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Seasonal Variability of Rainfall and Thunderstorm Patterns in Kenya

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ABSTRACT

This paper presents an analysis of spatial and temporal variation of rainfall and thunderstorm occurrence over Kenya from January 1987 to December 2017. The meteorological data used were obtained from the Kenya Meteorological Department (KMD) for the same period. This included the monthly thunderstorm occurrences and rainfall amounts of 26 synoptic stations across the country. The characteristics of monthly, seasonal and annual frequency results were presented on spatial maps while Time series graphs were used to display the pattern for annual cycle, seasonal variations and the inter-annual variability of rainfall amounts and thunderstorm occurrences. A well-known non-parametric statistical method Mann Kendall (MK) trend test was used to determine and compare the statistical significance of the trends. Thunderstorm frequencies over the Eastern, Central and Coast regions of the country showed a bimodal pattern with high frequencies coinciding with March-April-May (MAM) and October-November-December (OND) rainy seasons. Very few thunderstorm days were detected over June-July-August (JJA) season. The areas to the western part of the country, near Lake Victoria, had the highest thunderstorm frequencies in the country over the three seasons: MAM, JJAS and OND. The annual frequency showed a quasi-unimodal pattern. These places near Lake Victoria showed significantly increasing thunderstorm trends during the MAM and OND seasons irrespective of the rainfall trends. This shows the effects of Lake Victoria over these areas, and it acts as a continuous source of moisture for thunderstorm formation. However, most stations across the country showed a reducing trend of thunderstorm frequency during MAM and JJA seasons. The importance of these findings is that they could support various policy makers, and users of climate information, especially in the agriculture and aviation industries.

Keywords: Rainfall; Thunderstorm; Lake Victoria; Kenya; Mann Kendall

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1. Introduction

Thunderstorms are usually associated with deep convective clouds in Kenya [1]. Virtually, these thunderstorm clouds can occur in any month due to the large water bodies and the position of the country on the equator. Close to the equator, there are light winds, intense heating and low-level convergence. The rising warm air causes instability in the atmosphere. It cools, condenses and produces clouds. Deep convective clouds cause thunderstorms to develop due to the release of big quantities of latent heat into the atmosphere. Audible thunder is a sequence of degenerated shock waves formed by the massive expansion of air on the intensively heated lightning channel, during a lightning flash [2].

A thunderstorm day is defined as a day on which thunder is heard at an observing station [3,4]. It is recorded as such regardless of the actual number of thunderstorms heard on that day and therefore the records do not give information on the frequency of occurrence of individual thunderstorms or their time of occurrence. It should however be noted that lightning without thunder is not recorded as a thunderstorm day, this is because light travels faster than sound at a speed of 2.998×10^8 m/s and sound at 3.43×10^2 m/s. It is possible to observe lighting outside the station radius. The condition that thunder must be heard restricts the covered area to a circle with a maximum radius of about 20 km by each observing point [5]. It is also possible for two neighboring stations to hear and report the same thunderstorm if they are within a 35 km distance apart.

Changnon et al. (1984) [6] investigated the temporal distribution of global thunder days from 90 stations in Northern America and 131 stations across the world. The results suggested that the variations in thunder days' frequencies are due to a major shift in large-scale circulation oscillations. Enno et al. (2014) [7] in a study of the long-term changes thunder days frequency over the Baltic countries noted that a long-term reduction in the Thunderstorm Days frequency goes with an augmented frequency of northerly Circulation Weather Types (CWTs) that are negative for thunderstorm development. Meanwhile, the frequency of southerly and easterly CWTs that are positive to thunderstorm formation decreased.

In the central United States, the study of contrails showed that there was an upsurge in cloudiness and a reduction in sunshine from the 1930s at times and areas where thunderstorm frequencies seemingly reduced. Such variations in cloudiness and their causes may be pertinent and connected to the reduction in thunderstorms because high cloudiness should, on average, deter convective activity and thunderstorm growth [6,8]. This current study needs to investigate the variations of thunderstorms during seasons of cloudiness and sunshine.

In a study on the distribution of monthly and annual frequency of thunderstorm days over East Africa. Chaggar (1977) [5] reported that in March-April-May there is a slight northward movement in the patterns of the frequency of thunderstorm days but the maximum frequency is in the area east and north of Lake Victoria into Western Kenya. There is a decrease in May over most of Kenya except the western areas. A general reduction in most parts is in June and July. The study was done over 40 years ago using sparse data observed only during daylight.

While forecasting thunderstorms and detection of convective features in their early stages is important, it is still difficult to forecast thunderstorms without Meteorological tracking and detection systems. One of the objectives of Sendai Framework 2015–2030 is to mainstream and integrate Disaster Risk Reduction (DRR) within and across all sectors for sustainable development. A thunderstorm is the most common weather-related hazard, and its impact causes death, damage to property and loss of revenue especially to the airlines. Weather-related delays interfere with the organization of flight schedules and cause additional operational costs to the airlines [9]. It also causes inconvenience to travelers.

Understanding where and when thunderstorms are likely to occur is crucial in issuing early warnings, to avoid disaster. An achievement of relatively higher skill and accuracy in issuing meteorological forecasts and advisories to stakeholders results in better short and long term planning. Proper forecasting with lead time is an important factor in preventing local calamities from saving people [10].

Maloba (2015) [11] carried out a study on temporal and spatial characteristics of thunderstorms over the region east of Lake Victoria Basin in Kenya over the period 2000 to 2013 and established that the year 2016 MAM season recorded the highest frequency of thunderstorm occurrence during the study period while the lowest occurrence was 2007 for both MAM and September-October-November (SON) seasons.

