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Original Article

Analysis of Climate Variability Trends and Local Perceptions in Kieni West Sub-County, Kenya

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ABSTRACT

It is indisputable today that climate variability has taken place all over the world having huge impacts on ecosystems. Precipitation and rainfall are among the most notable changes of climate variability, majorly as a result of natural phenomena or anthropogenic activities contributing to global climatic extremes such as heatwaves, snow, droughts, and flooding. The aim of this study was to analyze trends of climate variability and local perceptions in Kieni West sub-county, Kenya. A mixed methods research design was employed where both quantitative and qualitative data were used. Gridded rainfall and temperature data was obtained from the Kenya Meteorological Department (KMD) for the period between 1988 and 2018. Mann-Kendall (MK) test statistic was used to detect climate trends in time series data and their statistical significance. Coefficient of Variation (CV) was employed to detect variations in seasonal rainfall both in short and long rain seasons. Pearson Coefficient of Correlation (r) was used to establish the relationship between rainfall and temperatures for the period 1988-2018. Quantitative data was analyzed using descriptive and inferential statistics whereas qualitative data was analyzed by establishing themes and patterns. Data presentation was done by use of figures, tables as well as narratives. The findings revealed that annual rainfall had been decreasing by 6.294mm/year ($p > .05$) while annual temperatures had been increasing significantly at 0.021oC/year ($p < .05$). Correlation analysis between annual rainfall and mean annual maximum temperatures revealed a weak negative correlation (r (29) = .23, p =.213) whereas there was an insignificant weak positive linear relationship between annual rainfall and mean annual minimum temperatures (r (29) = .08, p = .688). Additionally, Pearson's correlation analysis revealed a non-significant small positive relationship between mean monthly rainfall and mean monthly maximum temperatures (r (10) = .27, p = .391) and a significant large positive correlation between mean monthly rainfall and mean monthly minimum temperatures (r (10) = .79, p =.002). The majority of respondents observed decreased rainfall (83%) and increased temperatures (71%) in the area. The study concludes that climate variability is taking place in Kieni West sub-county, Kenya.

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INTRODUCTION

Climate change and variability are regarded as one of the biggest challenges that face the world in the 21st century (Abidoye & Adusola, 2015; Field, 2014; Reidmiller *et al.*, 2018). According to the Intergovernmental Panel on Climate Change (IPCC) (2022), there is evidence indicating that globally, temperature has increased over the last century which has brought about unpredictable as well as unparalleled changes in climate and its detrimental effects on human lives across the world. IPCC (2013) revealed that change in climate has been demonstrated by an increase in the global mean temperatures by about 0.74ºC ±0.18ºC in the last century. Past empirical studies have indicated that there is a global change in climate and they anticipate an increase in the rate of change (Amsalu & Adem, 2009; IPCC, 2007, 2014). IPCC (2013) anticipates that an increase in temperatures will be between 1.5ºC and 2ºC by the end of the 21st Century. Besides, the IPCC assessment report predicts that most of the world's regions exceptionally in tropical regions will experience increased mean surface air temperatures, scarcity of water in addition to unpredictable precipitation (IPCC, 2021). The degree to which rainfall amounts change both spatially and temporally (Pendergrass *et al.*, 2017) has also been changing worldwide.

Africa is one of the continents that is highly vulnerable to climate change and variability (Niang *et al.*, 2014) as a result of most countries depend on sectors that are sensitive to climate as well as their low adaptive capacity (IPCC, 2014; Mahmood & Jia, 2018; Mesfin *et al.*, 2020). This leaves the continent exposed and susceptible to high poverty rates, technological and financial constraints along with overreliance on rain-fed agriculture. Over the past few decades, the region has seen a significant seasonal rainfall variation in addition to an increase in average, minimum, and maximum temperatures (Gan *et al.*, 2016; Gebrechorkos *et al.*, 2019). Niang *et al.* (2014) observe that temperature is on the rise in the continent. For instance, past studies indicate that the Eastern African region has been experiencing an increase in seasonal average temperature and there is high confidence that there will be an increase in extreme temperatures (Anyah & Qui, 2011; Funk *et al.*, 2015; Moyo *et al.*, 2012; Opiyo *et al.*, 2014; Wagesho *et al.*, 2013). Nonetheless, according to IPCC, there will be a decline in rainfall in Northern and Southern Africa while there will be an increase in Eastern Africa towards the end of the 21st Century (Niang *et al.*, 2014).

In Kenya, the mean annual temperatures have been increasing at an average rate of 0.2ºC per decade since 1960 and there are projections that by 2050 temperatures will increase by between 2.4ºC-2.8℃ (GoK, 2013). In addition, it is projected that by 2100, climate change will result in an increase in temperatures by approximately 4ºC and a variation of rainfall by up to 20% (Bryan *et al.*, 2003; Kabubo-Mariara, 2008; Niang *et al.*, 2014) which will have considerable impacts on agricultural production, availability as well as

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access to water. On the other hand, for most parts of the country, precipitation is expected to decrease by 10% during the March-May seasons and is projected to increase by 8-10% during the October-December seasons extending January and February which are the hottest and driest months (Kariuki, 2016; Parry *et al.,* 2012). Central Kenya has experienced notable changes in precipitation as well as temperature trends. In particular, recent research has revealed that rainfall has been declining every 3 to 4 years (Karienye *et al.,* 2012). There are however limited empirical studies in the Kieni West Sub-county that focused on analysis of trends of rainfall and temperature variations and local perceptions. The objective of the study was therefore to analyze trends of climate variability as well as local perceptions in Kieni West sub-county.

LITERATURE REVIEW

Climate change and variability are the major global environmental problems facing the world today (Gupta *et al.,* 2019; Yu *et al.,* 2019). Increases in temperature (Horton *et al.,* 1997) and changes in precipitation patterns (Chen *et al.,* 2011; Gautam *et al.,* 2009) are among the main consequences of change in climate. Of the challenges caused by climate change, precipitation and temperatures are the most crucial variables that are often used as indicators of the extent and magnitude of climate change and variability (Rana *et al.,* 2017). Global temperatures as well as precipitation patterns have been changing spatially and temporally. For instance, there has been an upward trend of global seasonal temperature (Jemal *et al.,* 2022) and according to IPCC (2013), global land and ocean surface temperature has risen by 0.85°C during 1880–2012. The period between 2015 and 2019 was recorded as the warmest in history (Gemeda *et al.,* 2021) as it was estimated to be 1.1°C more than the pre-industrial times. In 2022, the global temperature was about 0.86ºC higher than the 20th century average of 13.9 °C (NOAA, 2022).

Arora (2019) observes that, since the nineteenth century, there has been a global rise in average temperature by about 0.9ºC and projections indicate that warming will continue at an average of about 3-4ºC over the next century (FAO, 2015). A recent Sixth Assessment Report (AR6) of the IPCC indicated a global warming of 1.09ºC between the Industrial Revolution period up to the present, causing climate change and variability and it is predicted that the warming will continue to rise up to an average of 1.5ºC in the 2030s (IPCC, 2021). While the earth is expected to warm generally with average temperatures rising throughout the year, the increases are anticipated to be more remarkable in certain seasons than in others (EPA, 2022). Chikezie *et al.* (2019) note that climate change results in a distortion of seasonal patterns and as a consequence, changes in temperature.

In Africa, temperature is on the rise, and the IPCC projects that the region will have higher temperature increases as compared to the increase in global mean temperature (Niang *et al.,* 2014). This will result in an increase in hot nights in addition to longer and more recurrent heatwaves. The strongest drying will be experienced in the western Sahel region with a notable rise in the maximum length of dry spells (Niang *et al.,* 2014). In East Africa which includes Kenya, an increase in temperatures has been observed in the major cities that almost double the global warming since pre-industrial times (Engelbrecht *et al.,* 2015; Daron, 2014; Gebrechorkos *et al.,* 2019; WMO, 2020). Rapid warming of about 1.9ºC as the maximum temperature and 1.2ºC as the minimum temperature has been observed between 1979 and 2010 (Gebrechorcos *et al.,* 2019) with a mean temperature rise of 2ºC between 1963 and 2012 (Daro, 2014). Due to global warming, the average temperature in Kenya is on the rise (World Bank, 2021). In particular, FAO *et al.* (2023) observe that the average annual temperature has risen by about 1.5 °C since 1990, hastened by climate change together with the strong influence of El Niño and La Niña periods. The annual mean temperature trend for the period 1991-2020 indicates a steeper slope than in the past. The General Circulation Models (GCMs) indicate that the mean annual temperature is anticipated to rise by 0.8oC -1.5ºC by 2030 and 1.6°C to 2.7°C by

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the 2060s (GoK, 2015). According to GOK (2018), an increase in temperature has been observed across all seasons between 1960 and 2013 but exceptionally from March to May and changes between localities.

