Drought Trend Projection in Makueni County, Kenya

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Abstract

Recurrence and varying intensity of natural forcing affect climates in various regions globally. Climatic forcing exemplified by varying Sea Surface Temperatures, atmospheric and terrestrial temperatures have resulted in increasing frequency and severity of droughts in Arid and Semi-Arid Lands globally. Frequent and severe droughts are key challenges to rain-fed cereal production and food security in drylands in Africa. Drought conditions in Kenya are exacerbated by location of the country along the equator, a long coastline of the Indian Ocean and a large surface area of low altitude covering 80% of the country. These factors play a pivotal role resulting in fluctuations in food production, hence food insecurity in the Arid and Semi-Arid Lands in Kenya. The study aimed at establishing historical drought trend and drought projections in Makueni County between 2024 and 2054. This study adopted explanatory sequential mixed methods research design. Rainfall data for 1990 to 2020 was used in the study. Standardized Precipitation Index was used for drought trend analysis while Autoregressive Integrated Moving-Average Models were used for drought projection. There were fluctuating and unpredictable rainfall patterns accompanied by 5 mild and 20 near-normal drought episodes in Makueni County. Single-year droughts were experienced over the period while multi-year droughts occurred between 2003 and 2005 and 2007 and 2009. An increasing frequency of seasonal droughts was projected due to declining March-April-May seasonal rainfall. The study projected decreasing seasonal drought frequency indicated by an upward trend in October-November-December seasonal rainfall. Information and data generated by this study can be used in formulation of drought adaptation and response policy, drought risk projection and development of adaptive capacity among smallholder cereal farmers in drylands. These efforts will result in improvement in food production and security in Kenya. The study recommends further research on influence of anthropogenic forcing on drought occurrence in Kenya.

Keywords: Arid and Semi-Arid Lands, Drought Trend, Anthropogenic Forcing, Drought Projection

Introduction

Uncertain global drought trends and regional drought fluctuations were accompanied by 52 global mega-droughts from 1951 to 2016 (Spinoni *et al*., 2019). Increasing drought frequency and severity was experienced in Africa in the last one century whereas severe droughts occurred in 1910s, 1940s, 1960s, 1970s, 1980s, 1990s, 2000s and 2010s thereby signifying the effect of climatic forcing (Funk *et al*., 2023; Gbegbelegbe *et al*., 2024; Han *et al*., 2022; Kew *et al*., 2019; Ruwanza *et al.,* 2022). Droughts affect and degrade Arid and Semi-Arid Lands (ASALs) which cover approximately 45% of land in Africa (Africa Group of Negotiators Experts Support [AGNES], 2020).

Central Africa experienced severe droughts in 1980s and 2000s (McCabe & Wolock, 2015) while an increase in drought frequency and severity was recorded in Southern Africa (Ruwanza *et al.,* 2022). Patil *et al*. (2023) projected increasing drought frequency in Eastern Africa. Eritrea, North-west Ethiopia and Eastern Somalia which are part of the Horn of Africa (HoA), experienced extreme droughts in 1940s, 1950s, 1960s, 1980s and 1990s signifying a decade return period (Han *et al*., 2022; Kew *et al*., 2019; Musei *et al*., 2021). Several drought episodes were experienced in North Eastern Africa in 1980s, 2000s and 2010s while central parts of East Africa experienced severe drought in 2003 (Haile *et al*., 2019). These droughts affected cereal yields significantly despite rapid increase in demand thereby making the continent food insecure.

Over ten severe droughts were recorded in East Africa since 1970s whereas Kenya recorded severe droughts in 2010, 2011 and 2012 (Haile *et al*. (2019). Nyangena (2020) established an increase in drought severity and frequency in ASALs in Kenya from 1990 to 2020. Further, Ondiko and Karanja (2021) reported a reduced drought return period in Kenya from five to three years. Furthermore, Han *et al*. (2022), Kew *et al*. (2019), Lam *et al*. (2023), Ondiko and Karanja (2021) and Venton (2018) revealed frequent recurrence of droughts in all the decades since 1900. The studies also indicate that severe droughts were experienced in Kenya in 1930s, 1940s, 1950s 1980s, 1990s and 2000s. In addition, periodic meteorological droughts ranged from mild to severe and affected ASALs such as Makueni County from 1997 to 2009 (Mutua *et al*. (2016).

