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Seasonal Occurrence and Distribution of Thunderstorm over Lokoja, Kogi State, Nigeria

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Abstract

The aim of the study was to ascertain the seasonal occurrence and distribution of thunderstorm (TS) in Lokoja. Data on monthly TS occurrence from 1980-2020 were obtained from the Nigerian Meteorological Agency (NiMet), Abuja and analysed for this study. Various statistical methods were developed and applied. Results showed the total monthly and inter-annual mean TS was 78 with 6 as the mean of mean. The major monthly mean occurrence was between April (average of 06) and October (average of 09). Lowest occurrence was observed in January and December, while highest of 14 was recorded in August and September. Highest positive mean deviation was 08 (August and September); least was 03 (May and October); highest negative mean deviation was -6 (January, February & December) with the least of -5 (March & November). Highest inter-annual mean TS of 08 occurred in 10 years with lowest of -2 (1997). Highest positive mean TS occurred in 10 years; while the least positive mean occurred in 1982 (04). Frequency count of mean TS occurrence showed 7 has the highest (17 years); while the least was 4 and -2 occurring once each. On inter-annual mean deviation, positive deviation occurred most frequently (18 years), followed by zero (0), 14 years; and lastly, negative deviation (9 years). Highest inter-annual positive mean deviation was 2; lowest was 1; while highest negative mean deviation was -9 with -1 as the least. Dry season percentage (%) occurrence was 4.8 % and 95.2 % for rainy season. Mean decadal TS signified 82.4 (2000-2009) as highest, while 75.3 (1990-1999) was the least; a projection to the 5th decade, 2020-2029 was 77.8. In conclusion, wet TS is the major type in this area. It was therefore recommended that, TS forecast should be included in the Seasonal Climate Prediction (SCP) and daily weather forecast by the Nigerian Meteorological Agency (NiMet); and TS occurrence should serve as early warning system of severe weather.

Keywords: ***dry season, forecast, rainfall, thunderstorm, wet season***

Introduction

All atmospheric components and occurrences are subjected to constant study due to their direct and indirect impacts on man and his environment. One of such atmospheric happenings is thunderstorm (TS) which is very common in Nigeria just like every other tropical area. As a result of the impact of TS, it is subjected to scientific study because of its positive and negative effects. According to Ben-Nun (2022), the study of thunderstorm (TS) is called "Brontology," while a line drawn through geographical points at a given phase of TS activity which occurred simultaneously is called 'Isobronts."

Thunderstorm (TS) is a signature to severe weather in Nigeria and is classified as severe if its wind reach equal to or greater than (≥) 58 mph. Ben-Nun (2022) stated that, severe weather including tornadoes, thunderstorms, wind and hail annually cause significant loss of life and property. According to Budnuka (2015), TS is a manifestation of convective overturning of deep layers in the atmosphere and in an environment in which lapse rate is sufficiently large to be conditionally unstable and the air at low level is moist. TS hardly occurs under clear atmosphere as its occurrence is usually associated with rain-bearing clouds especially cumulonimbus with heavy and prolonged rainfall. According to Budnuka (2015), TS is a process which takes heat and moisture near earth's surface and transports it to the upper level of the atmosphere. The bi-product of this process is cloud formation, rainfall, lightning and wind. Factors leading to TS occurrence include unequal heating of the surface which starts the process of upward movement of warm air; topography and adequate moisture (Ahrens, 1998).

No single factor is responsible for the occurrence of this weather condition. However, as intense heat and high influx of moisture occur in the lower atmosphere in particular, TS activity is initiated, sustained and triggered. Its outbreak, distribution, intensity and impact vary from place to place and time to time depending on the prevailing and favourable factors. According to Budnuka (2015), three (3) conditions are needed for the formation of TS. These are moisture in the lower to middle level of the atmosphere, instability and lift. TS may occur simply, in clusters or in lines. Lightning is a major secondary threat associated with TS. TS development is associated with a variety of boundaries in the earth's planetary boundary layer. Along with cold fronts and warm fronts, low-level TS outflows can trigger new TS. Although, different from a boundary, some terrain features are known to be preferred locations for the initiation of TS. Another type of boundary that can trigger it is a dryline. Forecasting TS development is an important "nowcasting" issue. At times, the environment on the moist side of a dryline can support TS (Grasso, 2003).