The precipitation pattern in the globe has also changed. There have been historical changes in global mean rainfall which are unpredictable, varying by season, and regions (Asfaw *et al.*, 2017; Jemal *et al.*, 2022). In Africa, rainfall is highly varied and it is influenced by climate change in addition to anthropogenic activities (Muchuru & Godwell, 2019) and there is evidence that variations in rainfall will increase as a result of climate change (Salack *et al.*, 2016; Sylla *et al.*, 2016). East Africa region is not an exception. Studies have reported high variations in rainfall as well as its related negative impacts in East Africa (Ongoma & Chen, 2017; Ongoma *et al.*, 2018; Viste *et al.*, 2013). The effect is mainly related to higher uncertainty in the inter-annual rainfall mainly affecting rain-fed livelihood groups (Kassie, 2014). Recent empirical studies indicated that rainfall variations in the East Africa region are mainly a result of the interaction of Pacific, and Indian together with Atlantic oceanic processes such as El Niño Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) along with other large-scale atmospheric phenomena, for instance, the Inter Tropical Convergence Zone (ITCZ) which include upper level winds for example Quasi-Biennial Oscillation (QBO) and with high pressure systems in the Indian and Atlantic oceans (Dubache *et al.*, 2019; Minda *et al.*, 2018; Tierney *et al.*, 2013; Urgessa, 2013; Wodaje *et al.*, 2016). Awange *et al.* (2014) and Omondi *et al.* (2014) opine that El Niño/Southern Oscillation has a significant impact on rainfall over Eastern Africa, especially during the October–December rainfall season. Previous studies conducted on multi-decadal climate variations in East Africa including Kenya, have revealed mixed results. Several studies have indicated declining trends in annual rainfall patterns whereas other studies revealed increasing rainfall trends (Asfaw *et al.*, 2018; Benti & Abara, 2019; Philipet *et al.*, 2018; Rowell *et al.*, 2015; Shawul & Chakma, 2020).

From the review of the related literature, there is evidence that temperatures and precipitation patterns have been varying in the recent past at the global and regional levels with temperatures showing generally increasing trends while rainfall patterns have revealed mixed results, especially in East Africa. However, there is little evidence in Kieni West sub-county on variability and trends of temperature and rainfall. The present study therefore sought to address this gap in the existing literature by examining variability and trends of temperature and rainfall. Understanding rainfall and temperature variability and trends is key for accurate prediction of climate extremes and the development of appropriate adaptation strategies that will assist in minimizing adverse impacts of climate variability besides guiding rural households in making deliberate, long-term resolutions that impact their well-being in the future.

MATERIALS AND METHODS

The study was carried out in Kieni West Sub-county, Nyeri County, Kenya (Figure 1). Kieni West sub-county covers an area of 1230 Km^2 with a population of 88,525 people according to the Kenya National Bureau of Statistics (KNBS, 2019). Administratively, the sub-County is subdivided into 6 locations namely: Endarasha, Gatarakwa, Laburra, Mweiga, Mwiyogo, and Mugunda. It is situated between the equator (0^o) and latitude 0^o 38″ South and between longitudes 36^o 38″ East and 37^o 20″ East. The main physical features are Mount Kenya to the East at 5,199m above sea level and Aberdare ranges to the West at 3,999m above sea level. The mean monthly temperatures range between 12.8^{o}C and 20.8^{o}C while the mean annual rainfall ranges between 500mm and 1600mm (GoK, 2013).

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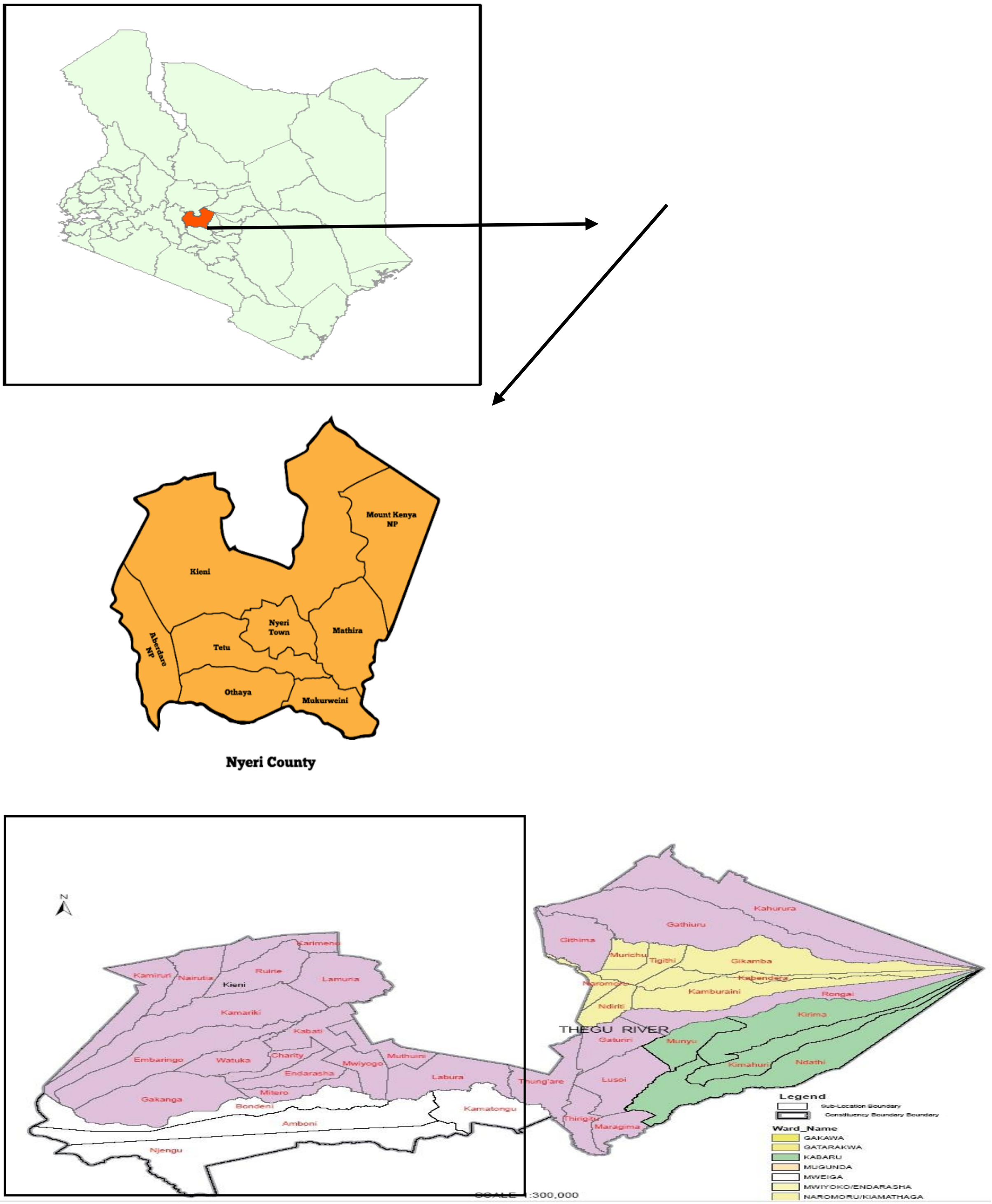
Figure 1: Map of Kieni West Sub-county



Source: *Independent Electoral and Boundaries Commission (IEBC, 2012)*

The study used both quantitative and qualitative data. Gridded rainfall and temperature data was acquired from the Kenya Meteorological Department (KMD) for a period of 31 years (1988-2018). This was because there were no ground meteorological stations in the study area (Nashwan *et al.*, 2018). Additionally, local community perceptions of climate variability as well as an understanding of the trends were collected using household questionnaires survey. Qualitative information on climate data was collected using Focus Group Discussions (FGDs) so as to follow up on findings from quantitative data in addition to having a better understanding

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of the actual meaning of figures. A simple random technique was used to get 384 household heads while purposive sampling was employed to obtain nine key informants as well as six focus group discussions consisting of 6-8 participants of mixed gender to allow gathering of different opinions from men and women. Before data collection, a research permit was obtained from the National Council for Science Technology and Innovation (NACOSTI/P/21/10666). Also, respondents were briefed on the purpose of the study before administering the questionnaires. The information collected from them was treated with confidentiality.