Ayugi et al. (2016) [12] analysed the monthly, seasonal and annual scales of rainfall variations over Kenya data from 1971 to 2010. In agreement with Ongoma and Chen (2017) [13], the findings showed that among the two seasons, there was a noticeable decrease in rainfall over the MAM season and a slight increase over the OND season. Further results showed an overall significant decrease in annual rainfall over Kenya. Later studies have shown that there were some increasing trends over the short rainfall season (OND) and these were credited to Sea Surface Temperatures (SST) warming in the western Indian Ocean [14].

A thunderstorm is made up of two or more thunderstorm cells and each cell has three stages of development, namely, the cumulus stage, the mature stage and the dissipation stage [15]. An average thunderstorm has a horizontal diameter of about 24 kilometers and depending on the conditions present may take about 30 minutes to complete the life cycle from development to decay.

Local circulations such as Lake Victoria, mountains and strong solar insolation cause steep temperature gradients between the water surface and the surrounding high grounds as a result of the overhead sun. These give rise to strong mesoscale circulations over the region. Deep convective systems are initiated around 0700 UTC in the morning to 1000 UTC in the afternoon and peak during the late afternoon and evening times around 1200 UTC to 1600 UTC [16].

Eastern Africa exhibits bimodal rainfall consisting of long rains (March–May) and short rains (October–December) and this is observed in Kenya as a country in East Africa. Remote teleconnections, namely the El Niño—Southern Oscillation and the Indian Ocean Dipole, exert a dominant influence on interannual variability [17]. The number, duration and timing of these rainfall seasons vary, driven principally by the movement of the intertropical convergence zone (ITCZ) [18].

The core objective of this study is to evaluate the recent thunderstorm climatology over Kenya, determine the trends and compare it with rainfall occurrence. The results obtained confirmed that higher concentrations of thunderstorms are to the West and over the highland parts of the country and thunderstorm days' occurrence can be broadly classified as either bi-modal or quasi-uni-modal in Kenya. Besides enhancement of the existing knowledge, the evaluation of thunderstorm climatology in Kenya aims to give a better understanding of where, when and how thunderstorms are likely to occur and their possible impacts. This will possibly result in a policy shift towards the improvement in the forecasting experience and exchange of information. Improved accuracy in meteorological forecasts and weather advisories, therefore, leads to reduced costs of operations, enhanced profit, safety and customer satisfaction in the aviation industry.

2. Materials and methods

2.1 The study area

The study was carried out in Kenya. The country lies between 5° north and 4° south and between longitude 32° and 42° east. **Figure 1** shows the spatial distribution of the stations which were used in the analysis.

2.2 Data

The thunderstorm data and observed monthly rainfall amounts used were obtained from the Kenya Meteorological Department (KMD). It included each month of the year from January 1987 to December 2017 for the 26 synoptic stations across the country. The stations were selected according to the availability of data from the source.

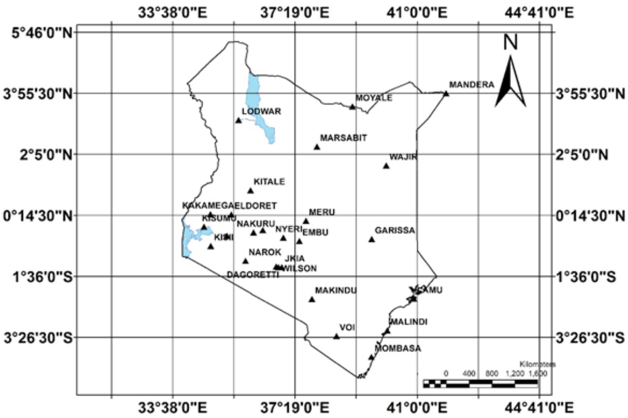

Figure 1. A map showing the location of the stations used in the study.

2.3 Estimation of missing data and homogeneity test

The arithmetic mean method (Equation (1)) was used to calculate the long-term mean, which was then used to fill the missing gaps. All the stations used in this study had missing data which was less than 10% for thunderstorm days while rainfall data had no missing data.

$$\bar{X} = \frac{1}{n}\sum x_i \tag{1}$$

where,

$\bar{X}$ = long term mean of thunderstorm days in a month;

n = number of years;

X_i = thunderstorm days in a month.

This is a technique recommended by the World Meteorological Organization (WMO) for estimating missing monthly, seasonal or annual meteorological data provided the percentage of the missing data does not exceed 10% of the total [3].

The next test was for data consistency or homogeneity test. It also checks the accuracy of data by identifying outliers or deviations from other related parameters or neighboring stations. This study adopted the Single Mass curves to assess the quality of the data. The total seasonal thunderstorm frequencies for each station were accumulated and plotted against the years. An almost straight line shows the data are homogeneous and the opposite is true [19].

2.4 Trend analysis of the thunderstorm days and rainfall

Using Mann Kendall's non-parametric trend test method [20,21], the assessment of whether there was a significant trend (at 95% confidence level) during MAM, JJA, and OND seasons, was determined for both rainfall and thunderstorm occurrences.

The MK test is used to determine statistically the significance of the decreasing and increasing trends in long-term temporal data [22]. The test is based on two hypotheses: when one is null (H_o) and the alternative which is (H_a) hypothesis. Mann-Kendall trend test interpretation was [23]:

H_o: There is no trend in the series.

H_a: There is a trend in the series.

If the computed p-value is greater than the significance level alpha = 0.05, one cannot reject the null hypothesis H_o because p > 0.05The MK formula is provided by the following Equation (2):

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sign(x_j - x_i),\ \ sign(x_j - x_i) = \begin{cases} +1\ (x_j - x_i) > 0 \\ 0\ (x_j - x_i) = 0 \\ -1\ (x_j - x_i) < 0 \end{cases} \tag{2}$$

where n is the number of data points, X_j and X_i are annual values in years j and i, j. 1 and sign ($X_j - X_i$) are calculated using the equation: A positive S value indicates an upward trend, while a negative value indicates a downward trend.

