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Trend Analysis of Rainfall and Temperature Variability in Arid Environment of Turkana, Kenya

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Abstract: Scrutiny of seasonal, monthly and inter-annual temporal and spatial variability of rainfall and temperature in a changing climate is vital to assess climate-induced changes and suggest adequate future adaptation strategies for vulnerable communities in arid and semi-arid environments. This present study focused on temporal trends analysis of in-siturainfall and temperature record for Lodwar in Turkana County, Kenya using non-parametric Mann-Kendall test statistic (Z) at 5% significance level. The datasets used were rainfall (1950 to 2012) and temperature (1979 to 2012). The findings showed that the highest and lowest annual rainfall recorded was in 1982 (725.1 mm) and 1984 (54.2 mm), respectively while the month of December in 1961 was the highest single monthly rainfall (197.7 mm). Further results revealed that among the seasons, a notice able decrease of rainfall was observed in March to May (MAM) and slight increase in October to December (OND) based on trends analysis, though one of the seasons was statistically significant at 95% confidence interval. January recorded the highest mean monthly temperature of 36.97°C while December had the lowest 20.22°C. All the seasonal maximum and minimum temperature trends were statistically significant. In overall, the findings demonstrated that a significant rise in both maximum and minimum temperatures occurred between 1979 and 2012 and this is in line with recent trends of global warning as reported by the latest Intergovernmental Panel on Climate Change (IPCC) report. The significance of these findings is that it could support various policy makers and development partners working in Kenya arid and semi-arid environments to see, on a local scale what temperature changes are being observed and to aid in better planning for a changing climate.

Key words: Climate variables, Mann-Kendall, trend analysis, non-parametric tests, Kenya

INTRODUCTION

Rainfall variability and reliability have recently received considerable attention by the scientific community at different scales in the ongoing debates on climate change. In fact, climate projections suggest that variability is likely to increase in the future and extreme weather events might become more frequent in sub-Saharan Africa (Hulme *et al*., 2001; Cooper *et al*., 2008; Field, 2012, Omondi *et al*., 2013a). However, the reality is that the effects, risks and uncertainty with the science around the subject of climate change and projections are daunting, challenging and complex to understand at different levels. This is perhaps true that the subject of climate change is one of the most controversial in the entire science of meteorology and climatologyat present (Kalumba *et al*., 2013). Understanding dimensions of monthly, annual, seasonal rainfall and temperature therefore has become an important part of research studies helping to clarify climate change discourses and its effects on the natural behavior of ecosystems and arid systems. In the recent years, time-series studies of rainfall and temperature patterns in the region have been carried out at various spatial (e.g., regional, national) across the globeusing various statistical procedures (Hamed, 2008; Collins, 2011; Babar and Ramesh, 2013; Wagesho *et al*., 2013). Yet, very few have considered both in-situ long rainfall and temperature data as climate parameters in their analysis using non-parametric approaches such as Mann-Kendall test (Mann, 1945; Kendall, 1975) to analyze trends at and temporal (e.g., annual, seasonal, monthly) scales. Even though, non-parametric tests like Mann-Kendall statistical tests have some limitations, they provide a basic way of analyzing trend from data sets which have irregular sampling intervals and missing data (Hamed, 2008).

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Relevant reviews on trend analysis in rainfall time series using Mann-Kendall statistical test in the region include Mondal *et al.* (2012) and Wagesho *et al.* (2013). Nonetheless, information on trends of rainfall and temperature in either temporal or spatial scale leads to a better understanding of the challenges associated with effects of extreme climate event sespecially in sub-Saharan Africa where majority of the people reside in highly variable arid and semi-arid environments.

Previous climate trend studies (Kinh'Uyu *et al.*, 2000; Nicholson, 2000; Hulme *et al.*, 2001; Schreck and Semazzi, 2004; Mwangi and Desanker, 2007; Moyo *et al.*, 2012; Wagesho *et al.*, 2013) across Eastern Africa region revealed that there has been highinter-annual rainfall and temperature variability in the region, especially within the arid and semi-arid environments. Further, a range of climate models suggest median temperature increases between 3 and 4°C in Africa by end of the 21st century, roughly 1.5 times the global mean response (IPCC, 2007; Bryan *et al.*, 2013). In Kenya, global circulation models predict that by the year 2100, climate change will increase temperatures by about 4°C and cause variability of rainfall by up to 20% (WWF, 2006; Kabubo-Mariara, 2008). From the available literature, the daily temperature observations already show significantly increasing trends in the frequency of warm days and larger increasing trends in the frequency of warm nights (Kinh'Uyu *et al.*, 2000; Omondi *et al.*, 2012). However, WWF (2006) argues that the average number of warm days per year in Kenya have increased by 57% between 1960 and 2003. The rate of increase is seen mostly in March, April and May when the average number of hot days has increased significantly by 5.8 days per month thus an additional 18.8% of March, April and May days over this period. More broadly, other studies suggest that in the predominantly arid and semi-arid environments, there is significant rainfall variation from year to year and these trends may continue with the wet season increasing and at the same time offsetting decreases in the drier months (Nyong and Niang-Diop, 2006). Similarly, the seasonality in rainfall and temperature at inter-annual or monthly time scale makes the climatic variation understanding within a wider geographical scale even more complex. For instance, studies of extreme rainfall trends show increased frequency of more intense rainfall events in many parts of Kenya whereas the number of rainy days and total annual precipitation decreased, with considerable reduction in the length of the growing season in the arid and semi-arid environments (Galvin *et al.*, 2001). Kenya's intra-seasonal component is intrinsically unpredictable (Moron *et al.*, 2013). In contrast, Thornton *et al.* (2002) observed that other parts of Kenya including parts of the Southern rangelands may become wetter with increases in the length of the growing seasons. Comparably, in the neighboring Southern Ethiopia, Deressa *et al.* (2011) observed a complex rainfall and temperature trend patterns, with average minimum and maximum temperature increase of about 0.25 and 0.1, respectively, over the past decade whereas rainfall patterns was characterized by unpredictable trendsfor the past 50 years. Angassa and Oba (2007) on the other handrevealed decreasing trends in the mean annual rainfall analysis at Borana in the Southern Ethiopia. In contrast, Seleshi and Zanke (2004) reported that there was no recent trend in rainfall over the North Western and Southern Ethiopiafor the period 1965 to 2002. It was therefore concluded that variability in rainfall and temperature at different scales is seen as normal occurrence in the arid climates, most prediction models agree that temperature in the region including Kenya will increase in the coming years (Thornton *et al.*, 2006; Christensen *et al.*, 2007; Herrero *et al.*, 2010; Vizy and Cook, 2012; Cook and Vizy, 2013).