Data analysis was done using descriptive and inferential statistics where means, frequencies, percentages, and Coefficient of Variation using Statistical Package for Social Sciences (SPSS) version 23 were computed for climate variability data. Trend analysis for rainfall and temperatures was done using Microsoft Excel spreadsheets. Later, a non-parametric Mann-Kendall (MK) test was applied to test the statistical significance of trends in climate variables (rainfall and temperatures) (Kendall, 1975; Mann, 1945) at a 95% confidence level. Change detection in annual and seasonal trends using the MK test is slightly influenced by climate outliers (Birsan *et al.*, 2005; Sen, 1968). The presence of a trend that is statistically significant is assessed using the *Z* value. An increasing or decreasing trend is noted if 'Z' is positive or negative and the calculated Z-statistic is either lesser or greater than the z–value that corresponds to the 5% significance level respectively. When the calculated Z-statistic is zero then, it denotes that there is no trend.

Coefficient of Variance was employed to detect variations in seasonal rainfall both in short rain season (OND) and long rain season (MAM) for the period under analysis using the equation:

$$CV = \frac{s}{\bar{x}} \times 100 \quad (1)$$

Where *CV* is the coefficient of variation, ***s*** is the standard deviation and $\bar{x}$ is the mean of the observation period. According to Hayelom *et al.* (2017), CV is used to categorize the level of variation as low when CV is less than 20%, moderate when the CV is less than 30%, high when the CV is above 30%, and very high when the CV is more than 40%.

Pearson Coefficient of Correlation (***r***) was used to establish the relation between rainfall and temperatures for the period 1988-2018 (Equation 2).

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}} \quad (2)$$

Where ***r*** is the correlation coefficient, x_i and y_i are the variables being correlated, $\bar{x}$ and $\bar{y}$ are the means of variables x and y respectively. Mukaka (2012) opines that, when Pearson's *r* is close to 1, it means that there exists a strong correlation between the two variables whereas when Pearson's *r* is close to 0 it means that there exists a weak correlation between the two variables. Pearson's positive value of ***r*** reveals that an increase in one variable causes an increase in the second variable and vice versa. Similarly, Pearson's negative value of ***r*** reveals that a decrease in one variable causes a decrease in the second variable and vice versa. A p-value that is equal to or less than 0.05 is usually considered as being statistically significant. Contrarily, a p-value that is equal to or greater than 0.05 is considered statistically insignificant.

Analysis of qualitative data obtained from focus group discussions was done where results were transcribed and translated in addition to

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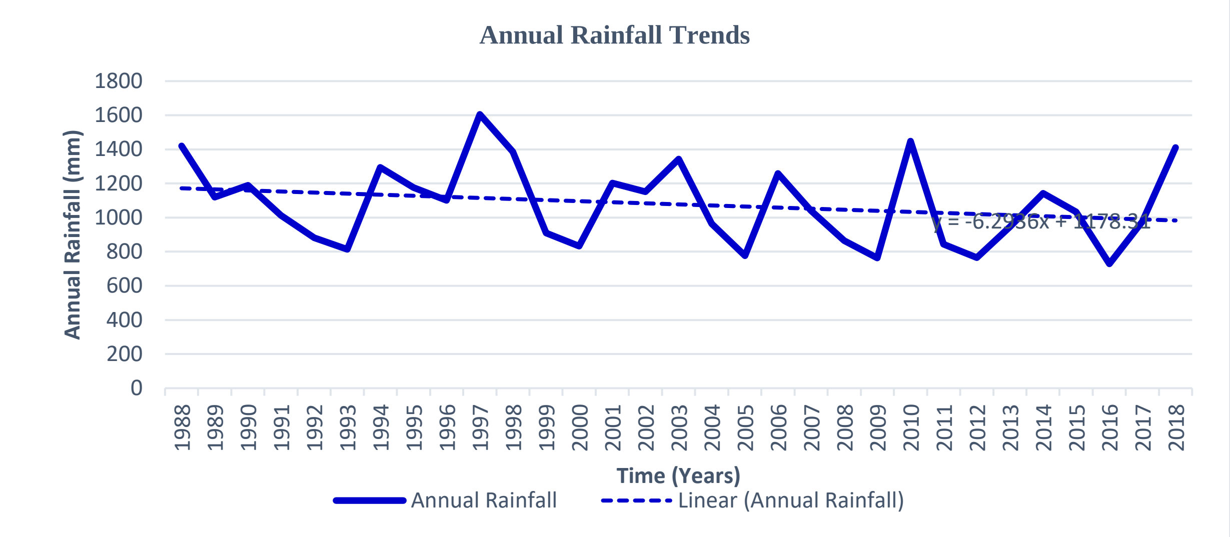
establishing relationships, patterns, themes, and categories and making conclusions based on the objective of the study. Moreover, data from the key informant interviews was analyzed by establishing themes along with content analysis which involved counting the frequencies of specific statements that occurred (Newing, 2010). Quantitative data was presented by use of graphs while quantitative data was presented in narratives and verbatim quotes.

RESULTS

Annual Rainfall Trends

Results reveal that annual rainfall fluctuated between the lowest levels of 728.59mm in 2016 to the highest levels of 1605.42mm in 1997 (Figure 2). The mean annual rainfall for the entire period was 1077.55mm.

Figure 2: Annual Rainfall Trends



Source: *Kenya Meteorological Department (KMD, 2022)*

The highest averages were recorded in 1988 (1420mm), 1997 (1605mm), 1998 (1385mm), 2010 (1448mm), and 2018 (1410mm) with a sharp increase in rainfall between the years 1997 and 1998. The lowest averages were recorded in 1993 (814mm), 2000 (883mm), 2005 (776 mm), 2009 (763 mm), 2012 (765 mm) and 2016 (728mm). The annual rainfall linear trend portrayed by the equation (y=1178.31-6.294x) shows that annual rainfall has been on a downward trend decreasing by 6.294mm per year. Mann-Kendall test statistics, however, reveal that the trend was insignificant (p = 0.14)

Annual Rainfall Variations

Out of the 31 years, 15 years were above average whereas 16 years were below average (Figure 3). The wettest years include: 1988 (1420.92mm), 1997 (1605.42mm), 1998 (1385.61mm) 2010 (1448.90mm), and 2018 (1410.27mm) with the year 1997 being the wettest of them all. The driest years include: 1993 (814.79mm), 2005 (776.51mm), 2009 (763.66mm) 2012 (765.30mm), and 2016 (728.59mm). Nevertheless, 2016 was the driest of them all. There were more dry years between years 2011 and 2018 as compared to the other two decades with only two years above average. The 1990s and 2000s were six and five years above average respectively.

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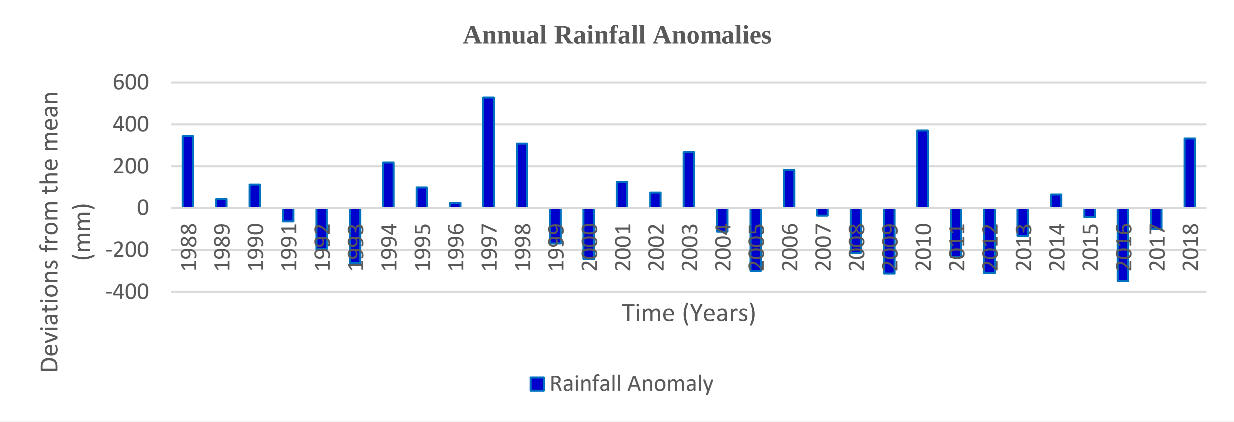
Figure 3: Annual Rainfall Anomalies