Drought conditions in Kenya are exacerbated by geographical location of the country along the equator and a long coastline of the Indian Ocean. Further, vast low altitude areas and widespread ASALs covering 80% of the surface area increase levels of vulnerability and affect smallholder livelihoods due to frequent droughts. High frequency and severity of droughts, hence resulting food insecurity in Makueni County, is a key concern to the Government of Kenya (GoK), the County Government of Makueni (CGoM) and smallholder cereal farmers in Eastern region of Kenya. Therefore, this study focused on historical drought trend and projections for the period 2024 to 2054. The study provides information and data that will enable drought policy formulation, response and adaptation hence improvement in food production and security in Kenya.

Material and Methods

Study Area

This study was conducted in Makueni County, located 200 kilometres Southeast of Nairobi city in 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) (County Government of Makueni [CGoM], 2016). 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 (CGoM, 2016; KNBS, 2019). The sample study sites were Kibwezi West sub-County, Kibwezi East sub-County, Makueni sub-County and Kilome sub-County. Makueni County is classified as Agro-Ecological Zone V (AEZ 5) which is an ASAL in Eastern Kenya (Kitinya *et al*., 2012). The county experiences similar agro-ecological conditions and Tropical Semi-Desert climate of the Central and Northern areas with bimodal rainfall regimes. The long rainfall season is March-April-May (MAM) while the short rainfall season, which is the main rainfall season is October-November-December (OND) (Amukono, 2016). Rainfall received in the study area ranges from 800 millimetres (mm) to 1200 mm per annum in the Northern highlands of the county and an average of 500 mm per annum mostly in the Southern lowlands of the county (CGoM, 2016). The county experiences high temperatures with a mean ranging from 24.0^0 Celsius (C) to 35.8^0C (CGoM, 2016; GoK, 2013). High temperatures in the lowlands of Makueni County result in hot climatic conditions (GoK, 2014).

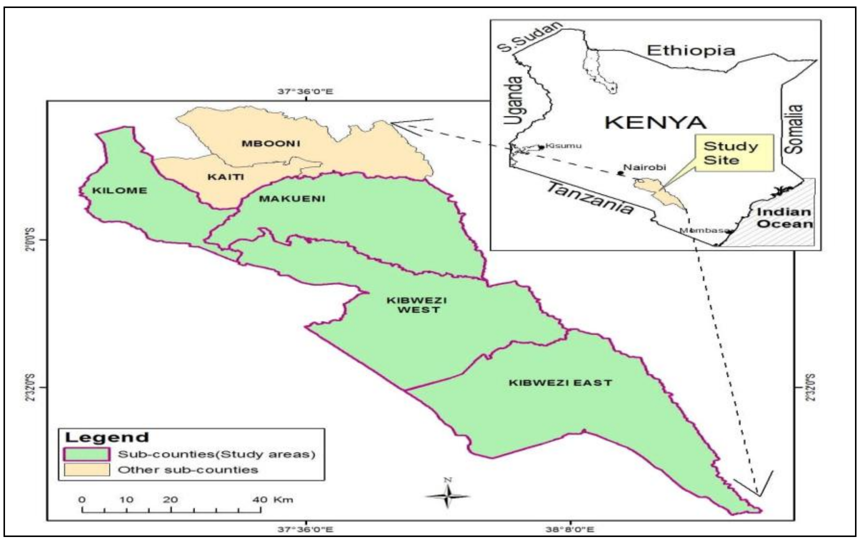

Figure 1: Map of the Study Area Showing the Study Sites.
Source: Independent Electoral and Boundaries Commission (IEBC) (2013)

Data Collection

This study was based on explanatory sequential mixed methods research design. The collection and analysis of quantitative data was undertaken for annual rainfall data for 1990 to 2020. Data was acquired through extraction from secondary sources from Kenya Meteorological Department (KMD) for Salama Meteorological Station in Kilome sub-County, Makindu Meteorological station in Kibwezi West sub-County, Kathoonzweni Meteorological Station in Makueni sub-County and Dwa Meteorological station in Kibwezi East sub-County (Table 1).