Nigeria experiences rainfall annually which is widely used mostly in agriculture because according to Nwaogu & Cherubin (2024), it is very necessary to provide sufficient food for the growing population. Rainfall can be altered by climate change (Musa, 2024), while it is mostly associated with TS. Audu *et al*. (2020) discovered in a study that, TS has the strongest relationship with heavy rainfall over Lokoja, Kogi State, Nigeria and the entire Guinea Savanna Zone of Nigeria. The most common and important rain in Nigeria is convective rain which is usually associated with TS. According to Adelekan (1998); Ayoola *et al*. (2016) TS rainfall due to local convection is one of the three (3) major types experienced in Nigeria and West Africa at large. NOAA National Severe Storms Laboratory (n.d) stated that, TS is a great way for the atmosphere to release energy as well as helps to keep the earth in electrical balance. According to Ayoola *et al*. (2016), the percentage (%) contribution of TS to total wet season rainfall increases significantly from the coastal areas inland; with coastal, middle and northern sections of the country recording 17.8 %, 30 % and 35.8 % respectively. According to Orji (2016), at wet season; a lot of convection takes place over high terrain, especially at late afternoon/evening as with adequate moisture supply, hills and mountains sometimes behave as "thunderstorms generator." When TS cells form in aggregations, then the collection of storms can live for a much longer time than the individual cells (which retain their 20-to-30 minutes lifetimes). This means that, the hail and wind events produced by such groupings of TS is intermitted, rather than prolonged (as with super cells), as cells form and decay within the group.

There is more TS in northern part of Nigeria than in the south due to the presence of moisture at wet season and more intense heat received in the daily, monthly and annually. The importance of TS lies in the fact that, it contributes significantly to flooding and soil erosion episodes due to their high intensity and torrential rainfall characteristics. High winds generated by TS can cause damage to homes, overturn vehicles, uproot/damage trees or blow down utility poles causing wide spread power outrage (ALL HAZARDS, n.d). TS is made up of both wet and dry. Wet TS is accompanied with rainfall, while the dry type is without rain. According to Balogun (2001), Abuja experiences frequent occurrence of squall lines which is a weather condition that is herald by occurrence of cumulo-nimbus clouds and accompanied by thunder and lighting.

Severe TS can have devastating impacts (Koch *et al*., 2021). Thunderstorm (TS) aside its contribution to rainfall also have negative effects such as destruction of buildings, big trees and killing of animals and humans in extreme cases. TS is an electric generator which drives upward currents in the global electric circuit and produces peak current up to a few tens of kilo ampere (KA). This electric field produced by TS-driven current may affect Exothermic Brazing (EXB) plasma drift causing the redistribution of plasma density in the ionosphere and hence perturbation in electron density. It could also cause electrocution and ill-health in a severe case such as asthma (Yamamoto, 2023).

In a research conducted by Ologunorisa & Chinago (2004) on annual TS fluctuations and trends in Nigeria, it was discovered that, six (6) periods of maximum annual TS and frequency in Nigeria were observed in 1975, 1979, 1985, 1991, 1994 and 1997; while six (6) periods of minimal occurrence were recorded in 1977, 1983, 1988, 1992, 1996 and 1998. In addition, there is a statistically significant positive trend for the stations such as Sokoto, Enugu, Ibadan and Nigeria (average); while those stations that showed positive correlation which are statistically significant at 95 % probability level are Nguru, Katsina, Bauchi, Yola, Minna, Lagos, Calabar, Warri and Port Harcourt.
In a study conducted by Budnuka (2015) on the statistical analysis of seasonal temperature variation and TS activity over Yola North, Nigeria; it was discovered that, season temperature does not influence or have any impact on TS; range in seasonal temperature inversely affect TS occurrence; and 85.4 % of the total TS occurrence during the period of study is attributed to or accounted for by seasonal temperature range. The lower the range of seasonal temperature, the higher the TS expected to occur. Result on annual TS occurrence shows a decrease in TS activity over time.