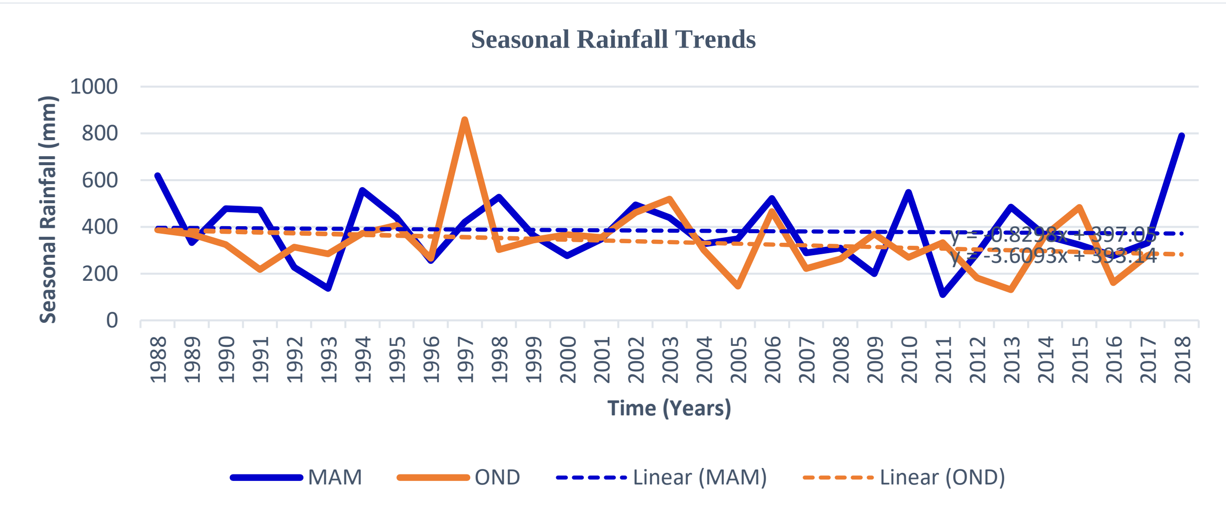
Source: *Kenya Meteorological Department (KMD, 2022)*

Annual rainfall anomalies ranged from -312.25mm in 2012 to +527.87mm in 1997 (Figure 3). The highest rainfall anomalies above average were noticed in 1988 (+343.37mm), 1997 (+527.87mm), 1998 (+308.06mm), and 2018 (+332.72mm). The highest rainfall anomalies below average were recorded in 1993 (-262.76mm), 2000 (-244.10mm), 2005 (-301.04mm), 2009 (-313.89mm) and 2012 (-312.25mm).

Seasonal Rainfall Trends

Results reveal that the average rainfall received during the short rain season (OND) was 337.60mm while the average rainfall received during the long rain season (MAM) was 385.31mm (Figure 4). During the MAM season, high amounts of rainfall were recorded in years: 1988 (618.87mm), 1994 (556.44mm), 2006 (522.35mm), 2010 (548.14mm), and 2018 (789.61mm) while low amounts of rainfall were recorded in years: 1993 (135.58mm), 1996 (255.80mm), 2009 (200.05mm), 2011 (109.53mm) and 2016 (276.26mm).

Figure 4: Seasonal Rainfall Trends



Source: *Kenya Meteorological Department (KMD, 2022)*

During the OND season, high amounts of rainfall were recorded in years: 1997 (859.14mm), 2002 (462.42mm), 2003 (519.26mm), 2006 (464.75mm) and 2015 (484.39mm) whereas low amounts of rainfall were recorded in years: 1991 (218.12mm), 2005 (145.94mm), 2012 (182.40mm), 2013 (131.07mm) and 2016 (161.03mm).

Results also indicate that seasonal rainfall during the long rains has been declining gradually by

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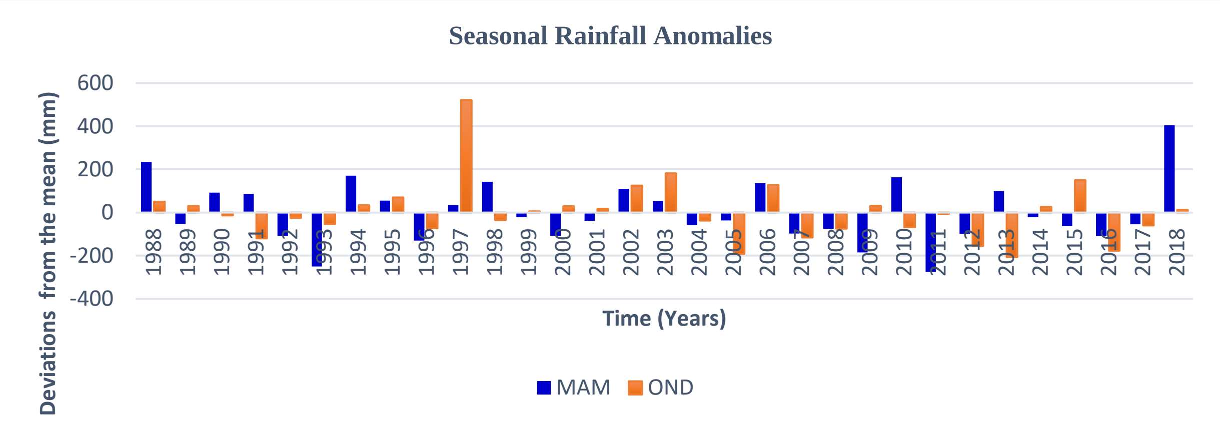
0.83mm annually as demonstrated by the trend line equation (y=397.052-0.83x). Similarly, seasonal rainfall during the short rains has been on a downward trend (y=388.71-3.194x). The Coefficient of Variation results was 40.36% and 37.97% for the short rain season and long rains season respectively.

Seasonal Rainfall Variability

Seasonal rainfall variation during the long season ranged from (+404.3mm) in 2018 to (-275.78mm) in 2011 while variation in seasonal rainfall during the short rains season ranged from (+521.54mm) in 1997 to (-206.53mm) in 2013 (Figure 5).

Figure 5: Seasonal Rainfall Anomalies



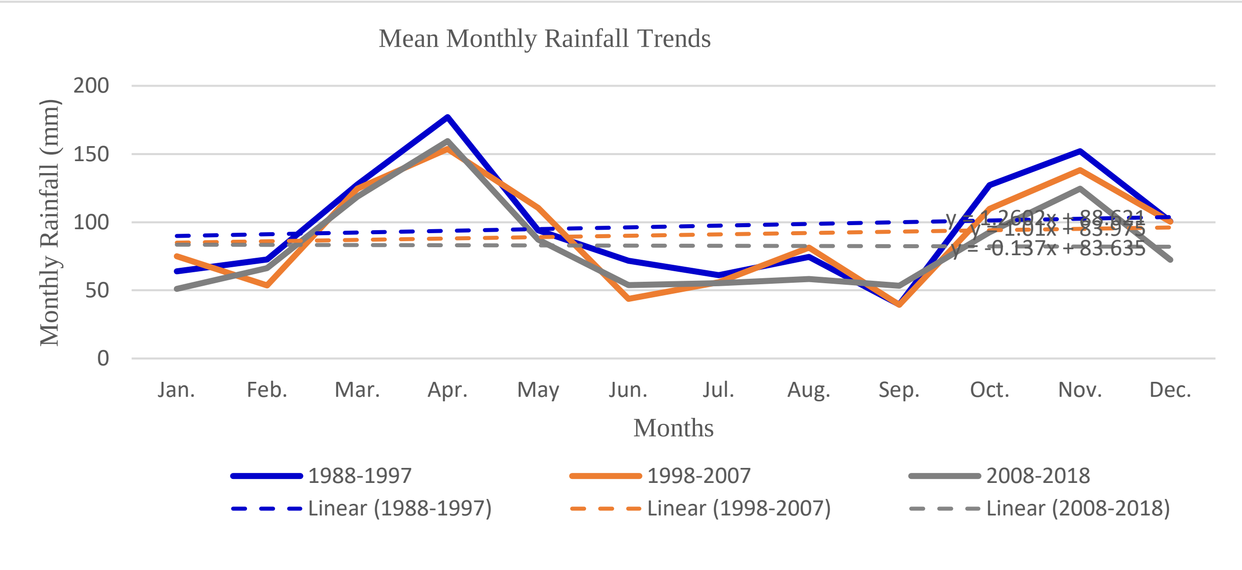
Source: *Kenya Meteorological Department (KMD, 2022)*

Long rain season had the highest below-average rainfall variations in 2011 (-275.78mm), 1993 (-249.73mm), and 2009 (-185.26mm) whereas years 2018 (+404) and 1988 (+233.87) had the highest above-average rainfall variations. Short rain seasons had the highest below-average rainfall variations in 2013 (-206.53mm), 2005 (-191.66mm), 2016 (-176.57mm), and 2012 (-155.2mm) while years 1997 (+521.54), 2003 (+181.66) and 2015 (+149.79) had highest above-average rainfall variations.

Mean Monthly Rainfall Trends

Results indicate that the mean monthly rainfall was 96.81mm, 90.54mm, and 82.74mm for the 1st (1988-1997) 2nd (1998-2007), and 3rd (2008-2018) decades respectively (Figure 6).