Table 1: Weather Stations in the Study Area

Station Name	Station ID	Latitude (^{0})	Longitude (^{0})	Altitude (m)	Sub-County	Ward
Makindu Meteorological Station	9237000	2.284171	37.820833	1004	Kibwezi West	Nguumo
Salama Meteorological Station	9137033	-1.85	37.25	1524	Kilome	Kiima Kiu/ Kalanzoni
Kathoonzweni–Makueni	9137077	-1.98	37.76	914	Makueni	Kathonzweni
Dwa Sisal Estate	9237002	-2.24	37.98	914	Kibwezi East	Kikumbulyu

Source: GoK (2018)

Data Analysis

Nature of Drought

Annual rainfall means for 1990 to 2020 was analysed based on March 12-month time series in which Standardized Precipitation Index (SPI) (World Meteorological Organization [WMO] & Global Water Partnership [GWP], 2016; Kimaiyo *et al*., 2023) was used in the study to establish the nature of droughts in Makueni County. SPI was used to establish meteorological droughts where agricultural effects are assessed using precipitation 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 sources of data at specified data points. Further, SPI varies from -2.0 to 2.0. A drought episode is recorded when SPI becomes negative while the episode ends when the SPI becomes positive. The SPI uses the gamma function for descriptions of precipitation changes (Lin *et al*., 2020).

Trend Analysis using Autoregressive Integrated Moving Average (ARIMA) Models

Autoregressive Integrated Moving Average (ARIMA) Models were used to project annual and seasonal drought trends in the study area for 2024 to 2054. The ARIMA Models were fitted, and a goodness of fit was examined by plotting Autocorrelation Function (ACF) of the residuals of the fitted model for the time series data for Makueni County. ACF is the coefficient of correlation between two values in a given set of time series. Most of the sample autocorrelation coefficients of the residuals were within the limits of $\pm 1.96\sqrt{N}$ where N denotes the number of observations on which the model was based.

Selection of parameters to be used in projection using ARIMA Model was based on ACF and Partial Autocorrelation Function (PACF) of the time series. Once significant lags were identified from ACF and PACF, ARIMA Models were then used to establish models with the lowest Mean Squared Errors (MSE) and Mean Average Error (MAE). The MSE indicated the mean or average of the square of the difference between actual and estimated ARIMA values. The MAE indicated the mean of the absolute values of the projection errors. All details of the ARIMA Models which were used for projection, accuracy of the MSE and MAE and primary performance evaluation criteria, were used to explain details of the results of SPI data series.

Results and Discussion

Annual Rainfall Trends in Makueni County

This study revealed fluctuations in amount of rainfall from 1990 to 2000. There was a significantly high amount of rainfall in 1998 due to El Niño event. On the other hand, fluctuations were recorded in the amount of rainfall received between 2008 and 2017. The study found that the even distribution, reliability and hence effective nature of the short rains make OND, the main cropping period in the county. In addition, rainfall showed an increasing trend from 2018 to 2019 then a declining trend in 2020 (Figure 2).

The results of this study are in concurrence with those of a study done in Southern Ethiopia by Shibru *et al.* (2023) which 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.

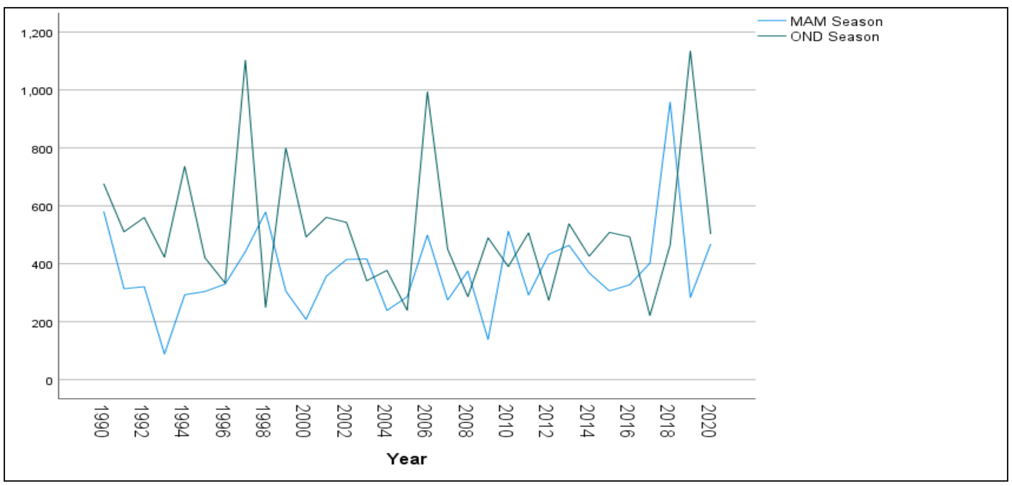

Figure 2: Seasonal Rainfall Characteristics in Makueni County

Annual Drought Characterization in Makueni County

This study established 20 episodes of near-normal droughts and 5 mild droughts that were indicated by SPI values (-0.99 to 0.99) and (-1.00 to -1.49), respectively. The droughts were experienced in Makueni County between 1990 and 2020 (Figure 3). Mild droughts occurred in 1992, 1996, 2000, 2005 and 2012. 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. Furthermore, multi-year droughts occurred from 2003 to 2005 and 2007 to 2009. These drought conditions were indications of erratic, unpredictable and fluctuating rainfall which significantly impacted cereal production and yields in Makueni County.

