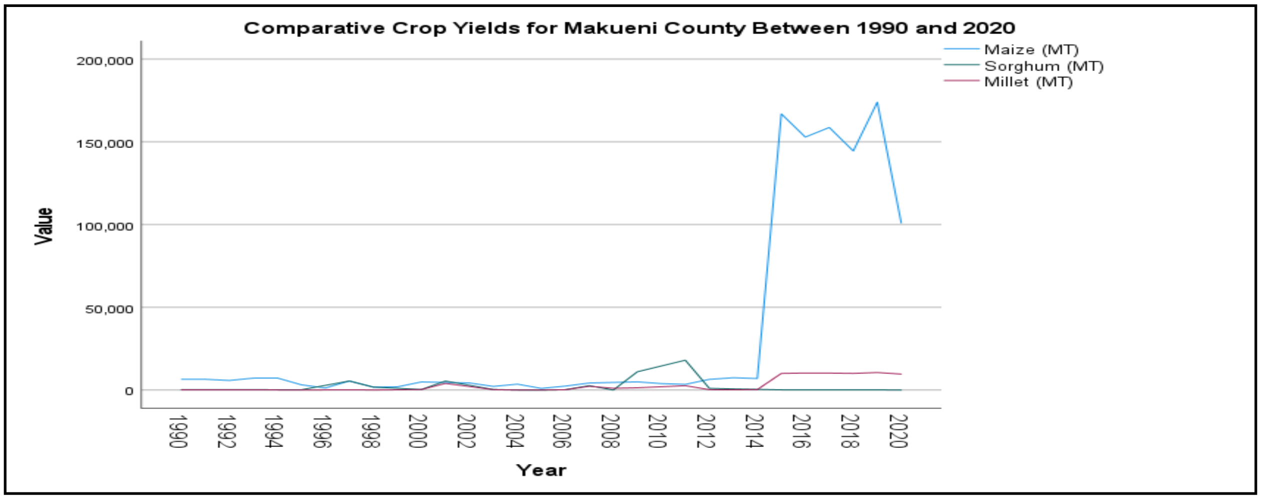

Figure 4: **Cereal Yields Trend in Makueni County**

Source: Field Data (2023)

3.5 Correlation of Drought and Cereal Yields

The results of the correlation analysis of rainfall and cereal yields show that there was a significant, strong, positive correlation between rainfall and sorghum yields in Makueni County, r (29) = .699, p<0.01 (Table 2). The existence of a strong positive correlation between rainfall and sorghum yields is an indication that increase in amount of rainfall leads to an increase in sorghum yields in Makueni County and vice versa.

The results of this study show that there was a significant, weak, positive correlation between rainfall and finger millet yields in Makueni County, r (29) = .359, p<0.01 (Table 2). The weak positive correlation between rainfall and finger millet yields shows that increase in amount of rainfall leads to an increase in finger millet yields in Makueni County. On the other hand, a reduction in amount of rainfall leads to decrease in finger millet yields in Makueni County.

The results of this study show that there was a significant, weak, positive correlation between rainfall and maize yields in Makueni County, r (29) = .346, p<0.01 (Table 2). The existence of a weak positive correlation between rainfall and maize yields shows that increase in amount of rainfall leads to an increase in maize yields in Makueni County while a deficit in amounts of rainfall hence drought conditions significantly affects maize yields.

These results of this study corroborate those of a study which was conducted in South Africa by Chivangulula *et al*. (2023) which established that droughts significantly impacted socioeconomic activities between 1991 to 1992. The study also established that up-to 20 million people were affected by famine in the country.

Table 2: Correlation between Rainfall and Cereal Yields

Correlations

		Makueni County Averaged Rainfall (mm)	Maize (MT)	Sorghum (MT)
Makueni County Averaged Rainfall (mm)	Pearson Correlation	1	.175	-.072
	Sig. (2-tailed)		.346	.699
	N	31	31	31
Maize (MT)	Pearson Correlation	.175	1	-.244
	Sig. (2-tailed)	.346		.186
	N	31	31	31
Sorghum (MT)	Pearson Correlation	-.072	-.244	1
	Sig. (2-tailed)	.699	.186	
	N	31	31	31
Millet (MT)	Pearson Correlation	.171	.958**	-.089
	Sig. (2-tailed)	.359	.000	.634
	N	31	31	31

Source: Field Data (2023)

3.5 Effect of Drought on Cereal Yields

The high frequency of droughts in Makueni County indicated by 18 near-normal drought episodes between 1990 to 2020 (Figure 2); significantly affected cereal production and yields in the region. The effect of drought on cereal yields in Makueni County is shown by low cereal yields whereby majority, 43% of the cereal farmers produced between 1 to 10 bags of sorghum (Table 3). The effect of drought on sorghum yields is also shown by the small farm sizes used for cereal production whereby majority, 32.9% of the smallholder cereal farmers produced sorghum on 0.1 to 0.5 hectares of land (Table 5). The use of small hectarage for cereal production in Makueni County is a potentially a result of the effects of droughts, hence a cause of low cereal yields.