Research Questions

1. What is the mean thunderstorm (TS) occurrence in the study area?
2. What is the mean percentage occurrence of TS in dry and wet seasons?
3. What is the mean decadal TS?
4. What is the projection mean TS in the study area?

Objectives of the Study

1. To determine the mean thunderstorm in the study area
2. To compute the mean percentage occurrence of TS in dry and wet seasons
3. To ascertain the mean decadal TS
4. To project the mean thunderstorm to the next decadal (2020-2029)

The Study Area

The study area is Lokoja which is the capital of Kogi State, Nigeria and the headquarters of Lokoja Local Government Area (Adewala & Love, 2018). It is located between longitudes 6°30’-7°0’ East and latitudes 7°30’-8°0’ North (Figure 1) and lies within the Guinea Savanna Ecological Zone of Nigeria (Musa *et al*., 2020). According to Francis (2017), the meteorological station where data were acquired for this study is located on longitude 6.7°E, latitude 7.8°N, an elevation of about 062 and World Meteorological Organisation (WMO) station number of 65243. Lokoja derived its name from Hausa words, tree and colour. “Loko” means iroko and “ja” is the word for red. When the two English words are put together, they form red iroko (tree). Iroko tree was very common in Lokoja especially along River Niger. Kogi, as a Hausa word means a river. The confluence of Rivers Niger and Benue is found in the study area with an elongated and large floodplain which is visible from Ozi village in Kogi Local Government Area along Abuja-Lokoja Road. The study area observes both wet and dry seasons (Animashaun *et al*., 2020) with rainy season occurring between April-October, while dry season is from November-March (Akpen *et al*., 2019). Highest annual rainfall within the period under study occurred in 1999 (1767.1 mm), lowest of 804.5 mm occurred in 1982 (Audu *et al*., 2022); while the climatological mean rainfall is 1213.2 mm (Audu *et al*., 2018). Climatological mean temperature is about 28.03°C with March being the hottest month. Wind speed is at its peak between March and April, while average daily vapour pressure is about 26 Hpa (Alabi, 2012 cited by Adewale & Love, 2018). Its total landmass is about 3,518 km^2 and covers about 12 % of the total landmass of Kogi State (Abenu *et al*., 2016). It has a population of about 305, 210 (National Population Commission projection, 2021). River Niger is the major source of fish, domestic water, industrial water and water transportation in the study area, but under-utilised for tourism, electricity generation, recreation and large scale irrigation within the study area