The variance of the rainfall is calculated to obtain the Z value. The normal Z test statistic is calculated by Equation (3). This equation uses S–1 if S > 0, S+1 if S < 0 and Z is 0 if S = 0. A positive value of Z indicates an increasing trend. Otherwise, it indicates a downward trend.

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} if S > 0$$
$$0\ if S = 0$$
$$\frac{S+1}{\sqrt{VAR(S)}} if S < 0 \tag{3}$$

The Sen's slope estimator is a test recommended by the World Meteorological Organization as part of trend detection in rainfall data F [24]. The trend is assumed to be linear and shows the quantification of the time change and the test is not affected by the number of outliers and data errors when compared with the linear regression test. The Sen's Slope Equation (4) for a number of N data sample pairs is expressed as follows:

$$Q_i = \frac{(x_j - x_i\ )}{j-i}\ , i = 1,2,3, \ldots, N \quad (4)$$

x_j and x_i are data values at time j and i (j > i), respectively. If there are n values of x_j in the time series, there will be N = n(n-1)/2 slope estimates. The N value of Q_i is sorted from smallest to largest, then Sen's Slope used median Q_i (Qmed). A two-tailed test estimated the value of Qmed at a confidence interval of 90% and 95%, which is calculated as demonstrated in Equation (5).

$$Q_{med} = \begin{cases} Q_{\left[\frac{N+1}{2}\right]} & if\ N{=}odd \\ \frac{Q_{\left[\frac{N}{2}\right]} + Q_{\left[\frac{N+1}{2}\right]}}{2} & if\ N = even \end{cases} \quad (5)$$

3. Results and discussions

Out of the 36 stations of which thunderstorm datasets were considered, 26 stations had more complete sets and only 10 of them had more than 10% missing data and were therefore discarded. The rainfall data used for the same stations had no missing data and was good for comparison purposes.

The spatial distribution of thunderstorms in the country showed that higher concentrations are to the West and over the Highlands, as shown in **Figure 2**. The results in the current study are consistent with those [5,11,25,26] which showed that Western Kenya was the most thundery place.

3.1 Annual cycle

The annual cycle of the thunderstorm days showed that they can be broadly classified as either bi-modal or quasi-uni-modal. The bi-modal thunderstorm occurrence pattern was mainly observed over the North Eastern, Central and Coast regions of the country. There are two peaks: in April and November, as shown for Moyale station in **Figure 3**. This frequency coincides with the March-April-May (MAM) commonly referred to as the long rainfall season and October-November-December (OND) which is often referred to as the short rainfall season.

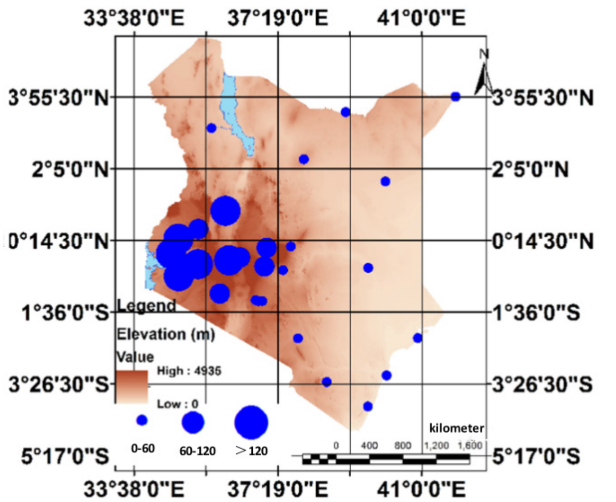

Figure 2. A map showing the spatial distribution of thunderstorms over Kenya.

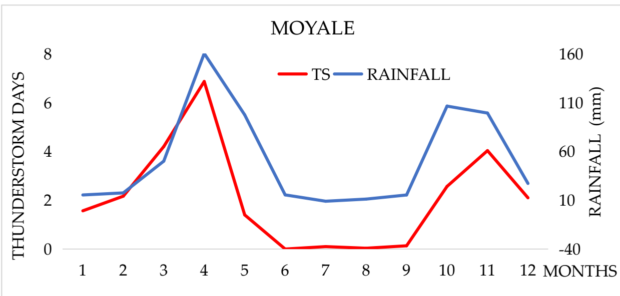

Figure 3. Annual cycle of rainfall and thunderstorms over Moyale in North-Eastern Kenya.

The quasi-uni-modal thunderstorm occurrence pattern has only one peak month but the timing of this peak varies from one location to another. This pattern was observed over the highland West of Rift Valley and the Lake Victoria region as shown in **Figure 4**. These areas to the western part of the country near Lake Victoria reported almost equal number of thunderstorms days over the three seasons: MAM, JJA and OND. The current study agrees with previous studies [5] on the maximum frequency of thunderstorm occurring over MAM in these areas. However, the previous study did not capture the varying peak months from one location to another over these areas.

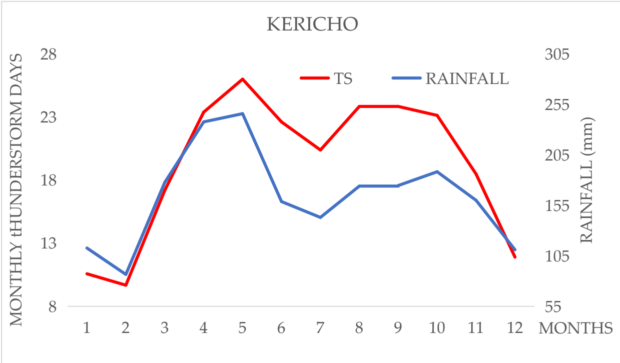

Figure 4. Annual cycle of rainfall and thunderstorms over Kericho in Highland West of Rift Valley.