Hitherto, limited scientific studies have focused on local and temporal analysis of climatic parameters at micro-scale in the arid and semi-arid environment of northern Kenya. There are few detailed research on rainfall and temperature related trend studies over Turkana County for instance in the recent past using observed climate records. Yet, this region in the recent past has experienced extreme weather events and micro climatic variability reported to have had huge influence on ecosystem dynamics and human welfare, especially in this environments (Conway *et al.*, 2005; Herrero *et al.*, 2010). Understanding climate trends and magnitude is critical to mitigate the adverse impacts of climate change and variability and would guide communities to make strategic, long-term decisions that affect their future well-being. Therefore, by studying the trends and changes in the rainfall and temperature with a simple yet direct approach, the results hope to show how policy makers and the communities can better prepare for natural extremes and reduce the loss of life and property. The objective of this study therefore was designed to analyze rainfall and temperature trends and seasonal changes spanning the period between 1950 to 2012 and 1979 to 2012, respectively using non-parametric Mann-Kendal statistical test approach. In particular, this study focused on analyzing trends at monthly, seasonal and annual time-scales for rainfall and temperature using Lodwar weather station records. Additionally, the current research explored seasonality in rainfall and temperature relationships. The findings of this study are intended to contribute towards information on long-term trend patterns for rainfall and temperature changes which could possibly serve as an important proxy during modelling procedures for projecting local climatic trends in Turkana County. Similarly, it highlights areas of further research on temporal rainfall and temperature trends and variability as well as the causes of differences in trend and means for seasonal rainfall and temperature.

MATERIALS AND METHODS

Study area: This study was conducted using a metrological data records from Lodwar, located in Turkana County Northwestern part of Kenya. Geographically, Lodwar is situated at 3°7'20.00"N latitude and 35°36'36.00"E longitude and it is a part of the arid and semi-arid lands (Fig. 1). Turkana County has an altitude ranging from 369 m in the East near the shores of Lake Turkana to 900 m at the foot of the escarpment marking the Ugandan border to the West. According to the 2009 Kenya Population and Housing Census results, Turkana's human population stood at 855,399 or 2.5% of the Kenyan population within a total area coverage of about 71,597.8 km^2 (KNBS, 2009). Turkana is projected to have a total human population of 1,036,586 in 2012 and 1,427,797 in 2017. These projections are based on a population growth rate of 6.4% assuming constant mortality and fertility rates.

Turkana County is characterized by bimodal rainfall distribution with high temporal and spatial variability, with rainfall patterns highly skewed in distribution. Rainfall

