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Statistical Analysis of Seasonal Temperature Variation and Thunderstorm Activity over Yola North-East Nigeria

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Abstract The study examines in detail the relationship between seasonal temperature and thunderstorm occurrence in one hand and thunderstorm characteristics over Yola, North- East, Nigeria in the other hand. These include annual fluctuations, diurnal and trend. Data for this work were extracted from the archive of Nigerian Meteorological Agency, Oshodi Lagos from 1970 - 1999 for analysis. The result shows that season temperature does not influence or have any impact on thunderstorm (TS) occurrence during the study period. It was however discovered that range in seasonal temperature inversely affect TS occurrence. The study shows that 85.37% of the total TS occurrence during the study period is attributed to or accounted for by seasonal temperature range. The lower the range in seasonal temperature the higher the TS expected to occur. This implies that the higher the temperature range, the most likely TS will not occur. The result on annual TS occurrence shows a decrease in thunderstorm activity over time during the study period. It was observed that more TS tend to occur during wet season than during dry season. Thunderstorm activity within Yola exhibitsa mono peak or a single maximum in August. Further analysis reveals that the diurnal pattern of thunderstorm occurrence shows a late evening peak. The study also reveals among other things that there is statistical difference in diurnal, seasonal and annual variation of thunderstorm at 95% level of confidence in the study area. Finally, it was revealed that there is significant relationship between seasonal range in temperature and TS occurrence over Yola throughout the period of study The study also shows that there are months in the study area without a peal of thunderstorm. Full understanding of thunderstorm occurrence will be of great help to policy makers. Death resulting from TS strike will be avoided if children are prevented from playing during the peak hours and when range in temperature is low especially during rainy season.

Keywords: *annual fluctuation, diurnal variation, seasonal occurrence, seasonal temperature, thunderstorm characteristics, Yola*

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1. Introduction

Thunderstorms are manifestation of convective overturning of deep layers in the atmosphere and in an environment in which the decrease of temperature with height (lapse rate) is sufficiently large to be conditionally unstable and the air at low level is moist.

Heating of earth’s surface often causes thermal or parcel of warm air to rise to level of condensation. If the parcel contains sufficient moisture and the atmosphere is conditionally unstable, towering cumulus cloud form. Under suitable condition the cumulus tower may merge to form cumulonimbus cloud and in turn produces TS which are local storms accompanied always by lightning and thunder, often by strong gusts of wind and heavy rainfall and occasionally tornadoes and hail. Trewatha and Ham, Stated that TS is a thermodynamic machine whose potential energy of latent heat of condensation in moist, unstable air is converted into kinetic energy of violent vertical air current, characterized by thunder, lightning, gusty wind, and sometimes hails. Thunderstorm occurs when the atmosphere is unstable and moist, warm air near the ground becomes buoyant. The air rises, producing much fair weather cumulus cloud that at first form and dissipate without producing rain or electric discharge. As the day proceeds, the cloud increase in size and vapour until finally several of them combine. They surge upward to form a large cloud that in few months yields rain and lightning [8].

Athunderstorm is a process which takes heat and moisture near earth’s surface and transports it to the upper level of the atmosphere. The by-product of this process is cloud, precipitation, lightning, and wind. The birth of thunderstorm occurs when warm, humid air rises in conditionally unstable environment. The trigger needed to start air moving upward may be the unequal heating of the surface, the effect of terrain, or the lifting of warm air along zones. Diverging upper level wind coupled with converging surface winds and rising air, also provides a favourable condition for thunderstorm development [2].

The roaring and rumbling of the cloud and lightening associated with it, had over the year invoke fear on millions. Many associated it to gods, others to eventuality [3]. The challenge thunderstorm posed on aviation industry, air force and naval personal during the Second World War cannot be underestimated. This spurred scholars to study all aspect of thunderstorm.

Barry and Chorley stated that a thunderstorm cell is an elementary unit of a storm structure. As the updraft causes the growth in the cumulus state, air flows in through the sides or (entraining) and mixes with the downdraft. With continued upward motion large amount of water condenses and eventually fall as precipitation. This falling water initiates the downdraft because of viscous drag of the water on the air and evaporative cooling of the air.

All thunderstorms, whether or not they become severe, must have three conditions present in order to form. The first necessary condition is moisture in the lower to mid-level of the atmosphere. As air rises in a thunderstorm updraft, moisture condenses into water drops, which form clouds and eventually precipitation. When the moisture condenses, heat is released into air, making it warmer and less dense than its surrounding. The added heat allows the air in updraft to continue rising.

