Long-term observed Precipitation Trends in Arid and Semi-arid Lands, Baringo County, Kenya

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The research was conducted to validate the pastoralists’ and agro-pastoralists’ claim that there has been an increasingly variable and changing climate in the study area. The station average and Theissen polygon methods were used to estimate the mean areal precipitation of the small (Mogotio and Baringo South sub-counties) and the large area (Baringo County), respectively. The aim of the current study is to analyse rainfall time series over long term observed precipitation and a wide area, detecting potential trends and assessing their significance. Monthly precipitation data for the period 1974-2003 from six weather stations, located mainly in Mogotio and Baringo South sub-counties and covering 3906km² were used in the analysis. The data were quality controlled to ensure no missing data and any inconsistencies. Linear regression analysis of the database highlighted that; the trends were predominantly negative, both where the average and Theissen polygon methods were used and over the whole reference period. The negative trends are not significant. This finding implies that the study area has been suffering a precipitation decrease especially in the period under review.

Keywords: climate change, Theissen Polygon, Weather Stations, Variability

INTRODUCTION

Erratic rainfalls and increasing temperatures are the most serious global problems associated with climate change. They are considered to be some of the most serious threats to sustainable development with adverse impact on the environment, human health, food security, economic activities, natural resources and physical infrastructure (Jiri et al., 2014). The arid and semi-arid lands (ASALs) are hardest hit by the above-mentioned problem. It accounts for more than 40% of the world’s land area and are home to over two billion people, of whom 325million are in Africa. Yet they are among the regions in the world where climate change impacts on ecosystems, livelihoods and human health are potentially the greatest (IPCC, 2014) as cited by (Nyasimi, 2014). The main challenge that confronts farmers in arid and semi-arid areas of Sub-Saharan Africa is managing unreliable rainfall (Tumbo et al., 2010). In Kenya’s ASALs, for example, more than three million pastoralist households are regularly hit by drought, costing the economy an estimated $12.1 billion in 2008–2011 (ILRI, 2014). The risks expose the ASALs in the region to the challenge of high costs of inputs occasioned by unreliable, highly variable, and scarce rainfall for their livestock and crop production (Tol et al., 1998; Bhatt et al., 2006; Cooper et al., 2012).

Netherlands Development Organization-SNV (2012) reported that climate change and variability in the ASAL is evidenced by more extreme oscillations between dry and wet periods, and between the availability of natural resources in different areas, leading to greater variability in livestock production.

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Therefore, climate change and variability are increasingly becoming serious problems to pastoralists. Kibria et al. (2017) reported that pastoralist communities live in ASALs where their livelihoods are highly dependent on natural resources which are sensitive to changes in climatic conditions. The aforementioned livelihood makes pastoralists more vulnerable to climate change and variability. Saitabau (2014) noted that pastoralists use indigenous knowledge to model weather events and livelihood management. However, indigenous knowledge systems are now failing to predict the weather events; for example, weather variations have become so phenomenal that droughts which used to occur every ten years now occur every two years or less, and the trend continues to worsen. Annual rainfall is now more erratic than in the past and figures continue to decline, while people experience warmer dry months than in the past. Thus, the current trend of changing climate poses a threat to livelihoods. The influence of seasonal weather patterns on crop and livestock production suggests that agricultural applications of seasonal weather predictions may be highly valuable to the society (Jones, 2000). Climate information (including observations, research, predictions, and projections) plays a central role in both adaptation and mitigation of climate change (Zillman, 2009).

According to Chin (2007), there are three (3) common ways to estimate mean areal precipitation: namely the station average method, Theissen polygon method and isohy et al method. Each method has its advantage and constraint. The Theissen method involved drawing perpendicular bisectors (Figure 2) between two nearby rain gauge points, converging data point with two other bisectors to form a polygon for each representative point (Linsley et al., 2000). The method provides weights proportional to the size of polygon area, pivoted by each rain gauge. The method is widely used because of its practicability and it is less time consuming with relatively high accurate estimates (Damant et al., 1983). Vaes et al. (2004) reports that the station average method is recommended for very small catchments, of up to one (1) km radius evenly installed with rain gauges. Further, Chin (2007) recommends Theissen method for large area coverage.

The objective addressed in this paper is to validate the pastoralists and agro-pastoralists claim that there has been an increasingly variable and changing rainfall in the study area. To achieve this objective rainfall time series over a long-time interval and wide area was analyzed, detecting potential trends and assessing their significance.