3.2 Seasonal variability of rainfall and thunderstorms

During MAM season rainfall activities were reported throughout the country in varying amounts. The rainfall amounts increased towards the western parts of the country, as shown in **Figure 5**. With the availability of moisture from the long rain season, the high ground areas over the western parts of the country recorded high frequencies of thunderstorms. The terrain of an area affects thunderstorm formation, moisture tends to rush up the mountain. This is explained by **Figure 6** where the frequencies over Meru station are higher than the frequencies over Marsabit over MAM season. Meru station is influenced by Mount Kenya, and lies on the windward side of the mountain.

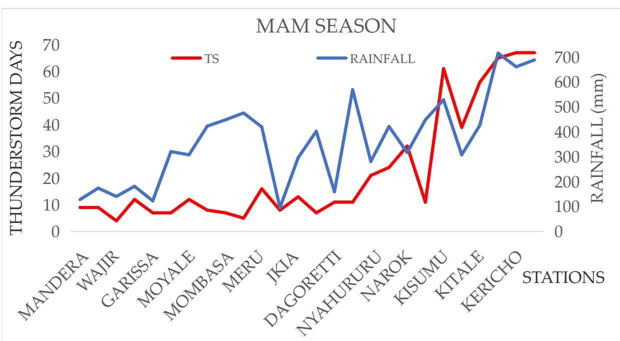

Figure 5. Seasonal variation of rainfall and thunderstorms over various stations during MAM over Kenya.

Over the June-July-August (JJA) season negligible number of thunderstorm days were reported over the Highland East of Rift Valley, North Eastern and the Coast of Kenya, as shown in **Figure 6**. Higher frequencies were observed over the highland west of Rift Valley [27]. Nakamara (1968) in the study of equatorial westerlies over East Africa showed that frequent incursions of these winds resulted in heavy thunderstorms over the Highlands of Kenya but a lee effect was evident in the regions east of the highlands.

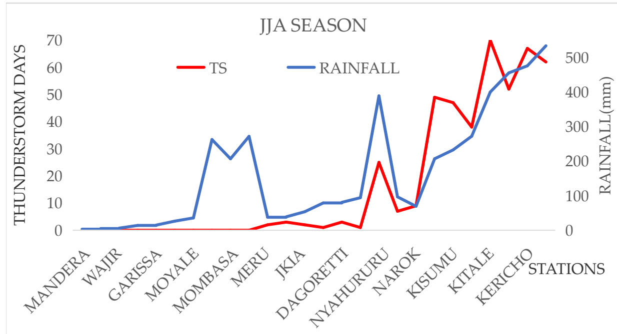

Figure 6. Seasonal variation of rainfall and thunderstorms over various stations during JJA over Kenya.

During the short rainy season (OND) the eastern half of the country reported low frequencies of Thunderstorms whereas there was a notable peak over the western part of the country. The western part of the country has a high influence from the Lake Victoria basin as its source of moisture and therefore, the latent heat over these areas is higher than the highlands in Central Kenya. The triggering mechanisms also include the orographic upslope. Even though there were peaks of rainfall frequencies over Central Kenya (Meru, Embu, Nyeri) thunderstorm frequencies were minimal, as shown in **Figure 7**.

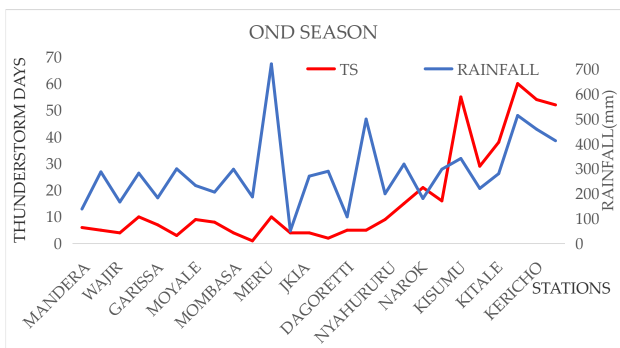

Figure 7. Seasonal variation of rainfall and thunderstorms during OND over Kenya.

3.3 Inter-annual variability of rainfall and thunderstorm

The observed thunderstorms and rainfall changed both in space and time over the study area during the period of study.

Over the North Eastern parts of the country, the thunderstorm days were mainly observed during MAM and OND rainfall seasons with slightly higher frequencies during the OND season. It also appeared to be a consistent tendency for peaks and troughs in thunderstorm frequency to coincide with the El Nino events (1987, 1991, 1992, 1994, 1997, 2002, 2004, 2006, 2009 and 2015) or La Nina events (1988, 1995, 1998, 1999, 2000, 2005, 2007, 2010, 2011, 2016 and 2017) during OND season in the northeastern parts of the country, as shown in **Figure 8**.

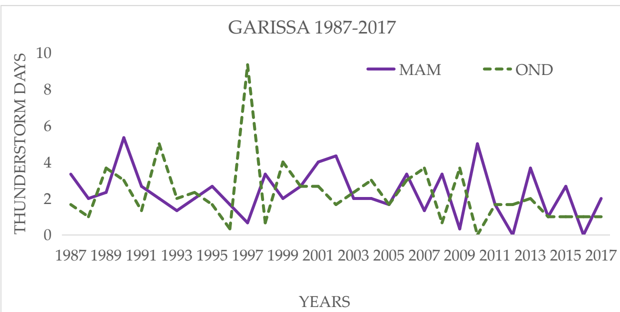

Figure 8. Inter-annual variability of thunderstorms over Garissa.

The coastal areas had a similar pattern as that of the northeastern parts but the MAM season had higher frequencies of thunderstorms than OND, as shown in **Figure 9**.