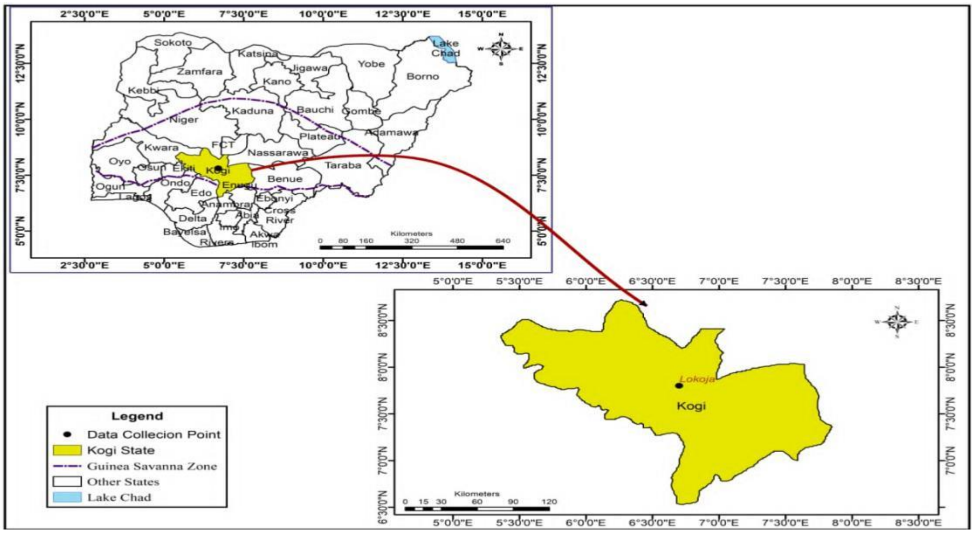

Figure 1: Map of the study area showing data collection point
Source: Department of Geography, Federal University Lafia, Nasarawa State, Nigeria (2023)

Materials and Methods

The data used for this study were the monthly TS occurrence over the study area, 1980-2020 (41 years) obtained from the archives of the Nigerian Meteorological Agency (NiMet), Abuja.
To analyse the data, the period under investigation was divided into four (4) decades of ten (10) years each (1980-1989, 1990-1999, 2000-2009 and 2010-2019), while 2020 forms the base for the projected decadal.

The annual thunderstorm (TS) for the study area was derived from monthly TS as thus:

$$Annual\ thunderstorm = \sum_{i-1}^{m} p_i \qquad 1$$

Where: $i = 1,2, \ldots\ldots\ldots\ldots . m$; $m = number\ of\ months = 12$

$p = monthly\ thunderstorms$

From the annual thunderstorm (TS), annual mean TS was derived as thus:

$$Annual\ mean\ thunderstorm = \frac{1}{m}\sum_{i-1}^{m} p_i \qquad 2$$

The climatological mean for both annual and monthly TS was computed thus:

$$\overline{Clim} = \bar{\bar{x}} = \frac{1}{k}\sum_{i-1}^{k} \bar{x}_i \qquad 3$$

Where: $k = number\ of\ years/months$; $\overline{Clim}$=climatological mean

$\bar{x} = mean$; $\bar{\bar{x}} = mean\ of\ mean$

Annual mean deviation of TS form the climatological mean was calculated as:

$$AmDev = \overline{x_i} - \bar{\bar{x}} \qquad 4$$

Where: $\overline{x_i} = \frac{1}{m}\sum m_i$; $AmDev = Annual\ mean\ Deviation$
$m_i = number\ of\ months = 12$

The annual climatological mean TS was calculated thus:

$$\overline{ClimA.T} = \sum_{i-1}^{m} p_i \qquad 5$$

Where: $i = 1,2, \ldots\ldots\ldots\ldots\ldots m$; $m = number\ of\ months = 12$

$p = monthly\ thunderstorms$

The monthly climatological mean TS was calculated thus:

$$\overline{ClimM.T} = \frac{1}{m}\sum_{i-1}^{m} p_i \qquad 6$$

Where: $m, p\ and\ i\ are\ as\ earlier\ defined$

The climatological mean deviation for both annual and monthly was calculated as:

$$ClimDev = \overline{x_i} - \bar{\bar{x}} \qquad 7$$

Where: $\bar{x} = \frac{1}{m}\sum m_i$; $ClimDev = climatological\ annual\ deviation$

Other parameters are as earlier defined.

The percentage dry season mean TS was calculated thus:

$$\%\ dry = \frac{mean\ thunderstorms\ for\ dry\ months}{mean\ thunderstorms\ for\ all\ the\ months}\ x\ 100 \quad 8$$

Where: Dry season months in this study over the study area include January, February, March, November and December (5 months).