Figure 6: Mean Monthly Rainfall Trends



Source: *Kenya Meteorological Department (KMD, 2022)*

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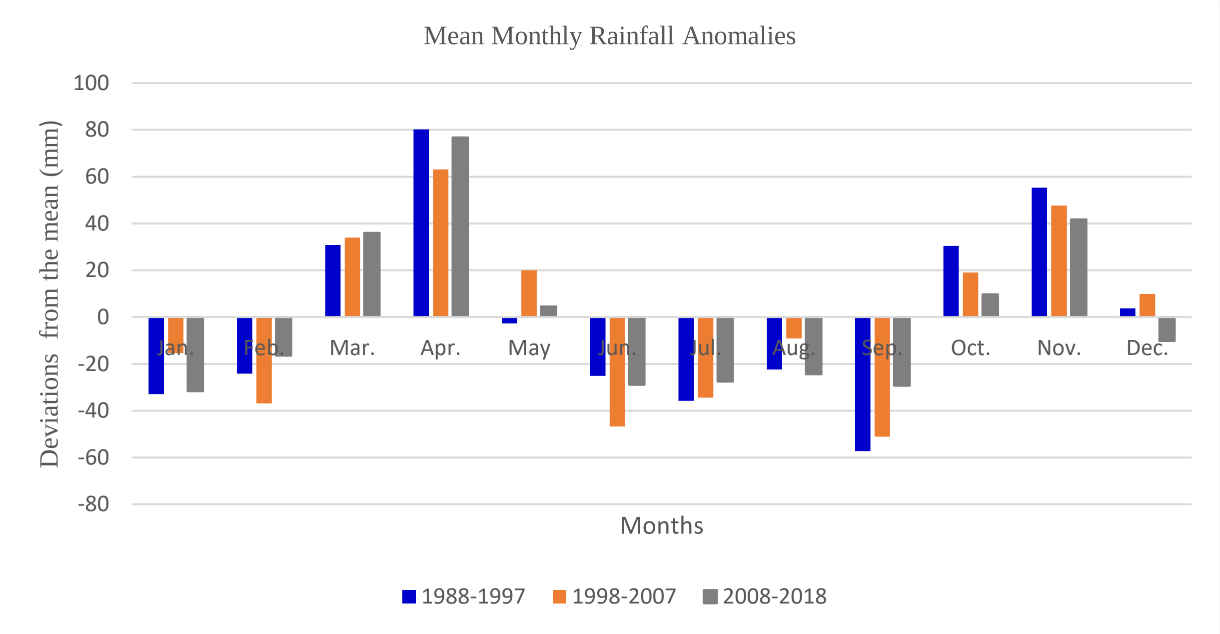
The highest amount of rainfall was received in April whereas the lowest amount of rainfall was received in September for the three decades. The years started with two dry months (short dry season) that is January and February (JF) before the long rain season. The long rain season runs for three months namely March, April, and May (MAM), and is followed by a long dry season that starts from June, July, August, and September (JJAS) followed by the short rain season that begins in October and ends in December (OND). The trend line equation revealed that the mean monthly rainfall has been rising although marginally for the 1st (y =88.621+1.26x) and 2nd decade (y =83.975+1.01x) whereas a gradual decline was noticed in the third decade (y =83.635-0.137x). Nevertheless, there were no clear trends in the three decades ($p = 0.83$).

Mean Monthly Rainfall Variations

The highest mean monthly rainfall below average variation was -57.23mm, -51.15, and -31.68mm for the 1st (1988-1997), 2nd (1998-2007), and 3rd (2008-2018) decades respectively (Figure 7). The highest negative variations were recorded in September except for the last decade when the highest negative variation was observed in January (-31.68mm).

Figure 7: Mean Monthly Rainfall Anomalies



Source: *Kenya Meteorological Department (KMD, 2022*)

The highest mean monthly rainfall variation above average was +80.22mm, +63.16mm and +76.72mm for the 1st (1988-1997), 2nd (1998-2007) and 3rd (2008-2018) decades respectively and all was recorded in the month of April.

Annual Temperatures Trends

Results indicate fluctuations in annual temperatures where the lowest annual temperature recorded was in 1989 (15.01°C) and the highest in 2017 (16.33°C) (Figure 8).

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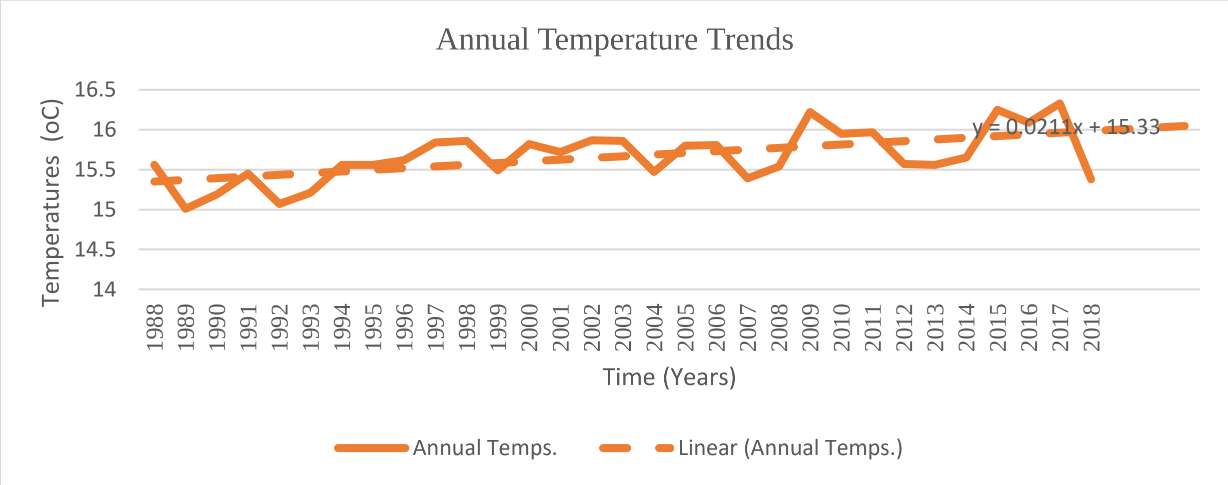
Figure 8: Annual Temperature Trends



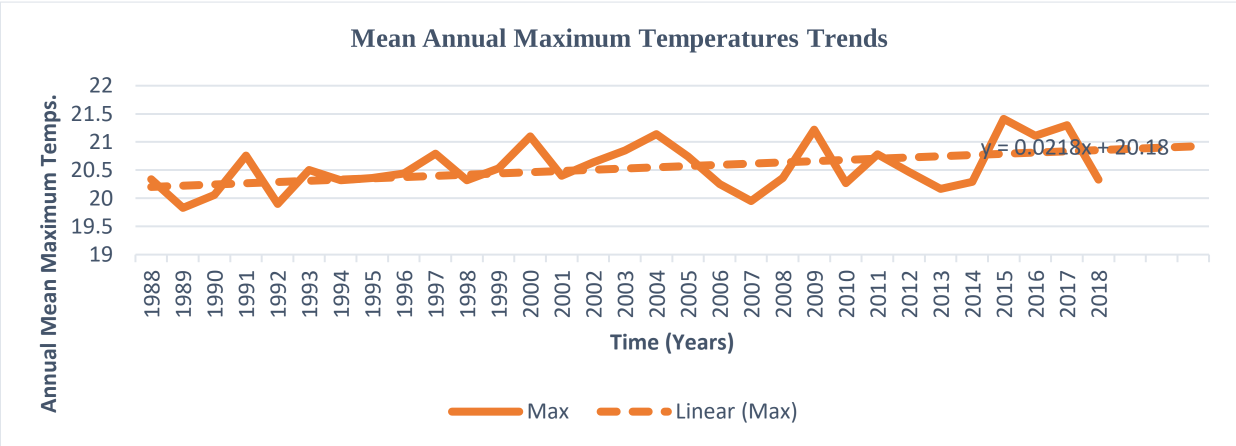
Source: *Kenya Meteorological Department (KMD, 2022)*

The annual temperatures demonstrated an overall upward trend from 1988 to 2018 (*y* = 15.327+0.0211x) indicating that annual temperatures have been rising gradually at 0.0211°C/year translating to an increase of 0.654°C annual mean temperatures for the total period under analysis (Figure 8). This indicates a statistically significant trend of annual temperatures as demonstrated by Mann-Kendall test statistics ($p < .001$).