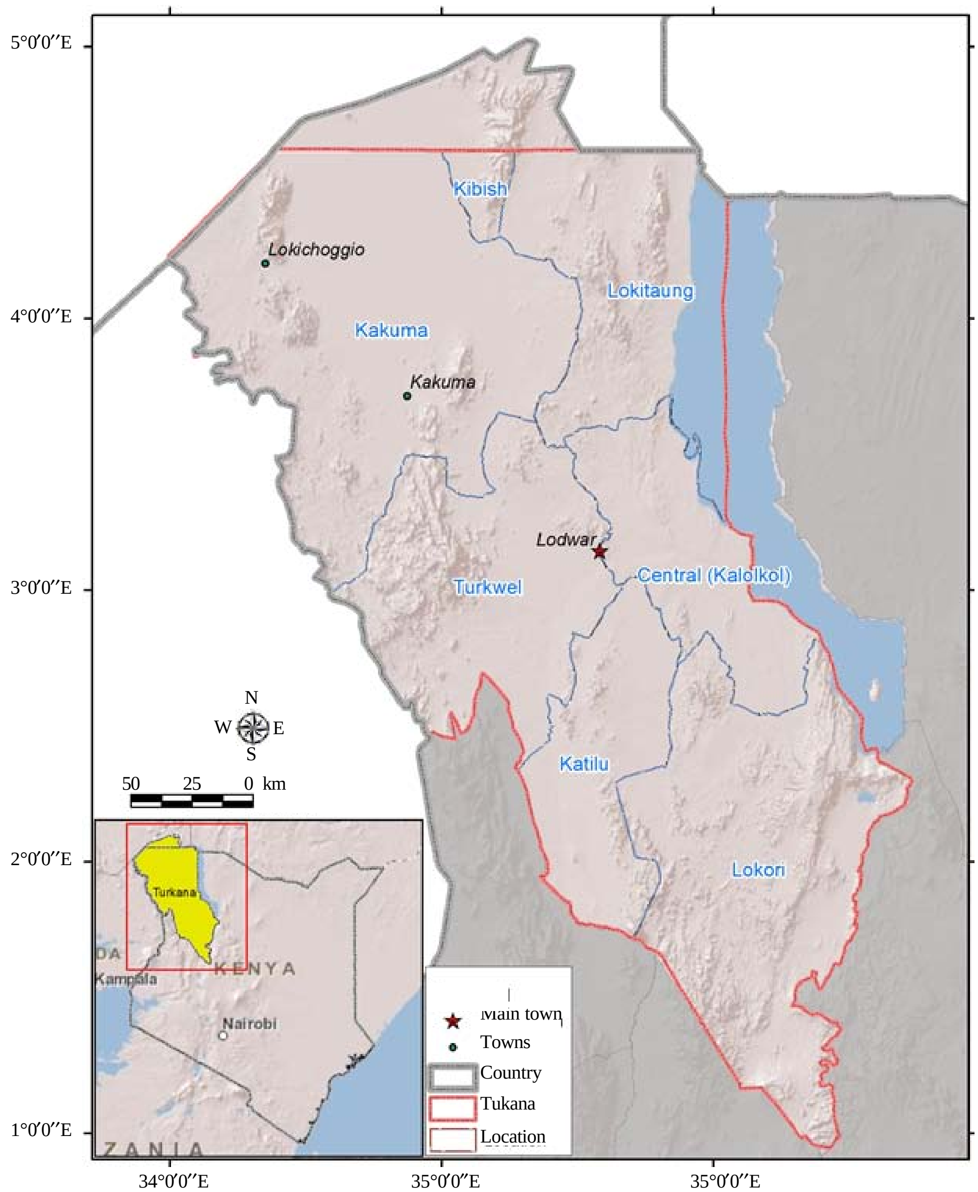

Fig. 1: Geographical location of Lodwar in Turkana County

ranges between 120 and 500 mm per year and is erratic in distribution and timing. The intra-year coefficient of variation is >50% throughout the district with peaks of 75% and more in the driest Western areas. The known rains falls in March to May (akiporo) and the remaining expected in October to December (akicheres) while the other months are relatively dry (akamu). Annual mean temperatures experienced in the area range between 23 and 38°C with a long term mean of 30°C (Jaetzold and Schmidt, 1983; GoK, 2013). The Northern part of the County towards Southern Sudan and Ethiopia are more arid than the Western towards Uganda which is more semi-arid. The area lies in agro-ecological zones IV and V (Pratt *et al*., 1977) and is hot and dry throughout most of the year.

Rainfall and temperature data: The rainfall and temperature data for Lodwar station managed by the Kenya Meteorological Services (KMS) were used to evaluate trends and variability of Turkana County, Kenya. Lodwar station was selected based on rainfall and temperature records availability for at least 40 years and it is fairly a representation of the entire Turkana homogeneous climatological zone identified by Matayo *et al*. (2000). The datasets obtained included monthly averages rainfall together with both monthly minimum and maximum temperature. To ensure that trend results are accurate, strict quality control processes were performed on the entire data set to determine data completeness. There was no missing data, so the datasets were generally considered to be comprehensive enough for the estimation of rainfall and temperature related variables.

Seasonality delineation for the period under study was based on summing the corresponding monthly averages for rainfall and temperature recorded during 1950 to 2012 and 1979 to 2012, respectively in Lodwar. Subsequently, each calendar year was divided into four climatic seasons based on Northern Kenya's weather patterns namely; long rains March to May (MAM), short rains October to December (OND), dry spell December to February (DJF) and another dry June to August (JJA) seasons. Because Turkana being part of Northern Kenya lies as tride the equator, experiences two rainy seasons occurring when the Inter-Tropical Convergence Zone (ITCZ) traverses the region in its Southward and Northward migrations. A longer rainy season starts around March through to May, with the peak centered around April. The shorter rainy season runs from October and December (OND). Similar monthly clustering of season used in this present study has been widely adopted by other previous studies across the region (Collins, 2011; Camberlin and Philippon, 2002; Omondi *et al*., 2013b; Kansiime *et al*., 2013; Nicholson, 2014). For this study, mean rainfall values were calculated based on monthly, seasonal, yearly and 30 years normal (with first normal periods 1961 to 1990 and second normal period 1971 to 2000 and temperature on 30 years (first normal period 1981 to 2010) recommended classification. The averages for each month and year provided values for statistical analysis.

Analytical methods: In this study, Mann-Kendall Statistical Test Method was applied to the monthly, annual and seasonal temporally distributed rainfall and temperature data trends at 1 and 5% level of significance. The Mann-Kendall Test Method does not require the data to be normally distributed. Similarly, the test is a non-parametric statistical procedure that is well suited for analyzing trends in data over time and has low sensitivity to abrupt breaks due to in homogeneous time series. A non-parametric test is preferred over the parametric one since it can evade the problem roused by data skew (Yue and Wang, 2004; Hamed, 2008; Mondal *et al*., 2012; Babar and Ramesh, 2013). The Mann-Kendall test does not require any assumptions as to the statistical distribution of the data, for example normal, lognormal, etc. and it can also be used with data sets which include irregular sampling intervals and missing data (Kendall, 1975). Mann-Kendall (MK) test was formulated by Mann (1945) as non-parametric test for trend detection and the test statistic distribution was for testing non-linear trend and turning point (Gilbert, 1987; Kendall, 1975). Studies (Yue and Wang, 2004; Karmeshu, 2012; Mondal *et al*., 2012; Babar and Ramesh, 2013) show that trend detection in a series is largely affected by the presence of a positive or negative autocorrelation.

The Mann-Kendall Statistic (S) measures the trend in the data. Positive (+) values indicate an increase in constituent concentrations over time whereas negative (-) values indicate a decrease in constituent concentrations over time. The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic (where large magnitudes indicate a strong trend). However, the data used for the Mann-Kendall analysis should be in time sequential order. The MK statistic (S) is defined as the sum of the number of positive differences minus the number of negative differences (Sneyers, 1990) as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{Sign}(x_j - x_k) \quad (1)$$

where, Sign (x_j-x_k) is an indicator function that results in the values -1, 0 or 1 according to the sign of x_j-x_k where j>k, assuming that (x_j-x_k) = θ, the value sign θ is computed as follows:

$$\text{Sign } \theta = \begin{cases} 1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases}$$

This statistics represents the number of positive differences minus the number of negative differences for all the differences considered. To deal with the non-monotonic character of trends in the data, the Kendall (1975) was used to estimate a normal-approximation test for large data set sets with >10 values; the test is conducted using a normal distribution (Helsel and Frans, 2006) with the mean and the variance as follows:

- Calculate S a described in question 1
- The variance of S is calculated, VAR (S) by the following equation:

$$\text{VAR(S)}\frac{1}{18} = \left[n(n\text{-}1)(2n\text{+}5)\text{-}\sum t(t\text{-}1)(2t\text{+}5)\right] \quad (2)$$

Where:

n = The length of data set (zero difference between compared values)

t = The number of data value in a group of determination

The standard normal deviate (Z-statistics) is computed as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & \text{if } S < 0 \end{cases} \quad (3)$$

To compute the probability associated with the normalized test statistics. The probability density function for a normal distribution is described by the following equation:

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{-z^2/2} \quad (4)$$

In this analysis, the null hypothesis was tested at 95% confidence level. The trend is decreasing if Z is negative and the computed probability is greater than the level of significance. Similarly, the trend is increasing if the Z is positive and the computed probability is greater than the level of significance. However, if the computed probably is less than the level of significance, there is no trend detected. To further reflect the comparisons, the Pearson's correlation coefficient was used to calculate and detect the seasonal association between precipitation and temperature considered in this study.