The percentage wet season mean TS was calculated thus:

$$\%\ wet = \frac{mean\ thunderstorms\ for\ wet\ months}{mean\ thunderstorms\ for\ all\ the\ months}\ x\ 100 \quad 9$$

Where: Wet season months in this study over the study area include April, May, June, July, August, September and October (7 months).

The decadal mean thunderstorm was calculated thus:

$$Decadalmean = \frac{1}{m}\sum_{i-1}^{n} x_i \quad 10$$

Where: $i = 1,2, \ldots\ldots\ldots\ldots. n$; $n = 10$ years period ; $x = annual\ thunderstorm$ $Decadalmean = 10\ years\ annual\ mean\ thunderstorm$

For the projected decadal mean thunderstorm (2020-2029), the following equation was applied:

$$y = 0.41x + 77.35 \quad 11$$

Where: $y = projected$; $x = incremenal\ Decadal\ period$

Results and Discussion

In Figure 2, the occurrence and distribution of thunderstorm (TS) follow the seasons and rainfall pattern. January and December have zero (0) occurrences because they are dry season months. This does not imply a complete absence of occurrence; but the long term monthly mean TS is negligible hence resulted to zero (0). The study of Olutimayin & Aribisala (2020) designated January-March and November-December as dry season in Lokoja. According to Audu *et al*. (2022), the zero (0) occurrence of monthly mean rainfall frequency in January, February and December in Lokoja and Environs, Kogi State, Nigeria does not signify total absence of rainfall. The highest mean monthly TS (14 %) occurred in August and September which corresponded with the months having highest rainfall in the study area. According to Olatunde & Adejoh (2018), September has the peak rainfall with the average of about 210 mm and slight difference of about 2.4 mm when compared with August average rainfall (208.2 mm) in Lokoja. The long term mean TS is 78, while the long term of mean of mean is 6. The monthly mean deviation from long term mean of mean (6) shows negative values for January, February and December (-6 each); while March and November have deviation of -5 each. April percentage (%) mean TS is zero (0), lowest positive % occurred in May and October (03 each); while the highest positive % occurred in August and September (08 each).

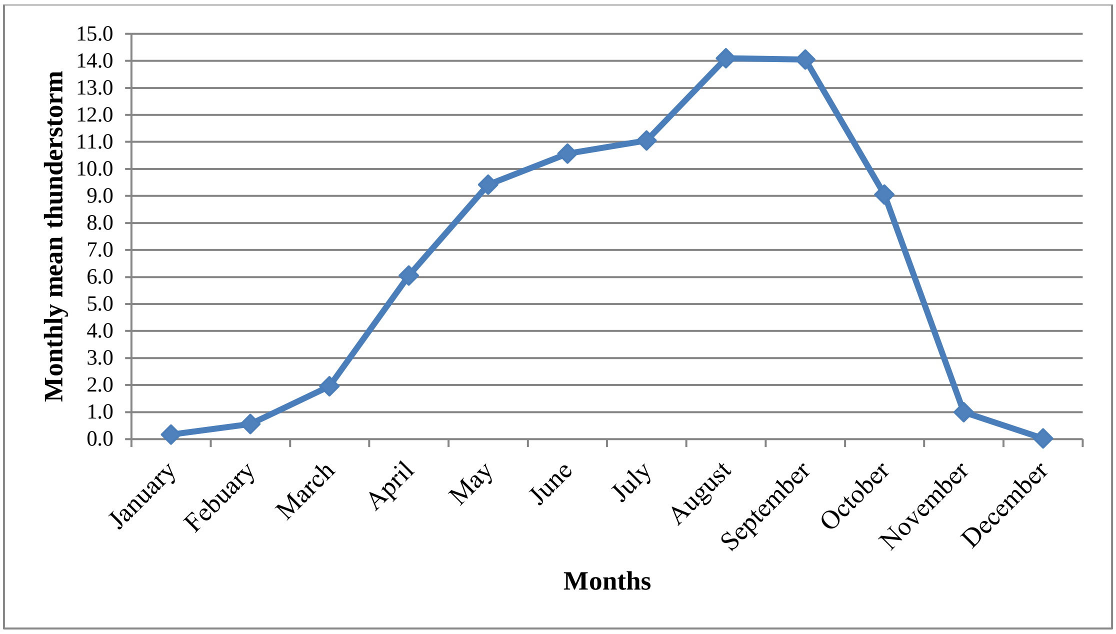

Figure 2: Monthly mean thunderstorm over Lokoja
Source: Authors' computation, 2024