The second necessary condition is instability. If the air mass is unstable, air which is pushed upward by some forces are relatively cold (usually dry) air in the mid and upper levels of the atmosphere. As the low level air raises in updraft it become less dense than the surrounding air and continues to rise. This process is often augmented by added heat due to condensation. The air will continue to move upward until it become colder and denser than its surroundings

The third necessary condition is a source lift. Lift is a mechanism for starting an updraft in a moist, unstable air mass. The lifting source can take on several forms. The most common source is called differential heating. As sun heat the earth's surface, portion of the surface (and the air just above the surface) will warm more readily than areas close by. "These warm pockets" are less dense than areas around it, so it will rise. If the air has sufficient moisture and is unstable, a thunderstorm may likely form.

Apart from precipitation in the tropics, temperature is the most talked about element of weather and climate. Temperature of a body is determined by the balance between incoming and outgoing radiation and its transformation into sensible and latent heat. So temperature of a body is the degree of hotness or coldness of a body or place as measure by a thermometer [5].

The seasonal variations in temperature result largely from the seasonal variations in the amount of insolation (Incoming Solar Radiation) received at any giving location on the globe.

Temperature tends to increase during summer when insolation amount is at its peak or largest and lowest in the winter when insolation receipts are lowest.

Adelekan [1] examined the spatio-temporal variations in thunderstorm rainfall over Nigeria. The work pointed out that thunderstorm rainfall increases from the south to north up to latitude 11°N Others who had carried out research on thunderstorm activity in Nigeria include, Mulero [17] on seasonal distribution of thunderstorm days in Nigeria for the period (1962 — 1971); Balogun [6] on season and spatial variation of thunderstorm activity in Nigeria; Oladipo and Mornu [19] discussed the characteristics of thunderstorm in Zaria, Nigeria; Omotosho [24] was concerned with the individual contribution of thunderstorm line squall and Monsoon, to the total rainfall in Nigeria over five years. Salau [26] discussed the influence of Jos Plateau on the occurrence of thunderstorm activity in Jos, Zaria, and Kaduna in her work on temporal and comparative analysis of thunderstorms and related phenomena (hail, squall and Lightening). Ologunorisa, 1991; 21; 2007. Alexander [4] compared thunderstorm occurrence and rainfall in his work comparative analysis of thunderstorm and rainfall occurrence over Nigeria.

Outside Nigeria, scholars have also worked on thunderstorm activity [7,13,14,15,16,22].

Though attempt has been made to study thunderstorm in all its aspect — diurnal, seasonal, annual, and trend in a single study. The station investigated was a coastal station. Therefore it is imperative to study thunderstorm away from coastal station to ascertain the effect of river on thunderstorm pattern and to also observe the effect of seasonal temperature and its range on thunderstorm. Therefore Yola was chosen. This study seeks to carry out a detailed analysis of thunderstorm activity over Yola. Besides this study also seek to investigate the impact of seasonal variation of temperature on thunderstorm. Most of the comparative studies in Nigeria were on thunderstorm and rainfall, so, this work seeks to differ especially as temperature is also a vital element of climate in the tropics.

2. Study Area

Yola was established in 1841 as a capital city of a Fulani state. Today Yola is the capital of Adamawa State in Nigeria. The city is situated on altitude 186m. The geographical coordinates are 09°14'N and 12°28'. Yola is located on the Benue River. The city is made up of two parts the old and new Yola. Jimeta (new Yola) is about 5km North West of the old Yola. Yola northern boundary is Mandara mountains and in the south by Shebshi mountain with Dimlang (Vogel) peak, the second highest point (2042m) in Nigeria after ChappalWaddi (Mountain of death).

Yola has the tropical wet climate also called tropical hinterland climate. Locally Yola climate is called High Plateau climate. The climate fits into Aw of Koppen classification of climate.The temperature is moderate. It has mean temperature of 28.3°C. The range in temperature is about 8°C to 23°C in some months, especially during dry season months. Yola has mean sunshine hour of about 2954 per year.

Rainfall is between 1500 – 2000m per annual, with high relative humidity. The wet seasons last for over six months every year. She has montane type of vegetation. The windward sides support thick vegetation's, whereas the leeward sides support little grasses and scattered short trees.

The dominant type of soil in Yola is the laterite soil. This soil is associated with guinea er crops like yam, cocoyam, etc. The soils are heavily leached due to rainfall [12].