RESULTS AND DISCUSSION

Monthly and seasonal rainfall trends: According to the performed analysis, maximum monthly rainfall (197.7 mm) was observed in 1961 during the month of December. The study findings revealed that nearly all the months show below normal mean rainfall for the period 1950 to 2012, except for March, May, August, September, October, November and December (Fig. 2). In this study, the Mann-Kendall test was applied to detect monthly rainfall trends for Lodwar stations. Table 1 summarizes Mann-Kendall (Z) statistical tests for the monthly rainfall at 95% confidence level. The test results showed that December (0.04) depicted positive increasing trends while the months of January (-0.06), February (-0.01), April (-0.11) and July (-0.05) showed negative trends and the rest of the months showed a fluctuating increasing and decreasing scenarios which were not statistically significant (at α = 0.05) for the period 1950 to 2012. In addition, the rainfall data were split in two discrete parts to ascertain the temporal trends. First

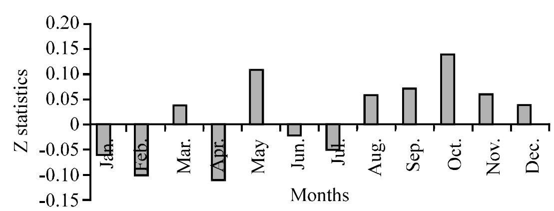

Fig. 2: Trend of Z-statistics for monthly rainfalls of 62 years period 1950 to 2012

Table 1: Mann-Kendall derived trend values for rainfall estimates for Lodwar, Turkana

Variables	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Period
Monthly rainfall trend (MK* test stat)	-0.06	-0.10	0.04	-0.11	0.11	-0.02	-0.05	0.06	0.07	0.14	0.06	0.04	1950 to 2012
Monthly rainfall trend-1st climatology (MK test stat)	-0.06	-0.07	-0.01	-0.10	0.08	0.05	-0.06	-0.12	0.23	-0.21	-0.15	0.15	1961 to 1990
Monthly rainfall trend-2nd climatology (MK test stat)	-0.16	-0.02	0.08	-0.12	-0.13	-0.03	-0.11	0.01	-0.28	0.04	0.01	0.16	1971 to 2000

MK*: Mann-Kendall test with positive (+) for increasing and negative (-) for decreasing

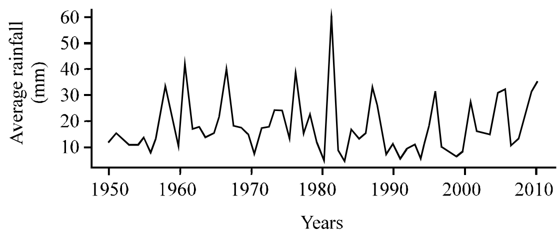

Fig. 3: Monthly average rainfall trend from 1950 to 2012 for Lodwar, Turkana

normal, for the period 1961 to 1990, January, February, March, April, July August, October and November had decreasing trends. For second normal period 1971 to 2000, the rainfall had a mixture of increasing and decreasing trends but the trend values were equally not statistically significant for all the months.

The positive trends were observed in March, August, October, November and December while the other months had negative trends. This result suggests a seasonal movement toward concentrated rainfall in OND during the short rainy season. However, it should be noted that these trends are non-significant. Previous studies (Camberlin and Philippon, 2002) show that most part of the region receives significant amount of rainfall during the months of March to May. Mutai and Ward (2000) observed that the rainfall trends in East Africa region are higher during the long rains in MAM when compared to the OND season. Nonetheless, it was also apparent from the findings that there is no clear rainfall trend observed overtime in Turkana (Fig. 3), suggesting that the monthly rainfall trends were likely to be unpredictable. Similar observations were made by Amissah-Arthur *et al.* (2002) when they characterized effects of El Nino events on rainfall trends in Kenya.

This seasonal results show that rainfall is not only low but highly variable and unpredictable over time in the study area. The Mann-Kendall test statistics for trends performed on a seasonal scale to examine if there are patterns in the data at this scale showed varied results. Figure 4 illustrates seasonal rainfall trend patterns for the period 1950 to 2012. The OND season recorded the highest rainfall of 197.7 mm in December 1961 while DJF recorded 111.2 mm in 1958 January and JJA recorded 171.4 mm in August 1982. Considering the entire MAM dataset, April 1967 received the highest amount of rainfall (185.7 mm) and lower amounts observed in May, June and July with some of these months recording 0 mL of rainfall. Turkana rainfall patterns are bimodal and occur in March to May (MAM-akiporo) commonly referred as the long rainy seasons with peaks rains in end of March and April. The short rains are experienced between

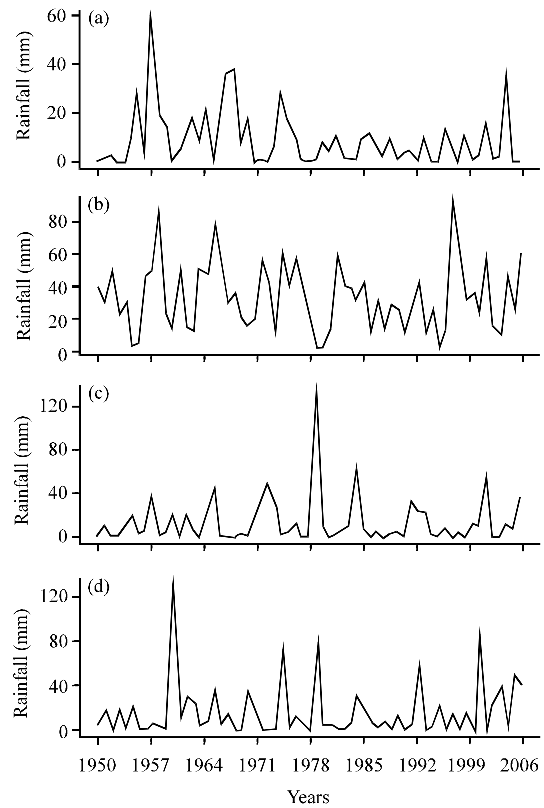

Fig. 4: Seasonal rainfall trend: a) DJF; b) MAM; c) JJA and d) OND for Lodwar between 1950 and 2012

October and December (OND-akicheres) with the peak in November. The rest of the calendar years are known to be dry seasons except June and July which occasionally experiences slight precipitations. The seasons for arid and semi-arid environment in Kenya are well differentiated and the details can be found by Jaetzold and Schmidt (1983).