Results of this study mirror those of a study conducted by Wang *et al.* (2023), which 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 addition, Southwestern China experienced more severe droughts in 1962, 1963, 1967, 1987, 2009 and 2010. The study revealed that the severity of the 2009 and 2010 droughts had not been felt in the 120 years under study. Chivangulula *et al*. (2023) established a high frequency of droughts in South Africa that were indicated by a three to five-year return period between 1980 and 2007. 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.

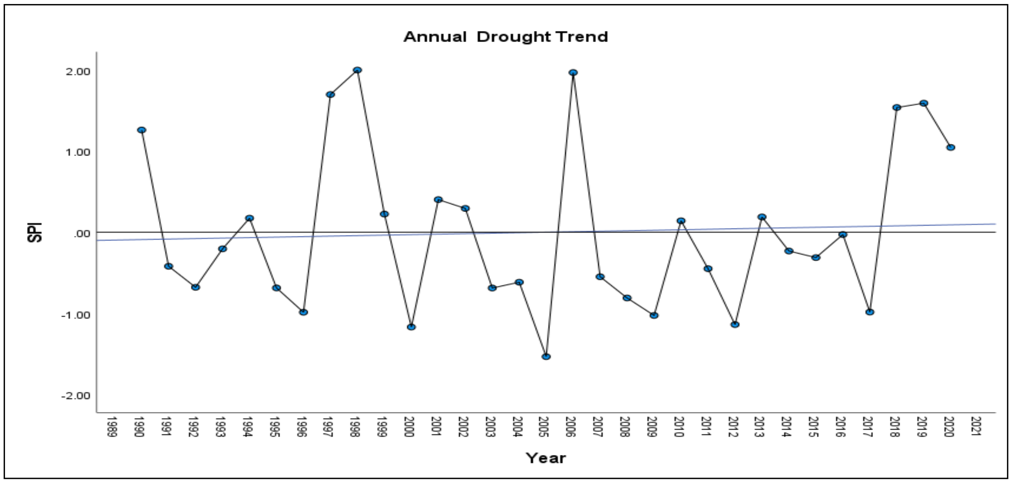

Figure 3: Drought Trends in Makueni County

Annual Drought Projection in Makueni County using ARIMA Models

This study found that ARIMA (12, 3, 0) Model provided the best performance for projection of the time series for Makueni County based on residual ACF and PACF for the time series data (Figure 4). The study projected an increasing frequency of droughts in Makueni County from 2024 to 2054 (Figure 5).

Results of this study are consistent with the results of a drought projection study conducted in Central Asia and Africa by Jiang and Zhou (2023) and Ayugi *et al*. (2022), respectively, which projected increase in drought conditions in the regions due to variability in atmospheric and oceanic circulations in the Indian Ocean. In addition, the results of this study mirror those of a study conducted in South Asia by Ullah e*t al*. (2022) which projected an increase in frequency and magnitude of droughts in the region by mid-21st Century.