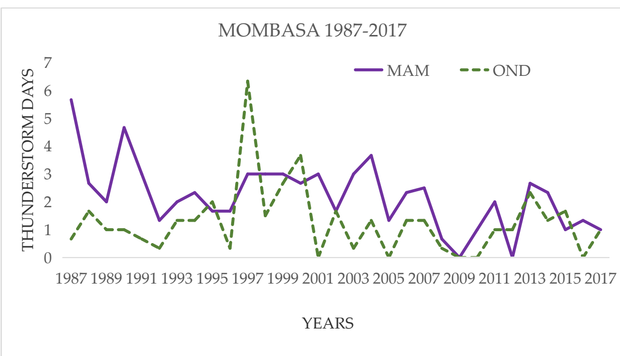

Figure 9. Inter-annual variability of thunderstorms over Mombasa.

The comparison of thunderstorm and rainfall frequencies over the coast confirms the coinciding peaks and troughs as shown in **Figure 10**.

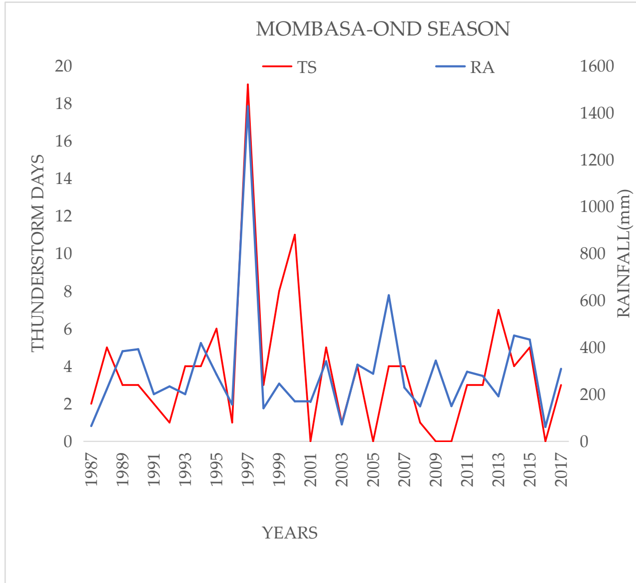

Figure 10. Inter-annual variability of thunderstorms and rainfall over Mombasa.

The analysis of thunderstorm data in areas around Lake Victoria showed that thunderstorm frequency did not vary significantly over MAM, JJA and OND rainfall seasons as shown in **Figure 11**. There were almost equal frequencies. These stations Kericho, Kakamega, Kisumu and Kisii are highly influenced by Lake Victoria which acts as a constant source of moisture.

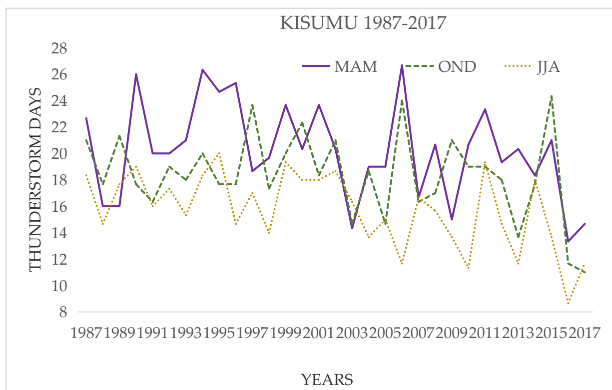

Figure 11. Inter-annual variability of thunderstorms over Kisumu.

The comparison of thunderstorm and rainfall frequencies over the same areas during the same period depicts the same pattern as shown in **Figure 12**.

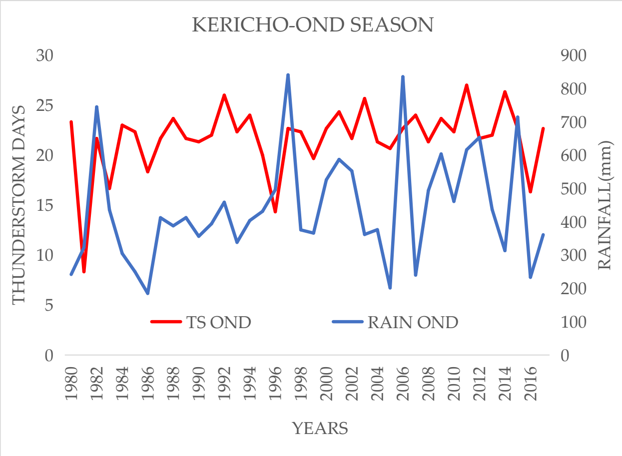

Figure 12. Inter-annual variability of thunderstorms and rainfall over Kericho.

3.4 Results of trend analysis for thunderstorms and rainfall

During the study period, thunderstorms and rainfall trends varied over different regions of the country in each season. The findings of the study confirmed previous studies that there was a noticeable decrease in rainfall over MAM and a slight increase over the OND season [13,14] as shown in **Table 1**.

During the MAM season, stations near the Lake Victoria Basin, Central and the Highland East of the Rift Valley had a non-significant reducing trend of rainfall but an increasingly significant and non-significant trend of thunderstorms. Over Northeastern and the Coastal regions, the reducing significant trends of thunderstorms agreed with the reducing non-significant trends of rainfall.

During the JJA season, areas that had a non-significant increasing trend were near Lake Victoria. The coast and the North Eastern region had a significant decreasing trend of rainfall and a non-significant trend for thunderstorms. Some stations had insignificant trends for both rainfall and thunderstorms. This was mainly observed during the JJA season over the North Eastern parts of the country and the Coastal Region.

During the OND season, western Kenya had a significantly increasing trend of thunderstorms while rainfall was increasing insignificantly. Areas where convergence occurs experience upward motion of air resulting in cloud formation. This leads to the formation of thunderstorms/precipitation if there is enough moisture and condensation nuclei [28]. Rather than the availability of moisture, the physical features (elevation) of a location contributed to thunderstorm occurrences. Though the findings of the current study on the rainfall trends over MAM and OND were agreed with the previous studies [14,29], the significance level differed, there were non-significant trends for the reducing MAM and the increasing OND rainfall trends. These are shown on the various maps (**Figure 13**).