Further analysis results of seasonal trends depicted both slight negative (MAM) and slight positive (OND) seasonal trends for period 1950 to 2012. Although, none of the season's trends observed are statistically significant (at $\alpha = 0.05$). The study results is consistent with other seasonal analysis (Mutai and Ward, 2000; Schreck and Semazzi, 2004; Shisanya *et al.*, 2011) where MAM season rains showed a downward trend while the OND season appeared to have a slight upward trend in parts of arid environments of Kenya. Although, these seasonal rainfall time series results did not reveal a statistically significant (at $\alpha = 0.05$) trend. The seasonal rainfall upward and downward trends in the time series were observed in Lodwar. In overall, the observed monthly, seasonal and annual rainfall variability implies that rainfalls are highly unpredictable and therefore the region exhibit non-equilibrium dynamics as described

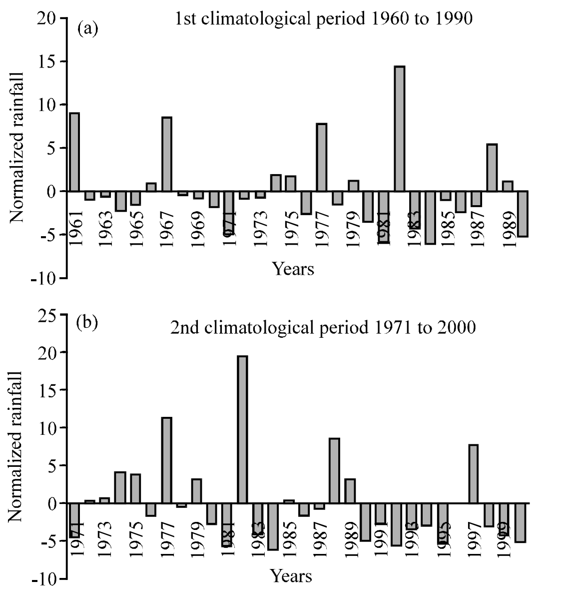

Fig. 5: Normalized annual rainfall for; a) 1st period 1961 to 90 and b) 2nd period 1971 to 2000 for Lodwar

by Ellis and Galvin (1994) in similar ecosystems in sub-Saharan Africa. The unpredictable rainfall trends in temporal domain, provides the incentives for debating on the rainfall variability in the arid environment and by extension on climate change. However, previous studies by Mutai and Ward (2000) have confirmed that the East African short rains in October to December (OND) have a positive correlation with El Nino-Southern Oscillation (ENSO).

Trends analysis for annual rainfall: The study findings showed that long-term mean annual rainfall estimated during 1950 to 2012 for Lodwar was 216.77 mm, with the highest and lowest rainfall recorded in 1982 (725.1 mm) and 1984 (54.2 mm), respectively. In Lodwar, the highest and lowest rainfall monthly mean totals were observed in 1982 (60.42 mm) and 1984 (4.51 mm), respectively. Figure 5 illustrates annual total rainfall trend pattern for Lodwar for the period between 1950 and 2012.

Mann-Kendall test statistic result for period 1950 to 2012 showed that there was a positive value for overall annual total rainfall in Lodwar though the trend was not significant at 5%. The same is observed for the two intervals identified. The first climatology (1961 to 1990) with a mean of 235.7 mm indicates that 1961, 1966, 1967, 1974/5, 1977, 1979, 1982 and 1988/9 had normal mean rainfall precipitation based on the standardized residuals estimation. For the second climatological period 1971 to 2000, there seemed to be an evidence of ageneral decrease in rainfall regime though generally not statistically significant at 95% confidence level. The result from the two periods 1961 to 1990 and 1971 to 2000 mean statistical test show that there was no evidence of any climatological change. The normal mean rainfall was recorded for 1972/3, 1974/5, 1977, 1979, 1982, 1985, 1988/9 and 1996/7 based on rainfall standardized residual calculation (Fig. 5). A closer look at the results further revealed that there was no trend observed for the rainfall received in all the rainfallregimes. However, the first climatology (1961 to 1990) had more years with below normal rainfall though not as severe as that the subsequent period observed between 1971 and 2000 in Turkana. The amount of annual rainfall and its seasonal distribution are crucial factors for understanding the spatial distribution of different ecological units (Bailey, 1998; Herrero *et al*., 2010). Therefore, the study results could be of great importance for detecting climatic impacts on arid and semi-arid ecosystems in the region.

The findings of this study corroborates and is similar to other previous studies conducted in other parts of Eastern Africa region by Kinh'Uyu *et al.* (2000), Mutai and Ward (2000), Hastenrath *et al.* (2011), Omondi *et al.* (2013a) and Cook and Vizy (2013). Previous findings observed that inter-annual rainfall variability in the Arid and Semi-Arid Lands (ASALs) of Kenya was decreasing significantly (Shisanya *et al*., 2011) in contrast to Lodwar weather station where seasonal and annual rainfall show a non-statistically significant results (at α = 0.05) with implication that there was no trend observed over the last six decades. It is essential to note that most of the rainfall was received during the long rains growing period in MAM, though April which known to be the peak recorded decreasing trend.

It is argued in this study that knowledge of trends and variations of current and historical climate variables is pertinent to future development and sustainable management of arid and semi-arid environments. That not with standing, the amount of annual rainfall and its seasonal distribution are crucial factors for understanding the spatial distribution of different ecological units (Kinh'Uyu *et al*., 2000). It is convinced that rainfall is one of the most important factors influencing natural resources because changes in rainfall patterns may lead to floods or droughts in different areas. This results presented on temporal climate variability of rainfall series is of profound significance from both the scientific and practical point of view in the management of the drought prone region of Turkana. However, as observed there was no overall annual trend over time, even on small scales time frame, hence it is particularly hard to gauge the rainfall changes in Lodwar. Lastly, there is limited evidence to suggest that there have been significant rainfall changes in the area to warrant what is commonly referred as climate change over Turkana. The climate data analyzed show rainfall variability to be a normal characteristic of the study location over the past 63 years.