**MATERIALS AND METHODS**

The study was conducted in Baringo County, Kenya, and focused on the sub-counties of Mogotio and Baringo South (Figure 1). The monthly precipitation data for the years 1974-2003 was sourced from the Kenya Meteorological Department (KMD). Specifically, the data came from six weather stations namely; Snake farm, Chemususu, Kimose, Lake Bogoria, Perkerra and Talai covering 3906 km² (Table 1). The percentage of missing rainfall data in the aforementioned weather stations was less than 10% and the data spread over 20 years, hence met the requirements of World Meteorological Organization with regard to climatological analysis. The data were quality controlled to ensure no missing data or inconsistencies. Radi et al. (2015) recommended imputation approaches to fill in missing rainfall data. For this study multiple imputations method were used to overcome underestimation of standard errors and confidence intervals typical of single imputation. The method involved estimation of missing rainfall data from the observations of rainfall (rainfall data sets) at the same station and period but different years and filling in of them missing data with substituted values. The imputed data sets were combined and average worked out. According to Ochieng et al. (2017) the missing rainfall data PX was estimated using the following formula:

\[
P_X = \frac{1}{n} \sum_{i=0}^{n-1} P_i \quad \text{Equation (1)}
\]

Where:
- \( n \) = the number of rainfall data sets
- \( P_i \) = rainfall data from the \( i \)th data set
- \( PX \) = missing rainfall data

For this study, the station averages the station average and Theissen polygon methods were used. Apart from the two aforementioned methods, annual precipitation for an individual station was also analyzed. The average method was applied for four weather station namely; Snake farm, Kimose, Lake Bogoria and Perkerra all located in Mogotio and Baringo South Sub-counties, covering an area of 1867 km². For the large area in this study two weather stations from outside the study area namely; Chemususu and Talai were added to the four weather stations used in the small area. Therefore, rainfall data used in the study came from a total of six weather stations, covering a cumulative area of 3906 km². Equation 2 was used to estimate the Thiessen values from the Thiessen polygons. Polygons for Baringo County were generated using ArcGIS software (Table 1). The data on spatial annual average rainfall from the five stations was estimated using the Thiessen polygon method (weighted values) with the Thiessen value using the Equation 2 below:

\[
\bar{p} = \frac{P_1A_1 + P_2A_2 + P_3A_3 + P_4A_4 + P_5A_5}{A_1 + A_2 + A_3 + A_4 + A_5} = \sum_{i=1}^{5} \frac{P_iA_i}{A_i} \quad \text{Equation (2)}
\]

Where:
- \( \bar{p} \) = is the weighted average
- \( P_i \) = are measurements
- \( A_i \) = are areas of each polygon (Table 1)
Statistical analysis of the data computed from both the station average as well as from Theissen method was performed by using Microsoft Excel and Statistics Package for Social Scientists (SPSS). The linear regression analysis was used to generate the mean areal precipitation trends, potential trends, their descriptive and assessing their significance.

**RESULTS**

Table 1 shows the six weather stations whose long term observed precipitation data were used in this study. It further shows the area coverage of each station in square kilometers. This data was used in the construction of the Theissen polygons (Figure 2) in the process of computing the Theissen values/weighted averages.

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**Figure 1**: Map of Kenya and the study area location, Baringo County. Mogotio and Baringo South are shown with Weather stations (Source: Author 2017)
Table 1: Area in Km² covered by respective weather stations in Baringo County

<table>
<thead>
<tr>
<th>S/No</th>
<th>Station Name</th>
<th>Area in Kilometers squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Snake Farm - Lake Baringo</td>
<td>306.724</td>
</tr>
<tr>
<td>2</td>
<td>Chemususu Forest Station</td>
<td>348.842</td>
</tr>
<tr>
<td>3</td>
<td>Kimose Agricultural Holding Ground</td>
<td>889.485</td>
</tr>
<tr>
<td>4</td>
<td>Lake Bogoria National Reserve</td>
<td>880.314</td>
</tr>
<tr>
<td>5</td>
<td>Perkerra Agricultural Research</td>
<td>680.039</td>
</tr>
<tr>
<td>6</td>
<td>Talai Agricultural Station</td>
<td>800.355</td>
</tr>
</tbody>
</table>

Figure 2 shows the distribution and location of seven weather stations in Baringo County. The long-term observed precipitation data for Kabimoi Agricultural Holding could not meet the threshold for the analysis since it lacked data for five years unlike the other six weather stations. It was therefore, omitted in any further process and analysis. Figure 2, further demonstrates the bisected perpendiculars, generated polygons and km² coverage of each polygon. The area covered by each polygon was used in Equation 2 for the computation of the weighted averages/Theissen values, which were further used in plotting the mean areal precipitation trends.