4. Conclusions

The results obtained confirm that higher concentrations of thunderstorms are to the West and over the Highland parts of the country; areas around Lake Victoria which act as a source of moisture for thunderstorm formation. The Coastal and North Eastern regions reported the lowest frequencies of thunderstorms, this is because of the lack of moisture over the North Eastern region and the low elevation for the formation of deep convective clouds over the Coast region.

Thunderstorm days' occurrence can be broadly classified as either bi-modal or quasi-uni-modal in Kenya. The bi-modal thunderstorm occurrence pattern was mainly observed over the Eastern, Central and Coast regions and mostly coincides with the March-April-May (MAM) and October-November-December (OND) rainfall seasons. The quasi-unimodal thunderstorm occurrence pattern was observed over the Highland West of Rift Valley and the Lake Victoria region. These areas reported almost equal numbers of thunderstorm days from March to December.

Both significant and non-significant thunderstorm and rainfall trends were observed during all three seasons. For rainfall, both MAM and JJA seasons had decreasing trends over most stations. However, the decrease for the MAM season was not statistically significant. OND season showed an increasing trend over most stations, though it was not signifi-

Table 1. Thunderstorms trend values and their corresponding statistics.

MAM							JJA				OND			
	Lat	Lon	Trend	p value	Tau	Gradient	Trend	P value	Tau	Gradient	Trend	p value	Tau	Gradient
Dagoretti corner	**–1.30**	**36.75**	▲	0.078	0.23	0.063	▲	0.063	0.253	0.021	▲	0.115	0.208	0.04
Jkia	**–1.32**	**36.92**	▼	0.102	–0.211	–0.083	▼ (red)	0.005	–0.379	–0.028	▼ (red)	0.031	–0.288	–0.037
Eldoret	**0.27**	**35.40**	▲	0.079	0.228	0.128	▼	0.932	0.013	0.000	▲ (red)	0.002	0.409	0.133
Wilson	**–1.32**	**36.82**	▼	0.959	–0.009	0.000	▼	0.453	–0.107	0.000	▲	0.888	–0.022	0.000
Embu	**–0.53**	**37.45**	▼	0.056	–0.248	–0.100	▼	0.655	–0.069	0.000	▼	0.572	–0.076	0.000
Meru	**0.08**	**37.65**	▲	0.798	0.035	0.000	▲	0.936	–0.014	0.000	▼	0.645	–0.062	–0.013
Nyeri	**–0.43**	**36.97**	▲ (red)	0.015	0.315	0.104	▲	0.111	0.210	0.037	▲	0.081	0.230	0.067
Nyahururu	**–0.20**	**36.35**	▲	0.932	0.013	0.011	▼	0.529	–0.083	–0.058	▲	0.124	0.202	0.044
Garissa	**–0.47**	**39.63**	▼	0.192	–0.173	–0.033		0.968	0.012	0.000	▼	0.136	–0.197	–0.039
Mandera	**3.93**	**41.87**	▼ (red)	0.000	–0.464	–0.146	▼	0.099	–0.256	0.000	▼	0.265	–0.148	–0.021
Marsabit	**2.32**	**37.98**	▼ (red)	0.003	–0.394	–0.080	▼	0.358	–0.126	0.000	●			
Moyale	**3.53**	**39.05**	▼	0.054	–0.251	–0.095	▼	0.920	-0.020	0.000	▼	0.109	–0.209	–0.058
Wajir	**1.75**	**40.07**	▲	0.361	0.123	0.012	●				▼	0.668	0.059	0.000
Makindu	**–2.28**	**37.83**	▼ (red)	0.026	–0.291	–0.078	●	1.000	0.004	0.000	▼	0.337	–0.128	–0.019
Malindi	**–3.23**	**40.10**	▼ (red)	0.001	–0.436	–0.083	▲	0.810	0.042	0.000	▼	0.311	–0.150	0.000
Mombasa	**–4.03**	**39.62**	▼ (red)	0.006	–0.364	–0.061	▼	0.240	–0.186	0.000	▼	0.503	–0.091	0.000
Kakamega	**0.28**	**34.77**	▲	0.658	0.059	0.024	▼	0.798	–0.035	0.000	▲ (red)	0.022	0.296	0.188
Voi	**–3.40**	**38.57**	▼	0.150	–0.190	–0.053	●				▲	0.645	0.062	0.012
Lodwar	**3.12**	**35.62**	▼ (red)	0.036	–0.274	–0.067	▲	0.205	0.172	0.013	▲	0.208	0.169	0.019
Lamu	**–2.27**	**40.90**	▼ (red)	0.009	–0.337	–0.111	▼	0.443	–0.120	0.000	▼	0.384	–0.114	–0.033
Kitale	**1.00**	**35.98**	▲	0.066	0.239	0.093	▼	0.932	–0.013	0.000	▲	0.102	0.212	0.104
Kisumu	**-0.10**	**34.58**	▲	0.941	–0.008	0.000	▼ (red)	0.037	–0.214	–0.074	▲	0.116	0.162	0.065
Kisii	**-0.68**	**34.78**	▼	0.540	0.081	0.002	▼	0.366	–0.119	–0.062	▲	0.071	0.234	0.083
Kericho	**–0.37**	**35.27**	▲ (red)	0.000	0.363	0.133	▲ (red)	0.001	0.333	0.117	▲ (red)	< 0.0001	0.488	0.247
Nakuru	**–0.27**	**36.07**	▼	0.508	–0.068	–0.028	▼ (red)	0.032	–0.221	–0.062	▲	0.139	0.153	0.049
Narok	**–1.13**	**35.83**	▲	0.762	0.032	0.009	▼	0.613	–0.053	0.000	▼	0.927	–0.010	0.000