Monthly and seasonal temperature trend analysis: Temperature time series of Lodwar station were also investigated for temporal trends such as monthly, seasonal and annual to provide a micro scenario for 1979 to 2012 temperature variability. Result showed that January had the highest mean monthly temperature of 36.97°C and December with the lowest 20.22°C. Mean monthly annual highest and lowest temperatures were observed in December 1999 (23.7°C) and July 2011 (11.1°C), respectively (Fig. 6-8). However, the lowest of the maximum temperatures and highest of the minimum temperature were recorded in May 2012 (25°C) and December 2006 (19.1°C), respectively. The Mann-Kendall test statistics results on both minimum and maximum temperatures for the Lodwar station are shown in Table 2. For the increasing trend, it's only the months of August and November for the entire study period had trends with maximum temperature values which were statistically significant. Even though most of the months showed slight negative and positive trends both for minimum and maximum temperature data, the changes were not statistically significant at $\alpha = 0.1$ or 0.05 (Table 2).

This assertion could be compared with studies by Schreck and Semazzi (2004) and Omondi *et al*. (2013b) that similarly highlighted a general increasing warm extreme, particularly at night while cold extremes are decreasing in the Horn of Africa region. However, the temperature data for period 1979 to 2012 in general are dominated by increasing maximum temperature trend though not statistically significant, expect for the months of January, August and November. Similarly, results from the minimum temperature showed annegative Z values only for the month of March, May and October which were statistically significant at $\alpha = 0.05$ which implies that the range of minimum temperatures in these 3 months is decreasing.

Results of seasonal standardized temperature trends between 1979 and 2012 are illustrated in Fig. 7-10. The findings show that 42% of months had positive trends value for seasonal maximum temperature based on

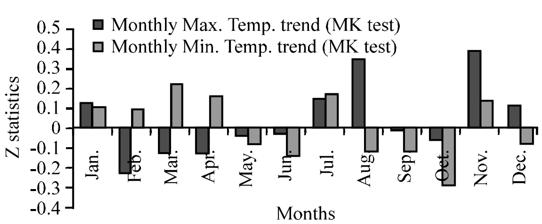

Fig. 6: Trend of Z for monthly maximum and minimum temperature between 1979 and 2012 in Lodwar, Turkana

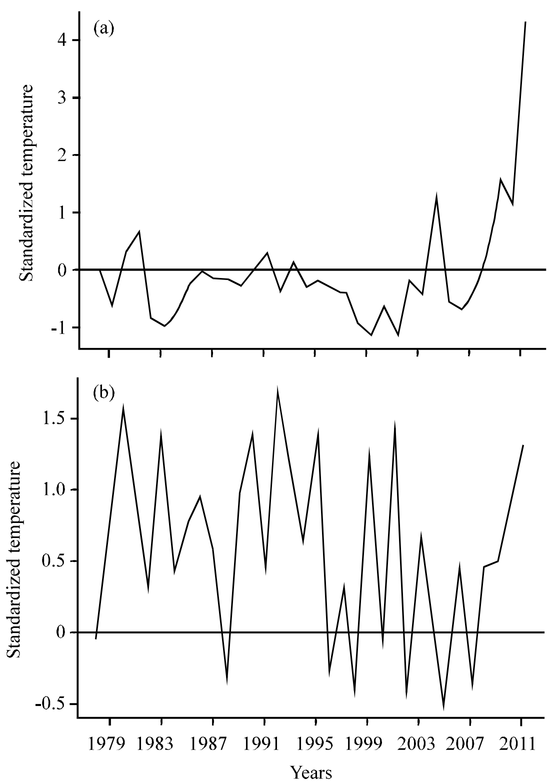

Fig. 7: DJF standardized temperature trend analysis; a) Minimum and b) Maximum for 1979 to 2012

Table 2: Mann-Kendal derived trend values for temperature estimates for Lodwar

Variables	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Period
Monthly Min. Temp. trend (MK test stat)	0.103	0.096	0.223	0.1600	-0.0800	-0.140	0.170	-0.020	-0.120	**-0.290***	0.136	-0.080	1979 to 2012
Monthly Min. Temp. trend-1st climatology (MK test)	-0.014	-0.014	**-0.414***	0.0214	**-0.2680***	-0.223	-0.185	-0.155	-0.197	**-0.259****	0.055	-0.162	1981 to 2010
Monthly Max. Temp. (MK test stat)	0.130*	-0.230	-0.130	-0.1300	-0.0400	-0.030	0.150	**0.350***	-0.010	-0.060	**0.390***	0.110	1979 to 2012
Monthly Max. Temp. trend (C)-1st normal (MK test)	0.055*	**-0.309***	-0.116	-0.1940	0.0243	-0.009	0.160	**0.350***	-0.065	-0.137	**0.280***	0.021	1981 to 2010

*Highlighted bold values show linear trends that are statistically significant at 5%

Table 3: Mean seasonal temperature statistics between 1979 and 2012 in Lodwar

	DJF dry-season		MAM long-rains		JJA dry-season		OND short-rains	
Seasons (°C)	$T_{max.}$	$T_{min.}$	$T_{max.}$	$T_{min.}$	$T_{max.}$	$T_{min.}$	$T_{max.}$	$T_{min.}$
Mean	36.270	21.120	34.860	22.500	33.540	21.420	35.160	20.87
SD	2.320	1.210	3.040	0.620	2.070	0.500	1.890	0.69
p-value (Z Stat.)	0.061[a]	0.053[a]	0.091[a]	0.062[a]	0.088[a]	0.056[a]	0.059[a]	0.10

[a]Seasonal data shows statistically significant trend (at α<0.1) with an increasing trend