In Figure 3, There are positive and negative inter-annual mean TS with the positive occurring in almost all the years (40 years) except for 1997 (1 year). The inter-annual mean TS shows the highest occurrence of 08 in ten (10) years (1989, 1990, 1991, 1994, 1995, 1999, 2002, 2007, 2009 & 2012); while the least is -2 (1997). The highest positive mean TS of 08 occurred multiple years; while the least positive occurred in 1982 (04). 1999 which was one of the years with the highest positive inter-annual mean TS agreed with the year of highest rainfall of 1767.1 mm in the study area (Audu, 2019). 1982 which recorded the least mean TS corresponded with the year of lowest rainfall between 1981-2020 in the study area (Audu, 2019). Frequency count of mean TS shows that, 7 has the highest mean (17 times), followed by 8 (10 times), 6 (8 times), 5 (4 times), 4 (once) and -2 (once). In terms of inter-annual mean deviation, positive deviation occurred most frequent (18 years), followed by zero (0) which occurred in 14 years and lastly, negative deviation (9 years). Recent study on rainfall trend showed the study area is observing increasing rainfall (Francis *et al*., 2024) hence responsible for the highest frequency of positive deviation since it is an established fact that; TS occurrence is strongly associated with rainfall over the study area. The highest positive inter-annual mean deviation is 2; lowest is 1; while the highest negative mean deviation is -9 with -1 as the least. The time series trend shows a downward trend in the inter-annual mean TS. The coefficients of determination indicate that, year-to-year contributes about 0.1 % to the decline in inter-annual mean TS with TS declining by about 0.1 % as well. This result showed that other factors such as the inter-annual rainfall, climate variability and climate change contributed about 99.9 % to the decline in TS.