▲: Increasing trend
▼:Decreasing trend
▲ (red):Significant increasing trend
▼ (red): Significant decreasing trend
●: No trend

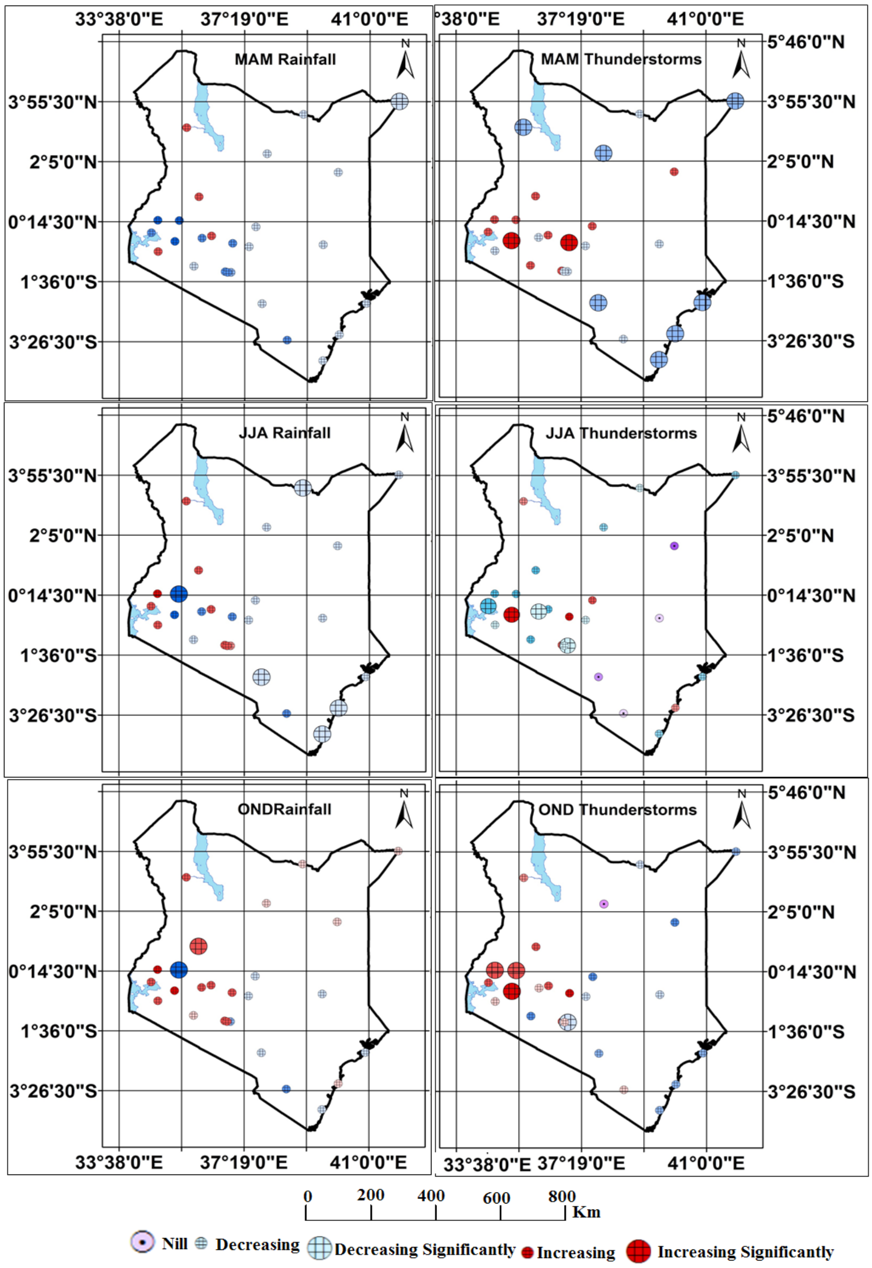

Figure 13. Comparison of trend results for thunderstorms and rainfall at seasonal time-scale over Kenya.

cant. For thunderstorms, a reducing significant trend was observed over most stations during the MAM season. In JJA season, most stations over the eastern half of the country observed nil thunderstorms while the western half had to reduce significant trends. During the OND season, most stations had increasing significant trends. In contrast, the stations around the Lake Victoria region mainly had an increasing trend during the MAM and OND seasons. In summary, the results indicated that the increasing/reducing trends of rainfall over the seasons were not converting to increasing/reducing trends of thunderstorms. The importance of these findings is that they could support various policy makers, and users of climate information, especially in the agriculture and aviation industries.

This study focused on thunderstorm frequencies and trends. It also analysed the same for rainfall in comparison to thunderstorms. The results were interesting, thus there is a need, to replicate this research to the other related parameters like temperature and establish the relationship between thunderstorms and temperatures in Kenya. Thunderstorm days' data were used to analyse the frequencies, it will be important also to look at the daily frequencies to determine the intensity and duration of a thunderstorm in a given area.

Conflict of Interest

The author declares that there is no conflict of interest.

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References

[1] Okoola, R.E., 2005. Transition from the Southern to the Northern Hemisphere summer of zones of active convection over the Congo Basin. Meteorology and Atmospheric Physics. 84, 255–265.
DOI: https://doi.org/10.1007/s00703-003-0002-6

[2] Yuhua, O., Ping, Y., 2012. Audible thunder characteristic and the relation between peak frequency and lightning parameters. Journal of Earth System Science. 121, 211–220.
DOI: https://doi.org/10.1007/s12040-012-0147-0

[3] World Meteorological Organization (WMO), 1992. International meteorological vocabulary. World Meteorological Organization: Geneva.