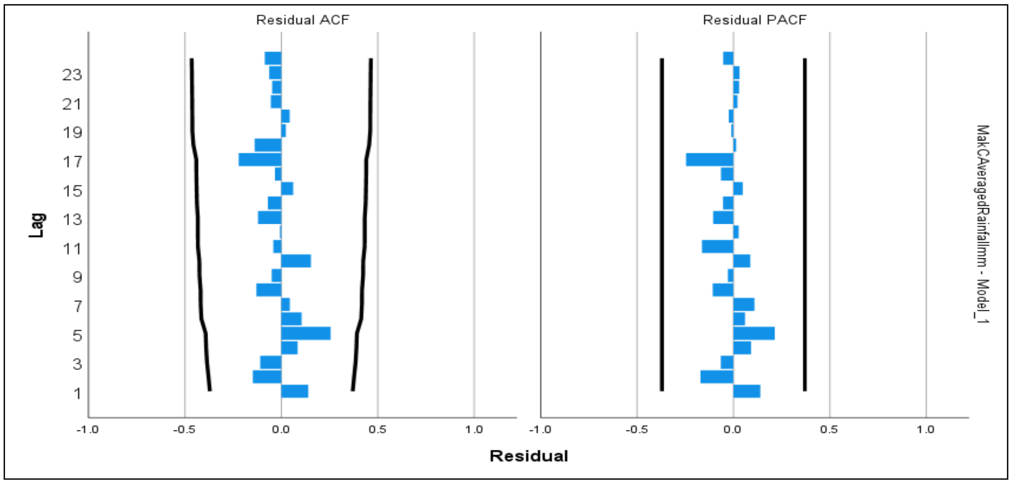

Figure 4: Residual Autocorrelation Function and Residual Partial Autocorrelation Function for Rainfall

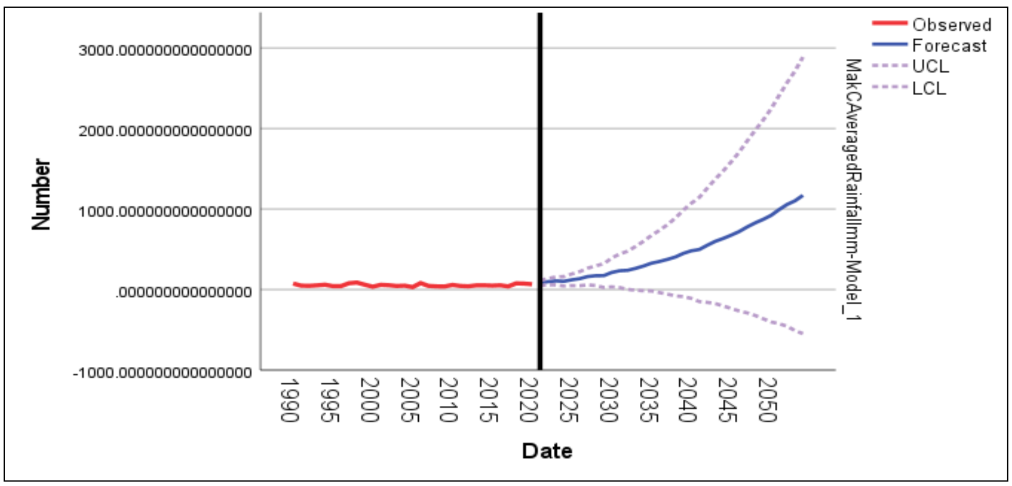

Figure 5: Annual Projection of Drought Trend in Makueni County for 2024 to 2054

Seasonal Drought Projection in Makueni County using ARIMA Models

This study found that ARIMA (4, 3, 1) Model provided the best performance for projection for seasonal time series for Makueni County based on the ACF and PACF (Figure 6). The study projected a declining MAM seasonal rainfall, pointing to increasing episodes of droughts in Makueni County from 2024 to 2054 (Figure 7). On the other hand, the study projected an upward trend in OND seasonal rainfall in Makueni County from 2024 to 2054 (Figure 7).

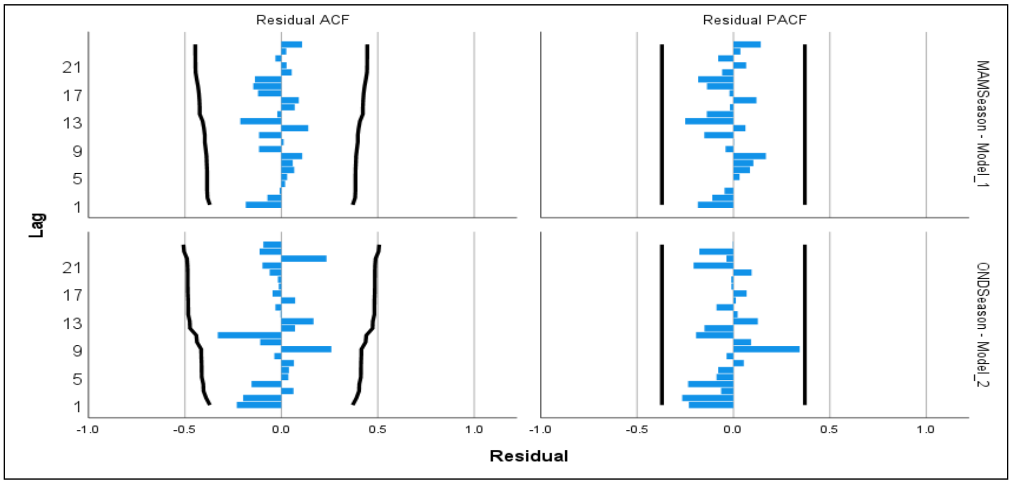

Figure 6: Residual Autocorrelation Function and Residual Partial Autocorrelation Function for Seasonal Rainfall