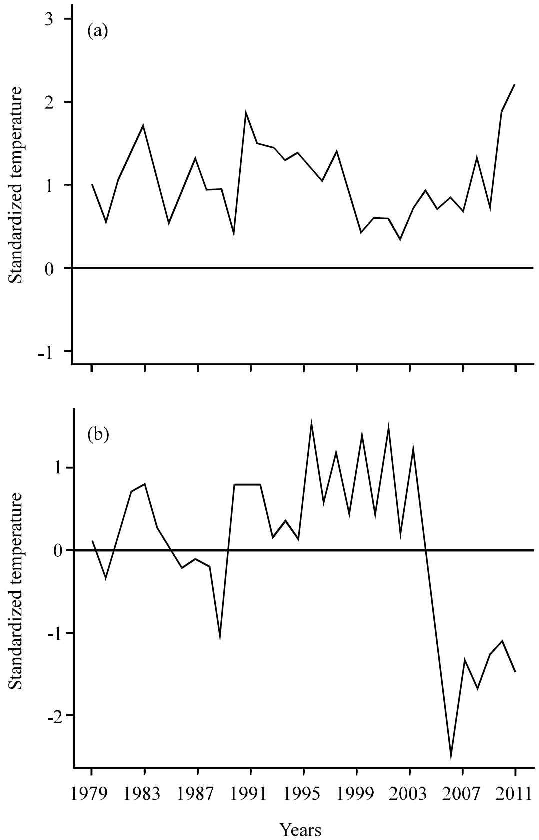

Fig. 8: MAM standardized temperature trend analysis; a) Minimum and b) Maximum for 1979 to 2012

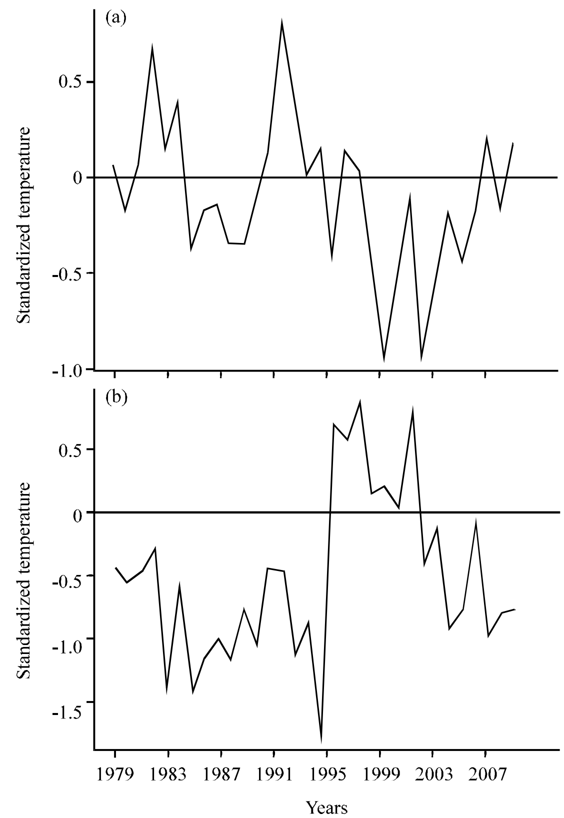

Fig. 9: JJA standardized temperature trend analysis; a) Minimum and b) Maximum from 1979 to 2012

Mann-Kendall test statistics and the computed probability was statistically significant at 90% confidence interval (Table 3). On the other hand, mean minimum temperature, for JJA reveal an increasing statistically significant trend at α = 0.1. At the same time, result show that the season with the highest mean maximum temperature ($T_{max.}$) trend is DJF and that with the lowest trend is OND. This is consistent with previous studies in the region by Kinh'Uyu *et al.* (2000), Anyah and Semazzi (2006) on temperature variability trend anomalies. In general, DJF had the highest average annual seasonal temperature (36.27°C) while OND (20.87°C) experiences the least. The overall maximum temperature trend follows the seasonal distributions for the study period and all the seasons showed an increasing positive trend.

These results are consistent with Collins (2011) which indicated that rapid warming from 1979 onward was witnessed in Kenya. In fact, this study reported significant increasing temperature trends across each of the regions examined which include: hemisphere Africa, Southern hemisphere Africa, tropical Africa and subtropical Africa. This present study has examined trends in monthly, seasonal and annual rainfall and temperature on local scale for Turkana. Trend analysis of temperature data revealed an increasing trend for both maximum ($T_{max.}$) and minimum ($T_{min.}$) temperatures which was statistically significant at α = 0.1. In addition, it was DJF season with the highest mean temperature (36.27°C), and OND season had the lowest mean minimum temperature of 20.87°C between 1979 and 2012 in Lodwar (Table 3). The overall temperature trend follows the

Table 4: Pearson coefficient between seasonal mean rainfall and temperature and their associated significance levels (p-values)

	Temperature				Rainfall	
Seasons	$T_{max.}$	p-values	$T_{min.}$	p-values	Mean (mm)	SD
Mean rainfall MAM	-0.197	0.2546	-0.202*	0.0247	30.71	25.38
Mean rainfall OND	0.076**	<0.0001	-0.139	0.3356	17.08	18.24[a]

*Significant at $p<0.05$; **Significant at $p<0.01$

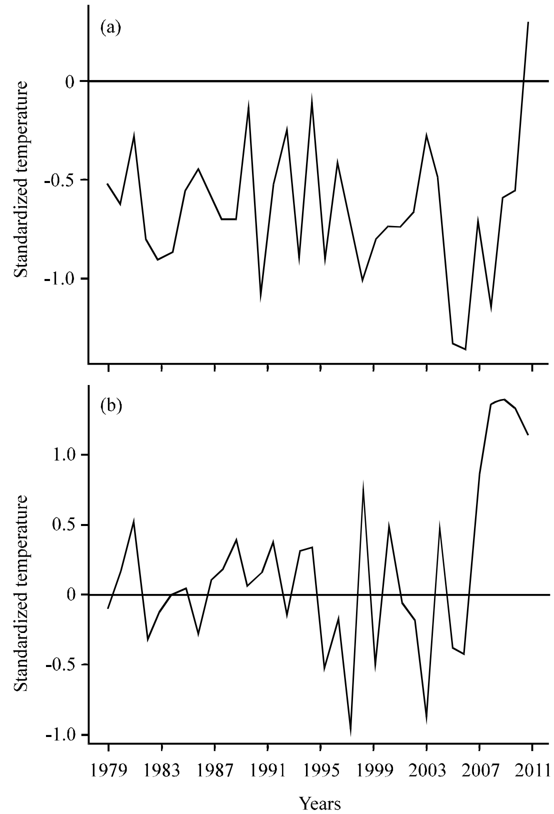

Fig. 10: OND standardized temperature trend analysis; a) Minimum and b) Maximum for 1979 to 2012

seasonal distributions for the study period and all the seasons show a high variability and anomalies. Previous studies by Kinh'Uyu *et al*. (2000) analyzed trends of minimum and maximum surface temperatures over Eastern Africa and their results also indicate a reversal of anomalies over the region with the Northern part of eastern Africa generally exhibits night-time warming whereas the southern region has been experiencing cooling during the more recent period. However, this present study analysis has not established the causes of the differences in the trend and means for seasonal temperature trends; this could probably be explained further with the aid of a general circulation models. Nonetheless, this result provides a clear understanding of the seasonal changing patterns in temperature at local level and confirms that global warning can be revealed even at local scales.