Figure 2: Map of Baringo County showing generated polygons and area each weather station is covering
(Source: Google map and Author 2016)

Mean Areal Precipitation Trend by use of Station Average Method

Figure 3 shows the estimated mean areal precipitation trend for four weather stations namely; Snake farm, Kimose, Lake Bogoria and Perkerra for the period 1974-2003 and covering 2757km² in Mogotio and Baringo South sub-counties. It further shows the highest and lowest estimated mean areal precipitation of 1081.10mm in 1977 and 277.90mm in 1984 respectively. The range between the highest and the lowest is 803.20mm, implying that there has been a big variation in the amount of precipitation in the years under review. Further analysis of the long term observed precipitation data for the aforementioned weather stations showed that 706.07mm ± 178.13mm, n = 30. This implies that the amount of mean areal precipitation observed and recorded was between 884.2mm and 527.13 mm within the span period of 30 years. This finding demonstrates the variability of the precipitation since the standard deviation (SD) reported is very high relative to the means.

From the trend equation, the predicted mean areal precipitation for the year 2018 (15 years from 2003) was 707.28 mm. The linear regression line shows a negative slope of 2.408mm per year. This finding indicates a general decreasing trend in the mean areal precipitation. The regression equation, $R^2=0.014$ implies that the time series explained only 1% of the mean areal precipitation. Further analysis showed that, there was no significant relationship ($P>0.05$) between the mean areal precipitation and the time series in the study area.
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Mean Areal Precipitation Trend by use of Theissen polygon method

Figure 3: Estimated mean areal precipitation trend by use of average method for four weather stations within the study area (Snake Farm, Kimose Agricultural Holding Ground, Lake Bogoria National Reserve and Perkerra Agricultural Research)
Source: KMD Observed Precipitation data (2016)

Figure 3 shows the estimated mean areal precipitation trend for the six weather stations namely; Snake farm, Kimose, Lake Bogoria, Chemususu, Talai and Perkerra for the period 1974-2003 and coverage of 3905.76km² in the larger Baringo County. It further shows that the highest and the lowest estimated mean areal precipitation was 1298.65mm in 1988 and 359.59mm in 1984, respectively. The range between the highest and the lowest was 939.05mm, implying that there has been a big variation in the amount of precipitation over the years under review. Further analysis of the long term observed precipitation data for the aforementioned weather stations showed 868.12 mm ± 221.37 mm, n = 30. The findings imply that the SD is very high relative to the mean within the span period of 30 years. Therefore, the annual precipitation received within the period under review (1974-2003) demonstrates a big variation. The linear regression shows a negative slope of 5.393mm per year indicating that the general amount of rainfall received in the station reduced progressively. The trend yielded an R² = 0.046, indicating that the time series predicts only 4.6% of the annual rainfall. There was no significant relationship (P>0.05) between the mean areal precipitation and the time series in the study area.

From the trend equation, the predicted mean areal precipitation for the year 2018 (15 years from 2003) was expected to be 870.47 mm. The linear regression line shows a negative slope of 4.72mm per year, indicating a general decreasing trend in mean areal precipitation, which suggests that the rainfall was decreasing in the study area. For regression line equation, the R² = 0.040, indicates that the time series could explain only 4% of the mean areal precipitation. When a further analysis was conducted, the findings showed that there were no significant relationships (P>0.05) between the mean areal precipitation and time series in the study area.

Individual Annual Precipitation Trends

The annual rainfall trends for the individual five weather stations namely; Chemususu, Perkerra, Kimose, Snake Farm and Lake Bogoria were plotted in one graph (Figure5). The Chemususu station trend recorded the highest precipitation of 1716 mm in 1977 and lowest of 656 mm in 1984 relative to all the others under review. It further showed 1139.16 mm ± 221.37mm, n = 30. The findings imply that the SD is very high relative to the mean within the span period of 30 years. Therefore, the annual precipitation received within the period under review (1974-2003) demonstrates a big variation. The linear regression shows a negative slope of 5.393mm per year indicating that the general amount of rainfall received in the station reduced progressively. The trend yielded an R² = 0.046, indicating that the time series predicts only 4.6% of the annual rainfall. There was no significant relationship (P>0.05) between the mean areal precipitation and the time series in the study area.