[4] Lavigne, T., Liu, C., Liu, N., 2019. How does the trend in thunder days relate to the variation of lightning flash density? Journal of Geophysical Research: Atmospheres. 124(9), 4955–4974.
DOI: https://doi.org/10.1029/2018JD029920

[5] Chaggar, T.S., 1977. Geographical distribution of monthly and annual mean frequency of thunderstorm days over Eastern Africa. EAMD Technical Memorandum No.26.

[6] Temporal Distributions of Global Thunder Days [Internet]. Illinois Department of Energy and Natural Resources. Available from: https://www.isws.illinois.edu/pubdoc/cr/iswscr-337.pdf

[7] Enno, S.E., Piia, P., Agrita, B., et al., 2014. Long-term changes in the frequency of thunder days in the Baltic countries. Boreal Environmental Research. 19, 452–466.

[8] Changnon, S.A., 1981. Possible effects of contrail generated cirrus on mid-western cloud and sunshine. Journal of Applied Meteorology. 20(8).

[9] Wu, C., 2005. Inherent delays and operational reliability of airline schedule. Journal of Air Transport Management. 11(4), 273–282.
DOI: https://doi.org/10.1016/j.jairtraman.2005.01.005

[10] Bhattacharya, S., Bhattacharyya, H.C., 2023. A comparative study of severe thunderstorm among statistical and ANN methodologies. Scientific Reports. 13, 12038.
DOI: https://doi.org/10.1038/s41598-023-38736-z

[11] Maloba, S., 2015. Spatial and temporal characteristics of thunderstorms over the eastern region of Lake Victoria Basin in Kenya [Master's thesis]. Nairobi: University of Nairobi.

[12] Ayugi, B.O., Wang, W., Chepkemoi, D., 2016. Analysis for spatial and temporal patterns of rainfall variations over Kenya. Journal of Environmental and Earth Science. 6(11), 69–83.

[13] Ongoma, V., Chen, H., 2017. Temporal and spatial variability of temperature and precip-

itation over East Africa from 1951 to 2010. Meteorology and Atmospheric Physics. 129, 131–144.
DOI: https://doi.org/10.1007/s00703-016-0462-0

[14] Gitau, W., Camberlin, P., Ogallo, L., et al., 2018. Trends of intraseasonal descriptors of wet and dry spells over Equatorial eastern Africa. International Journal of Climatology. 38(3), 1189–1200.
DOI: https://doi.org/10.1002/joc.5234

[15] The Thunderstorm. Report of the Thunderstorm Project [Internet]. U.S. Government Printing Office. Available from: https://onlinebooks.library.upenn.edu/webbin/book/lookupid?key=ha007160453

[16] Koros, D., 2014. Determining convective precipitation using cold cloud top temperatures and its impact on aviation industry over western Kenya [Master's thesis]. Nairobi: University of Nairobi.

[17] Gamoyo, M., Reason, C., Obura, D., 2015. Rainfall variability over the East African coast. Theoretical and Applied Climatology. 120, 311–322.
DOI: https://doi.org/10.1007/s00704-014-1171-6

[18] Palmer, P.I., Wainwright, C.M., Dong, B., et al., 2023. Drivers and impacts of Eastern African rainfall variability. Nature Reviews Earth & Environment. 4, 254–270.
DOI: https://doi.org/10.1038/s43017-023-00397-x

[19] Pinzari, L., Mazumdar, S., Girosi, F., 2018. A framework for the identification and classification of homogeneous socioeconomic areas in the analysis of health care variation. International Journal of Health Geographics. 17, 42.
DOI: https://doi.org/10.1186/s12942-018-0162-8

[20] Mann, H.B., 1945. Nonparametric tests against trend. Econometrica. 13(3), 245–259.
DOI: https://doi.org/10.2307/1907187

[21] Kendall, M.G., 1975. Rank correlation methods. Charles Griffin: London..

[22] Mallick, J., Talukdar, S., Alsubih, M., 2021. Analysing the trend of rainfall in Asir region of Saudi Arabia using the family of Mann-Kendall tests, innovative trend analysis, and detrended fluctuation analysis. Theoretical and Applied Climatology. 143, 823–841.
DOI: https://doi.org/10.1007/s00704-020-03448-1

[23] Gadedjisso-Tossou, A., Adjegan, K.I., Kablan, A.K.M., 2021. Rainfall and temperature trend analysis by Mann-Kendall test and significance for Rainfed Cereal Yields in Northern Togo. Sci. 3(1), 17.
DOI: https://doi.org/10.3390/sci3010017

[24] Aditya, F., Gusmayanti, E., Sudrajat, J., 2021. Rainfall trend analysis using Mann-Kendall and Sen's slope estimator test in West Kalimantan. IOP Conference Series: Earth and Environmental Science. 893. 012006.
DOI: https://doi.org/10.1088/1755-1315/893/1/012006

[25] Asnani, G.C., 2005. Tropical meteorology: Special features of tropical meteorology; Climatology of the tropics; Climatic change; Physics and dynamics of monsoon.

[26] Obiero, K., 2013. Thunderstorm hazards and their impact in the Lake Victoria basin of Kenya [Master's thesis]. Nairobi: Kenyatta University.

[27] Nakamara, K., 1968. Equatorial Westerlies over East Africa and their climatological significance. Geographical Review of Japan. 41(6), 359–373.

[28] Okoola, R.E., 1999. Mid-tropospheric circulation patterns associated with extreme dry and wet episodes over equatorial Eastern Africa during the northern hemisphere spring. Journal of Applied Meteorology and Climatology. 38(8), 1161–1169.
DOI: https://doi.org/10.1175/1520-0450(1999)038<1161:MCPAWE>2.0.CO;2

[29] Liebmann, B., Hoerling, M.P., Funk, C., et al., 2014. Understanding recent eastern horn of Africa rainfall variability and change. Journal of Climate. 27(23), 8630–8645.
DOI: https://doi.org/10.1175/JCLI-D-13-00714.1