Correlation between rainfall and temperature: The pearson correlation results onseasonal mean rainfall and temperature for the period 1979 to 2012 are listed in Table 4. The number reflects the correlation between these two sets of climate variables and it's within the range of -1 to +1. The number -1 means the variables are inversely correlated, meaning that they change over time in the opposite direction as each other. In this study, results showed that MAM seasonal rainfall had a negative correlation that was not statistically significant (at $p<0.01$) with the maximum temperature ($T_{max.}$), i.e., the higher the maximum temperature during MAM the lower the rainfall. Surprisingly, the OND seasonal rainfall in Lodwar had a positive correlation with the maximum temperature ($T_{max.}$) which implies that the two climate variables move exactly in the same direction in the same season with each other. The positive association was statistically significant at both 1 and 5%. However, another interesting pattern in the correlation was observed between MAM seasonal rainfall and minimum temperature ($T_{min.}$) which was negative and statistically significant at 5%.

This study finding corroborates to other previous results that revealed a significant correlation between the 'short rainy' season in OND and corresponding maximum temperature in the region (Camberlin *et al*., 2001). On the other hand, it was observed that the minimum temperature ($T_{min.}$) is not significantly correlated with OND seasonal rainfall in the area; this may be attributed to other factors that contribute to temperature variation other than precipitation. Overall, previous studies by Collins (2011) revealed that the climate change over Eastern Africa is likely not predominantly a result of variations in the El Nino-Southern oscillation. Instead the climate changes likely occur owing to other natural variability of the climate and or may be a result of human activity.

CONCLUSION

In this study, climatic variability trends have been analyzed using rainfall (1950 to 2012) and temperature (1979 to 2012) data records from Lodwar, North Western Kenya. Given the need to devise a robust meaningful method that will enable government and development agencies to discern the temporal dynamics of rainfall and temperature at a given location, this study have demonstrated how statistical analyses and historical rainfall data records could be used to characterize temporal rainfall and temperature trends at a local scale. Studies of climate variability and anomalies at local level are important for climate change impact studies: which are crucial in planning and management of natural resources among others. At the same time, potential impacts that any changes in climate could have on the ecologically sensitive ecosystems can be determined. As observed elsewhere, climate variability in the arid ecosystems could affect other sectors, especially pastoral production system which is the predominant land use activity in the arid and semi-arid land of Kenya. This study finding has critical ecological applications because the amount of seasonal and annual rainfall isa crucial factor for decision making in the management of arid environments in the region.

RECOMMENDATIONS

Overall, the findings of this study revealed the following key conclusions from the data records on the basis of analysis conducted:

- This study concluded that although there was large variability in magnitude of trend of rainfall data from Lodwar station, in overall, no clear trend pattern emerged. The Mann-Kendall test statistics showed that there were no significant changes or trends in annual rainfall for period 1950 to 2012 in Turkana. However, the result reinforces earlier observations that year to year, season to season variability is persistent in arid environment of Kenya (Shisanya *et al*., 2011; Nicholson, 2014)
- Despite no clear trend patterns observed for the overall annual rainfall in Lodwar, the Z-values for Mann-Kendall statistical test revealed positive and negative trends for the individual monthly rainfall observed. For example, the month of December showed positive trends while the rest of the months had no trend for the discrete periods observed except for January, February, April and July which showed decreasing rainfall pattern. However, there was no significant decreasing rainfall trend observed
- The rainfall seasonality results, revealed decreasing rainfall trend for MAM season while the OND rains had a slight decrease for the period 1950 to 2012. But none of the seasonal trends were statistically significant. This could partly be supported by recent studies by Shisanya *et al.* (2011) which established that the OND rains are becoming more reliable compared to the MAM rainfall seasonin the arid and semi-arid lands of Kenya
- During the period 1979 to 2012, January had the highest mean monthly temperature of 36.97°C and December with the lowest 20.22°C. When considering the monthly temperature, the result show that January is the warmest. Even though most of the months showed slight increase for both minimum and maximum temperature, it was only November with a significant increase in temperatures
- The Mann-Kendall statistical test results were positive for all seasonal maximum temperature values and the computed probability was statistically significant at 90% confidence interval. However, the result further suggested that while slight warning is observed across the study area during the period 1979 to 2012, the warming received in OND had a significant increase in temperature. This result is also consistent with Hulme *et al.* (2001) who examined the period 1901-95 and notes that a slightly larger warming in Africa occurs in the months of OND than in the months of MAM
- In general, the findings demonstrated that a significant rise in both maximum and minimum temperatures occurred between 1979 and 2012 and this is in line with the recent trends of global warning as reported by the latest Field (2012) report. The research shown here can help various stakeholders working in Turkana to see, on a local scale, what temperature changes are being observed and which will help them better plan for a changing climate.

However, this present study has not established the causes of differences in trend and means for seasonal temperature trends; this could probably be investigated further with the aid of a general circulation models. This study suggests that further research into the underlying local factors influencing the climate of the area, causes for the differences in monthly mean temperature, actual effects of ENSO on rainfall totals and the influence of Indian Ocean over northwestern Kenya area need to be conducted. At the same time aspects of the impacts of changing land use patterns, degradation and global warming on the micro-temperature also require more consideration in future research. It was recommended that future studies should build on this study finding to document similarities and differences in spatial-temporal rainfall and temperature trends using datasets from >1 metrological data records in Turkana County. In this study, the analysis was only based on rainfall (1950 to 2012) and temperature (1979 to 2012) datasets from one metrological station in Turkana which may not be a fair representative of a typical arid and semi-arid lands datasets used in computing anomalies in spatial climatological studies. Although, this present study does not constitute a climate prediction system, it is expected that it will lead to better-targeted efforts into the underlying mechanisms of rainfall and temperature trends in a manner that will allow new insights to positively influence decision making in arid environments planning and management. Lastly, this study represents an important contribution to climate change research in the region.

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