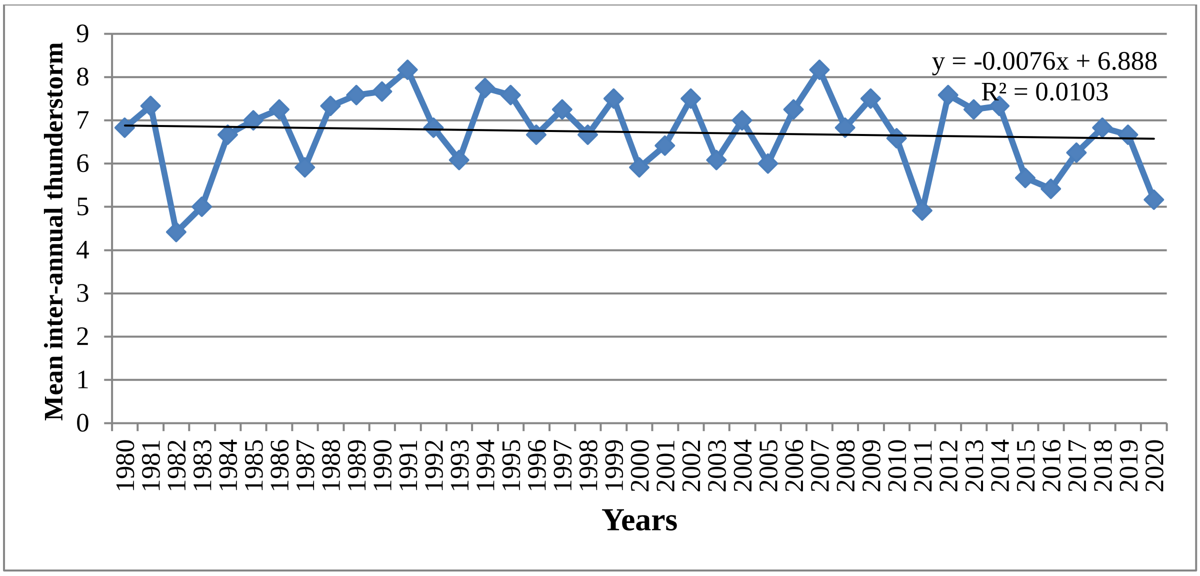

Figure 2: Inter-annual mean thunderstorm over Lokoja
Source: Authors' computation, 2024

In the area of distribution of TS between the two (2) seasons in the study area, 95.2 % occurred in wet season; while 4.8 % occurred in dry season. This can be substantiated with the fact that, the study area lies within the region designated by Koppen as "Aw" that is, Tropical Grassland or Savanna with distinct wet and dry seasons (Mngutyo, 2014; Adewale & Love, 2018), but with rainfall mainly in rainy season. The occurrence of mean TS in dry season months does not imply that it is dry TS. Dry season months does not imply total absence of rainfall. Audu (2012) observed that, Lokoja had mean monthly rainfall between 1981-2010 of 1.1 mm in January; February, 8.0 mm; March, 22.0 mm; November, 2.9 mm and December, 0.6 mm From the available rainfall data, Lokoja the study area had January rainfall of 45.7 mm in 1959; 1965, 2.5 mm and 1970, 1.1 mm. In February, 1951, there was rainfall of 2.5 mm; 1953, 27.9 mm; 1956, 33.0 mm; 1958, 2.5 mm; 1963, 15.2 mm; 1965, 55.9 mm; 1968, 7.6 mm; 1969, 8.0 mm; 1972, 10.9 mm; 1975, 3.3 mm; 1977, 4.0 mm and 1980, 6.4 mm. In December, 1956, there was rainfall of about 25.4 mm and 1990, 17.1 mm. These months are typically dry season months yet they had rainfall and the occurrence of TS. In addition, from 1951-2020, there is mean rainfall of 3.7 mm in January, 9.6 mm in February; 30.1 mm in March, 6.9 mm in November and 0.6 mm in December over Lokoja (Francis *et al*., 2024). In a study conducted by Budnuka (2015) on the statistical analysis of seasonal temperature variation and TS activity over Yola North, Nigeria, it was discovered that, more TS occurred at wet season than dry season.

There are four (4) decadals in this study (1980-2019) with an extra year (2020). Results on the decadal mean TS signifies that 1st decade is 78.4, 2nd is 75.3 (least), 3rd is 82.4 (highest), 4th is 77.4 and a projection to the 5th decade is 77.8 which does not significantly deviate from the results of the four (4) decadals. Within the 4 decades, there is a decline in the activities of TS. However, the projection shows a marginal rise hence the positive trend in time series. The R^2 indicated that year-to-year contributed 0.03 to the rise, while other factors especially rainfall contribute to about 99.93 % in the rising trend.