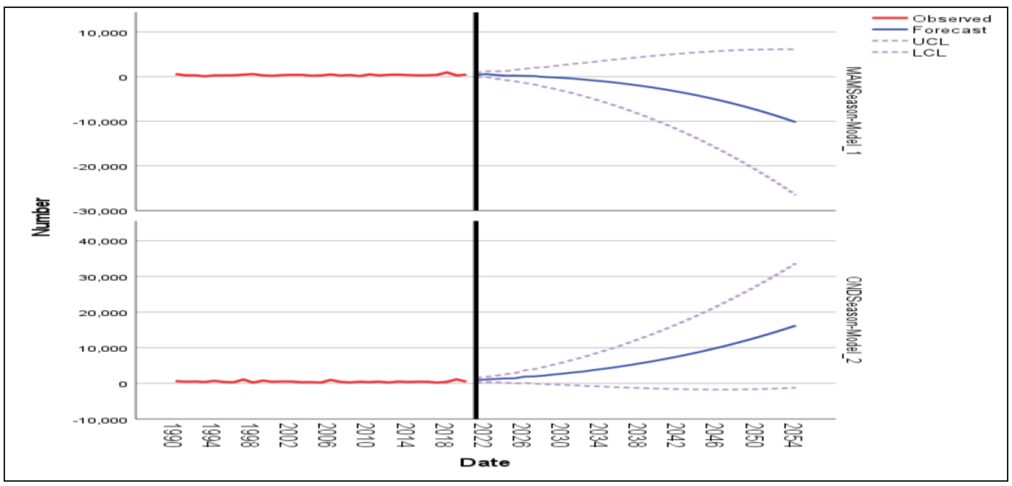

Figure 7: Projection for Seasonal Rainfall in Makueni County from 2024 to 2054

Results of this study are consistent with the results of a drought projection study conducted by Jiang and Zhou (2023) which projected significant reduction in seasonal rainfalls and increase in temperatures hence increasing drought trend in Central Asia. The study also indicated significant reduction in amount of soil moisture, a condition which was projected to last up-to the end of the 21st Century. Jiang and Zhou (2023) and Ullah e*t al*. (2022) also projected increase in frequency of droughts in Central and South Asia due to atmospheric circulations and circulations in the Indian Ocean. The results of this study are also consistent with those of studies conducted on the African continent and the Indian Ocean region by Ayugi *et al*. (2022) and Global Center on Adaptation (GCA) (2022). The studies linked droughts in Africa to varying precipitation patterns which are driven by atmospheric and oceanic circulations and climate variability.

Conclusions and Recommendations

There were 20 episodes of near-normal and 5 mild droughts that were experienced in Makueni County between 1990 and 2020. Mild droughts occurred in 1992, 1996, 2000, 2005 and 2012. Further, near-normal droughts occurred annually from 1992 to 1996, 1999 to 2002, 2007 to 2008 and 2011 to 2016. Multi-year droughts occurred from 2003 to 2005 and from 2007 to 2009. Drought projection indicated that 2024 to 2054 will have a more uniform upward trend. Seasonal drought projection indicated a declining MAM seasonal rainfall, pointing to increasing episodes of droughts in Makueni County from 2024 to 2054. An upward trend in OND seasonal rainfall was projected in Makueni County for 2024 to 2054 signifying a decreasing frequency of seasonal droughts. The Government of Kenya and the County Government of Makueni, in partnership with other policy makers and stakeholders in cereal production in Kenya, should establish and equip meteorological stations in the country. The government should also train personnel to improve monitoring of weather conditions, collection and recording of climate data in Makueni County. The study recommends further research on the influence of anthropogenic forcing on drought occurrence in Kenya for complementarity, effective and wholesome policy formulation directed at drought response and adaptation in Arid and Semi-Arid Lands in the country.

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