Annual Maximum Temperature Trends

The average annual maximum temperatures were 20.5°C for the period under review (Figure 9). The highest mean annual maximum temperatures noticed were 21.41°C (2015) and 21.3°C (2017) while the lowest mean annual maximum temperatures noticed were 19.83°C (1989) and 19.9°C (1992). The results reveal that year the 2015 was the warmest while 1989 was the coldest. The results also revealed that the lowest mean annual maximum temperatures were observed in July (18.04°C) whereas the highest was observed in February (23.07°C).

Figure 9: Mean Annual Maximum Temperature Trends



Source: *Kenya Meteorological Department (KMD, 2022)*

The trend line equation for the mean annual maximum temperatures (y = 20.183+0.0218x) reveals a statistically significant ($p = 0.02$) increase in temperatures by 0.0218°C/year over the study period (1988-2018) translating to an increase of 0.68°C for mean annual maximum temperatures for the period between 1988 and 2018.

Annual Minimum Temperature Trends

The minimum mean annual temperatures were 10.83°C. The highest mean annual minimum

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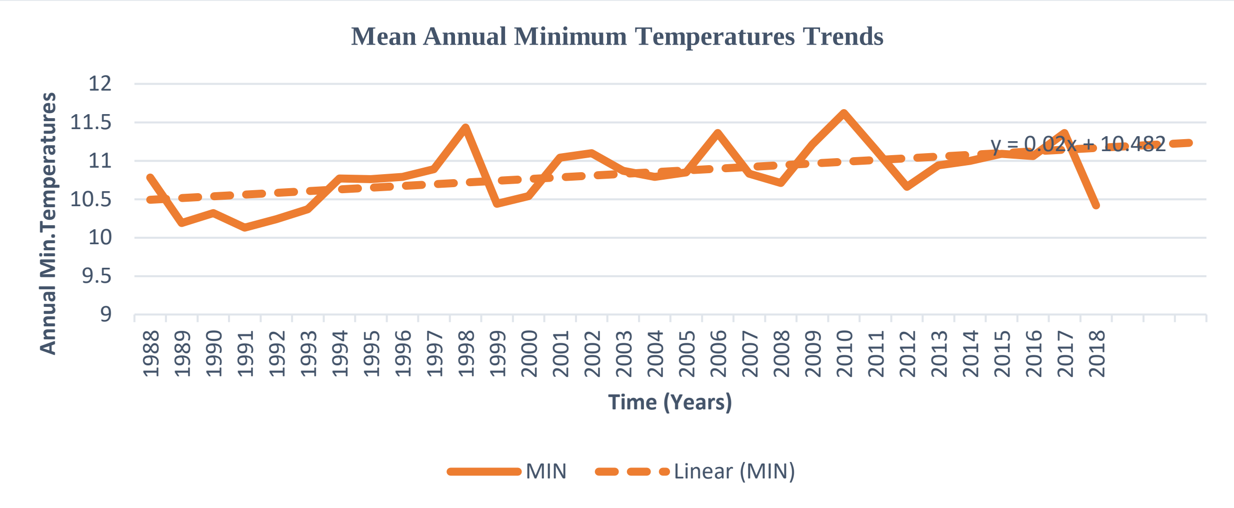
temperatures noticed were 11.62°C in 1998 and 11.43°C in 2010 (Figure 10). The lowest mean annual minimum temperatures noticed were10.19°C in 1989 and 10.13°C in 1991. In addition, the months of March and July recorded the highest and lowest mean annual minimum temperatures at 11.55°C and at 9.62°C respectively.

Figure 10: Mean Annual Minimum Temperature Trends



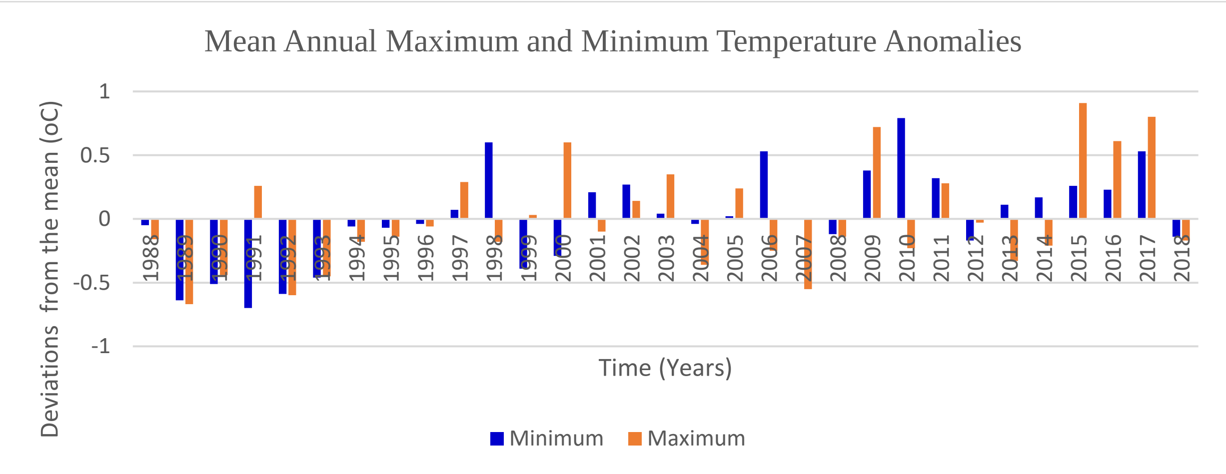
Source: *Kenya Meteorological Department (KMD, 2022)*

The trend line equation (y =10.482+0.02x) reveals that there has been a gradual rise in mean annual minimum temperatures by 0.02°C/year for the period from 1988 to 2018. This translates to an increase of 0.62°C for mean annual minimum temperatures for the three decades which was statistically significant at a 95% confidence level ($p < .001$).

Annual Maximum and Minimum Temperature Variability

The highest mean annual maximum temperature variations were recorded in 2009 (+0.72 °C), 2015 (+0.91°C), 2016 (+0.61°C), 1989 (-0.67°C), 1993 (-0.45°C) and 2007 (-0.55 ° C) while the highest mean annual minimum temperature variations were recorded in 2006 and 2017 (+0.53°C), 2010 (+0.79°C), 1989 (-0.64°C), 1990 (-0.51°C), 1991 (-0.7°C), 1992 (-0.59°C) and 1993 (-0.46 ° C) (Figure 11).

Figure 11: Mean Annual Maximum and Minimum Temperatures Anomalies



Source: *Kenya Meteorological Department (KMD, 2022)*

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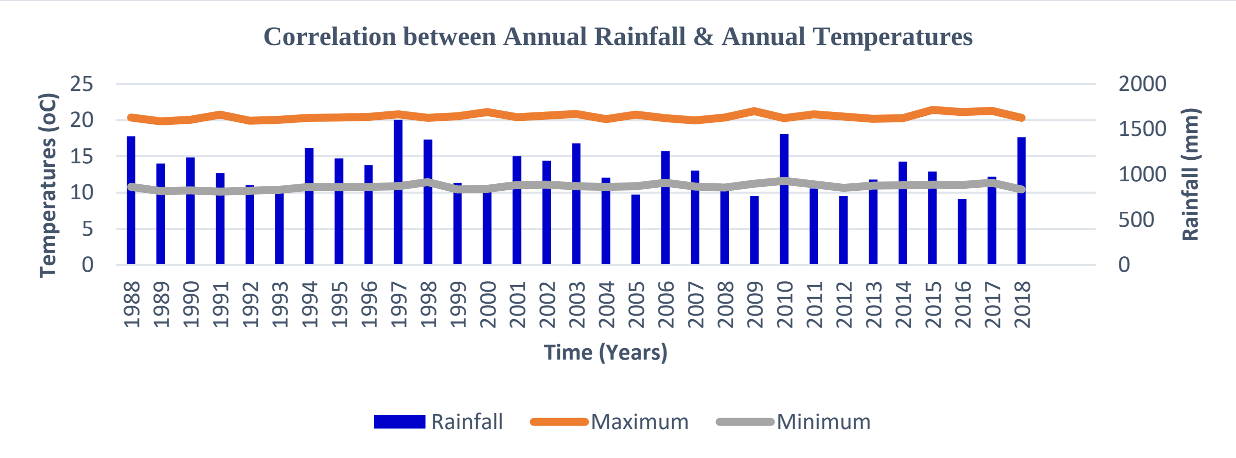
Out of the 31 years, the mean annual maximum temperatures for 19 years were below the mean while the mean annual maximum temperatures for 12 years were above the mean. On the other hand, there was an equal number of years below and above the mean annual minimum temperatures for the period under review.

Correlation Analysis Between Annual Rainfall and Annual Temperatures

Correlation results reveal that during low-temperature years, high amounts of rainfall were received whereas, during years of high temperatures, low amounts of rainfall were received as demonstrated by the behaviour of the annual rainfall peaks and dips and their corresponding annual minimum and maximum temperatures for the period under analysis (Figure 12).