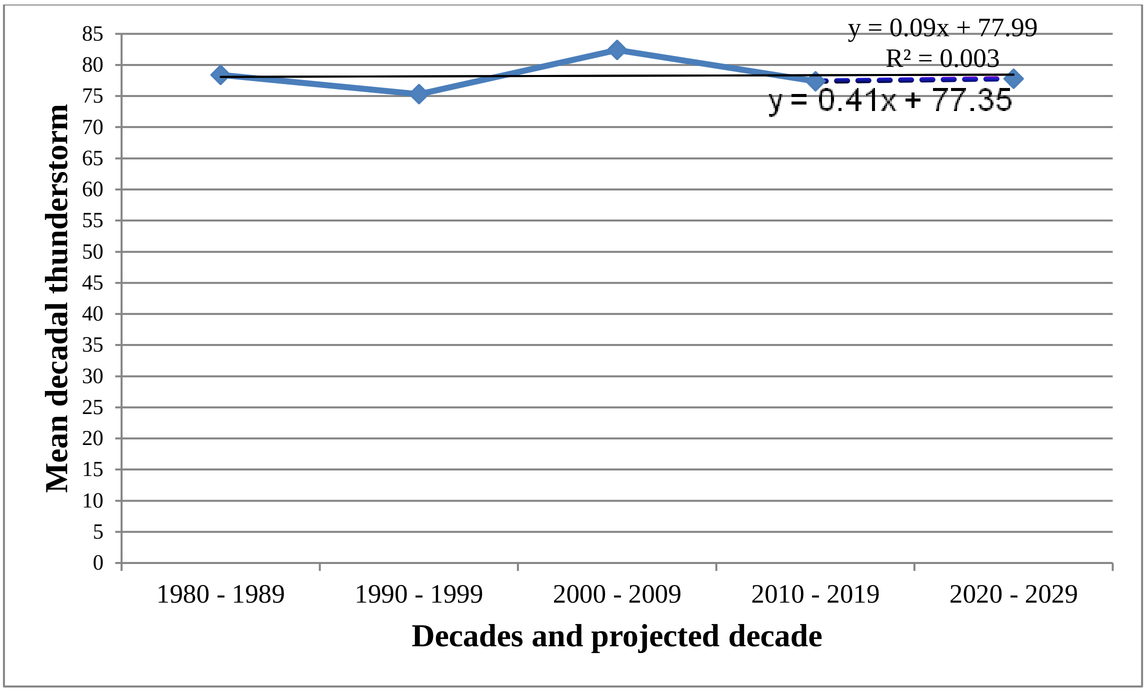

Figure 4: Decadal mean and projected mean thunderstorm over Lokoja
Source: Authors' computation, 2024

Conclusion and Recommendations

Thunderstorm (TS) occurrence in Lokoja, Kogi State, Nigeria is observed across all months and inter-annually according to this study. The total monthly and inter-annual mean is 78 and mean of mean of 6. TS occurs side-by-side with rainfall hence it is mostly wet TS. Even though it occurs in both dry season (4.8 %) and rainy season (95.2 %), its occurrence is predominantly during the wet season. The major occurrence is between April with the average of 06 and October with average of 09. The lowest occurrence is observed in January and December, while the highest mean is 14 (August and September). The highest positive mean deviation is 08 (August and September); least is 03 (May and October); while the highest negative mean deviation is -6 (January, February & December) with the least of -5 (March and November). The highest inter-annual mean TS of 08 occurred in 10 years with the lowest of -2 (1997). The highest positive mean TS occurred in 10 years; while the least positive mean occurred in 1982 (04). Frequency count of mean TS occurrence showed that, 7 has the highest occurring in 17 years; while the least is 4 and -2 occurring once each. In terms of the inter-annual mean deviation, positive deviation occurred most frequent (18 years), followed by zero (0) which occurred in 14 years and lastly, negative deviation (9 years). The highest inter-annual positive mean deviation is 2; lowest is 1; while the highest negative mean deviation is -9 with -1 as the least. In the area of distribution of TS between the two (2) seasons, 95.2 % occurred in wet season; while 4.8 % occurred in dry season. Results on the mean decadal TS signifies that 82.4 (2000-2009) is the highest, while 75.3 (1990-1999) is the least. A projection from all the decadals to the next decadal that is, 2020-2029 is 77.8. The study concluded that TS occurred side-by-side with rainfall hence it was mostly wet TS. It is therefore recommended that, TS forecast should be included in the Seasonal Climate Prediction (SCP) and daily weather forecast by the Nigerian Meteorological Agency (NiMet); rain forecast should be based on TSs, flood forecast should be based on TSs; and TSs occurrence should serve as an early warning system.

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