Yola is an access point to the Gashforest reserve, the Mambilla Plateau, The Surkur UNESCO World heritage site, which is Africa's first cultural landscape to receive World Heritage List inscription. The Yadin Waterfalls, The Kiri Dam on the Gongola River, the Benue National park in nearby Cameroon, The Waza National Park and Cameroonian town of Garoua, which lies across the Border, on the Benue River. Yola is home to varios institutions of learning, such as the: America University of Nigeria, Adamawa State Polytechnic, ModibboAdama University of technology, Yola.

Tourist sites within Yola include: The three sister hills, which are three scenic rock formations standing side by side at the same height. The Njuwa Lake fishing festival, The Lamido's palace and the annual horse riding durbar, etc [29].

Yola has a population of 336648 (NPC, 2010). Majority of these population were farmers.

Figure 1. Map of Yola Capital of Adamawa State.(Source [11])

3. Methodology

The data used in this work were extracted from form 100/5 of daily weather register of Nigerian methodological Agency Oshodi, Lagos. The study covered 30 years (1970-1990).

The method of data analysis includes descriptive and inferential statistics. Descriptive statistics such as means, percentage and co-efficient of variation (C.V) were used. The C.V was used in determining the variation in diurnal and seasonal occurrence of thunderstorm. Ologunorisa [20] and Alexander [4] used it in their work.

$$CV = STD / *100 \quad (1)$$

Inferential statistics used include Spearman rank correlation use for annual distribution and regression analysis for trend in thunderstorm activity over Yolar´ is given as

$$r' = 1 - 6\sum d^2 / N\left(n^2 - 1\right) \quad (2)$$

Where, Σd^2 is the summation of the squared differences of the ranked data. N is the sample size, and n^2 is the square of sample size.

$$y = a + bx \quad (3)$$

y is the regression line examination, where a and a are constants, while x is the dependent variable.

To test for the significance of the seasonal and annual occurrence of the thunderstorm, student t" test was used.

$$t = r\sqrt{n-2} / \sqrt{\left(1 - r^2\right)} \quad (4)$$

The results are presented in table and graphs

4. Discussion and Result

(1) Seasonal Temperature and Thunderstorm occurrence.

The Seasonal Temperature and mean TS occurrence over Yola is shown in Table 1a and Figure 2a. The least occurrence in temperature was recorded between January and December, 25.5°C and 25.8°C respectively, while the highest occurred in the months of March and April with 32.1°C and 33.3°C respectively. The mean seasonal temperature distribution did not show any definite pattern. The seasonal occurrence of thunderstorm over Yola shows that February had no trace of thunderstorm occurrence, while January and December recorded 1 and 2 peals respectively. The month of August had the highest thunderstorm occurrence of 849 peals; September was second with 771 peals of thunderstorm.

The dry season months of November, December, January, February, March and April accounted for 416 peals ofTS representing 9.08% of the total TS occurrence. The wet season in the other hand accounted for 4162 peals representing about 90.92% of the station thunderstorm during the study period. This implies mathematically, that for every wet season at least about 138.73 peals of

TS occurred meaning that about 11.56 peals occur every wet season months.

Table 1a shows that there is no statistical relationship between seasonal temperature and mean TS occurrence over Yola. The calculated r' = 0.08222, and the t-test result = 0.0009, coefficient of determination = 0.68, these shows that whatever seemly relationship is by chance. At 95% level of confidence, it is obvious that temperature cannot explain TS occurrence in Yola.

Table 1a. Seasonal Temperature and Mean TS of Yola

MONTH	TEMP	THUNST
JAN	25.5	0.03
FEB	26.9	0
MAR	32.1	1.6
APR	33.3	11.67
MAY	30.9	22.67
JUN	28.8	23.4
JLY	27.5	25.13
AUG	26.7	28.3
SEP	27	25.7
OCT	26.2	13.53
NOV	27.3	0.5
DEC	25.8	0.07
TOTAL	338	152.6
r' =	0.08222	
t-test	0.000896	
r²*100	0.676	