This study also revealed that drought negatively affected the production and yields of finger millet in Makueni County. Majority, 42% of the finger millet farmers in the study area produced between 1 to 10 bags of the cereal, whereas only 5% of the farmers produced above 11 bags of the cereal in Makueni County (Table 3). The low annual finger millet yields were associated with frequent drought episodes in Makueni County. The low cereal yields are also corroborated by a study conducted in India by Patel *et al*. (2022) which established low finger millet (Ragi) yields in the rural regions of Chhattisgarh in India with yields at 0.253 tha^{-1}. In addition, 30.2% of the smallholder cereal farmers produced finger millet on small farms ranging from 0.1 to 0.5 hectares of land in Makueni County (Table 5).

Even though majority, 60% of the cereal farmers produced 1 to 10 bags of maize annually in Makueni County (Table 3), the low yields are a key challenge to food security in the region. The study also revealed that only 29% of the cereal farmers produced above 11 bags of maize annually;

signifying depressed maize yields under frequent drought conditions. The frequent near-normal drought episodes potentially resulted in small hectarage under maize where 24.4% of the smallholder cereal farmers produced the cereal on only 0.1 to 0.5 hectares of land in Makueni County (Table 5). The small farm sizes used for cereal production are a pointer to the significant negative effect of drought on cereal production and yields in the study area.

The results of this study concur with the results of a study conducted in South Africa by Chivangulula *et al*. (2023) which established that droughts significantly affect crop production and yields in the region where food insecurity and malnutrition were recorded. Further, Ayugi *et al*. (2022) established widespread drought episodes which affected the rainfed agricultural activities of majority of the population hence food security in East Africa.

Table 3: Annual Cereal Production in Makueni County

Type of Cereal	**Production (90 kg bags)**							
	0-10	**11-20**	**21-30**	**31-40**	**41-50**	**51-60**	**61-70**	**>70**
Sorghum	43%	3%	1%	0%	0%	0%	0%	1%
Finger Millet	42%	4%	1%	0%	0%	0%	0%	0%
Maize	60%	16%	5%	4%	1%	1%	1%	1%

Source: Field Data (2023)

Table 4: Effect of Drought on Cereal Yields

Effect of the drought on cereal yields	**No. of Respondents**	**%**
Reduction in yields	193	91.1
No change	10	4.9
Increase in yields	9	4.0
Total	**212**	**100.0**

Source: Field Data (2023)

Table 5: **Farm Size in Hectares in Makueni County**

	Sorghum		Finger Millet		Maize	
	No. of Farmers	Percent	No. of Farmers	Percent	No. of Farmers	Percent
No response	103	48.4	115	54.2	15	7.1
0.0-0.5	70	32.9	64	30.2	52	24.4
0.6-1.0	14	6.7	12	5.8	33	15.6
1.1-2.0	14	6.7	13	6.2	49	23.1
2.1-3.0	7	3.6	6	2.7	38	17.8
>3.1	4	1.8	2	0.9	25	12.0
Total	212	100.0	212	100.0	212	100.0

Source: Field Data (2023)

5. Conclusions

The occurrence of 18 near-normal drought episodes in Makueni County between 1990 and 2020 is an indication of frequent droughts. These frequent droughts were also indicated by cases of multi-year droughts. Occurrence of severe droughts in Makueni County also reflected the significant effects of the events on cereal production in the County. Recurrence of near-normal, mild and severe droughts in Makueni County have also resulted in increased vulnerability of smallholder farmers. The frequent droughts have also resulted in adverse cereal production conditions which have significantly affected cereal yields and food security in the region. The significant and positive correlation between rainfall and sorghum, finger millet and maize yields also score the role of drought in influencing food security and nutrition in Makueni County. Even though majority of the smallholder farmers produce less than ten bags of cereals annually as a result of the adverse production conditions caused by frequent droughts, drought adaptations can potentially improve cereal production and food security in Makueni County.

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