Figure 12: Correlation between Annual Rainfall and Annual Temperatures



Source: *Kenya Meteorological Department (KMD, 2022)*

Correlation between Mean Monthly Maximum and Minimum Temperatures and Mean Monthly Rainfall

Pearson's coefficient of correlation (***r***) results displayed a weak negative correlation for annual rainfall and annual maximum temperatures with values of (*r* (29) = .23, *p* = .2132) (Figure 13). This indicated that when annual maximum temperatures increased, annual rainfall decreased though the decrease was insignificant. Contrarily, there was a non-significant and weak positive linear relationship for annual rainfall and annual minimum temperatures with values of (*r* (29) =.0752, *p* = .6876) indicating that when annual minimum temperatures increased, amounts of rainfall also increased while when the annual minimum temperatures decreased low amounts of rainfall were received.

Results also show that the area experiences two seasons of high rainfall that is between March and May (MAM) for the first season and between October and December (OND) during the second season (Figure 13). Similarly, the study area experiences two seasons of low rainfall. The first season lasts for a short period between January and February (JF) whereas the second season lasts for a longer period between June and September (JJAS) which results in a dry period.

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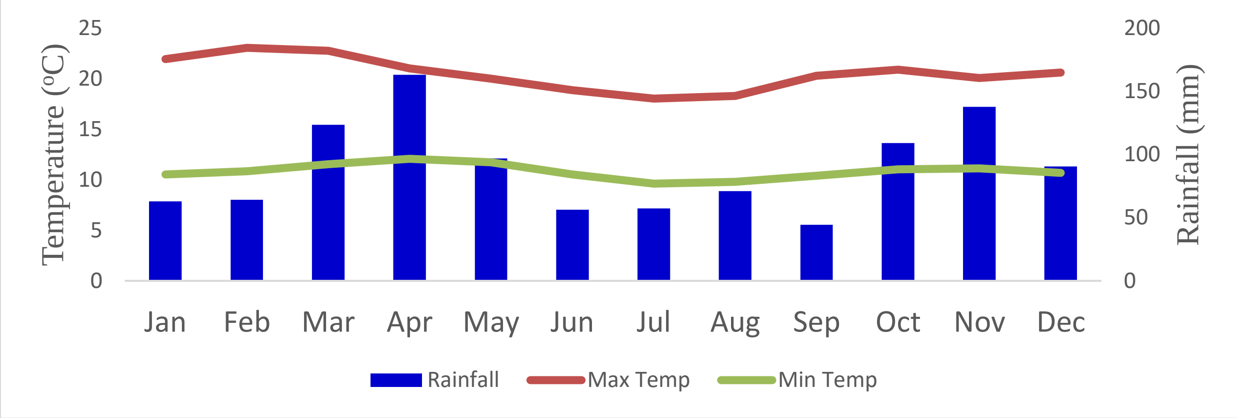
Figure 13: Correlation between Mean Monthly Rainfall, Mean Monthly Minimum and Maximum Temperatures.



Source: *Kenya Meteorological Department (KMD, 2022)*

Over the same period under analysis, the area encountered two seasons of increase in temperatures. Specifically, the minimum and maximum temperatures increased between March and May and again between October and December. The two seasons of temperature and rainfall create a clear pattern and relationship between temperatures and rainfall. When temperatures begin to increase, the area begins to experience increased amounts of rainfall.

Mean monthly minimum temperatures and mean monthly maximum temperatures increased with an increase in mean monthly rainfall received and vice versa for both long and short rain seasons. This depicted a positive linear relationship between the two variables because when the lowest amounts of rainfalls were noticed, the lowest temperatures were also noticed in June through September. Likewise, when the highest amount of rainfall was noticed, the highest temperatures were also noticed for instance in April and November. Pearson's coefficient of correlation (***r***) results revealed an insignificant small positive relationship between mean monthly rainfall and mean monthly maximum temperatures (r (10) = .27, p = .391) and a significant large positive correlation for mean monthly rainfall and mean monthly minimum temperatures (r (10) = .79, p =.002).

Perception of Local Climate Variability

The majority of respondents (83%) indicated that they had noticed a decrease in rainfall, 11% had noticed an increase in rainfall, and 79% reported that rainfall was erratic in the last 20 to 30 years (Figure 14). Rainfall was also reported to be starting late (73%) and ceasing early (69%). In regard to temperatures, 71% noticed an increase in temperatures whereas only 6% of respondents revealed that they had noticed a decrease in temperatures. The perception of local climate variability is consistent with meteorological data which indicated that temperatures had significantly (p = < .001) increased by 0.0211ºC per year as depicted in Figure 8. However, it contrasts with meteorological data which revealed an insignificant (p = 0.14) decrease in rainfall as portrayed in Figure 2.

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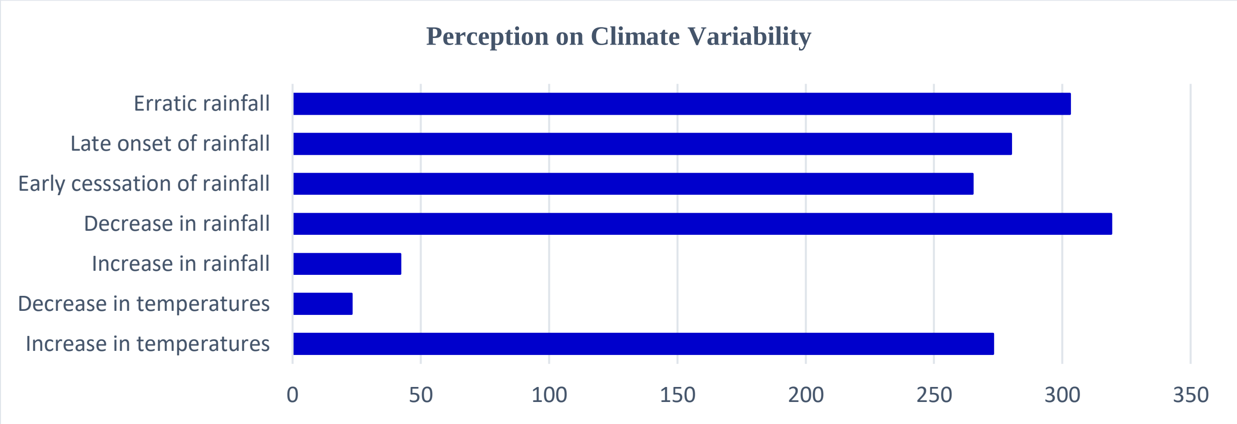
Figure 14: Perception of Climate Variability



Source: *Field Survey (2022)*

The findings reveal that while there is a general increase in temperatures, residents have also noticed some change in the cold season which is usually experienced in July. In the words of one of the focus group discussants:

> "*Temperatures have been increasing every year over the last 20 to 30 years in this area. However, we have also noticed that during the month of July when we usually experience a cold season, temperatures have been decreasing making the season to be colder than in the past. Also, in the recent past, the cold season has become longer as it extends up to the third week of August which is very different from what used to happen in previous years. Sometimes the cold season starts as early as the end of May. Moreover, the season is both cold and dry with little moisture unlike before when the season was cold with some moisture which allowed growth of some food crops in our farms.*"

DISCUSSION

The study analyzed trends of climate variability and local perceptions in Kieni West sub-county, Kenya. Results of the analysis of temperature and rainfall time series data indicate different changes in climatic conditions of the study area. The findings generally reveal an increase in temperatures and a decline in rainfall. Annual rainfall has been fluctuating over the years with the highest averages being recorded in 1997 and 1998 while the lowest averages were recorded in 2009 and 2016. The highest averages corroborate with Karienye *et al.* (2012) and UNEP (2008) report which revealed that Kenya received El-Niño rains between the years 1997 and 1998. Similarly, the lowest averages resonate with the periods associated with La Nina that took place in 1991/1992, 1999/2000, 2004/2005, 2008/2009, 2012/2013, and 2016/2017. The findings also indicated a declining rainfall trend which could have been a result of below-average rainfall received in some of the years under review. These results are contrary to those of Asamoah and Ansah-Mensah (2020) who found an upward trend in rainfall in northern Ghana. Likewise, in northern Benin, Ezin *et al.* (2018) observed an increasing trend of rainfall.