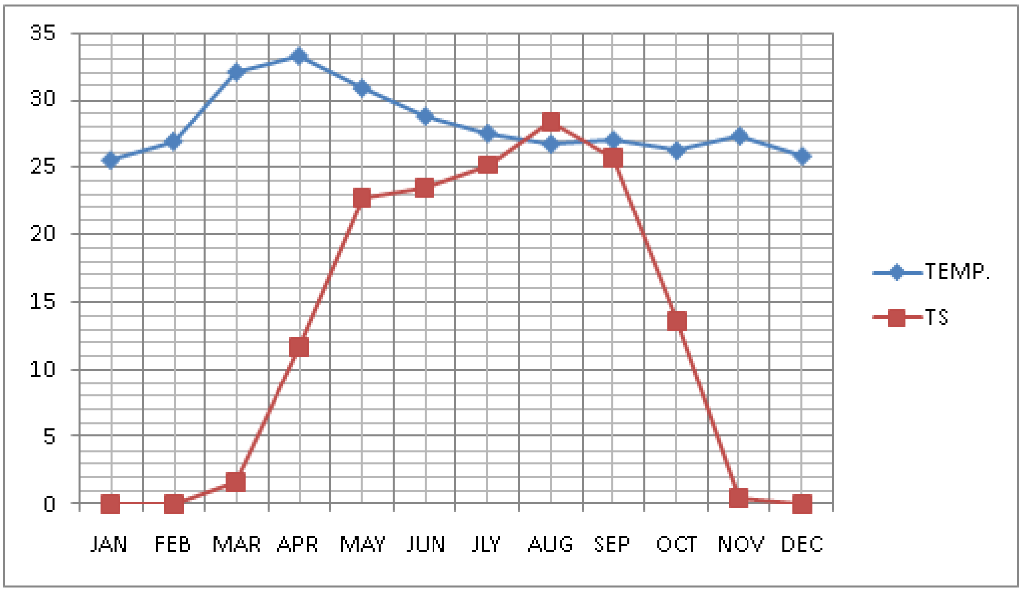

Figure 2a. Relationship between Seasonal Temperature and Thunderstorm Occurrence over Yola

Table 1b. The Relationship between Seasonal Temperature and Thunderstorm Occurrence

MONTH	TEMP	TS
JAN	22.5	0.03
FEB	16.7	0
MAR	15.3	1.6
APR	13.1	11.67
MAY	11.2	22.67
JUN	9.5	23.4
JLY	8.6	25.13
AUG	8.2	28.3
SEP	9	25.7
OCT	15.1	13.53
NOV	17.3	0.5
DEC	17.7	0.07
r'	-0.924	
r²*100	85.37%	

Figure 2a also shows that there was no relationship between seasonal temperature and TS occurrence, the diagram agrees with the statistical explanation above.

Table 1b and Figure 2b shows the seasonal range in temperature and mean TS occurrence during the study period. From the table and the statistics that follow, it shows that at 95% level of confidence there is a significant relation between range in seasonal temperature and TS occurrence in Yola. 85.37% of thunderstorm occurrence can be explained by range in seasonal temperature.

From Figure 2a it is observed that seasonal temperature range varies inversely with TS occurrence over Yola during the study period. Note the month of August has the highest TS occurrence, and it also has the lowest range in temperature. The five months with least range in temperature corresponds or are the same months with least TS distribution. Similarly, months with high TS occurrence, had low range in temperatures. The months of

April and October are transition months, so they had little variation from the normal trend.

Figure 2b explained the seasonal occurrence of thunderstorm over Yola (1970 — 1999) from the graph it was observed that February had no trace of thunderstorm occurrence, while January and December recorded 1 and 2 peals respectively. The month of August had the highest thunderstorm occurrence of 849 peals; September was second with 771 peals of thunderstorm.

The dry season months of November, December, January, February, March and April accounted for 416 peals ofTS representing 9.08% of the total TS occurrence. The wet season in the other hand accounted for 4162 peals representing about 90.92% of the station thunderstorm during the study period. This implies mathematically that for every wet season at least about 138.73 peals of thunderstorm occur, meaning that about 11.56 peals occurs every wet season months.