From the amount of precipitation observed in Kimose weather station, a trend was generated as indicated in Figure 5. From the trend, it is clear that there were variations in the observed amount of precipitation throughout the 30 years period (1974-2003). This scenario is an indication that climate variability is tantamount to climate change, since precipitation is a climatic parameter. The highest annual rainfall observed in the station was 1341 in 1997 while the minimum was 365 mm in 1981. From the annual rainfall observed from the station, the annual rainfall trend from 1974-2003 showed 857.19mm ± 236.82mm, (n = 30). This shows that there has been a big variation in the amount of rainfall received over the period.
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Figure 4: Estimated mean areal precipitation trend by use of Theissen polygon method for six weather stations, 1974-2003
Source: KMD Observed Precipitation data (2016)

Figure 5: Combined Individual Stations Annual Rainfall Trends from 1974-2003
Source: KMD Observed Precipitation data (2016)

in reference. This is because the SD is relatively high to the mean. The linear regression line shows a negative slope of 2.413 mm per year, indicating a continuous decrease of the annual rainfall received. There was no significant relationship (P>0.05) between the mean areal precipitation and time series in the study area.
A trend was generated for the annual rainfall observed in Snake Farm around Lake Baringo as presented in Figure 5. There was evidence of variation in the annual rainfall amount over the 30 years (1974-2003). From the trend, the highest amount received was 1115 mm in 1988 where the lowest 362 mm was observed in 1984. From the recorded annual rainfall in Snake Farm Station, showed 668.31mm ± 194.57mm, n = 30. This indicated that there has been great variation in the annual rainfall received for the 30 years. The linear regression line shows a negative slope of 4.071mm per year indicating a continuous decline of annual rainfall. There was no significant relationship (P>0.05) between the mean areal precipitation and time series in the study area.

Figure 5 above shows the trend of annual rainfall recorded in Lake Bogoria National Reserve for 30 years (1974-2003). The trend shows clearly that, there has been variation in the annual rainfall received during the study period, the maximum annual rainfall recorded was 1010 mm in 1978 and the minimum was 247 mm in 1984. Further, the result shows (658.36mm ± 198.36mm, n = 30). This shows that there has been highly dispersed rainfall observed over the 30 years. The slope of the regression line is negative 0.851mm per year indicating the annual rainfall is reducing over the 30 years period under review. There was no significant relationship (P>0.05) between the mean areal precipitation and time series in the study area. As indicated in Figure 5 the intensity of variation in the annual rainfall recorded in Perkerra Agricultural Research Station is noted in every year within the entire study period of 30 years. The maximum annual rainfall recorded was 1087 mm in 1977 and a minimum 264.8 in 1984. The analysed annual rainfall recorded for the 30 years showed 612.32 ± 179.27mm, n = 30, indicating that the variation of annual rainfall is evident for the study period (1974-2003).

The trend yielded a linear regression line showing a negative slope of 9.178mm per year depicting that the annual rainfall observed is continually decreasing. There was no significant relationship (P>0.05) between the mean areal precipitation and time series in the study area.

**DISCUSSION**

The trend demonstrated by Figure 3 on the mean areal precipitation, corroborates Lelenguyah (2013) findings that Baringo South/Marigat has been experiencing an oscillating trend in rainfall with a significant peak observed in 1977. Other observable peaks are those of 1988-89 and 1997-98 from 1971-2007. These are the four major peaks with the highest amounts of rainfall over the last four decades. It is worth noting that the area has been receiving heavy rainfall in every ten years over 1971-2010 periods. Also, this study finding agrees with Ochieng et al. (2017) who reported a declining long-term seasonal rainfall trend in the drylands of Baringo County. Further, Wakachala et al. (2015) reported a decreasing trend in annual rainfall during March-April-May season and high variability within seasons in the Great Rift Valley of Kenya. Although the study area has been experiencing an oscillating trend in rainfall, it is important to note that, the amount of annual average rainfall has been decreasing with time. The linear regression lines with negative slopes in Figure 3, 4 and 5 supports the decrease in rainfall. It is perhaps associated with the aspect of climate change and variability.

Figure 4 shows the trend of variation for amount of rainfall observed annually that demonstrates a decrease in the amount rainfall throughout the study period. It corroborates Omoyo et al. (2015) where rainfall trend analysis for 1994-2008 revealed that four of the six weather stations in Machakos County, Kenya were declining up to 3 mm pa. A similar study by Mwaura et al. (2017) reported that rainfall in semi-arid Ijara in Garissa, Kenya, has increasingly become uncertain and the trend analyzed using KMD data (40 years) period indicates a definite decline. However, Recha et al. (2017) also analyzed precipitation data for 10 years in Semi-arid Tharaka District, Kenya and reported similar results that showed a declining trend between the 1970s and mid-1980.