According to Pendergrass *et al.* (2017), rainfall variability is the level of spatial and temporal variation of rainfall amounts. Out of the 31 years, 15 years were above average whereas 16 years were below average suggesting that the period under analysis experienced almost equal years of dryness and wetness. The highest rainfall anomalies above average corresponded with high rainfall periods related to El Niño that were experienced in 1997/1998. Likewise, the highest rainfall anomalies below average correspond with drought periods related to La Niña that occurred in 1991/1992, 1999/2001, 2004/2005, and 2008/2009. Kisaka *et al.* (2015) noted that high rainfall variability is a result of La Niña and El Niño events. They observed that although they are not of equal magnitude, they contribute remarkably to weather patterns which are highly unpredictable. Kieni West Sub-County is an arid

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and semi-arid land (ASAL) and the variation results are in concurrence with Omoyo *et al.* (2015) and Shisanya *et al.* (2011) who opined that ASALs in Kenya have been affected negatively by high variations in rainfall. According to Mubiru *et al.* (2012), rainfall has become more varied and unpredictable with negative impacts on soil moisture content as well as availability resulting in a reduction in crop yields or total crop failures.

Analysis of seasonal rainfall was based on the two main seasons experienced in the study area, that is, the long rainfall season that occurs between March to May as well as the short rainfall season that occurs between October to December. This is consistent with Gitau (2012) who opined that annual rainfall in Kenya follows a strong bi-modal pattern of season alternating with dry season. The finding on high seasonal rainfall amounts recorded during the short rain season agrees with high rainfall periods related to El Niño that occurred in 1997/1998, 2002/2003, 2006/2007, and 2009/2010. Comparably, the low seasonal rainfall amounts recorded concur with drought periods related to La Niña that occurred in 1991/1992,1995/1996, 1999/2001, 2004/2005, 2008/2009, 2014/2015, and 2016/2017.

The results also revealed a downward trend in both long and short seasons which corroborates with a study conducted in the East Africa including Kenya by Shisanya *et al.* (2011) who noted a downward trend during the long rain season. However, the finding is contradictory to another study done in the East Africa region which predicted an increase in rainfall over the region particularly the short rains which are significantly affected by El Niño (Gebrechorkos *et al.*, 2018; Tierney *et al.*, 2013). Likewise, GoK (2013) indicated that the short rain season has shown an increase in rainfall in some areas attributable to short rain seasons which extends to January and February as witnessed in recent years.

Coefficient of Variation results for short (40.36%) and long rains (37.97%) suggest that rainfall received during short rain season had varied substantially compared to that of long rain season. It also implies that the long rain season was more consistent and therefore more predictable. These findings support Few *et al.* (2015) who observed that although there is rainfall variation in Kenya, significant variability is felt during the short rain season as opposed to the long rain season. Also, Kisaka *et al.* (2015) noted that rainfall patterns have become unpredictable with the short rain season starting in late October and early November, unlike the usual onset of mid-October. Nonetheless, the results are in contrast with Nicholson (2017) who revealed that in East Africa long rains are persistently less predictable.

Mean monthly rainfall trends results suggest that mean monthly rainfall has been declining over the last three decades. In addition, it indicates that the last decade has been drier compared to the 1st and 2nd decades. The highest amount of rainfall received in April and the lowest amount of rainfall received in September for the three decades indicated that April has been the wettest while September has been the driest month for the past 30 years. Trend analysis results imply that the last decade has been significantly affected by climate change and variability as compared to the other two decades. The highest mean monthly rainfall variation above average for the 1st (1988-1997), 2nd (1998-2007), and 3rd (2008-2018) decades recorded in the month of April could be a result of the high amounts of rainfall that was received in April for the three decades.

Temperature is key in establishing spatial climate change and variability if used for a longer period of time (Graff Zivin *et al.*, 2018; Grbec *et al.*, 2019; Turco *et al.*, 2018). The highest annual temperatures recorded in 2017 (16.33^{o}C) correspond to the period between 2016 and 2017 when a severe drought was experienced in Kenya. The annual temperatures were observed to be rising gradually at 0.0211^{o}C/year translating to an increase of 0.654^{o}C annual mean temperatures for the total period under analysis. IPCC (2018) observes that the earth's warming will be at 1.5^{o}C by 2050 and that by 2100 average temperatures will be 2^{o}C. An increase in temperatures in the study area of +0.654^{o}C may thus have contributed to the overall global warming index. The lowest mean annual maximum temperatures observed in

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July (18.04ºC) and highest mean annual temperatures observed in February (23.07ºC) is an indication that February and July were the warmest and coldest months respectively for the period under review. The highest mean annual minimum temperatures in the month of March (11.55ºC) could be attributed to the high minimum temperatures experienced in the month of March which precedes the long rain season. An equal number of years below and above the mean annual minimum temperatures for the period under analysis suggests that there was an equal distribution of mean annual minimum temperatures. The finding is consistent with a study conducted in semi-arid lands in Kenya which revealed that there was inter-annual variability in annual maximum temperatures (Gichangi *et al.,* 2015).

Pearson's coefficient of correlation (***r***) results displayed a weak negative correlation between annual rainfall and annual maximum temperatures which corroborates with Koimbori *et al.* (2018) who noted a negative correlation between mean annual rainfall and mean annual maximum temperatures in their study on the analysis of rainfall and temperature trends in Bahati sub-county, Kenya. On the other hand, Pearson's coefficient of correlation (***r***) revealed a significant large positive correlation between mean monthly rainfall and mean monthly minimum temperatures. The finding is in support of Zhao *et al.* (2017) who found a positive correlation between temperatures and rainfall.

The results on the perception of local climate variability are in congruence with Teye *et al.* (2015) who noted that about 80.2% of respondents in their survey had perceived a rise in the mean temperatures for a period of three decades. Previous studies in Ethiopia (Alemayehu & Bewket, 2017; Asfaw *et al.*, 2018; Thesome *et al.*, 2021; Weldul, 2016) reported that temperatures were increasing at an alarming rate. With respect to rainfall, the findings are consistent with that of Ezenwa *et al.* (2018) who pointed out that there was a decline in rainfall in Baringo and Jigawa State in Kenya and Nigeria respectively. Earlier empirical studies (Abrha & Simhadri, 2017; Habtemariam *et al.*, 2016; Tadesse *et al.*, 2017; Weldegebriel & Prowse, 2017) indicated that in Ethiopia farmers had perceived a downward trend in the amounts of rainfall received over the years. The findings however contradict Cudjoe *et al.* (2021) who observed that 97% of maize farmers in Ashanti Region, Ghana noticed more rains.

On onset and cessation of rainfall, the study findings support Etana *et al.* (2020) who observed that more than 90% of household heads in Central Ethiopia indicated delayed onset and early cessation of rainfall. Similarly, Cudjoe *et al.* (2021) perceived changes in the onset of rains (98%) in Ejura Sekyedumase Municipality, Ghana. Existing literature has also reported late-onset as well as the early cessation of rainfall, reduction of rainfall duration along with general inconsistency of rainfall (Abdi *et al.*, 2015; Adaawen, 2021; Asare-Nuamah & Botchway, 2019; Chepkoech *et al.*, 2018). Moreover, MoALF (2016) indicated that in the past, the cold season in the study area started in July to August but now it starts in May and ends in August.

The finding on the perception of local climate variability suggests that while respondents were able to accurately perceive temperature variability, they were unable to accurately perceive changes in rainfall. This is in line with several studies that reported a convergence between farmer perceptions of rainfall trends with meteorological data (Darabant *et al.*, 2020; Diem *et al.*, 2017). Nevertheless, other studies indicated a divergence between farmers' perceptions and meteorological data (Esayas *et al.*, 2019; Goudaar *et al.*, 2021).

CONCLUSION, IMPLICATION OF THE STUDY AND ACKNOWLEDGEMENTS

Conclusion

The study concludes that Kieni West sub-county is experiencing climate variability. It also concludes that the area is becoming drier as evidenced by decreasing amounts of annual rainfall over the years. Rainfall received during the short rain season has been varying more as compared to the long rain season thus making long rains to be more consistent and predictable. Additionally, the study area is gradually becoming warmer as demonstrated by the upward trends in annual temperatures with the last decade being exceptionally warmer compared to the other two decades. Despite the accurate perception of increasing temperatures, most respondents inaccurately perceived a decrease in rainfall.

Implications of the Study

The study has implications for practice and policy from its findings. From the seasonal rainfall trend analysis, for instance, the study revealed that the area is receiving more consistent and therefore predictable long rains compared to short rains. This information can help smallholder farmers make informed decisions when planning future agricultural activities such as crop cultivation and livestock keeping which largely depend on rainfall. Better planning will ensure maximum benefits from the agricultural activities undertaken by the smallholder farmers. In addition, the finding that the study area is experiencing climate variability could help policymakers and the county government in formulating policies on appropriate mitigation and adaptation mechanisms in the face of the globally changing climatic risks. These will help to minimize the negative impacts of climate change and variability on livelihoods in the study area.

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