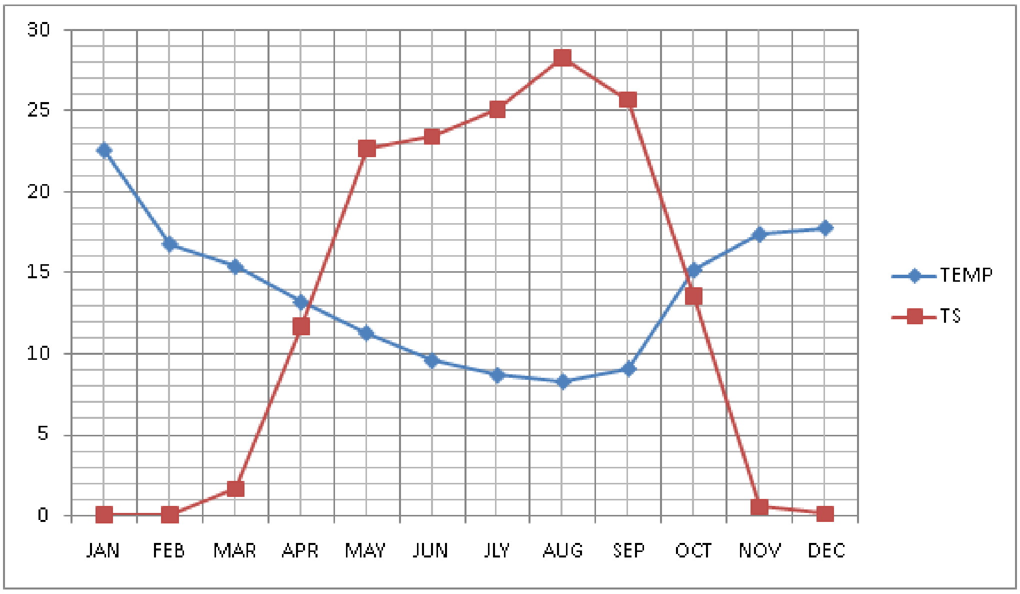

Figure 2b. Range in Temperature and Mean Thunderstorm Occurrence over Yola

The reason for high thunderstorm during wet season can be explained by number of factors such as, the effect of altitude, availability of moisture, sporadic wind, differential temperature, and most especially low range in temperature during wet season.

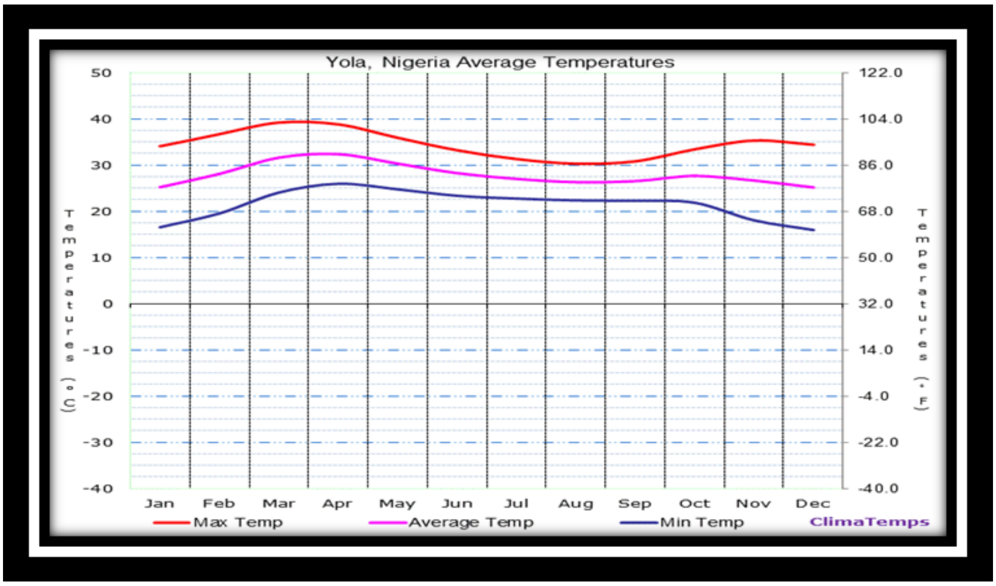

Figure 2c. Seasonal Temperature over Yola (Source [29])

Figure 2c shows that the highest maximum temperature occurred during month of March and April, follow closely by November and December. The least minimum temperature was recorded in the months of December and January. August has a relative low maximum temperature and not too low minimum temperature, and that is suitable for TS cultivation.

The seasonal variations of thunderstorm, mean, true mean and coefficient of variation (C.V) over the period of study were calculated as shown in Table 2c. The seasonal C.V during the study period over Yola is large. The result shows a range of 282.84%. January has the highest CV of 282.84, while February has zero variation. Thunderstorm tends to be reliable during wet season than during wet season. The result also shows that dry season months has higher CV. Thunderstorm occurrence varies with and within seasons.

Table 2c. Seasonal Variation of Thunderstorm.

Month	**Total**	Mean	T-Mean	STD	CV	%
Jan	1	0.03	0	0.35	282.84	0.02
Feb	0	0	0	0	0	0
Mar	48	1.6	0.13	5.68	94.7	1.5
Apr	350	11.67	0.97	27.25	62.28	7.6
May	680	22.67	1.89	36.43	42.86	14.9
Jun	702	23.4	1.95	26.66	30.38	15.3
Jul	754	25.13	2.09	26.07	27.66	16.5
Aug	849	28.3	2.36	32.84	30.95	18.6
Sep	771	25.7	2.14	25	25.94	16.7
Oct	406	13.53	1.13	31.37	61.83	8.8
Nov	15	0.5	0.04	1.46	104.5	0.3
Dec	2	0.07	0	0.46	185.1	0
Total	4578	152.6	12.72	213.57	949.04	100
Mean	381.5	12.72	1.58	17.7	79.1	8.3
T-Mean	12.72	0.42	0.04	0.55	0.09	0.3