From the combined individual station’s annual observed precipitation trend at Chemususu Forest Station (Figure 5) it was evident that there is climate change and variability as depicted by some observed rainfall variations. This indicates that the annual rainfall received over the 30 years (1974-2003) has not been consistent as indicated by the negative slope of 5.393mm per year. The general amount of rainfall received in the station has been reducing during the study period.

From the amount of rainfall observed in Kimose Agricultural Holding Ground weather station, a trend was generated as indicated in Figure 5. From the trend, it is clear that there are variations in the observed amount of rainfall throughout the 30 years period (1974-2003). This scenario is an indication of climate variability, which is tantamount to climate changes. This shows that there has been a big variation in the amount of rainfall received in a year for the 30 years in question. From the trend equation, the predicted annual rainfall amount for the year 2018 is expected to be 785.92mm. This confirms that the annual rainfall amount was decreasing consistently from 1974. A trend was generated for the annual rainfall observed in Snake Farm around Lake Baringo as presented in Figure 5. There was evidence of variation in the annual rainfall amount over the 30 years (1974-2003).

Figure 5 above shows the trend of annual rainfall recorded in Lake Bogoria National Park Reserve for the 30 years (1974-2003). The trend clearly shows that there has been variation in the annual rainfall received. For the study period, the maximum annual rainfall recorded was 1010 mm in 1978, and the minimum was 247 mm in 1984. The standard deviation computed from the observed rainfall is highly dispersed over the 30 years.
As indicated in Figure 5, the intensity of variation in the annual rainfall recorded in Perkerra Agricultural Research Station is noted in every year within the entire study period of 30 years. The p-value of 0.012<0.05 which shows that for Perkerra Agricultural Research Institute Station, the relationship between the time series and the annual rainfall recorded is significant at 5% levels of significance.

The individual annual rainfall trends for the combined 5 stations from 1974-2003 clearly shows that there has been variation in the annual amount of rainfall received in the five weather stations (see Figure 5). From the trends of the stations, it is clear that there is an annual rainfall variation across the stations and eventually reduced annual precipitation. The findings of this study confirm Luseno et al. (2002) citation in (Galvin et al., 2001) that climatic variability is especially pronounced and crucial in dry lands. It also supports Easterling et al. (2000) that, results of observational studies suggest that in many areas that have been analysed, changes in total precipitation are amplified at the tails. Comparing the annual rainfall as displayed in the trends, it was evident that Chemususu recorded the highest amount of rainfall, followed by Kimose, Snake Farm and Lake Bogoria while Perkerra recorded the lowest. The findings in this study corroborate IPCC (2007) who reported that, as climate changes, observations show that changes are occurring in the amount, intensity, frequency and type of precipitation. These aspects of precipitation generally exhibit large natural variability.

CONCLUSION

Based on all the trends analysed using the two methods for estimating the mean areal precipitation namely; Station Average and Theissen polygon methods it is clear that precipitation was decreasing respectively across and within the area covered by the four stations and for the six stations in Baringo County, Kenya. This is evidenced by the negative slope along the linear regression line. It is also reported that in both methods there was no significant relationship between the mean areal precipitation and time series.

The same scenario is reported in the individual combined stations annual precipitation trends. It is evident that the general amount of rainfall received in all stations is decreasing and from all the trends it is apparent that there are variations. This confirms that the annual rainfall amount is decreasing consistently from 1974 to 2003 and all the linear regression equation generated predicted that the amount of rainfall expected in 2018 in all the stations is generally decreasing in amount. This aspect of decreasing amount of precipitation for the long period of analyses confirms that the pastoralist and agro-pastoralists claim of the presence of climate change and variability in the study area. Therefore, it is prudent to conduct further research on the adverse effect posed on the pastoralist and agro-pastoralist and come up with appropriate interventions to counteract the effects of the climate variation and change on the livelihoods in the ASALs.

ACKNOWLEDGEMENT

The authors wish to acknowledge the National Commission for Science, Technology and Innovation (NACOSTI) for providing the funds to undertake this study. Further, the authors appreciate the Kenya Meteorological Department (KMD) for the provision of the observed precipitation data used in the study.

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Accepted 9 December 2017


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