5. Annual Distribution of TS and Trend

The annual TS distribution is explained in Table 2 and Figure 3. 1972 recorded the highest peals of thunderstorm 322, followed by 1971 and 1973 with 274 and 249 peals respectively. 1982 recorded the least thunderstorm occurrence of 49 peals during the study period. This is closely followed by 1996 and 1997 with 75 and 82 peals respectively. Figure 3 shows the fluctuations over the years. It was observed that 7 years had peak thunderstorm occurrence. These include 1972, 1978, 1985, 1988,1991, 1994, and 1998; the minimum frequency during the same period are 1977, 1982, 1987, 1989, 1993, and 1996. The peak here does not mean the highest TS occurrence of, rather it mean sharp edges before a fall in distribution.

Using Spearman Rank correlation for analyses, it was observed that there is significant relationship between thunderstorm occurrences with time. Further using student 't' test shows that the relationship was negative at 95% level of confidence.

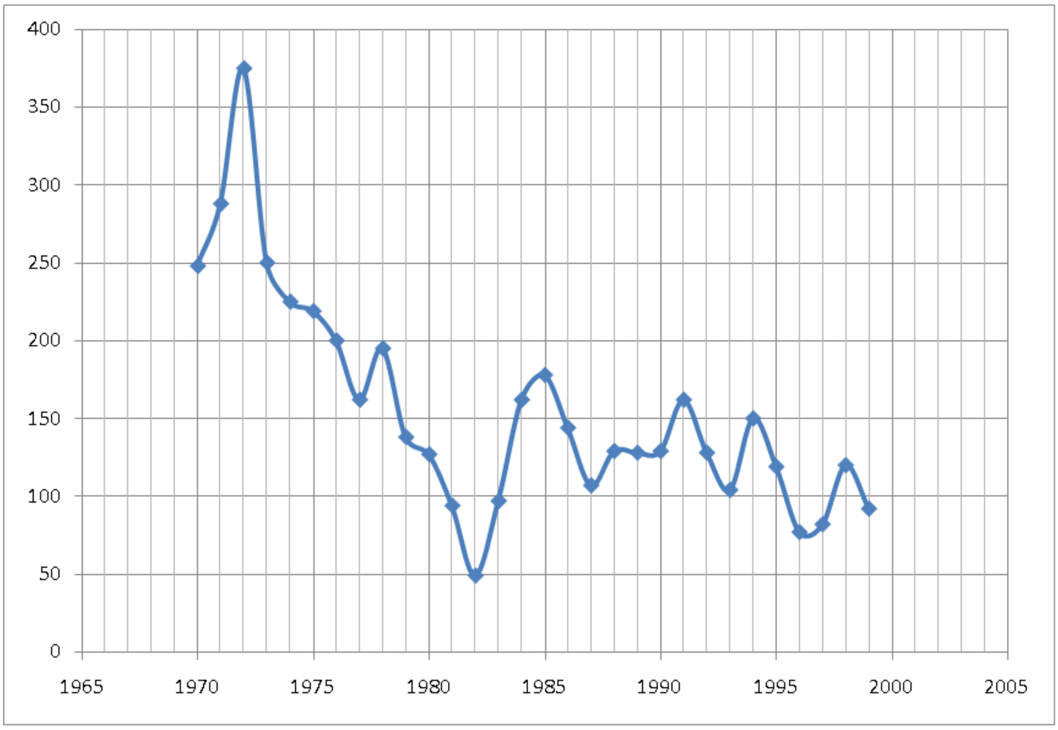

Figure 3. Annual Thunderstorm Fluctuation over Yola

5.1. Trend Analysis

The result on trend analysis shows a negative or downward scope over the years. This implies that TS occurrence in Yola decreases with time. The negative correlation co-efficient showed that the relationship was not by chance. The negative scope is an indication of a linear tendency toward a general decrease in TS occurrence over the study period and thus a downward trend.

The decrease in TS could be as a result of reducing rainfall resulting from reduction in moisture contained in the atmosphere around the study area. It can also be explained by the higher range in temperature within the study area in recent time. This point to a changing climate.

Table 2. The Annual Variation of Thunderstorm.

Correlation	STD X	STD Y	Critical value	Coefficient determination	Students
Coefficient "r"			Value	r^2 x 100	"t" test
-0.74	8.80	63.76	±2.05	54.76%	- 5.82

Note: 54.76% of thunderstorm occurrence in Yola is explained by time or years.

The result r = -0.74, shows a negative relationship. This agrees with the descriptive statistics above. The "t" critical is > T-calculated (-5.82). This indicates a significant relationship between TS activity and time over Yola. The

(-) points to a negative trend. The regression analysis is shown in Table 3 below

The regression analysis points to the fact that TS decreases over years during the period of study 1970 - 1999 in Yola.

Table 3. The Annual Trend of Thunderstorm.

Regression Coefficient	Regression equation	t-critical	t-calculated
- 5.5	Y =237.9-5.5x	±2.05	-5.82

Table 4. Diurnal Thunderstorm Activity

Time	Total TS	Mean	T Mean	STD	CV	%
0000-0300	492	16.4	2.05	38.04	92.79	10.7
0300-0600	460	15.33	1.92	38.41	100.21	10
0600-0900	375	12.5	1.56	32.11	100.74	8.2
0900-1200	355	11.83	1.48	32.91	111.26	7.8
1200-1500	582	19.4	2.43	50.17	103.44	12.8
1500-1800	885	29.5	3.69	65.61	88.96	19.3
1800-2100	857	28.56	3.57	61.12	85.58	18.7
2100-0000	572	19.06	2.53	43.56	91.39	12.5
Total	4578	152.58	19.08	361.93	774.37	100
Mean	572.25	19.08	2.39	45.24	97.04	12.5
T-Mean	19.08	0.64	0.08	1.05	3.23	0.41

Diurnal Distribution of Thunderstorm The diurnal distribution of thunderstorm in Yola is shown in Table 4 and Figure 4. The least occurrence was recorded between 0900 – 1200 GMT hours with 355 peals, while the highest occurred in the late afternoon hours of 1500- 18000MT with 885 peals. This is also a period with minimal temperature range.

Obviously the explanation of afternoon - evening types of diurnal thunderstorm over Yola is complex. Different researchers have proposed divergent mechanisms [6,19]. (1) Those based on thermo-dynamic process e.g. solar radiation that affects the static stability. (2) Those based on dynamic processes that influence the mass convergence within planetary boundary layers (3) Those based on semi-diurnal pressure wave (Wallace, 1975), and (4) those based on the role of radiation difference between organized Meso-Scale Cloud regions [9]. So there is no single hypothesis that can be used to explain the afternoon - evening regime in Port Harcourt. Therefore, the afternoon-evening regime is as a result of multi-dynamic and circumstantial processes.

The diurnal co-efficient of variation of thunderstorm (C.V), percentage and mean were calculated. The result shows that diurnal C.V is generally moderate. The range in C.V is 25.68%. The 1800-2100GMT hours has the least variability of 85.58%, while 0900-1200 GMT hours has the highest variation of 111.26%.

The period (hours) with lesser than (<) 100 peal C.V are considered low diurnal hours. These include 1800-2100, 1500-1800, 2100- 0000, and 0000- 0300 hours, with85.58%, 88.96%, 91.39%, and 92.79% respectively. The high diurnal hours are those that records above 100%, these includes 0300-0600, 0600-0900,1200-1500, and 0900-1200 GGMT, with record value of 100.21%, 102.74%, 103.44%, and 111.26% respectively. The hours between 1200-0000 GMT accounted for over 63% of the total thunderstorm occurrence over Yola, while the hours between 0000-1200GMT contributed lesser than 37% of Yola's thunderstorm during the period of study. The concept of true mean is used to address statistical illusion as shown in Figure 4.

Note - true mean = total thunderstorm occurrence/duration of study * the hourly interval.

The thunderstorm for Yola for the 30 years is 4578 peals. The hourly interval for diurnal occurrences is 8 (i.e. 24hrs / 3). The true mean = 4578/ (30*8) = 19.08 peals. The true mean explain the ideal daily thunderstorm occurrence over a station and any particular parameter of interest. True mean = mean of mean.

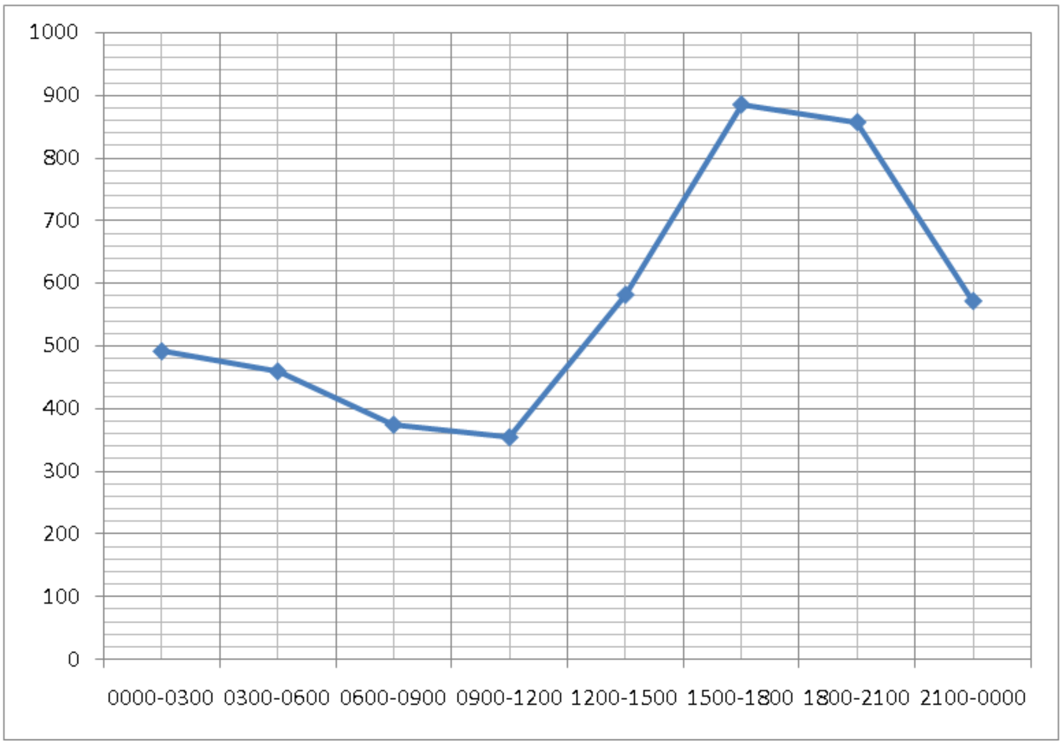

Figure 4. Diurnal Thunderstorm Occurrence over Yola

6. Recommendation

Thunderstorm plays a vital role in formation of rainfall, which dictates the farming calendar in Nigeria. The study recommend that thunderstorm data should be well analyse before cultivation is carried out. This is because the resultant rainfall from thunderstorm is always flood, storm, and torrential rainfall, which leads to soil erosion and extensive runoffs.

Construction workers should consult experts on climatological and weather related issues to minimize thunder related risks. Aviation industries must take note of diurnal implication of thunderstorm activity.

Understanding ranges in temperature is very vital, especially during wet season; large range in temperature is an indication that TS occurrence probabilities is low and in real sense that it is unlikely to occur. A prediction of low range in temperature is a strong indication that TS is most likely to occur.

It is hoped that in future, study on prediction and warning of thunderstorm on both micro and macro scale be carried out. Government and Non-governmental organizations should involve themselves in the study of thunderstorm, either as a source of energy or to avoid its destructive consequences.

Understanding of TS occurrences will help in harvesting rainfall effectively, since TS precedes rainfall occurrence. Finally Children should be discouraged from playing out door from 1500-1800 GMT hours especially in August to avoid TS strike.

7. Conclusion

The study of thunderstorm occurrence is a complex one, especially in a developing country like Nigeria.

The study shows a late afternoon- and early evening diurnal peak. It also reveals that wet season accounted for majority of the thunderstorm occurrence during the period of study. The month of August recorded the highest thunderstorm occurrence; in addition the study shows that TS occurrence decreases with time over years. There is statistical relationship between thunderstorm occurrence and time; the relationship is negative at 95% level of confidence. The study further revealed that the Month of February had no peal of thunderstorm over the 30 years of study. January and December had just 1 and two respectively. This is a serious finding. It implies that rain fall and thunderstorm cannot disrupt social activities during these months.

TS show a late afternoon/evening diurnalpeak occurrence around 1500-1800 hours. TS occur more during wet season than dry season. It was observed that TS has a double seasonal peak (double maxima)

Among the revelation of this Work is the inverse impact of range in temperature on TS occurrence. The peak TS occurrence time are mostly period when the range in temperature is low, like late evening as this work indicated in the diurnal occurrence of TS. Wet season is another period when temperature range is minimal, this correspond to peak TS occurrence season.

The study of TS activity in Yola will help Administrators', Planners, and Policy Makers. Farmers yield are poor because of undermining the onset of rainfall, end and duration of rainfall, which can be predicted by studying TS activity.

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